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SATELLITE PHOTOGRAPHY AS A GEOGRAPHIC TOOL
FOR LAND USE MAPPING OF THE SOUTHWESTERN U.S.,

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Abstract

Geographical studies have often focused on land use since it represents a visible expression of man's imprint on the earth's surface. Satellite photography is regarded as a potentially important data source for, at a minimum, analyzing the nature and areal extent of such phenomena. A program was initiated at the University of California, Los Angeles (U.C.L.A.) to investigate the utility of such imagery for generalized land use mapping at intermediate and small map scales.

Photography of the southwestern United States from the Gemini and Apollo missions was used in the study. The objectives of the project were to: 1) determine what land uses are visible on satellite photography; 2) devise a land use classification system compatible with data obtainable from such imagery; and 3) construct land use maps at scales of 1:250,000 and 1:1,000,000.

The investigation resulted in 1:250,000 working base maps for the portion of the southwestern United States imaged on the Gemini and Apollo missions and a 1:1,000,000 reduction of these map sheets. A land use classification system was designed in conjunction with these efforts. The system was constructed with a view towards flexibility since it was obvious that the acquisition of improved satellite photography would permit a more in-depth study of land use. The framework can be expanded to include categories not found in the Southwest and refined to incorporate more detailed data about particular categories.

Various land use categories are interpretable from the photography, although some are difficult to distinguish (e.g., unimproved grazing land and woodland). Accuracy was found to be a function of the degree of dependence on spectral characteristics and the consequent amount of inference necessary for an interpretation. Nevertheless, the photography proved a useful data source when supplemented by limited field investigations and the geographical knowledge of the investigators. Such imagery certainly would be a valuable tool for mapping and analyzing land use in developing countries, where it would be difficult, expensive, and in some instances impossible to conduct such a survey utilizing conventional techniques of data acquisition.

SATELLITE PHOTOGRAPHY AS A GEOGRAPHIC TOOL

FOR LAND USE MAPPING OF THE SOUTHWESTERN UNITED STATES

Section 1 Introduction

Geography as a discipline often concerns itself with the direct expression of man's activities on the face of the earth. The nature of land use patterns is one such expression which is of current interest because of the world's rapidly increasing human population. There is a definite need to inventory and record the actual and potential resources of the earth in order to more efficiently meet the needs of the rising population. A critical initial step towards such an inventory is mapping the types and areal extents of present land uses on a broad scale. A map of this nature is needed because countries in many parts of the world (particularly developing ones) often do not possess reliable records of even such basic data as this. Furthermore such information can form the base from which in-depth analyses can proceed. The value in obtaining data for such a map should, therefore, not be minimized.

Remote sensing techniques--observation and recording of phenomena without being in intimate contact with them--are regarded as potential tools for a rapid and accurate inventory of earth resources. The research summarized in this report concerns the application of one type of remote sensor, satellite photography, to a particular problem, generalized land use mapping of the southwestern United States. The hypothesis of this investigation was that satellite photography could be used as the basic source of input data for the construction of a land use map of a very large region at both intermediate (1:250,000) and smaller (1:1,000,000) map scales. In conjunction with this, a land use classification system compatible with relevant observable phenomena on the photography was to be developed; i.e., a system determined by the photography.

The southwestern United States was selected as the region of investigation for a variety of reasons: 1) the existence of a range of human activities that have a corresponding landscape expression; 2) nearly complete satellite photographic coverage of the area by Gemini IV and V, Apollo 6, and Apollo 9 is available in a variety of forms (e.g., transparencies, prints, mosaics); 3) most of the photography is unobscured by cloud cover the region being essentially an arid environment with a high proportion of cloud free days; and, 4) the region is accessible to the University of California, Los Angeles (UCLA) campus for field checking of interpretations. Initial mapping utilized only imagery from the Gemini IV and V missions. The Apollo 6 and Apollo 9 photography, acquired at a much later stage in the project, was used to supplement and improve the mapping accomplished from the Gemini missions. The resulting maps are a composite of the data obtained from all these missions and display the maximum areal extent of the land uses covering the time period from the summer of 1965 to the spring of 1969. The investigators regarded this as a reasonable form of presentation because: 1) the orientation of the project was towards a single land use map as an

end-product, and, 2) the amount of change over such a short period of time was expected to be minimal.

The organization of the body of the report reflects the approach taken by the investigators to develop a land use classification system appropriate for satellite photography and to produce a map for the southwestern United States exemplifying such a system. In Section II, following, the procedures used for interpretation of the photography are presented, accompanied by a discussion of the results of, and difficulties encountered in, the interpretation process. Section III concerns the verification methods used to check the interpretations, and the insights and problems that resulted from the check. Section IV explains the classification system developed from interpretation of the satellite photography and the resultant land use maps. Finally, conclusions concerning the utility of satellite photography for land use mapping and recommended follow-on programs are presented in Section V.

Section 11 Interpretation of Satellite Photography

Four satellite missions--Gemini IV and V, Apollo 6, and Apollo 9--formed the basic photographic source materials for this study. However, during the early phases of research when interpretation procedures were being formulated, only materials from the two Gemini missions were available. Consequently imagery from these missions defined the extent of the area to be investigated as shown on the Gemini photomap mosaic of the southwestern United States prepared by the U.S.G.S. Basic interpretation procedures were also developed relative to the Gemini coverage. The late arrival of photography from the Apollo 6 and 9 missions made it necessary to place them in the category of materials serving to check, correct, and amend Gemini interpretations. In this way the photography from the later missions were helpful, but also created certain problems which will be discussed later in this report.

During the course of the investigations a procedure for interpreting the Gemini photography, with a maximum utilization of the available imagery, was developed. Interpretations were performed directly from color prints onto acetate overlays. This technique provided the basic input data on land use and color-textural patterns. Transparencies (using image projection or magnification with an 8X tube magnifier on a light table), black and white prints (both rectified and unrectified), and controlled Gemini mosaics of the southwestern U.S. were used as supplemental sources of information to the color prints. Data acquired from these source materials were then transferred onto acetate sheets at a map scale of 1:250,000. This was accomplished in order that the land use information, after being consolidated into more general categories, could be mapped directly onto existing U.S.G.S. 1:250,000 scale topographic maps. Image interpretation resulted in the delimitation of a number of identifiable land use phenomena and color-textural associations from the Gemini photography.

Agricultural fields were generally the most distinct and visible landscape features on the photography. Geometric shapes, mostly oriented according to the United States Land Survey System, and the large sizes of individual fields or groups of fields facilitated immediate identification of these phenomena. There were a range of spectral responses that might be useful for crop identification, but the only obvious distinction was

between ploughed and fallow fields on the one hand and vegetated cropland on the other.

Transportation features were another readily identifiable land use. Linearity and extensive length were the principal interpretation keys since associated reflectance characteristics ranged from very light to very dark, probably resulting from different construction materials or, in the case of trails, a dirt surface. It proved impossible to differentiate roads from railroads because there were no apparent indicators on the photography to justify such a distinction. Airports and airfields, however, could be differentiated from roads and railroads on the basis of shorter length of features and complex configurations. Landing strips often crossed or were parallel to each other at larger airports; many smaller airfields exhibited a triangular, or simpler patterning. Geometric patterns permitted immediate identification despite the variability of spectral responses that were undoubtedly related to the surface materials of the landing strips.

Urban identification was made on a dichotomous decision basis. Large urban centers were easily interpreted according to street patterns and grayish, coarse textured signature criteria. Sizes and shapes were clearly discernible on the photography. Smaller centers were more difficult to interpret because street patterns could not be observed, but the spectral signature, mentioned above, and locational criteria, such as breaks in transportation lines, proved very useful.

Hard rock mining operations had a marked spectral response that in many cases immediately focused attention on them. They were generally characterized by a whitish or tan colored, mottled textured signature. However, other factors were of equal importance for establishing an identification: 1) frequent presence of tailings ponds; 2) geographical location on mountains or hilly areas; and, 3) existence of well-developed transportation systems in the larger operations. Oilfields were also clearly distinguishable, although only found in the Texas portion of the area of investigation. They were generally an area-extensive feature characterized by a regular patterning of small, circular white-appearing signatures.

Preliminary identification of solid stands of coniferous forest was possible on the photography. The two major criteria utilized were a characteristic dark blue signature and location at higher elevations of various mountain ranges. In the arid Southwest, woodland areas were also delimited on the basis of locational criteria, lower mountain elevations and hills, and a light blue signature. The criteria for woodland became difficult to apply in the more humid southwest where it was apparent that such simple relationships did not provide sufficient data to formulate a decision.

The remainder of the area, possibly 80% of the total Southwest region that was investigated, consisted of a complex association of various spectral responses that gradually merged into each other with no obvious, discernible patterning. A map of these responses, grouped into over twenty categories on the basis of color and texture, was prepared for the Tucson-Willcox Dry Lake area of Arizona with the purpose of determining what caused the signatures and how they might be related to land use. It was hypothesized that they were probably related to natural phenomena such as vegetation and soils, and represented woodland,

grazing activities, and unproductive land; however, this remained only a speculation until it was checked.

Acquisition of Apollo 6 and Apollo 9 photography (though late) was useful for improving the quality of land use mapping, but also added a temporal dimension that created initial problems. The Apollo 9 mission had limited utility because it covered only a small portion of the area being investigated and was imaged at a time of excessive cloud cover over the region. The ensuing comments, therefore, primarily concern the Apollo 6 mission which had a greater impact on the land use mapping.

The Apollo 6 photography, imaged in the summer of 1967, was of very high quality. The imagery is nearly vertical, has an average resolution of about 250 feet, possesses sufficient overlap for stereoscopic viewing, and has very good color differentiation even though somewhat underexposed. These qualities were invaluable for locating features more accurately and delimiting their boundaries with a higher degree of precision than was possible from the generally more oblique Gemini photography. Furthermore, from the Apollo imagery the researchers could identify additional examples of land uses that were unobservable on the Gemini pictures, such as small urban centers and agricultural fields located in stream washes. The time dimension implicit in the photography initially posed a definite problem. It was very apparent on the imagery that some land uses--e.g., cropland and open pit mining--had experienced expansion and/or contraction of areal extent since the Gemini missions. The difficulty lay in how to express such changes on the single map that was envisaged as the end-product of this research. It was finally decided that these new data could be incorporated onto the map by displaying the maximum areal extent of the highest land uses in terms of assumed economic return over the period of time reflected by the different satellite missions. This was considered a justifiable representation because it portrays the landscape in terms of man's ability to utilize the landscape for his own ends.

Section III Verification of Interpretations

The previous section concerned the methods utilized to interpret the satellite photography and the results of such interpretations. A basic dichotomy existed among the phenomena observable on the imagery: 1) those that could be identified with a high degree of certainty; and, 2) those that could only be delimited as color-textural areas with no real certainty of identification. In both cases identification and verification procedures are necessary to explain the nature of the phenomena.

There are several alternative sources for identification and verification that can be used. The researchers decided that a combination of these would be divided into four general types: 1) published materials; 2) large scale aerial photography; 3) personal communication with knowledgeable individuals; and, 4) field check.

Published materials, in the form of maps, were consulted initially to obtain a first approximation of what types of features were being recorded on the satellite photography. Various up-to-date commercial road maps, Morrison's Reconnaissance Soil-Association Map Overlay to Gemini 1:1 Million Photomap, Humphrey's Arizona Natural Vegetation, 1963, Kuchler's Potential Natural Vegetation of the Conterminous United States, and Thaman's A Study of the Feasibility of Mapping Vegetation on a World

Scale Using Satellite Imagery are examples of such sources (see bibliography). The maps and associated studies were useful for checking broad patterns, but were limited in regard to generalizations and recency of information.

Current large scale air photos were seen as a possible means of updating published materials. Unfortunately most available air photos were also out-of-date, although they were useful for a detailed examination of more enduring features--e.g., landforms and vegetation associations. These photos were obtained from the University of Arizona and from the U.C.L.A. Fairchild collection. In addition Dr. Robert N. Colwell made available recent (1969) low altitude infrared ektachrome (CIR) photography of the vicinity of Willcox, Arizona. This was very useful for examining vegetation, cropland, mining, and transportation. Air photos were useful for detailed visual inspection of limited areas because of their large scale (as large as 1:2,000 in some cases), but, for the most part, were out-of-date for phenomena that are subject to moderate change over short periods of time, e.g., agricultural, mining and urban forms.

The information from the two previously discussed categories of sources provided substantial data for checking an area as broad in extent as that investigated in this land use mapping project. However, there were obvious spatial and temporal gaps discernible in this data which necessitated on-the-spot field investigation by the researchers. Time, distance, and financial constraints made it necessary to conduct the field check at two levels. It was decided to do: (a) an in-depth investigation of a 9,600 square mile area in southern Arizona centering on Tucson and Willcox Dry Lake--this region being deemed representative of a major portion of the southwestern U.S.--and, (b) a cursory investigation of the region west of this area. Approximately two weeks (10-23 December, 1968) were spent in the field driving through the total area to assess the character of the landscape with many stops to spot-check interpretations made on the satellite photography. More time would have permitted detailed examination of a larger area, but the researchers felt that sufficient data had been collected, which could be incorporated with data from other sources, to permit appreciation of the land use information recorded on the photography.

The final category of source data, personal communication, arose from the field checking accomplished in December, 1968. While in Arizona, various members of the Geography Department and the Division of Economic and Business Research, both of the University of Arizona, were consulted. Dr. Leaming of the Division of Economic and Business Research was constructing a land use map of Arizona based on published materials, and, hence, was very familiar with land use patterns in the state. These researchers were helpful in assisting in recognition of landscape features visible on the satellite photography, explaining how people perceive and use their environment, and suggesting the relative economic value of land uses found in the area.

The information acquired from these sources was invaluable for establishing levels of interpretation confidence. Identification and verification were achieved satisfactorily for the areas field checked, but problems arose when these data and photographic information were integrated and then extrapolated eastward especially in the Texas portions of the Southwest. A different environmental complex was encountered and unforeseen interpre-

tation difficulties became manifest. In particular, the greatest problems concerned identification of color-textural patterns on the photography. The following selected examples are given to illustrate the results of verification and subsequent extension to an area not field checked.

Agricultural field patterns were clearly discernible on the satellite photography. Interpretation keys used for identification of this land use have been presented in the previous section. Through checking various sources it was established that these fields could be identified with a high degree of accuracy. A very small proportion of fields were unidentified and this was because they occurred within highly vegetated stream washes, where the reflectance characteristics of the native vegetation and the crops were so similar that, generally, the phenomena were classified as natural vegetation. For the most part, however, agricultural fields, fallow or in crops, could be identified with high reliability and little difficulty. It was possible to identify open pit mining, oil extraction, and large urban centers with a somewhat lower degree of reliability. In most cases, spectral response played only a minor role in the interpretation procedures.

Forested areas were identified on the basis of locational factors and reflectance characteristics. Checking revealed that this land use was interpreted reasonably well, although boundaries could have been more precisely demarcated. Woodland phenomena were delimited on the same basis, with slightly more emphasis on spectral response. Again, problems concerning boundary drawing became apparent and resulted in even greater imprecision than for forest areas. Smaller urban centers were identified using similar criteria (location and spectral response), the major problem being an inability to recognize many centers because their spectral signatures appeared similar to the surrounding environment. The identification of these land uses represents a balance between the employment of reflectance characteristics and other criteria (e.g., location or shape) for interpretation.

Unproductive land and grazing land presented many interpretation problems. These areas were delimited almost exclusively on the basis of spectral signatures because integration of environmental phenomena on which they are dependent are exceedingly complex. Therefore, the spectral response is highly variable and no single criteria can be generalized for differentiation. The boundary delimitation between grazing and unproductive land became largely a matter of inference. The reliability of such interpretations on photography is low and must be substantiated by ground checking or other sources. Checking of the arid Southwest clearly demonstrated the reality of this problem, but no effective way to combat it, other than some form of checking, was discovered. This is an area of research that must be more thoroughly investigated than was possible in the present study.

Extrapolation into the Texas portion of the Southwest presented additional difficulties to those indicated above. The problem of delimiting boundaries in this area, where the range of reflectance characteristics associated with land uses overlapped, was further compounded by a wide range of camera exposures and the more humid conditions found in Texas. Under these circumstances, it became very difficult to apply even some of

the crude reflectance criteria learned from the investigation of the more arid parts of the Southwest. Consequently, there was an emphasis on logical extrapolation from photography of the arid Southwest and inference based on the interpreters' geographical knowledge of man-land relationships and the nature of their distribution.

Some of the difficulties mentioned in the preceding discussion of land use features are illustrated by the sets of photographs at the end of this report. Representative phenomena, i.e., agriculture, forest, woodland, and unproductive land, are shown first as they appear on Gemini photographs and then as they appear from the ground. These photographs demonstrate the range of reliability with which different types of land use can be differentiated on satellite photography.

Section IV Land Use Classification System

The goal of this project consisted of the development and field testing of a land use classification scheme which would incorporate land use data extracted from the imagery, and which would record land use of the Southwestern United States at the time of photography. The existing land classification systems of L. Dudley Stamp, F. J. Marschner and Demetrios Christodoulou were examined as a guide to the setting up of such a system.

L. Dudley Stamp's land use classification of the 1930's (see bibliography) was constructed at the large scale of one inch to one mile, allowing detailed examination and categorization. Such detailed land use mapping was not within the capabilities of the Gemini photography utilized in this project, although a few of the major categories used by Stamp (e.g. Unproductive Land, or Forest and Woodland) could be mapped. Stamp's sub-categories represented features too small to be identifiable on the imagery, or distinctions too fine to be interpreted at this smaller scale. F. J. Marschner's epic work on land use in the United States (see bibliography) published in 1959, concentrated on rural land use patterns, including aerial photographs as a complement to field and library research. Marschner selected air photographs at a scale of approximately 1:20,000 as representative of the agricultural land use of the conterminous United States. For the final map, Marschner used twelve basic land use categories:

1. Cropland and pasture land.
2. Cropland, woodland and grazing land.
3. Irrigated land.
4. Forest and Woodland Grazed.
5. Forest and Woodland Mostly Ungrazed.
6. Subhumid Grassland and Semiarid Grazing Land.
7. Open Woodland Grazed.
8. Desert Shrubland Grazed.
9. Desert Mostly Ungrazed.
10. Alpine Meadows and Mountain Peaks above Timber Line.
11. Swamp.
12. Marshland.

Marschner's map on the scale of 1:5,000,000 emphasized broad categories of land use and categories which reflected smaller areas of economic activity were not used. Some of these smaller categories (e.g. mining), however, are outstanding features on the Gemini imagery.

The other basic land use classification system considered, and that which was most amenable to use with the Gemini imagery, was a modification of the World Land Use Survey, by Demetrios Christodoulou (see bibliography). Using the World Land Use Survey as a base, he utilized black and white aerial photographs of Cyprus, and British land use studies, to produce an eight-fold categorization of land use at a scale of 1:250,000. These categories consisted of:

1. Settlements and Associated Non-agricultural lands.
2. Horticulture.
3. Tree and other perennial crops.
4. a) Irrigated crop land.
b) Unirrigated crop land.
5. Unimproved grazing land.
6. a) Dense Woodland.
b) Open Woodland.
c) Scrub.
7. Swamps and marshes.
8. Unproductive Land.

Christodoulou's combination of broad land use patterns together with small and specific land use features (e.g. extractive industry) was considered a suitable format on which to base a land use classification system from Gemini photography. However, in terms of the types of categories used, several extensive modifications of Christodoulou's system were made because of the differing nature of the human use of the land between that found in Cyprus and that in the southwestern United States.

The Project classification system represents categories of land use interpreted directly from the satellite imagery, or inferred by association of the photography with geographical knowledge of man-land relationships. The tentative classification system thus derived included nine major categories and ten subcategories:

1. Transportation
 - a) Airfields
 - b) Roads and Railroads
2. Settlements
3. Cropland
 - a) Irrigated
 - b) Non-irrigated
4. Arboreal Associations
 - a) Coniferous Forest
 - b) Woodland
5. Extractive Industries
 - a) Mining activities
 - b) Oilfields
6. Unimproved Grazing Lands

7. Water Bodies
 - a) Permanent
 - b) Seasonal
8. Unproductive
9. Uninterpretable

In the initial interpretation stage a distinction between irrigated and non-irrigated cropland was made. However, in the final compilation the two sub-categories were combined into one because non-irrigated fields occurred only in a limited area of sub-humid Texas and the areal extent was so small as not to permit a fair assessment of this land use. Within the category of Arboreal Associations, the imagery provided sufficient means to make the distinction between Coniferous Forest and Woodland, on the basis of tone, texture and spectral response. The agricultural, forestry and recreational functions of forest and woodland in the region justified the inclusion of this major category. The areal extent and economic importance of mining and of oil extraction sufficed for their inclusion in a major category--extractive.

While "Unimproved Grazing Land" was impossible to determine directly from the Gemini imagery, two inferences aided its identification: 1) livestock grazing is common in arid and semi-arid areas where there is sufficient vegetation and where no other land use pre-empts the space, 2) the work of Thaman and Morrison (see bibliography) plus field examination, shows that color-textural patterns of soils and vegetation roughly correlate with this land use.

The tentative classification scheme denoted two sub-categories of water bodies--permanent and seasonal. However, the overall category is only of limited usefulness in the Southwest since washes are the predominant fluvial feature, although permanent water bodies assume a greater importance in Texas. Only permanent water bodies were considered in the finalized category, and the seasonal hydrographic features which may have water for only a very short time were classified as either "unproductive," or "Unimproved Grazing Land" dependent upon the inferences that could be made from the photography.

Unproductive Land was identified often on the basis of a whitish color and very fine textural pattern, correlating on the ground with sandy areas of sparse to no vegetation, such as Willcox playa. Non-forested mountains with no indication of other activity (e.g. mining) were also classed a "Unproductive." It was thought vital to have a category "Uninterpretable" in order to incorporate areas which it was impossible to identify accurately from the imagery because of such phenomena as cloud cover, film defects, etc.. Finally, where an area was interpreted as having multiple uses, it was designated according to the use producing the highest economic return within the area. The final, modified Land Use Classification system used for this interpretation of Gemini imagery is as shown in Table 1 below:

Table 1. Gemini and Apollo Land Use Classification System.

1. Transportation
 - a) Roads and Railroads
 - b) Airfields

2. Settlements
3. Cropland
4. Arboreal Associations
 - a) Forest (Coniferous)
 - b) Woodland
5. Extractive Activities
 - a) Mines and Quarries
 - b) Oilfields
6. Grazing Land (unimproved)
7. Water Bodies
8. Unproductive Land
9. Uninterpretable

The first stage in the mapping phase of the project was the compilation of the 1:250,000 scale working base. Boundaries were drawn and colored zip-a-tone was put directly on the U.S.G.S. topographic sheets of the area (some 40 sheets in total). On the completion of this transfer to 1:250,000 base-scale, the map was reduced to 1:1,000,000 scale onto the second base map, which was an overlay on a dimensionally stable photo negative of the U.S.G.S. "Gemini Photomap of the Southwestern United States and Northern Mexico." Only the United States section of this base, which also includes a large area of northern Mexico, was used. In the reduction from 1:250,000 to 1:1,000,000 a remarkable amount of the detail of the larger scale was preserved. Thus the resulting map illustrates the relative lack of man's activities in arid lands and a greater overall use in progressively more humid environments. This is extremely well illustrated in the west to east progression on the 1:1,000,000 reduction.

The final 1:1,000,000 scale map was prepared for publication in the Annals of the Association of American Geographers (Volume 60, number 1, March 1970). The 1:250,000 maps are to be a manuscript record of the land uses identifiable on Gemini and Apollo photography at the date of this imagery.

The classification system described in this section is necessarily generalized owing to the quality of available satellite photography. However, the system has been specifically constructed to permit expansion which can be accomplished by adding major categories to the proposed listing and by extended subdivision of existing and new categories to the degree that improved photography will allow or that consideration of other areas makes mandatory. Flexibility has been a dominant factor in the formulation of the categories, since it was realized that undoubtedly better quality imagery will be forthcoming in the future and that other types of landscapes are, and will be, considered if satellite photography is to be put on an operational basis.

The true test of such a land use classification system is the reliability of its application to the real world. In the verification section it was suggested that land use phenomena could be identified with varying levels of confidence. Table 2 (following page) summarizes the findings of this study regarding the "Levels of Reliability of Land Use Identifications." The table is designed to show how reliability is a function of the degree to which identification was related to spectral response criteria. A high

TABLE 2

Levels of Reliability of Land Use Identifications

Reliability Dependence on Spectral Response	High Reliability (Positive Identification)	Intermediate Reliability (Recognition)	Low Reliability (Inference)
Low Dependence	Cropland Oilfields Major Urban Settlements Transportation		
Intermediate Dependence	Water Bodies Mines and Quar- ries	Forest Woodland* Minor Urban Settlements	
Heavy Dependence			Unimproved Grazing Lands Unproductive Land Woodland*

*Reliability of woodland identification depends on location and type of environment, e.g., climate.

level of reliability was attached to what is termed "positive identification"--that is, there is hardly any question as to what is being observed and there is little difficulty in delimiting its spatial dimensions. Intermediate level reliability refers to "recognition" categories--i.e., land uses that can be identified on the basis of locational relationships and photographic qualities, but whose areal extent is more difficult to determine. Finally, low level reliability is equated with "inference" categories. These are land uses which depend heavily on the use of spectral signatures and consequent subjective judgement on the part of the interpreter; the background of a geographer, or any other earth scientist, and his understanding of man-land relationships is of critical importance if such inferences are to be considered as having validity.

There is a definite relationship between reliability of land use identification and dependence on spectral signatures. At orbital altitudes a single photographic resolution cell represents the integration of a variety of spectral responses associated with a number of phenomena and their condition--i.e., a resolution cell represents a gross generalization (or aggregation) of the area it is imaging. Consequently, generalizing a variety of such cells into land use categories requires sophisticated interpretation and inference. Geographical knowledge and interpretation skills are important here, but, since it is doubtful that any two people would discriminate boundaries at exactly the same loci, such identifications will probably be the best possible compromise that judgement permits. Automation techniques would be useful for the high reliability categories, but the other categories will probably require a man-machine interface until their identification can be standardized by a presently non-existent system.

Section V Conclusions and Recommendations

The investigation of the Gemini and Apollo photography has led to the development of a methodology for extracting land use data from satellite imagery and a tentative classification system to structure the data for land use mapping. The kinds of land use information interpretable from the photography necessitated the construction of a fairly generalized classification scheme. A working map scale of 1:250,000 was deemed the most suitable for cartographically displaying the observable land uses. A map possessing even greater potential value and importance is the 1:1,000,000 reduction. This shows the interpretable land uses in the southwestern U.S., and also includes, as part of the map, a Gemini photo-mosaic base. A person examining this map, therefore, is able not only to observe broad land use categories, but can also see the relationship between land use and certain elements of the physical environment. The map thus acquires added usefulness because not only is it based on remote-sensing images, but utilizes these as an integral part of the final product. The research leading to the map revealed certain strengths and limitations of satellite imagery.

The strengths of the photography include coverage, scale, speed of interpretation, reduction of field work, and potential periodic coverage. The extensive coverage provides up-to-date information about areas in the U.S. where little available conventional aerial photography of recent

date exists. Of course for some areas in the world satellite imagery may be all that is available. The scale of satellite photography permits a very large area to be recorded on a single frame--which is a definite advantage in terms of areal perspective. The problem inherent in the mosaicing of numerous smaller photographs to cover the same area with the tonal and textural variations resulting from such mosaicing is, of course, solved. The speed of interpretation, compared to performing the same tasks on the ground, involves savings of months or even years of field work. Field work cannot be completely eliminated, but satellite photography can at least relieve the investigator of many routine procedures, e.g., mapping the size and shape of agricultural fields delimiting urban area, etc. The potential of future periodic coverage (perhaps on a monthly or yearly basis) is very important for studying the dynamics of land use changes. All of these factors greatly facilitate the task of the researcher to map land uses or investigate aspects of land use.

There are limitations to satellite photography, but some, perhaps most, can be overcome. Among these are the lack of systematic overlapping coverage, limited stereoscopic viewing opportunities, poor resolution, and varying image quality. These are important problems, associated with the technical aspects of photography, and can be met by improved technology and/or a more systematic approach to the acquisition of imagery. Concerted efforts are being made to provide solutions to these problems as evidenced by the improved image quality and systemization of coverage of the Apollo 6 and Apollo 9 missions in comparison with the Gemini photography.

There are problems, however, that center on the interpreter. Mapping of land uses from satellite photography involves the delimitation of boundaries. Phenomena such as agricultural fields or mining can be delimited with reasonable precision because geometry as well as spectral signatures can be used. However, drawing a boundary between categories such as grazing and woodland areas becomes very difficult since reflectance characteristics are the principal bases for differentiation. Such distinctions place a higher reliance on judgment and inference than required for distinguishing between more discrete categories as indicated above. The importance of knowledge of man-land relationships and also field work is very evident in this situation, both for determining the nature of unknown signatures and increasing the precision in distinguishing between similar signatures. The point should be made that, although there is a subjective element involved, photographic interpretation materially reduces the number of areas that actually need to be field checked for verification purposes (especially for such broad categories as are involved in the present investigation).

This program clearly demonstrates that satellite photography has definite utility for land use mapping at intermediate or smaller map scales. The photography was certainly of variable quality, but a significant number of solid land use categories were extracted from data generated by the imagery. The value of such generalized mapping might be questioned, but it is certainly a requisite first step in any analysis of resources in an area. In developing countries, even rudimentary land use maps may not exist, or be of such quality as to be almost useless.

Satellite photography can be a valuable geographic tool for land use mapping, but it must not be pushed beyond photographic limits and the geographical knowledge of the investigator.

This investigation is certainly not the final word on the subject. Several possible programs are logical extensions of this work: 1) in-depth research on particular resources, such as crop types and crop yields is feasible; 2) a study of land use changes through time could be conducted; 3) a foreign area investigation in an arid country such as Peru or the Sudan might be undertaken to test the implications of this study. More research is clearly necessary to determine and evaluate the potentials of satellite photography as a geographic aid in land use mapping and other related activities.

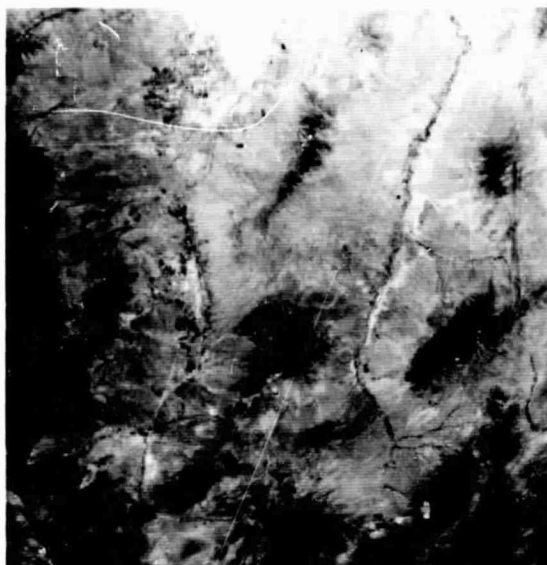


Figure 1. Satellite photograph of agricultural fields located in the San Pedro River valley, southwest of Willcox Playa. Arizona (GT 4 - R 8 - FR 13)



Figure 2. Ground photograph of agriculture in the San Pedro River valley. View is looking west towards the Huachuca Mountains. (December, 1968).

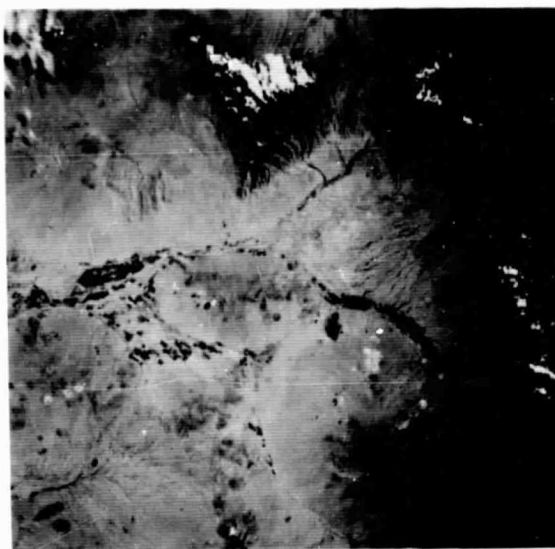


Figure 3. Forest cover on Santa Catalina Mountains, northeast of Tucson, Arizona, as recorded on Gemini photography. (GT 5 - R 1 - FR 16).

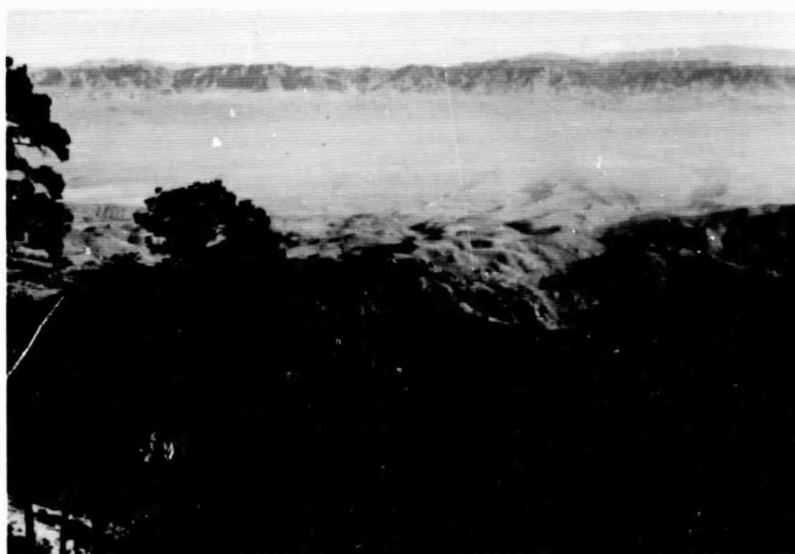


Figure 4. Terrestrial photograph shows forest cover on the north slope of the Santa Catalina Mountains, looking northeast towards the San Pedro River valley. (December, 1968).

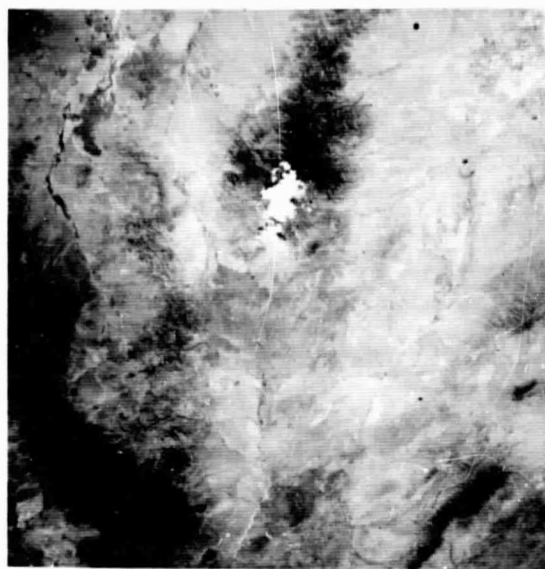


Figure 5. Woodland area on the Huachuca Mountains as imaged by a Gemini mission. (GT 4 - R 8 - FR 11).



Figure 6. Ground picture of the woodland area on the Huachuca Mountains, looking west over the Fort Huachuca residential quarters. (December, 1968).



Figure 7. Gemini photograph of Willcox Playa, Arizona, a feature classified as unproductive. (GT 5 - R 1 - FR 17).



Figure 8. Terrestrial picture of Willcox Playa. View is looking to the east. (December, 1968).

BIBLIOGRAPHY

- Alexander, Robert H. "Geographic Research Potential of Earth Satellites," Proceedings of the Third Symposium on Remote Sensing of Environment. Ann Arbor: University of Michigan, 1964, pp. 453-67.
- Christodoulou, Demetrios. The Evolution of the Rural Land Use Pattern in Cyprus. London: A. P. Tayler & Co. Ltd., 1959.
- Christodoulou, Demetrios. Land Utilization Map of Cyprus. London: A. P. Tayler & Co. Ltd., 1959. Map supplement.
- Colwell, Robert N. (ed.) Manual of Photographic Interpretation. Menasha: George Banta Company, Inc., 1960.
- Colwell, Robert N. "Determining the Usefulness of Space Photography for Natural Resource Inventory," Proceedings of the Fifth Symposium on Remote Sensing of Environment. Ann Arbor: University of Michigan, 1968, pp. 249-289.
- Earth Photographs From Gemini III, IV, and V. Washington, D. C.: National Aeronautical and Space Administration, NASA SP-129, 1967.
- Humphrey, R. R. Arizona Natural Vegetation 1963. Tucson: University of Arizona, College of Agriculture, Bulletin A-45, 1965. Map.
- Jacks, G. V. "Land Classification For Land Use Planning," Imperial Bureau of Soil Science, Technical Communication No. 43, 1946, pp. 1-90.
- Kuchler, A. W. Potential Natural Vegetation of the Conterminous United States. New York: American Geographical Society, Special Publication No. 36, 1964. Manual and map.
- Leaming, Dr. George F. Personal Communication, Tucson: University of Arizona, Division of Economic and Business Research, December, 1968.
- Marschner, F. J. Land Use and Its Patterns in the United States. Washington, D. C.: United States Department of Agriculture, Agriculture Handbook, No. 153, 1958.
- Morrison, A. and J. B. Bird. Photography of the Earth From Space and Its Non-Meteorological Applications. Ann Arbor: Institute of Science and Technology, 1964.
- Morrison, Roger B. Reconnaissance Soil-Association Map Overlay to Gemini 1:1 Million Photomap. Houston: National Aeronautical and Space Administration, NASA-111, 1968.
- Senger, Leslie W. "Land Use Mapping Potential of Gemini Satellite Photography." Los Angeles: University of California, Department of Geography, unpublished Master's Thesis, 1969.

- Senger, Leslie W. "Land Use Mapping of the Southwestern United States from Satellite Imagery." Paper presented at 32nd Annual Meeting of the Association of Pacific Coast Geographers, June, 1969.
- Simonett, David S. "Present and Future Needs of Remote Sensing in Geography," Proceedings of the Fourth Symposium on Remote Sensing of Environment. Ann Arbor: University of Michigan, 1966, pp. 37-47.
- Smith, John T. (ed.) Manual of Color Aerial Photography. Menasha: George Banta Co., 1968.
- Stamp, L. Dudley. The Land Utilization Survey of Britain. London: University of London, 1935.
- Thaman, Randolph R. "A Study of the Feasibility of Mapping Vegetation on a World Scale Using Satellite Imagery." Berkeley: University of California, Department of Forestry, unpublished Master's Thesis, 1967.
- Thrower, Norman J. W. "Graduate Training in Remote Sensing for Geographers." Yearbook of Pacific Coast Geographers, Vol. 32, 1970 (in press).
- Thrower, Norman J. W. and Leslie W. Senger. "Land Use Mapping of the Southwestern United States from Satellite Imagery." Paper presented at National Meeting of the American Astronautical Society, October, 1969.
- U. S. Army Corps of Engineers. Earth Resource Surveys From Spacecraft. Washington, D. C.: National Aeronautical and Space Administration, NASA, Vols. 1 and 2, 1967.
- U. S. Army Corps of Engineers. "Cartographic Changes From a Space Photo," Earth Resource Surveys From Spacecraft, Vol. 1, 1967, pp. B10-B11.
- Wilson, Richard C. "Space Photography As Applied to Forestry," Earth Resource Surveys From Spacecraft, Vol. 1, 1967, pp. C2-C6.
- Wobber, Frank J. Environmental Studies Using Gemini Photography. Bethesda: International Business Machines Corporation, 1968.