REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

FORESTRY REMOTE SENSING LABORATORY,
BERKELEY, CALIFORNIA—

A Coordination Facility Administered By

The School of Forestry and Conservation,
University of California in Cooperation with the
Forest Service, U.S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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THE FEASIBILITY OF INVENTORYING NATIVE VEGETATION AND RELATED RESOURCES FROM SPACE PHOTOGRAPHY

By

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Department of Range Management
Agricultural Experiment Station
Oregon State University

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ABSTRACT

Space photography taken during the Gemini IV overflight of southern Arizona is being studied to assess the appropriateness of this system of remote sensing for inventorying native vegetation and related resources. Close examination of frame S-65-34681 and experience in relating images to their vegetation and soil subjects indicate that a meaningful inventory of these resources can be accomplished through the use of space photography. Indeed, the synoptic coverage makes this system unique among those alternatives readily available at this time. The need for a more accurate small-scale representation is real. A work flow chart presents ways to proceed toward this goal. The goal--an inventory--can be obtained through strict adherence to specified mapping concepts and ecological principles as they apply to several steps in the flow chart. In this way, photo images can be delineated and identified in a meaningful manner. Production of an inventory only follows successful solution of several problems in the development of ground-truth and image interpretation. Sub-sampling aerial photography has been investigated as a means for solving subject discrimination problems. Image to subject relationship problems are resolved by developing a phytosociological interpretation of the vegetation that is consistent with the scale and resolution of the space photography.

ACKNOWLEDGEMENTS

This research was performed under the sponsorship and financial assistance of the National Aeronautics and Space Administration for the Earth Resources Survey Program in Agriculture/Forestry, Contract Number R-09-038-002.

Appreciation is expressed to Robert N. Colwell, David M. Carneggie, Gene A. Thorley and Robert C. Heller for their contributions to the project through suggestions, conferences and response to inquiry for which they willingly gave their time.

We wish to acknowledge the willing cooperation and help of Dillard H. Gates, Range Management Extension Specialist, Oregon State University, and E. William Anderson, Soil Conservation Service, Portland, Oregon, for serving very enthusiastically as "guinea pig" interpreters in some of our tests. They have indicated an interest in continuing to serve the project in this way and we are both encouraged by and appreciative of their contributions to date.

Appreciation is also expressed to the Soil Conservation Service, Cartographic Division, Portland, Oregon, for allowing us to use their equipment to make a rectified enlargement of Gemini Frame 11. This greatly increased the accuracy with which we could locate on the Gemini imagery and permitted more critical consideration of subject-image relationships.

Thanks are expressed to Robert C. Heller, of the U. S. Forest Service, Pacific Southwest Forest and Range Experiment Station, who took some 70mm, sub-sampling aerial photography for us in both color infrared and ektachrome.

Under his project on the mapping of desert vegetation, Dr. Ray M.

Turner, U. S. Geological Survey, has had some imagery flown in this area with color infrared film in 5 x 5 inch format with a wide space 1 3/4 inch Aviogon lens from an altitude of 33,000 feet giving representative scales ranging from about 1:210,000 to 1:120,000. We graciously acknowledge the opportunity to examine this photography as a sub-sample in some of our problem areas and to use copies of key frames for illustration and study. Dr. Turner has been additionally helpful to our field crew in many ways.

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THE FEASIBILITY OF INVENTORYING NATIVE VEGETATION AND RELATED RESOURCES FROM SPACE PHOTOGRAPHY

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INTRODUCTION

The development of practical uses for earth resources photography taken from space platforms is of vital interest to the National Aeronautics and Space Administration. With the amount of photographic imagery now available and projected for the relatively near future, it is critically important that the use of available imagery be tested for all earth resources applications. This will make it possible to plan new tests with systems optimized on the basis of all relevant applications experience. One of the most important potential uses of this imagery is in the broad-scale analysis and synoptic treatment of the native vegetation resources (rangeland and forests) of our nation and the earth. According to a National Research Council Survey (cited by Lauer, 1967), only thirty percent of the world has been adequately mapped in terms of even small-scale resource maps. Highly productive rangelands comprise fully forty-six percent of the earth's land mass; and if one adds the useful "desert" vegetation types and grazeable, open forests, the figure goes much higher (Shantz, 1954).

On the domestic scene, rangeland comprises forty-nine percent of the area of the United States, excluding Alaska (Williams, 1968). Had the tremendous areas of tundra, meadow, and forage- and browse-producing forest openings been added to this figure, the grazing resource for domestic and big-game animals in the United States would greatly exceed half of our land area. Good figures do not exist on the specific contribution that rangeland resources make to our gross national product. Accurate estimates cannot be derived from the presently available information and statistics. In desperation, however, the senior author once attempted to estimate, from this deplorable base, the contribution that rangelands may make to our gross national product from domestic livestock grazing alone. The figure came out in the range of $500 to $700 million dollars per annum. This does not consider the value of game animals harvested annually from this same resource. No one knows an accurate, total dollar value, but it is very high in nine figures and may even reach to a billion or more dollars per annum.

On the local level the figures become a bit more reliable. In the State of Oregon, for instance, a representative western state, rangeland comprises close to fifty percent of our land area. Forestry and a highly diversified agricultural industry are our first and second ranking industries, respectively. In domestic livestock products alone, the rangeland resource accounts for twenty-eight percent of the agricultural income to our state. Many states of the West and southern coastal plain can equal or better this level in the importance of their range resources.

Looking at our national forests--where statistical information is reasonably good--one can derive from the reports of the Chief of the Forest Service and from the Economics Research Service the following information on the comparative value of the range resource on the national forests:

YEAR	STUMPAGE SALES	ANIMAL GAIN VALUES	% OF STUMPAGE SALES
1955	$ 73,187,364	$51,918,477	71.0%
1960	$139,900,000	$68,090,472	48.7%
1967	$208,603,585	$71,963,478	34.5%

Thus, it should be obvious to all that we are dealing with a resource sufficiently important that it cannot be overlooked in the conduct of the Earth Resources Program and that we do have some information needs that are appropriate to solution with space photography playing a potentially important role.

In recognition of the need for synoptic coverage in the analysis of rangeland resources, the American Society of Range Management is establishing an ad hoc committee to consider and make plans for "a comprehensive appraisal of the nation's grazing resources." The presently expressed hope of the Society is to involve the National Research Council, at least in the initial program planning and development venture. Similarly, the National Forestry Research Advisory Committee to the Secretary of Agriculture has repeatedly discussed and recommended a nation-wide survey and analysis of rangeland resources. In his 27 August 1968 Newsletter, Sam S. Studebaker, President of the National Association of Soil and Water Conservation Districts, urged the conduct of complete natural resource surveys. He quoted Mr. Elbert Roe, President of their Indiana association and Chairman of an Area Resource Planning Team, "...officials of every conservation district ought to have an up-to-date map showing all the natural resources within the district's boundaries as well as the current use and condition of these resources....such a map is utterly essential to effective functioning of a district in the resources field. . . Districts and counties can't make intelligent resource plans without such an inventory." Along similar lines, five counties in Oregon are currently attempting to compile comprehensive resource maps for use by county planning commissions. This program is literally handicapped by lack of synoptic photo coverage. It is certainly conceivable that space photography of appropriate type and quality could play a very important role in these kinds of programs.

Being active in research on methods of analyzing vegetation and soil resources on both range and forest land, some of the good quality Gemini IV photography "kindled a fire" of keen interest in the senior author. The potentiality of this new tool for synoptic vegetation resource analysis was obvious, particularly in the rangeland environments. A preliminary feasibility study was conducted by Poulton and Roberts in December, 1966 (Carneggie, Poulton and Roberts, 1967, p. 47-57). This study answered the question of feasibility in the affirmative and suggested that further work is not only feasible but justified and urgently needed to support the Earth Resources Program of NASA.

Subsequently, Colwell did similar work with Gemini photography taken over Australia with equally encouraging results. He published a good resume of potentiality and some of the uses of space photography when properly ground checked and interpreted (Colwell, 1968b). This work confirmed the feasibility of practical uses and the need for further applications research. As a result of his efforts, Colwell also published an effective general procedure for the study and use of space photography and demonstrated techniques for rapidly learning to interpret space imagery from low-flying aircraft (Colwell, 1968a).

The work of Poulton and Roberts tested a more detailed level of ground truth acquisition for use in areas where the plant community ecology and vegetation-image relationships had not been previously worked out. Our methods for gathering ground truth data also proved workable and, together, we showed that the use and application of space photography to vegetation resource survey and analysis would not require comprehensive preliminary studies in the development of methods--we were ready to get on with the job. Obviously, some adaptations of methods and procedures were indicated to meet the problems unique to the interpretation of Gemini-type imagery; but the problems were indicated as simple and the solutions easy.

Our 1967 Progress Report provided a comprehensive treatment of the importance of rangeland in the Earth Resources Program (Carneggie, et al., 1967, p. 8-17) and suggested areas in which the analysis of Gemini-type photography could aid in the orderly development and use of these resources (Ibid., p. 47-57). The 1966 procedures were briefly treated. Photographic comparisons were made between existing small-scale vegetation resource maps and some of the kinds of range resource features that were discernable on the Gemini photography. The usefulness of Gemini IV photography in identifying and locating naturally-vegetated areas for potential agricultural development was illustrated. The limitations and advantages of satellite photography for vegetation mapping were discussed to the extent they were understood at that time. The 1967 report recognized that useful ecological interpretation of vegetation (from Gemini-quality photography) cannot be made without research to acquire and analyze ground truth in relation to photo-image characteristics. This is the problem on which 1968 activity has concentrated.

One of the things that stimulated us from the 1966 work was the amount of interpretive information that seemed to be available from the Gemini IV photos. Some people with whom we discussed the work commented, "Just imagine how good it would be if our small-scale vegetation resource maps were on that kind of a photographic base." We were further encouraged to learn that, in spite of low resolution in relation to what we had become accustomed in conventional aerial photography, the more we studied the Gemini photos, the more we could see and interpret.

It is important for all concerned to recognize that there are certain resolution limitations placed on space photography and that one of the objectives of this and related research should be to learn what practical and useful applications may be made of the imagery within the framework of these limitations. Hopefully, these limitations will be relaxed in the future because of the added gains that the whole earth resources community can realize from advances in allowable ground resolution. In the meantime, indications of our research to date are that substantial use can be made of space photography of Gemini IV, V, VII and Apollo VI quality in the analysis of rangeland resources and in many other native vegetation applications.

The progress illustrated and discussed in this report covers the period May through September, 1968. The report period is limited in this way because funding was not confirmed until late in the second quarter and expanded activity did not begin until about the middle of the third quarter. The research is an integral part of the Earth Resources Program and is coordinated through the Forestry Remote Sensing Laboratory, Berkeley, California. This year's research represents an expansion of activity under added financing to Oregon State University. It is a continuation of the preliminary feasibility work referred to above.

Our contributing project has the following title and objectives: "Feasibility of Inventorying Native Vegetation and Related Resources from Space Photography."

Objectives:

1. Determine the potentialities and limitations of mapping and interpreting characteristics of native vegetation areas from space photography.
2. Compare vegetation maps prepared from this photography with other available vegetation resource maps.
3. Identify problems and limitations in the practical use of space photography in Earth resources applications.

Our work to date has contributed to all three of these objectives with effort focused primarily on objective one.

Personnel

With funding of this project in May, 1968, the study leader was able to devote substantially more time to the project and we were very fortunate to obtain two capable graduate research assistants, the second and third authors of this report, whose backgrounds of experience and training were admirably suited to work on this project. In addition, colleagues at Oregon State University, at the University of California and at the University of Arizona have expressed a willingness to serve as experimental photo interpreters in testing phases of the research. Two of them have already contributed by performing experimental interpretation tests.

Research Concepts and Principles

In our experience, it is necessary to present some of the more important concepts and principles that are especially applicable to research and application in the resource analysis field. These are best presented under three headings, General Concepts, Ecological Concepts, and Mapping Concepts (Culver and Poulton, 1968).

General Concepts:

The first general concept might be identified as the Concept of Simplification. This occupies the status of a principle that must not be violated. It may be stated, "simplification and generalization must follow, not precede, a reasonably thorough understanding of the subject or system being simplified." Many attempts to use ecology, and some attempts to make use of remote sensing capability, have fallen short of potential goals because the administrator or user pushed the research or staff scientist into a quick or pseudo-practical short cut. Systems well understood by a capable scientist or staff man can usually be effectively simplified to meet practical management needs; but attempts at simplification without understanding nearly always lead to error, important oversights and partial or complete failure. They nearly always require unnecessary repetition of the work.

Secondly, given a set of remote sensing data or photographs with specified resolution and quality for use in resource analysis, it is generally unwise and shortsighted not to separate, identify and characterize each of the unique images registered by the system. In some cases, imagery will detect subtle differences that are not biologically meaningful or important for any anticipated or imagined use. These may be disregarded once they are identified. Depending on the kind of imagery and the information needed, particular systems may also fail to discriminate all the classes of information needed; but generalization beyond the discernable, biologically significant and potentially useful information contained in the imagery represents a real information loss to the resource manager. Over time, such unwarranted generalization will usually require reinterpretation of the imagery or redoing the entire job--often at unreasonably increased total cost.

Ecological Concepts:

Some guiding ecological concepts, premises and principles are next in importance. In the analysis and mapping of native vegetation resources, we are not concerned with individual species, per se, but rather with the natural sociological groups of plants--that is, with the identification and mapping of the boundaries of natural plant groupings as these are found to extend contiguously or to be repeated at separate locations across the landscape. In actuality, we are concerned with the interpretation of the plant society or of the plant society and its associated soil surface and relief conditions as these are found to occur together in classifiable vegetation-soils-landform units on the landscape. Depending on the objectives or information needs to be met and on the kind of imagery being used, these classes may be at different hierarchical levels; but each class should be reasonably consistent with a natural, not a utilitarian, grouping and should be compatible with the amount of detail observable and/or interpretable in the imagery.

The dominant and guiding ecological concept or premise in this kind of work may be stated as follows: In native vegetation areas, the homogeneous communities or other hierarchical groupings of plants that occupy the landscape are the best indicators of the biological similarity of the areas so occupied and of the inherent productive capacity or site capability of the usually discontinuous areas that these similar vegetations occupy. Vegetation resource examination is, therefore, fundamentally ecological. An understanding of phytosociology and of vegetation-soil-climatic interrelationships provides the basis for extracting information from remote sensing data about these resources.

Some supporting ecological premises have been identified as follows:

1. Similar plant communities or hierarchical groupings are usually repeated across the landscape.
2. Key plant or vegetation indicators tend to remain on the site or location in spite of man's disturbance.
3. Application of vegetation indicator concepts is successful only when vegetation-soil relationships are studied at the same locations.
4. Ecological climax, site potential, and land productivity are interpretations from ground truth, remote sensing, and cartographic data. These interpretations must, therefore, follow acquisition of the basic resource information. It is unwise to map initially with a legend that denotes only these interpretations of the ecosystems.
5. Vegetation ecotones (zones of gradation on the landscape from one community or hierarchical grouping to another) may be sharp in response to an abrupt environmental change and either gradual or abrupt in response to a gradual environmental gradient (Daubenmire, 1968).

None of these types of ecotones negate accurate mapping of vegetation resource characteristics when delineating the plant community or hierarchical grouping boundaries. Abrupt ecotones nearly always appear sharp in remote sensing imagery regardless of scale. Gradual ecotones often become more clearly defined as the scale of imagery decreases. Even broad regional ecotones between major vegetation formations may become clearly evident and be more accurately mapped on synoptic space photography than on larger scale aerial coverage.

Mapping Concepts:

A failure to understand some long-established and widely used mapping concepts often contributes to semantics problems among those engaged in resource analysis work. It is important that we understand these concepts. They are as essential to the mapping of vegetation resource features from space photography as from any other kind or scale of imagery. These concepts are concerned with what has become widely known as Taxonomic Units, Simple Mapping Units, Complex Mapping Units, and Inclusions. All have to do with what and how features are cartographically represented. Of importance also are the concepts of symbolization and description of what is mapped.

As compared to conventional mapping experiences of most natural resources people, the only things that have changed with space photography are scale and ground resolution. More of the variation in surface features tends to be integrated into a uniform image--depending on the contrast in spectral reflectance or emission from the component subjects in relation to ground resolution of the imaging system. Our primary task as interpreters is to learn to discriminate and identify for useful purposes these more grossly integrated images.

The Taxonomic Unit is determined by the smallest class of surface features that is discernible in the imagery. In other words, it is the smallest hierarchical grouping of vegetation and soil surface features that can be consistently identified on space photography. Thus, individual examples of a taxonomic unit may be physically large or very small on the imagery available. It may or may not be cartographically feasible to map each taxonomic unit as a unique delineation in characterizing the resources from space imagery. The primary determinant here is scale. The photo interpreter or image analyst strives to identify the taxonomic unit found at each location on the imagery. This is based on the characterization and classification of both the ground-truth data and the images and on such consistent ground-truth to image relationships as the analyst can discover. Depending on the physical size and arrangement of these fundamental units, he then decides on a way to make a meaningful, cartographic representation of each area. This may be done by putting lines around single taxonomic units or by grouping them where intricate patterns require.

The Mapping Unit is the feature or features around which delineations are drawn. It is derived from a knowledge of the taxonomic units and an analysis of the imagery. Where cartographically feasible, mapping units should always define individual taxonomic units. In this case, they may be referred to as pure or Simple Mapping Units. Where intricate patterns of vegetation and other ground features require, mapping units may consist of two or more kinds of taxonomic units. These are appropriately referred to as Complex Mapping Units or complexes of taxonomic units.

Both simple and complex mapping units may contain small areas of unique and contrasting taxonomic units that are both too small to be mapped separately and negligible in terms of comparative area or size. These are called Inclusions and they are ignored purely for practical reasons both in data gathering and in symbolizing or describing the characteristics of the mapping unit in which they occur. Percentage area cutoff points are usually arbitrarily defined for inclusions, commonly ten to twenty percent of the delineation area.

Where the "lay of the land" requires that mapping units be made up of complexes of taxonomic units, it is exceedingly important that those delineations be characterized by identifying each taxonomic component separately. Only in this way can accurate resource information be conveyed. Common practice has often dictated that such complex units be identified by "averaging out" the separate components in a single description or symbol. Although the nature of inclusions is often mentioned in reporting resource analysis information, the practice of averaging their characteristics with those of the main component of the delineation is intolerable. When and if this is done, misleading resource information is presented.

PROCEDURES

Most of the procedures used in this project have been applied directly or adapted from previous experience in related projects conducted by the study leader and his graduate students. The Range Management Program at Oregon State University has been engaged in fundamental studies of plant sociology leading to vegetation classification in both range and forested environments and in vegetation-environment relationship studies for seventeen years. A portion of our staff has been deeply involved in research to develop improved methods for the ecological analysis of rangeland resources since 1962. In addition, we have been involved for three years in a practical survey and range resource analysis program on 700,000 acres of isolated state-owned rangeland in Oregon. These programs, particularly the latter, have made heavy use of aerial photo-interpretation as a means of: (1) increasing efficiency and cutting costs of the resource analysis, and (2) minimizing but not replacing ground work in the survey procedure. This background of experience has resulted not only in the identification of applicable principles and concepts, but the development of procedures that are directly useful in the analysis of vegetation resources from space photography. This experience was summarized into a flow chart and the procedural details adapted to the needs of this project.

Work Flow Chart

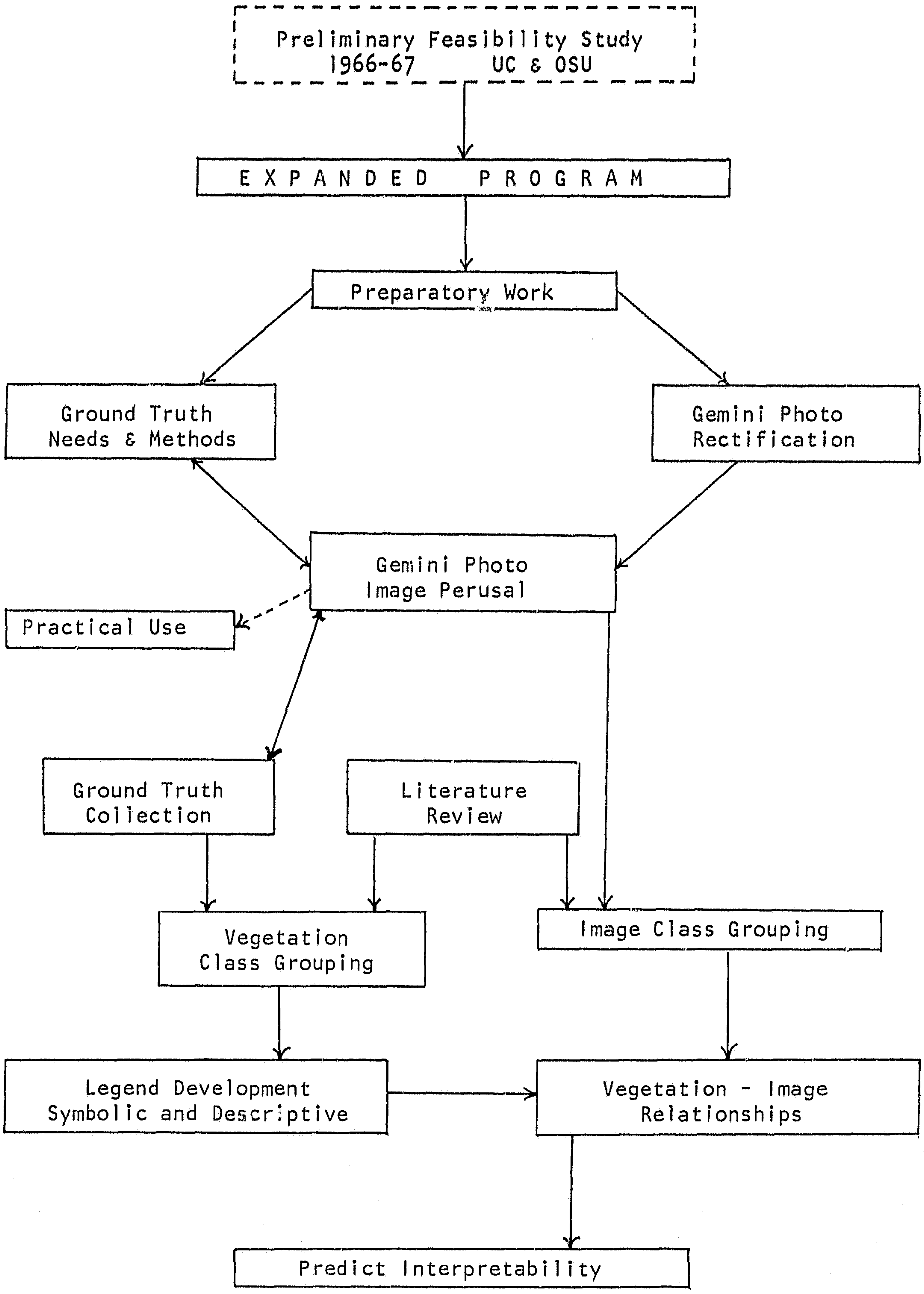
The first approximation of a work flow chart for the interpretation and practical use of space photography in vegetation and related resource analysis is presented in Figure 1. This is adapted from a flow chart for our range resource analysis work on state-owned rangeland in Oregon (Poulton, 1968).

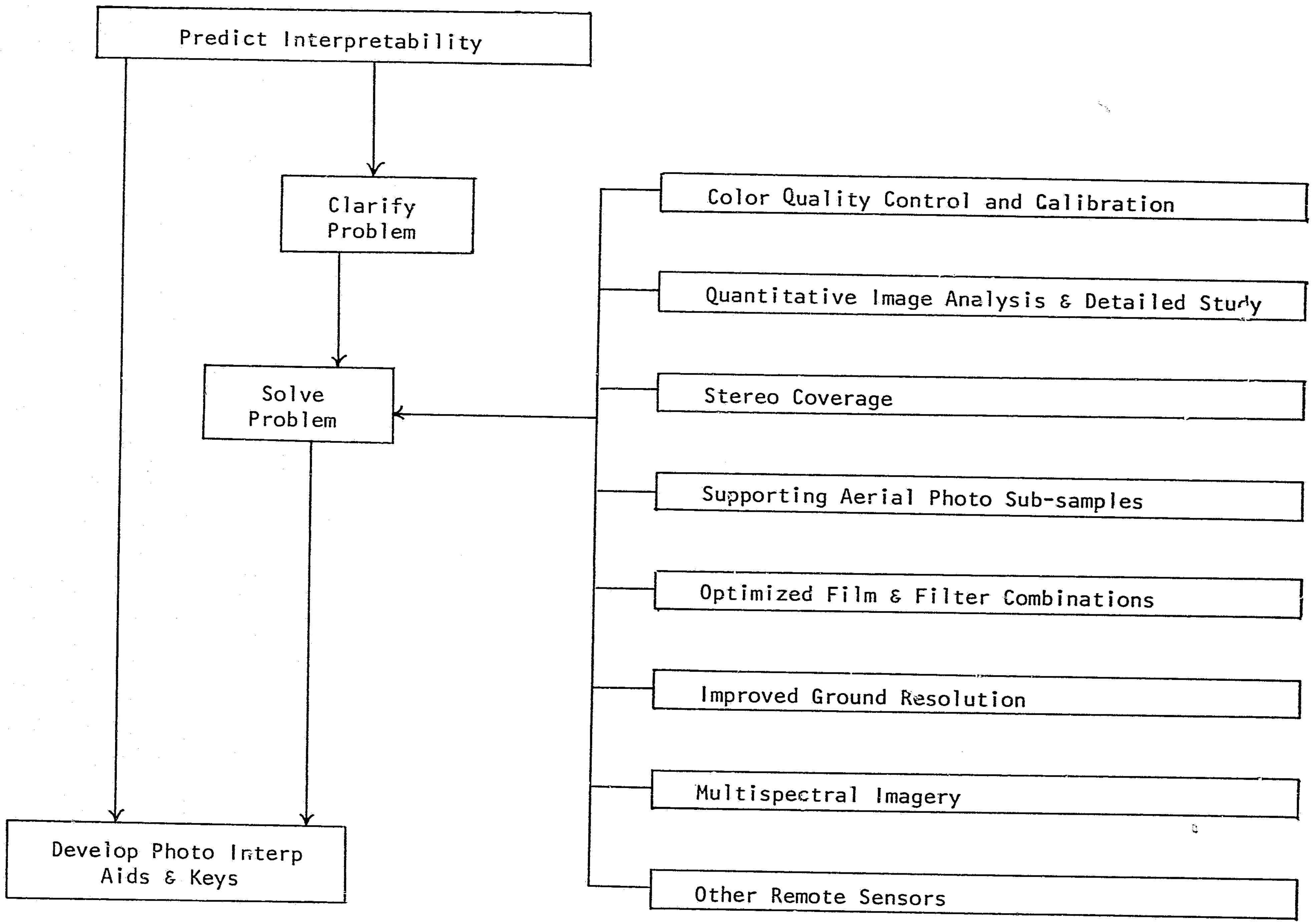
The major phases of work flow in the practical use of remote sensing photography for vegetation resource analysis are as follows:

1. Assembly and preparation of working materials,
2. Preparation of legends and photo interpretation aids,
3. Project survey or area resource analysis,
4. Compilation and reporting, and
5. Interpretation and practical use of information.

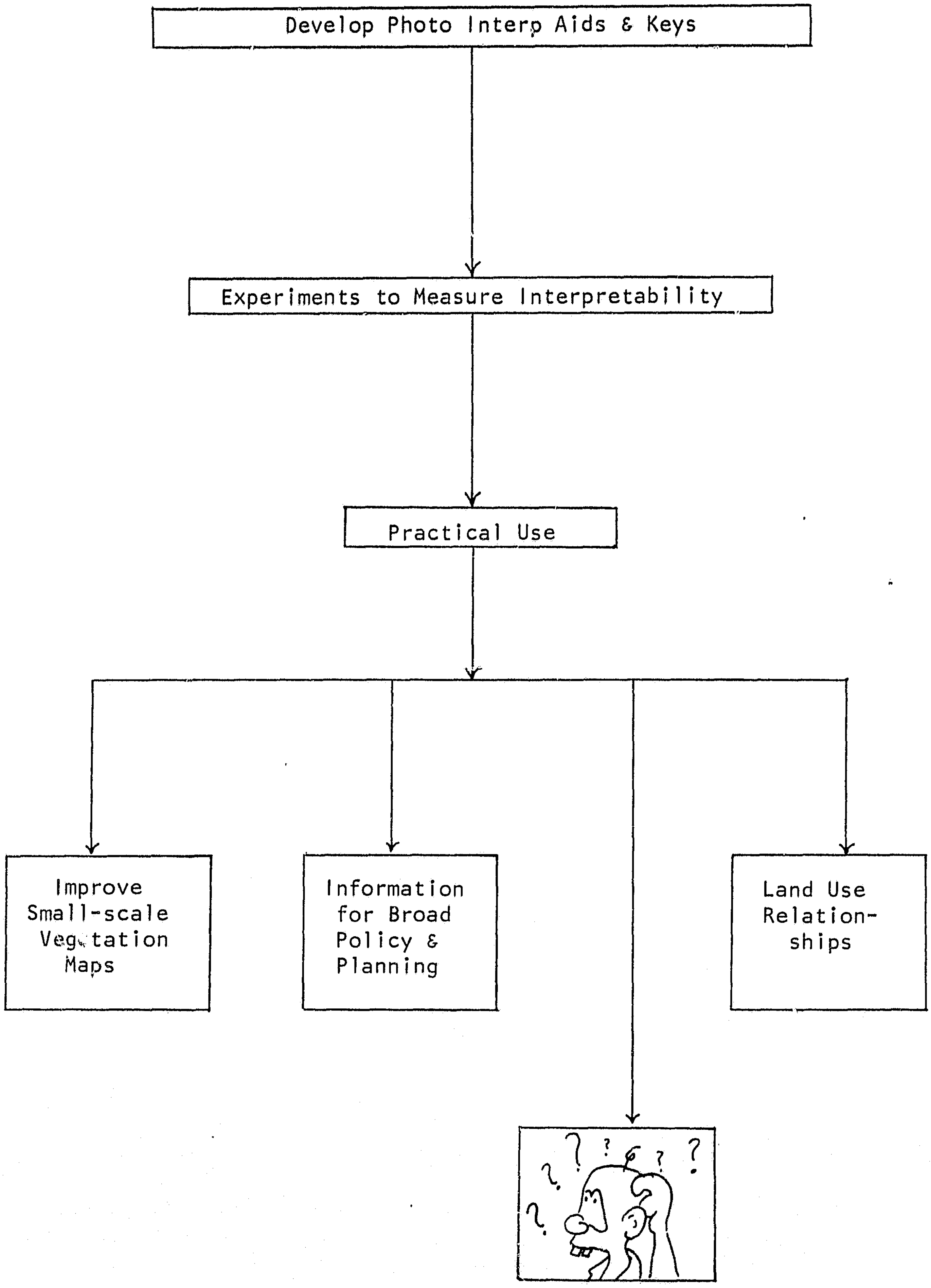
The flow chart presented in Figure 1 covers activity through Phase 2 and into Phase 3. Part of the activity under Phase 3 and all of Phases 4 and 5

Figure 1: The first approximation of a work flow chart for the interpretation and use of space photography in vegetation and related resource analysis is presented on the following three pages. Some sections of the flow chart will be expanded into greater detail as the research moves ahead. Notice that some information of practical value begins to spin off with the preliminary but intensive perusal of the space photography (page 15) and that the amount of practical use eventually made of the space imagery and information derived therefrom is very strongly dependent upon the imagination, originality, and resourcefulness of the user (page 17)--to say nothing of the interpreter who provides the information.


Preliminary Feasibility Study
1966-67 UC & OSU
EXPANDED PROGRAM
Preparatory Work
Ground Truth
Needs & Methods
Gemini Photo
Rectification
Gemini Photo
Image Perusal
Practical Use
Ground Truth
Collection
Literature
Review
Vegetation
Class Grouping
Image Class Grouping
Legend Development
Symbolic and Descriptive
Vegetation - Image
Relationships
Predict Interpretability



Predict Interpretability
Clarify Problem
Solve Problem
Develop Photo Interp Aids & Keys
Color Quality Control and Calibration
Quantitative Image Analysis & Detailed Study
Stereo Coverage
Supporting Aerial Photo Sub-samples
Optimized Film & Filter Combinations
Improved Ground Resolution
Multispectral Imagery
Other Remote Sensors


Develop Photo Interp Aids & Keys
Experiments to Measure Interpretability
Practical Use
Improve Small-scale Vegetation Maps
Information for Broad Policy & Planning
Land Use Relationships

are embodied in the concluding block of Figure 1, Practical Use (page 17).

In considering a work flow chart, it is important to realize that all blocks are not mutually exclusive. They are often intricately related by a complicated series of activities that merge into one another and sometimes back again. There is more mutual support among the blocks than can be depicted by the main-flow arrows. Some work in the initial blocks often contributes to accomplishments logically allocated to advanced blocks. One should also accept the fact that new discoveries made in the Practical Use stages may require that work originally considered complete be redone or strengthened. In the last few months and for the immediate future, activity will be concentrated on the last five activity blocks (bottom of page 15).

Selection of a Working Area

The selection of a working area falls in the Preparatory Work block on the flow chart. While area selection for our 1966 work was almost entirely one of convenience in travel out of Tucson, Arizona, it has proven to be fortunate as a selection. This question was reconsidered when our present effort began, and the same frame of Gemini IV photography, S-65-34681, Magazine 8, frame 11, was confirmed as best for our continuing work. Frames S-65-34678 through 34685, Magazine 8, frames 8 through 15, were considered. The selected frame covers the area from Tucson to Wilcox Lake and Nogales to Bisbee, parts of three counties. Its advantages as a study frame are:

1. good color balance in the copies we have and reasonably good ground resolution;

2. more ground truth stations from our 1966 work on this frame than any other;
3. its location facilitated travel from Tucson where we could benefit from contacts with consultants and potential colleagues at the University of Arizona; and
4. one frame spanned examples of four major vegetation resource areas in the southwest:
   a. The Sonoran Desert,
   b. The Chihuahuan Desert,
   c. The "Desert Grassland" or Southwestern Shrub Steppe, and
   d. The Chaparral and forested vegetation zones in numerous mountain ranges.

These photos were taken June 5, 1965 on Orbit 32 at 1742-1743 G.m.t. A hand held Hasselblad camera was used with a Zeiss Planar 80 mm. lens having resolution in excess of one hundred lines per millimeter from an orbital altitude estimated at approximately 105 miles. Exposures were 1/250 second at f 11 (personal communication - Richard W. Underwood, 1967).

Ground Truth Methods

The ground truth record card was also adapted from our other experience to meet the requirements for documenting vegetation, soil surface and physiographic factors that may influence the visible-spectrum images in space photography. Marginal, hand-sorted punched cards were used to facilitate data summarization as the number of records increased. The ground truth record provides notes on the major plant species in each stand examined, with individual dominance scores, ground cover percentages, and a score or rating for sociability or tendency of the plants to cluster. Special attention is given to soil surface color, to the cover of gravel, stones, and litter and to the amount of bare ground showing through the vegetation. Such notes of photo image characteristics as seemed appropriate at each examination point were also recorded (Figure 2).

In deciding on Ground Truth Stations, two procedures were used. Both are workable if the station locations can be transferred with sufficient accuracy to the space photography. The primary and most successful procedure was to locate unique and uniform images on the Gemini frame, go to a location well within the image area on the ground, and record the appropriate data. The second procedure was to document, in a road-log manner, the changes in the vegetation and/or soil surface conditions that were observed on the ground and then to relate these changes to variation in the Gemini imagery. Obviously, the success of this latter approach depended largely on how accurately the locations could be established on the photograph. The technique was partially successful.

Each Ground Truth Station and its record card were numbered sequentially and located on the Gemini frame. Ground truth records were made both with and without supporting ground photography. Thus, it was necessary to separately number a Photo Record Card which contained the additional photographic detail. This card was cross-referenced to its appropriate Ground Truth Station. Ground photos were taken primarily in color negative and in Aero Ektachrome Infrared with a Wratten 8 or 12 filter.

These records were further supplemented by color negative and color IR photographs taken from a small aircraft. Vegetation notes relative to the Gemini images were also recorded while flying at altitudes of 1,500

Figure 2: An Example of a Ground Truth Record Card. All of the major species are recorded giving: (1) a dominance score (5 being most important and 1 least important), (2) a cover rating in percent of ground surface covered by the normal herbage spread of the species, and (3) a sociability rating of the degree of aggregation of separate plants of each species within the stand (1 indicating least and 5 most aggregated or clumped in the manner of distribution). Soil surface color is recorded in standard Munsell soil color notations of Hue, Value and Chroma. Soil surface characteristics are recorded in percent of total ground area. Most other notations are self-explanatory. Each Ground Truth Station is located and identified by number on a rectified enlargement of Gemini frame 11.

290 GTS 229 PRC; Observer EGM and BJS Date 7-22-68

Location: T 18 S; R 15 E; Secc 22 N½ of SE ¼.

VEGETATION

Species	Dom	Cov	Soc	Species	Dom	Cov	Soc
Prve	5	25-30	1	Boer	2		2
Hate	4	30-35	1	Arsp	2	4-5	2
Open	3	2-3	1	Trpu	2		2
Opar	3	1-3	1				
Opfu	3	1	1				
Fosp	3	1	1				
Acgr	2	1	1				
Basr	2	1	1				
Eptr	2	1	1				
Opsp	2	1	1				
Fewi	2	1	1				
Atca	1	1	<1				
Masp	1	1	<1				

PHYSIOGRAPHY

Elevation 4360 Ft.

Land Form Slope

Macrorelief Hilly

Slope 1-5 % Aspect W

SOIL SURFACE CHARACTERISTICS

	Color dry	Color wet	Cover
Bare Soil Surface	Rained	7.5YR4/4	10-15
Gravel			40-60
Stones			< 1
No vegetation cover			25-30
Litter			< 1

Photo Image Characteristics:
Light reddish background with a light blue covering

Remarks:
Burroweed distributed very uniform on the area. Mesquite of all age classes present giving the impression that is invading the area.

and 3,500 feet over those portions of Gemini frame 11 where we had the best distribution of Ground Truth Stations.

A problem was encountered in checking out some Gemini image boundaries on the ground. It was not always possible to see far enough or to get an adequate perspective. Some interesting image areas were not easily accessible to ground travel. Aerial photo sub-sampling in these kinds of problem areas was tested as a means of refining ground truth data, of more accurately locating Ground Truth Stations, and of checking images and image boundaries that could not be effectively scrutinized from the ground. Robert C. Heller, Pacific Southwest Forest and Range Experiment Station, took some very useful color and color IR aerial photography for the project in five subsample areas on 70 mm. format at a scale of approximately 1:16,000. Four of these have been partially ground checked.

In addition, we had the opportunity to examine and use some color IR aerial photography obtained by the U. S. Geological Survey on their desert vegetation mapping project. This photography was taken in a 5-inch format with a 1 3/4 inch Wild Aviogon lens at a scale of about 1:200,000. It proved most helpful in solving one Gemini interpretation problem and was a tremendous aid in refining the location of Ground Truth Stations on the Gemini photo where this U.S.G.S. photography happened to cover our ground observation points.

Legend Development

The descriptive legends of ground-truth data are being developed by standard phytosociological methods used in the classification of vegetation. In brief, this amounts to grouping all ground truth stations according to similarities in the species comprising the plant societies at the respective examination points. These groups are then described on the basis of the data contained in the ground-truth record for the group. These groups are then correlated with the photo images to the point that it becomes possible to state which plant society groupings are represented either singly and uniquely or in combination by the various photo images. The written descriptions, data summaries, and supporting ground photographs representing those groupings that are related to the photo images become the descriptive legend. Thus, the descriptive legend presents those plant community or hierarchical groupings that can be identified from correctly interpreted photo images. It is from this information that photo interpretation keys and aids may be developed to make possible image interpretation by potential users. Before the final, practical application of the legends and keys can be made, a symbolic legend is required. This is an abbreviated notation, either connotative or non-connotative, that permits one to label each mapped delineation in terms of the descriptive legend units. This phase of the procedures will be more fully treated in later reports.

RESULTS AND DISCUSSION

Interpretive Capability Without Ground Checking

One of the major areas of potential applicability of space photography is in the development of vegetation and related resource maps for broad planning and policy determination at county, state, region, and national level--even at international level, speaking idealistically. Many counties across our nation, and some states, become repeatedly concerned about long-range, land-use planning as an aid in the wise guidance of resource development within their respective areas of governmental responsibility. These needs frequently develop from the requirements of citizen groups serving with or without professional assistance on county and/or state planning and resource development commissions. Their needs for information usually arise overnight with the deadline of delivery yesterday, by five o'clock today, or in the morning. Thus, time is usually at a high premium in meeting these information needs. Until recent years, and in most cases today, these information requirements have been met by the perusal of rapidly assembled information, some of it frequently coming off the top of the head of an experienced consultant. Few counties or states have benefited from a comprehensive county level resource analysis on a common base map with common legends throughout the county.

In addition, many citizen, business and professional groups in the United States have become extremely interested in the conservation and use of our natural resources. This interest and the activity of these groups is increasing rapidly and they have a strong impact on natural resources legislation, policy and management decision. They too are in critical need of natural resources facts. The need is usually for broadly generalized information--not the kind the resource manager needs. Often times the contribution of these citizen groups is constructive and fruitful, or it may be detrimental in proportion to the accuracy and adequacy of information available to them. The professional resource people in our nation owe it to both these groups, citizen and governmental, to provide them the highest possible quality of information in a format that is readily and clearly comprehensible.

As an example, five counties in Oregon are now in the process of putting together comprehensive maps of all county resources to be used by County Planning Commissions. To date, these have been prepared largely by generalizing the work and maps from numerous agencies onto a single, small-scale planimetric base map with summaries of relevant facts. The difficulties of resolving legend differences among agencies are extreme, to say nothing of the cartographic problem. With presently available funding and normal time limitations, an accurate map is impossible, yet full-time people are being hired to do the work. It is interesting that the available, "high-quality information" often turns up with much to be desired as these people strive to consolidate the data and maps from diverse sources. An adequate common base is not available. Common legends do not exist.

The availability of reasonably good resolution, small-scale, synoptic photo coverage such as the presently available Gemini and Apollo photography should be an aid to problems of this type. Existing map information could be used by experienced people to identify and interpret the photo images in the majority of cases. With limited ground checking, most disparities between available large scale maps and Gemini-like imagery could be worked out. One of the big problems in putting this kind of map together is filling gaps between the areas of jurisdiction of government agencies. Space photography should be better suited to solution of this problem than conventional aerial photography.

If we think of helping developing nations with their natural resources problems, or training them to help themselves, comparable problems would only be compounded. In the initial years of such programs, the interpretation of space photography with minimum ground truth knowledge would be the modus operandi. The question thus arises, "how accurately can an experienced man make useful statements about earth resources merely by examining photographic imagery obtained from space?"

We are conducting a photo interpretation experiment to help answer this and related questions.

If survey programs with space photography were to go operational next month or next year in counties where an interest could be aroused (incidentally, it already exists in Grant County, Oregon) or in developing nations, the survey would no doubt move forward on a minimum budget Thus, staggering responsibility would rest in the hands of the most capable interpreters available. They would be making interpretations with very cursory ground checks and sometimes without any immediate opportunity to obtain fully adequate ground truth. In other words, the interpreters would have to be people of long experience both in resource analysis and resource management; and their capability as photo interpreters would no doubt be highly variable. None the less, such synoptic resource surveys represent one of the most realistic uses of good quality, photographic imagery taken from space platforms.

We have some preliminary information from our experiment that is both interesting and encouraging and future reports will contribute additionally to answering questions of interpretability and usefulness. We have selected a group of "volunteer" interpreters with substantial, but variable, experience in natural resources work. They will be given Gemini frame 11 with the adjacent overlapping photos. Each man will examine and interpret this frame with the benefit of three levels of background information and will be scored after each succeeding interpretation. None of the participants will have had previous experience in the examination of space photography.

Interpretation level 1 will be without the benefit of any supporting information other than the Army Map Service 1:250,000 topographic sheet and the interpreter's own previous knowledge and experience. At the second level of interpretation, he will be given access to the key publications on the vegetation and related resources of the subject area. The third level will be to give the interpreter complete access to our ground truth records. At each level, his instructions are: Study the Gemini imagery carefully and delineate meaningful images about which you think you can make accurate statements. Turn your imagination loose, and write down any statements about the natural resources that you think are reasonable on the basis of this examination. Interpretations will be separately scored by each of the authors of this report and a consolidated score derived.

This experiment is just beginning and we have no conclusive results; but, as of this writing, two interpreters are partially through phase one. Their interpretation scores are interesting and may suggest the potentiality of interpreting vegetation and related resources from space photography of Gemini quality. In two hours time, observer one delineated six areas and made 27 separate interpretative statements about the six delineations. His score, as rated by one of the authors, was 40% correct, 26% partially correct, 30% erroneous and 4% uncertain. In a three-hour period, observer number two placed meaningful delineations on the entire area of Frame 11, classified the images into eight classes, indicated those he considered essentially the same, and made numerous statements about the eight delineation classes. His interpretations, as scored by one of the authors, were 25% correct, 25% partially correct, 50% erroneous.

Even though this reports on the mere beginning of a comprehensive test, the fact that range resource people with extensive experience in the interpretation of conventional aerial photography but with no first-hand ground truth and no previous experience with the interpretation of Gemini photography, could do this well is encouraging. If these kinds of results hold up and improve in phases two and three, space photography may be a real aid to those who must quickly assemble useful information on large areas and to those who have need of small-scale synoptic maps of vegetation and related resources for broad resource planning and policy development.

Locating Ground Truth Stations

In the 1966 feasibility study, all ground truth stations were located by pin pricking them directly on an 11 x 11 black-and-white enlargement of the Gemini frame, after having determined their location on color transparencies and by keeping a careful road log of distances and control points on routes of travel. This enabled us subsequently to chart locations on the Army Map Service 1:250,000 topographic sheets. Our intention was to transfer locations from the AMS topographic sheets to the Gemini photos; but because of photo distortion, this proved impossible. We solved the problem with reasonable satisfaction by rectifying an enlargement of Gemini frame 11 to its corresponding area and relief features on the AMS topog sheet. We then made an overlay from the topog sheet showing key road, cultural, and major drainage features (Figure 3). We were able to locate ourselves rather accurately on these topog sheets, often by reference to public land survey markers and by using a section and township grid on the AMS topog sheet overlay. While we know the location of ground truth stations with this technique is not perfect, we are confident that all are located within

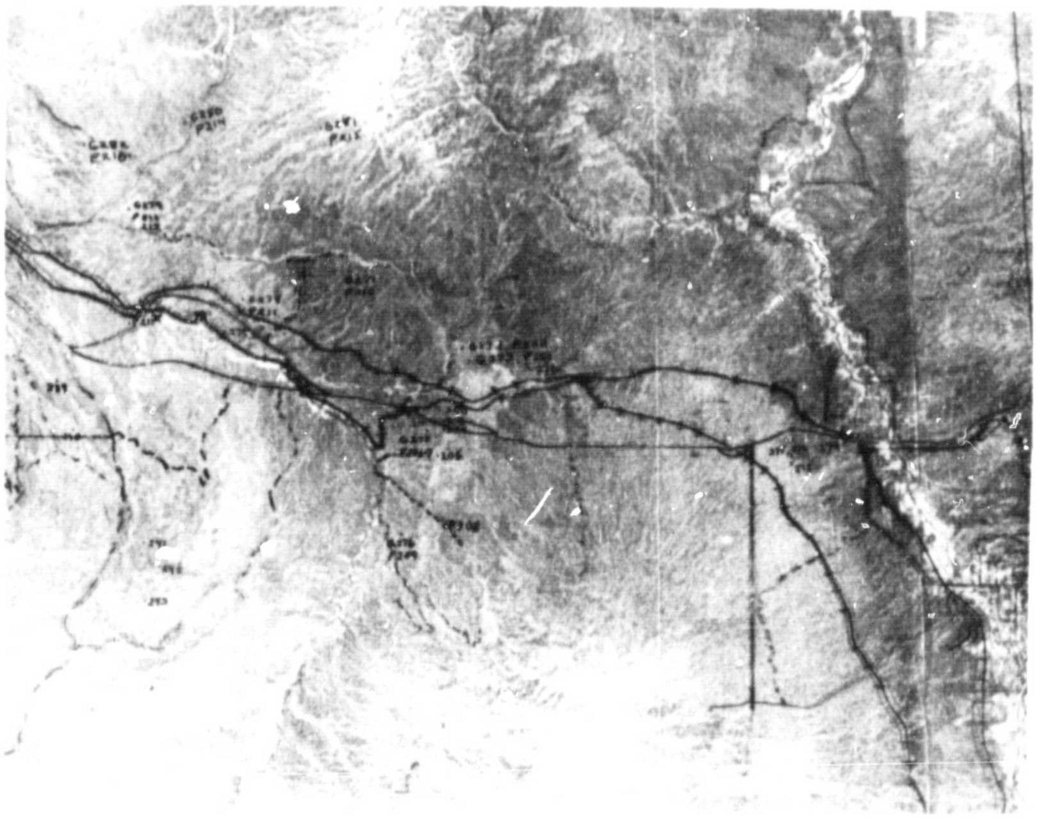


Figure 3. Part of a Gemini photograph enlarged and rectified to a U. S. Geological Survey topographic map (1:250,000 scale). The black lines are travel routes traced on an overlay and positioned over the rectified enlargement. This combination provided the means to relate ground-truth data to specific image components. Numbers indicate location of ground observations and where plotted while in the field.

their correct image component on the Gemini photography. Since the black-and-white enlargement was rectified to the AMS topog sheet, location of the stations was much faster and, we feel that most are also within ¼ to ½ mile of their true map position. Errors that would result from relating ground truth to an incorrect image component are certainly minimized.

We were able to check the most successful procedure for ground truth location a few days before writing this report. The small scale color IR photography which the U.S.G.S. has allowed us to study permits highly precise location of each and every ground truth station covered by their sample strips (Figure 7). Practically every unimproved road in the area is clearly visible on this 1:200,000 imagery. Drainage detail can very readily be matched with the Gemini imagery and in most cases, the boundaries of the same vegetation types are evident on both kinds of photography. Thus, the advantages of small-scale, aerial-photo sub-sampling should be seriously considered when planning future missions to image earth resources of major test sites from space platforms.

Classifying Vegetation Data--Preliminary Legend

This phase of the work has just barely gotten underway. All of the ground truth stations have been provisionally classified on a first approximation into six major groups and six lesser, miscellaneous groups. At the present time, we feel that the major, and some of the minor, groups are compatible with the image characteristics--that is, may be interpretable from image characteristics--but this hypothesis has not been tested. Continuing work will refine and fully characterize these classes, presenting them in descriptive legend and symbolic legend forms. The descriptive legend will include a summary of soil surface and physiographic characteristics associated with each vegetation class and legend unit. We are quite sure that these classes will be equally compatible with other photographic imaging systems and that the legends we are developing will also serve as vegetational ground truth for analysis of the capability of other imaging systems. The more we and others study ground-truth to image relationships and refine the vegetation and soils resource legends in this area, the more valuable it will become as a test site.

There are discernible differences in the images of forest vegetation areas on the Gemini photography. We have not been able to ground truth any of the forest areas above the oak and juniper woodland zone, but it is hoped that future investigations will permit us to check out some of these areas and determine if the image variations are meaningful. In the rougher, less accessible areas we may attempt the task through large scale aerial photo sub-sampling and photo interpretation of the forest characteristics, through the examination and generalization of forest cover type maps, or from low-elevation, aerial observation.

Vegetation-Image Relationships

Work to date under this category has been limited to a partial and preliminary classification of some of the photo images into three classes: (1) those highly and consistently interpretable, (2) those moderately interpretable with reasonable consistency, and (3) those with low interpretability. It may be possible to move images presently classed in the low group to a higher level of interpretability by: (a) better image quality control, (b) quantitative study and characterization of image features or (c) by the more thorough analysis of sub-sampling aerial photography in these problem areas.

An example of two highly interpretable images is presented in Figure 4 and one of two images with low interpretability in Figure 6a, page 40.

PROBLEMS ENCOUNTERED AND ANTICIPATED

The work to date has identified a few problems which may or may not have easy solutions. The solution of some is of critical importance in the successful use of any kind of photographic space imagery on an operational mapping scale. Other problems fall in less critical categories. Their solution would facilitate or enhance the usefulness of space photography but are not necessarily essential to success. The following discussion gives our assessment and current solutions of some problems of critical importance.

Image Quality Control

This subject considers a problem of terrific magnitude in all aspects of remote sensing. In making vegetation and related resource interpretations from remote sensing photography, variation in image quality forces the interpreter to lay aside one of the potentially most interpretable image features--in black-and-white photography, tone; and in color photography, hue, value, and chroma. Much has been written about the ability of the human eye to discriminate levels of tone and color but this tends to be lost at the present state of the applied art in photo reproduction. It need not be such a serious deterent to successful interpretation, considering the present state of technical art. At the present time, this problem stands strongly in the way of an operational photographic mission.

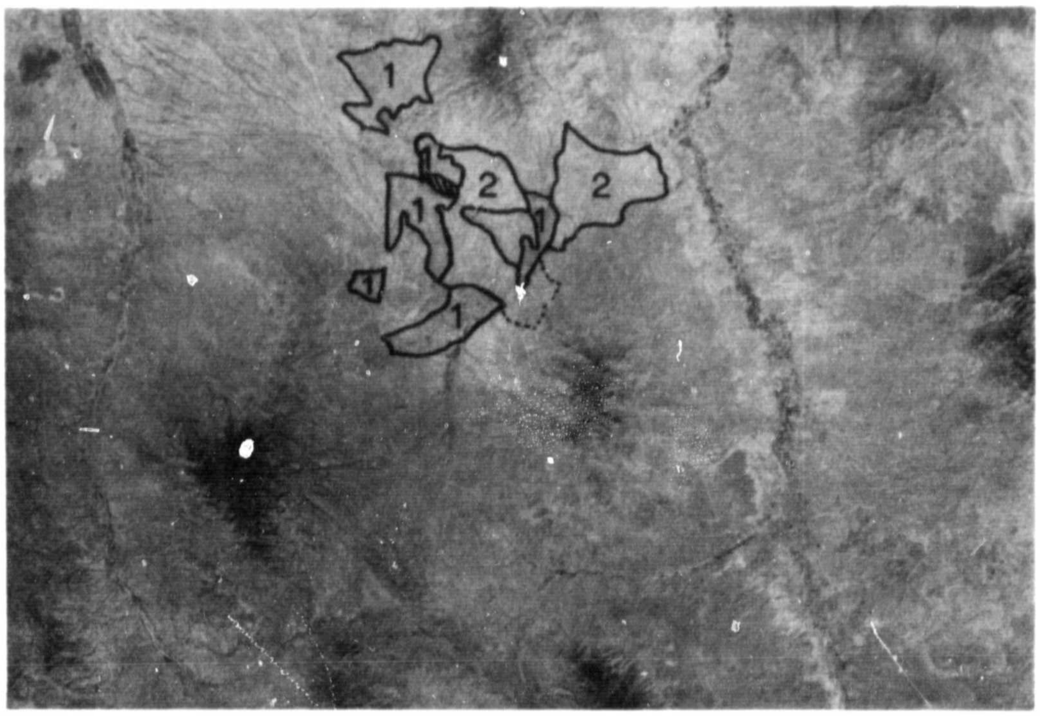


Figure 4. Some images on Gemini photography have a high degree of interpretability. The areas delineated (1) are identified by having whitethorn and the following three grasses: tobosa, slender grama, and three awns. Other species usually present are prickly pear, jumping and cane cholla, and mesquite. (2) is primarily a grassland; the principal grasses are black grama, side oats grama, and three awns. The grasses are accompanied by yucca, prickly pear, desert zinnia, and false mesquite. On the slopes and ridge tops having rocky, shallow soils, ocotillo usually prevails. While each of these images actually represents a group of ecosystems, these separate groups are based on consistency of vegetation components and appear to be highly interpretable from this Gemini IV photography.

As the tone and color quality control of photo images decline, the interpreter is forced to rely progressively more and more heavily on texture, pattern, and convergent and associated evidence in reaching his interpretative decisions. The machine or electronic aids to the human interpreter are no less disadvantaged. As color quality control breaks down in the reproduction of space or small-scale aerial photography, consistent interpretability can be maintained only by meeting certain minimums in ground resolution. Image texture and image patterns are the only remaining features that are directly interpretable. The rest comes from the experience, imagination and skill of the interpreter and from associated and convergent evidence. Desirable as resolution of the quality shown in Figure 7, page 41, would be, this seems obviously denied us in satellite photography. We must, therefore, do something about color and/or tone quality control. Whether color photography goes on future space missions or not, it is a remote sensing medium of extremely high potentiality from aerial platforms. Therefore, any energy spent in the NASA program to achieve high quality control of image color and tone will not be lost regardless of the future direction of space imaging programs.

While the authors have not at this writing seen the original transparencies of either Gemini or Apollo photography, Richard W. Underwood has informed us that the separate Gemini IV frames in this study location were of very high quality and uniform as regards color saturation. Unfortunately, we did not obtain some of our working prints from the NASA laboratory. Figure 5 illustrates the problem we have in ordering through commercial laboratories. It is our hope that through collaboration with the photo laboratory at NASA - Houston, we can solve this problem, at least as far as our experimental materials are concerned.

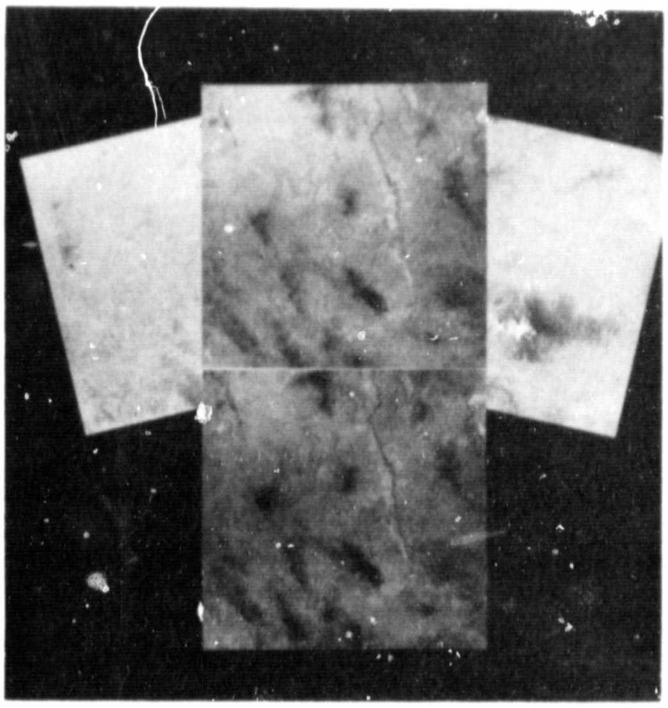


Figure 5. Color quality control immediately becomes a serious problem when color characteristics are used to identify photo images and the subjects represented. If color quality cannot be held consistent, then color characteristics can only be expected to be valid for the specific photographic print on which the colors are described. Color shifts on subsequently produced prints of the same photography or on adjacent prints of an overlapping series of photographs invalidates the use of one standard set of color descriptions among prints. In this figure the top three prints are illustrative of the variation received in our first order, even through the importance of the uniform color quality was emphasized when placing the order. The top center frame was returned to be used as a sample print for color balance on a reorder for a series of eight frames. The bottom center print represents what was received in the second order. All of these prints were quite uniform in color saturation but none matched the sample provided. They were considerably darker with a resulting loss of interpretability.

Inadequate Phytosociological and Vegetation-Environment Information

In spite of the fact that Tucson, Arizona, is the site of some of the most outstanding ecological research in our nation on relationships between plants and their environment, the area is lacking, in company with many others, in the amount of phytosociological information and completed vegetation-soil-climate relationship studies. These latter are essential in legend development for this kind of a project. Our literature perusal is not complete, but it is well advanced. We have found many bits and fragments of very useful information, but a comprehensive and co-ordinated treatment of the phytosociology of this region remains to be done. This means that we must put a usable vegetation classification together ourselves as a part of legend development and the interpretation of ground truth. Vegetation-image relationships cannot be established without a compatible classification of the vegetation on the one hand and of the remote sensing images on the other.

This is mentioned as a problem largely because the particular lack of information will be found to exist throughout much of the United States. Plans for space-borne remote sensing systems focused on native vegetation and soil resources must include provision for this supporting research to the extent that it is needed for legend development.

A substantial facet of the vegetation analysis and classification problem, as it relates to satellite photography and other imaging systems, will be in the need to generalize vegetation classification into higher hierarchical classes than vegetation resource people are usually accustomed to consider. The capable phytosociologist usually works and does his initial classification at the fundamental plant community level. Our work has strongly suggested that the individual plant communities can only rarely be interpreted from imagery of Gemini IV quality, yet meaningful vegetation interpretations can certainly be made from this imagery. Its interpretation will require the logical, biologically accurate, and managerially meaningful grouping of plant communities into larger hierarchical classes that are consistent with the interpretable image characteristics. We feel that we have made good progress in this direction but generally accepted classification schemes or patterns and procedures for accomplishing this are not developed and generally accepted in the United States. The interpreter of space photography will continually be faced with the problem of generalizing from the high amount of detail evident to him on the ground to match the grossly integrated images evident on space photography of low resolution. This problem has a practical and not too difficult solution for those who are willing to seek the common denominators that tie similar vegetations together above the specific plant community or "association" level.

Soil-Vegetation Interaction as Determinants of Image Characteristics

In some instances where the primary interest may be soils characteristics, the vegetation may so strongly obscure the soil as to deny it the opportunity to "show through" and directly influence the image characteristics, for example, in dense forest areas. In these instances, soils characteristics can be interpreted only from convergent evidence or from associations that are established by research between identifiable plant communities and the soils on which they are known to occur. In this instance, the ability to read soils characteristics from remotely acquired imagery is determined almost entirely by the fidelity and specificity of the vegetation-soil relationships and the ability of the imaging system to discriminate the relevant ecosystems.

On the other hand, in arid environments, the vegetation may be so sparse that the bare soil surface is the dominant feature controlling image characteristics. In sparse vegetation areas the vegetation itself may not create observable difference in the extremely small scale images produced by Gemini photography. This does not mean that vegetation characteristics cannot be interpreted accurately from space photography of these areas. Carneggie, et al., (1967) identified the image on Gemini frame 11 representing creosote bush vegetation of the Sonoran Desert (Figure 8, delineation 1, page 43). The only significant vegetation influence on this image is the mesquite and related shrubs and trees in the drainage ways. All of the flat land between arroyos, while covered by a sparse stand of creosote bush, is registering primarily the soil surface image, yet the pattern of these combined images is highly consistent and interpretable. Through vegetation classification and vegetation-soil-landform relationship studies, specific ecosystems can be identified and characterized. These, in turn, can then be related to specific photographic images. With this ecological backup as a part of the ground truth, it is possible to interpret certain ecosystems and/or vegetational and physical characteristics from space photography regardless of whether it is the vegetation or the soil surface features that override in determining the image characteristics.

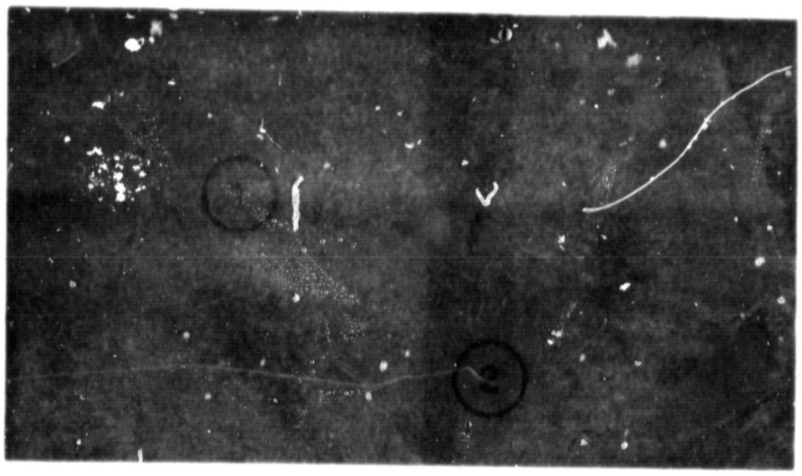
Inability of Gemini Color Photography to Discriminate Important Ground Subjects

Experience with the interpretation of aerial photography for other purposes clearly indicates that no single system can be expected always to provide all the information that may be desired or needed about a subject. Space photography is not unique in this respect and we should not be disappointed by failures or shortcomings that confr. . us at this time. Greater attention to film and filter combinations, season of photography, and subsampling with various supporting systems will improve the situation.

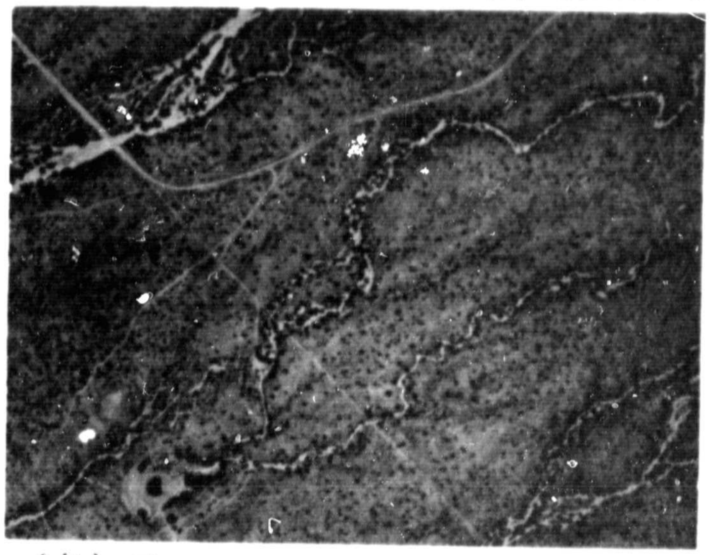
In dense forest areas the tallest tree layer exerts the dominant influence on image characteristics and as scale and resolution decrease, it becomes progressively difficult to do more than just class the area as "forest". The forest cover--as with dense shrub areas and even certain grasslands--may obscure important features of the ecosystems from direct visibility. To a degree as yet untested with space photograhy, this problem has at least a partial solution. Many of these "obscured" features of the ecosystem can be identified from associated and convergent evidence derived from a complete understanding of the ecosystem. This ability is based on knowing the complete phytosociological significance of a correctly identified upper layer in the forest or brushland.

Figure 6 illustrates this subject discrimination problem and suggests a potential solution. Figure 6b was obtained from photography taken by the Pacific Southwest Forest and Range Experiment Station. Another example of the same approach to solving some of these kinds of problems is illustrated in the study of the high-resolut.on 1:200,000 photography (Figure 7), which was made available to us by the U. S. Geological Survey. In the study of this kind of sub-sampling aerial photography, clues are often found which were overlooked in the original image examination. This second example has the advantage of being easily related to space photography because

Figure 6. Subject discrimination is not always readily accomplished by Gemini photography. Areas labeled (1) and (2) in photo (a) have similar images. Sub-sampling aerial photography shows the subjects of these two areas are indeed different. Sub-sampling with vertical (Photo b) or oblique (Photo c) photography permits one to identify these areas. These sub-samples show respectively that area (1) is covered with brush or small trees and that area (2) is a grassland with shrubs and trees only in the drainages. Photos (d) and (e) were taken at ground-truth stations in areas (1) and (2) respectively. The plants in (d) are mesquite, prickly pear, jumping cholla and burroweed. The undulating upland grassland in (e) supports blue, side oats and other grama grasses; three awn grass and shrubby buckwheat.

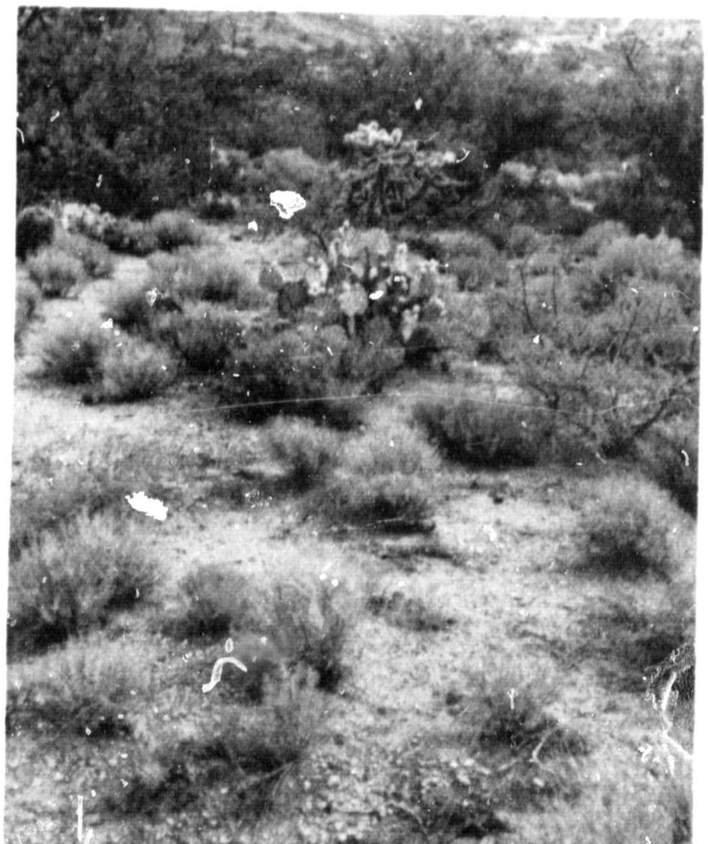


6 (a) Gemini IV photograph



6(b) Ektachrome Aero Infrared, Wr. 15 of area 1.

6(c) Ektachrome Aero Infrared, Wr. 8 of area 2.



6(d) Ektacolor ground photo in area 1.

6(e) Ektacolor ground photo in area 2.

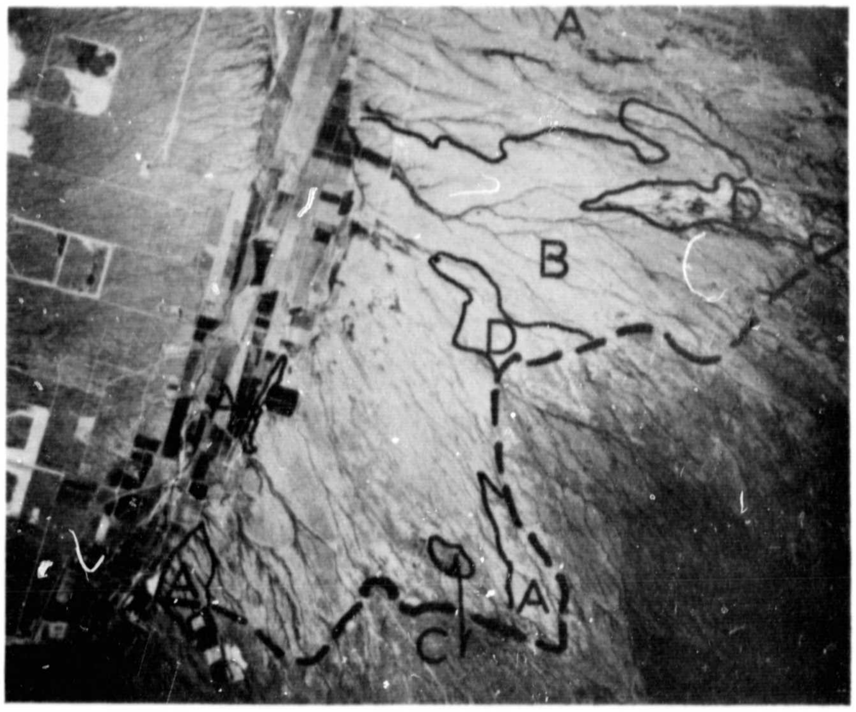


Figure 7. Small scale, high resolution photography with a different film and filter combination (Ektachrome Aero Infrared, Wr. 12), is another variation of aerial photography sub-sampling (compare with Figures 6b and c). (A) is an area of sparse vegetation dominated in the uplands by creosote bush and desert zinnia. The drainages are lined with mesquite. Vegetation in (B) is mesquite, four winged saltbush and creosote bush; (C) is mesquite, burroweed, three awns, and grama grasses; and (D) is primarily bare ground.

of scale. High ground resolution and the film-filter combination are the primary characteristics which allow solution of subject discrimination problems. In Figure 8, the line between delineations 1 and 4 was plotted only after studying Figure 7 and recognizing the distinction between delineations A and B.

Failing in these kinds of approaches, research on some of the alternatives suggested in the work flow chart (Figure 1, page 16) will probably be necessary. If the resolution, season of photography, or spectral band used does not provide sensitivity to the subtle differences in species composition that discriminate the ecosystems within the subject area, then information is lost. In this case, both the interpreter and user must be content with broader vegetation or legend classes--grassland, shrub steppe, savannah, forest, etc.--and the associated information these convey.

PRELIMINARY VEGETATION MAPPING ON GEMINI PHOTOGRAPHY

Building on all the foregoing in this report: photo image analysis, "ground truth" collection, identifying subject-image relationships, solving problems of poor subject discrimination, adherence to basic ecological and mapping principles and developing classification units based on a growing phytosociological understanding of the vegetation, enables us to make a first approximation at mapping native vegetation from space photography (Figure 8). All the classification units are based on ground truth information, except for number 5 which was only observed from a low flying aircraft. The mapped delineations are plotted on the basis of ground observations and photo interpretation. We are striving to develop workable mapping legends, closely related to image characteristics, that will permit interpreters to extract

Figure 8. Vegetation mapping on Gemini photography.

Legend:

1 - Creosote bush, desert zinnia. Mesquite lines the drainages.

2 - Agricultural area.

3 - Mesquite, burroweed, three awns, and grama grasses.

4 - Mesquite, four winged saltbush, and creosote bush.

5 - Ponderosa pine and Douglas fir.

6 - Juniper and oak woodland.

7 - Complex: Hilly area with much rock outcrop. Ocotillo, Aloysia and grama grasses on south slopes and valleys. Oak and chaparral species on summits and north slopes.

8 - Whitethorn, chollas, and slender grama, and tobosa grasses.

9 - Yucca, three awns, and black grama grasses.

10 - Mesquite, snakeweed, and fluffgrass.

C - Complex: Saguaro, palo verde, and brittlebush on dry slopes. Prickly pear on protected areas.

all possible information from space photography.

As with all remote sensing imagery, the major steps in practical use can be broken down into three phases: (1) delineation of unique and similar images, (2) identification of these images, and (3) interpretations of practical significance and usefulness. This latter step is the real proof of remote sensing value. Step 3 is the most difficult because it requires that the interpreter does not only steps 1 and 2 accurately but that he draws on his full spectrum of current experience, on all possible convergent and associated evidence, and that he logically relates these bits of information in making statements (inferences or interpretations) that are both accurate and meaningful in terms of some real information need. We recognize, therefore, that the quantitative evaluation of interpreter accuracy and identification of the nature of his errors must be a part of the research program.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This report places rangeland resources in perspective as a part of the concern of the Earth Resources Program of the National Aeronautics and Space Administration. The concepts and principles that are important in the analysis of the vegetational resources of the earth are discussed. These have been clarified by earlier research with conventional aerial photography at Oregon State University and confirmed as equally applicable in the use of space photography for resource inventory.

A procedure for the interpretation of vegetational resources from space photography is presented in a detailed chart of work flow. Steps are related from preliminary ground truth to practical application. Some appropriate areas in the latter category are discussed. Ground truth methods are presented, and the preparation of mapping legends is briefly discussed. Work progress to date is reviewed and illustrations are presented of key accomplishments. Some of the problems encountered in the use of space photography are discussed, primary among which is image quality control. This problem must be solved if large areas, involving more than single frames, are to be interpreted in operational resource survey programs that make effective use of space photography. Some important vegetations cannot be discriminated by direct interpretation from Gemini IV photography, but with aerial photo sub-sampling many of these problems can be solved.

This merely illustrates a point we all should recognize--namely, the general inability of a single imaging system, particularly broad-band small-scale photographic sensing, to discriminate among and thus permit identification of all of the subjects that the manager of vegetational resources finds important in making day-to-day decisions. This is true even with large-scale aerial photography.

In the viewpoint of those more strongly oriented to the needs of intensive resource management, space photography has an even greater shortcoming. It lies in the low ground resolution and small scale of the available space photography. These limitations will not permit us to meet the information needs of the resource manager who works on the land. He requires more detail than space photography of Gemini quality can provide. His remote sensing needs are best met by the interpretation of relatively large scale, high resolution photography.

Space photography is ideally suited, however, to mapping of vegetation and soil resources at synoptic scales for use by those who must set resource policy and perform broad planning functions. In addition, the needs of the generally interested and concerned citizen, student, scientist, politician and senior executive are actually served better by a highly accurate, carefully generalized picture than by the intricate detail that is the day-to-day concern of the resource manager. Space photography of Gemini IV quality seems ideally suited to meeting these needs.

Our primary recommendations are: 1) that future missions to photograph earth resources in intensively studied target areas from orbital altitudes be supported by purposefully planned aircraft missions over the same targets and as nearly as possible at the same time, and 2) that greater attention be given to photo quality control throughout the system from exposure to the processing of duplicates and prints for use by cooperating investigators. The performance of even an experienced photo interpreter, and thus the real value of space photography, is determined largely by the photo quality control that can be achieved from frame to frame, from copy to copy, and from mission to mission.

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