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THE COMPARATIVE EVALUATION OF ERTS-I IMAGERY FOR RESOURCE INVENTORY IN LAND USE PLANNING

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Final Report To
NASA GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

October 1974
OREGON STATE UNIVERSITY
Corvallis, Oregon

THE COMPARATIVE EVALUATION OF ERTS - I IMAGERY FOR RESOURCE INVENTORY IN LAND USE PLANNING

G. H. Simonson
D. P. Paine
R. D. Lawrence
W. T. Pyott
J. H. Herzog
R. J. Murray
J. A. Norgren
J. A. Cornwell
R. A. Rogers

OREGON STATE UNIVERSITY
Corvallis, Oregon 97331

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16. Abstract
Multidiscipline Team interpretation and mapping of resources for Crook County is complete on 1:250,000 scale enlargements of ERTS imagery and 1:120,000 hi-flight photography. Maps of geology, soils, vegetation-land use and land resource units have been interpreted to show limitations, suitabilities and geologic hazards for land use planning. Mapping of lineaments and structures from ERTS imagery has shown a number of features not previously mapped in Oregon. A multistage timber inventory of Ochoco National Forest has been made, using ERTS images as the first stage. Inventory of forest clear-cutting practices has been successfully demonstrated with ERTS color composites. Soil tonal differences in fallow fields shown on ERTS correspond with major soil boundaries in loess-mantled terrain. A digital classification system used for discriminating natural vegetation and geologic material classes has been successful in separating most major classes around Newberry Caldera, Mt. Washington and Big Summit Prairie. Computer routines are available for correction of scanner data variations; and for matching scales and coordinates between digital and photographic imagery. Methods of Diazo film color printing, elevation-slope perspective plotting with computer, and computer classification have been developed. The latter has been used in projects involving many state and federal agencies.

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INTRODUCTION & SUMMARY

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I INTRODUCTION AND SUMMARY

This is the final report for a multidisciplinary study of ERTS-1 applications for resource inventory purposes in land-use planning, which was supported by the National Aeronautics and Space Administration, Goddard Space Flight Center. Contributors consisted of teams from the following departments at Oregon State University; Forestry, Rangeland Resources, Geology, Soil Science, Electrical Engineering, and Computer Science. Overall objectives of the project were as follows:

1. Use a multidiscipline team approach to determine features that can be sucessfully monitored by ERTS-1 imagery for resource inventory, landuse planning, zoning, and resource development.

2. Using carefully selected sample areas, develop a comprehensive resource inventory mapping system for use in planning, zoning, and resource development.

Major efforts toward satisfying the overall objectives were concentrated in Crook County Oregon. This county is situated at the geographic center of the state and includes a wide selection of the range in natural environments common to the inland portions of the pacific northwest. Within its 7700 square kilometers, vegetation varies from sparse, semi-desert shrubs to dense, mixed coniferous forests. Extremes in average annual precipitation are nearly four-fold, and topography includes nearly level plains as well as hills, canyons and mountains.

Individual resource inventories of geology, soils and vegetation/land use were prepared at two scales from ERTS imagery, and at a larger scale using NASA high-flight photography. A combined, land resource inventory was compiled on two scales of ERTS imagery using inputs from the separate disciplines. Interpretive tables were assembled to aid land-use planning agencies in applying the information contained in these maps. A multistage timber inventory was completed of Ochoco National Forest, which lies largely within Crook County. This inventory relied heavily on ERTS imagery.

Many potential land-use applications of ERTS imagery could be best explored in parts of Oregon outside Crook County. Clearcutting practices and field burning were monitored in several parts of western Oregon. Renovation of sagebrush rangelands and expanding irrigation developments, in arid eastern Oregon, were successfully recorded both visually and by computer classification. Detection of faults and related linear landscape elements was found to be significantly aided by the use of ERTS imagery.

Techniques developed for computer classification of ERTS digital data were found useful for separating several natural vegetation types, rock units and cultural practices. This process also showed promise for detecting one type of forest insect infestation, and monitoring channel changes in the Columbia River estuary.

Widespread appreciation for the potential utility of ERTS information for land-use purposes is attested to by the number of state and federal agencies which have sought assistance from those participating in this project.

II RESOURCE INVENTORY OF CROOK COUNTY, OREGON

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II RESOURCE INVENTORY OF CROOK COUNTY, OREGON

A. Scope and Setting

This section includes resource inventory components for Crook County, Oregon contributed by the separate disciplines of geology, soil science and rangeland resources, as well as a combination of all three, which is called a Land Resource Map. The separate contributions have been presented in some detail so that their respective contributions to the integrated inventory can be assessed. An additional advantage to this complete presentation is that the relative suitability of ERTS imagery for investigations by these various disciplines can also be illustrated, at least for conditions in central Oregon.

It may well be that the nature and variety Crook County conditions are especially suited to being studied with ERTS technology. Due to a wide range in average annual precipitation, vegetation varies from sparse, semi-desert shrubs to dense coniferous forests. Consequently, reflectance is influenced largely by rock and soil at the arid extreme and completely by vegetation at the other. Pronounced seasonality of precipitation provides strong wet-dry season contrasts. While population pressure is low, land use intensity ranges from intensive, irrigated agriculture to virtually pristine natural vegetation. Geological diversity includes a variety of relatively young volcanic rocks and landforms, as well as older, folded and metamorphosed rocks. For remote sensing purposes it is especially significant that rock type correlates well with topography.

Maps were prepared at scales of 1:1,000,000 and 1:250,000 for each component discipline as well as for Land Resources, using ERTS imagery. For the individual disciplines, more detailed maps (1:120,000) were made using NASA color infrared high-flight photography. The latter provided ground truth and also served as a measure of comparison for the ERTS-derived products. Land resource maps were prepared at the two smaller scales only, because they are intended to aid in extensive land use planning rather than area management decisions. Legends and interpretive tables which accompany the land resource and individual discipline maps were designed to be used by county and regional agencies involved with land use planning problems.

B. Methodology

The inventory procedures used grew out of work done by C. E. Poulton and colleagues (Poulton, 1972). Their work on the utilization of conventional aerial photography, high-flight photography, and space imagery (Gemini and Apollo) for resource inventory through photo interpretation provided the foundation and the impetus for this ERTS investigation. Heavy emphasis is placed on photo interpretation in order to greatly reduce the amount of ground work necessary.

The vegetation/land use inventory involved two disciplines, Rangeland Resources and Forestry. Range carried out an ecological inventory of all the vegetation in the county, separating out land areas where the vegetation has been considerably altered such as urban and agricultural crop areas. Forestry carried out a timber volume inventory which is described in the Experimental Applications section.

Legend Development and Ground Truth

The collection of ground truth data from the field for vegetation/land use was limited primarily to that necessary for refinement and adaptation to Crook County of the hierarchical ecological resource legend developed by Poulton and colleagues. Those legend units quaternary and lowered were developed specifically for this inventory and are considered regionally applicable only. The higher, broader units are universal (Appendix R-1).

Reconnaissance trips were taken to Crook County during the summer of 1972 to determine the vegetation legend units required for the inventory. Observations, including 35 mm color ground photographs, were taken to characterize specific plant communities by their prominent species. Categories were similarly established for land characteristics other than vegetation (e.g., water) and for areas where human activity has considerably altered the landscape (e.g., urban and agricultural areas).

Additional ground truth was acquired from the field to resolve image identification problems. This required two trips to the county, one of which involved a low level flight by fixed wing aircraft. Low angle oblique 35 mm color photographs were taken on the latter trip. All of our ground and low level aerial photographs are filed in the Environmental Remote Sensing Applications Laboratory (ERSAL) in a UTM grid referenced storage system.

Photo Interpretation and Mapping

The photo interpretation process involved use of all the accumulated ground truth information as well as the collective knowledge and experience background of the interpreters. The ground truth information for vegetatio was synthesized on an uncontrolled mosaic of high-flight photography of Crook County (black and white from color infrared, 1:120,000). This information was then generalized for use in interpreting ERTS imagery at 1:1,000,000 and 1:250,000. Wherever possible, interpretation was done on color infrared imagery (simulated on ERTS) using steroscopic viewing.

Ground Truth Base. Our objectives in developing the ground truth base on high-flight photography were two-fold:

1. To establish a ground truth base for vegetation resources of Crook County for comparative evaluation of vegetation/land use inventory using ERTS imagery;
2. To develop a vegetation/land use map to supply resource information to land use planners in Crook County.

In order to achieve these objectives, we amalgamated information from a number of sources: base maps, field reconnaissance data, NASA high-flight imagery (U-2 aircraft) at three scales, ASCS flight index mosaics and various narrative reports and graduate student theses concerning the Cenral Oregon area. These materials have been catalogued and filed in the Environmental Remote Sensing Applications Laboratory or are available through the Rangeland Resources Program. Our objective in collecting this material was to minimize field work.

Maps include Bureau of Land Management range and forest surveys, U.S. Forest Service timber type maps for the Ochoco National Forest, U.S. Geological Survey topographic sheets (1:250,000, 7½ and 15 minute quadrangles), 7½ minute planimetric quadrangles and geologic maps. These were used both for geographic orientation on ERTS imagery and for ground truth input for image interpretation.

High-flight photography includes the following:

FLT # 72-063	Vinten, 19 Apr 1972 1 flight line SE to NW across Crook County
FLT # 72-072	Vinten/MSS, 5 May 1972 1 flight line W to E, N part of Crook County
FLT # 72-088	Vinten/MSS, 31 May 1972 1 flight line W to E, N part of Crook County
FLT # 72-114	Vinten & RC-10 (Color 1R) 17 Jul 1972 6 flight lines Crook County to the coast

FLT # 72-134	HC-730V, 6" (Color) 7 Aug 1972 8 flight lines E and W, Crook, Jefferson and Deschutes Counties Hr-732, 24" (Color 1R) 5 flight lines E and W, Crook County

We had an uncontrolled, black and white mosaic made from the 1:120,000 color infrared imagery (FLT # 72-114, RC-10) at contact scale. This mosaic served as the base for synthesis of our ground truth information as well as the mapping base for the resource inventory of Crook County. This gave synoptic coverage of the county and environs at a scale highly usable for planning purposes.

Reports we have, include the Oregon State Land Board Survey (Poulton and Isley, 1970), a general soil survey for the Oregon State Water Resources Board (1969), a U. S. Forest Service publication concerning the vegetation descriptions for adjoining Jefferson and Wheeler Counties. Also, we have available several graduate student theses concerning the vegetation and its environment in the Central Oregon area (Eckert, 1957; Driscoll, 1961; Tueller, 1962; Volland, 1963; and Hall, 1966).

High-flight Mapping. The color infrared (CIR) high-flight imagery (NASA flight 72-114, 17 Jul 1972, RC-10, 6" f.l., 1:120,000) was interpreted in stereo (60 percent forward lap, 10 percent side lap) using color prints. All mapping was done in black ink on acetate overlays using stereo triplicates (overlay made on alternate frames). All delineations were made using a scanning stereoscope (Old Delft). Identification was made of each delineation as it was drawn and labeled following the vegetation/land use legend (Appendix RA-1). A landform legend developed by Lawrence was also used in the high-flight mapping (Appendix GA-1). This was used in a few cases to separate vegetation/land use types. However, the primary purpose was to furnish information about the vegetation resource units to land use planners. A landform symbol, following the legend, was therefore incorporated into the delineation label as a denominator.

Mapping guidelines were as follows:

1. Map only pure types (one legend unit) if at all possible;

2. Complex units if they are so intricately related or of such low contrast that they cannot be separated. Draw type lines such that, as a rule, only two (at most three) legend units are complexed. Label complex map units such that the legend unit which appears first occupies the greater proportion of the aggregate area of the map unit.

3. Ignore legend units which are too small to delineate or make up less than 20 percent of the area (inclusions) of the map unit.

4. Delineate highly contrasting images as small as 1.25 x 1.25 cm (½ x ½") except for long, narrow types (e.g., stringer meadows) which may be as narrow as 0.3 cm (1/8").

Twenty-seven high-flight frames were required to cover the county. Time range per frame was from 15 minutes for those on the periphery of the county to two hours, 20 minutes for whole frames with diverse vegetation. Total time was 45 hours; average one hour, 40 minutes per frame.

The vegetation information thus mapped was then tranferred to an overlay on the photo mosaic at the same scale (made from black and white prints of the high-flight photography). Transfer of the delineations was done by placing the stereo model overlays under the mosaic overlay while on the photo mosaic base.

Mismatch disparities and distortions were corrected and map unit identifications and labels checked on the photo mosaic overlay. This overlay was then the final form of the ground truth base vegetation/land use map (see Figure 12) to be used for the comparative evaluation of ERTS imagery.

Areas were calculated for each of the map units using a planimeter. The basis for the area calculations was the total area of Crook County--2891 square miles.

Generalization of this information for use in mapping at ERTS scales utilized the hierarchical nature of the legend and the juxtaposition in the landscape of the various vegetation types. For example, the various kinds of sagebrush communities usually grow in the same general area so they could be consolidated at a broader level as a shrub-steppe.

The highflight map units were combined into major physiognomic and floristic groups based on similarities among the units. Complex types were grouped according to the legend unit composing the majority of the map unit or according to the unit having the greatest implications in land use. Land areas were also calculated for these groupings.

The intermediate groups were combined further into more general physiognomic groups (e.g., forest, shrub-steppe, agricultural, etc.) with major land use implications (timber, grazing, crop production, etc.), and areas calculated (Table 6). Except for major alterations of the landscape, the legend used in this inventory does not express land use <u>per se</u>, but implies the predominant land use (actual or potential) as can be inferred from the vegetation. Forest implies timber production, shrub-steppe implies grazing, etc., for example.

In addition, we calculated areas for approved and developing subdivisions in Crook County as interpreted from the same imagery as the vegetation/land use map. These interpretations were cross-checked with county records for approved subdividions. In this way, we could give the county a graphic indication of the changes that are occurring and the expected extent of change--where new development or extension of existing subdivision development is most likely to occur.

ERTS Mapping. At the latitude of Crook County, ± 44° N, the ERTS tracks overlap about 40 percent, making side lap stereo viewing of the ERTS imagery possible. We interpreted bands 4, 5, and 7 color reconstitutions and band 5 black and white. The information gain of the color over black and white made it much superior. The quality of our Diazo-produced color reconstitutions of the ERTS imagery equalled or surpassed commercial products and approached the quality of those produced by NASA-Goddard.

Multidate comparisons indicated that dry season ERTS imagery (e.g., July) provided greatest contrast and thus, better separation and identification of vegetation types. The spring flush of growth reflected so strongly in the infrared on May imagery that vegetation differences discernable in later imagery were almost completely masked.

Vegetation was interpreted and mapped on ERTS imagery at 1:1,000,000 (1292-18220, 11 May 1973; 1346-18212, 4 Jul 1973) based on color variation and gross macrorelief features. We followed the same mapping guidelines as we used for the highflight mapping. Interpretation and mapping of vegetation at 1:500,000 did not result in enough gain in detail to make it worthwhile. Use of a 1:250,000 enlargement of the 1076-18211, MSS 5 black and white, 7 Oct 1972, scene increased detail of the type lines and increased accuracy of delineation. Types too small or intricate to be delineated at 1:1,000,000 could now be indicated separately. Few of the complexes could be further simplified, however, because of the low contrast between intricately associated types. The final product at 1:250,000 was the result of synthesis of information from the generalized ground truth base and direct interpretation and mapping of vegetation on the ERTS imagery.

Land Resource Units were developed at both 1:1,000,000 and 1:250,000 by synthesizing information concerning geology, soils, and vegetation. The general procedure was to overlay the separate maps (at each scale) two at a time, and prepare a new map in which delineation boundaries and content were reconciled. That is, a delineation ideally would include one vegetation type on one kind of soil association on one rock type. Then a legend was written to characterize the integrated units in terms of the kinds of rock, soil, and vegetation they contained.

Drafting and Reproduction

Drafting involved the manual production of the final version of a map at the desired scale. Reproduction of maps, usually photographically and sometimes with enlargement or reduction, provided multiple copies for reports and distribution to other investigators and users in Crook County.

Original maps were made in black ink on clear plastic over an image base. A stable plastic was used over a stable positive transparency on final versions. Line maps to be reproduced in blue line by a blueprint machine were traced on tracing paper.

There were two kinds of photographic products: paper prints and transparencies. The positive paper prints were made by superimposing a black line clear overlay on the black and white negative of an image base. The line map thus came out in white on a black and white photo print.

For the transparencies, the overlays were reproduced separately, and the black and white positive transparencies of the image base were made from the negative. Both of the photographic products were produced at original scales of 1:120,000 and 1:250,000.

C. Geology

Introduction

Most of the rock units found in Crook County are geologically young materials of volcanic origin. All of them appeared within the last 10% of geologic time and the widespread units were all formed within the last 1% (figure 1). Most of the different varieties of volcanic rocks are found in the county as well as many kinds of sediments derived from these volcanic materials (see Appendix A-1). During the time when most of the rocks were deposited, the county was above sea level so that erosion processes operated continuously. As a result, the history of the county is one of competition between volcanism and deformation building the area up and erosion tearing it down.

During this project the county has been studied on infrared high flight photography and on ERTS multispectral scanner imagery. Little new field work has been possible so that where current interpretations differ from previous ones, the basis for the difference is in image interpretation and remains subject to field confirmation. The results presented here are mapping of the rock units, interpretation of the bedrock structures and surface landforms, and synthesis of the geologic history of the county.

Rock Units

In the discussion that follows, the rock units are described briefly in terms of historical sequence. Detailed descriptions and references to previous work are found in the descriptive legend to the geologic maps at 1:250,000 and 1:120,000 (Appendix A-1). These maps differentiate lithologies primarily, since this is the material that is of most value in land use decisions. This is in contrast to traditional geologic maps which differentiate similar rock types which differ in age. Commonly the most significant differences related to age are the degree of alteration of the unit and the depth of unconsolidated material (regolith) over it. The descriptive legend used here includes a means for making these distinctions where needed, whether they are related to age or not. Thus it is intended to be of particular utility to individuals working in land use analysis. The tectonic interpretations (figures 3 to 6), on the other hand, present the units in terms of historical sequence in the traditional manner. The groupings are generalized for ease of conceptualization, leaving the details to the geologic maps. These units are summarized on figure 7. The abundant and varied volcanism of the county required the use of numerous terms to differentiate these rocks in order to give an adequate account of them. Appendix A-3 gives a summary of the classification of volcanic rocks and some of the terms involved. It will be especially helpful in relation to the descriptive legend, in addition to the discussion which follows.

Pre-Tertiary Rocks. The oldest rocks in Crook County are exposed in a small area along its eastern border (figure 2). They include the oldest rocks exposed in Oregon where exposures covering a few acres have yielded Devonian fossils. Other, somewhat larger, areas of Upper Paleozoic

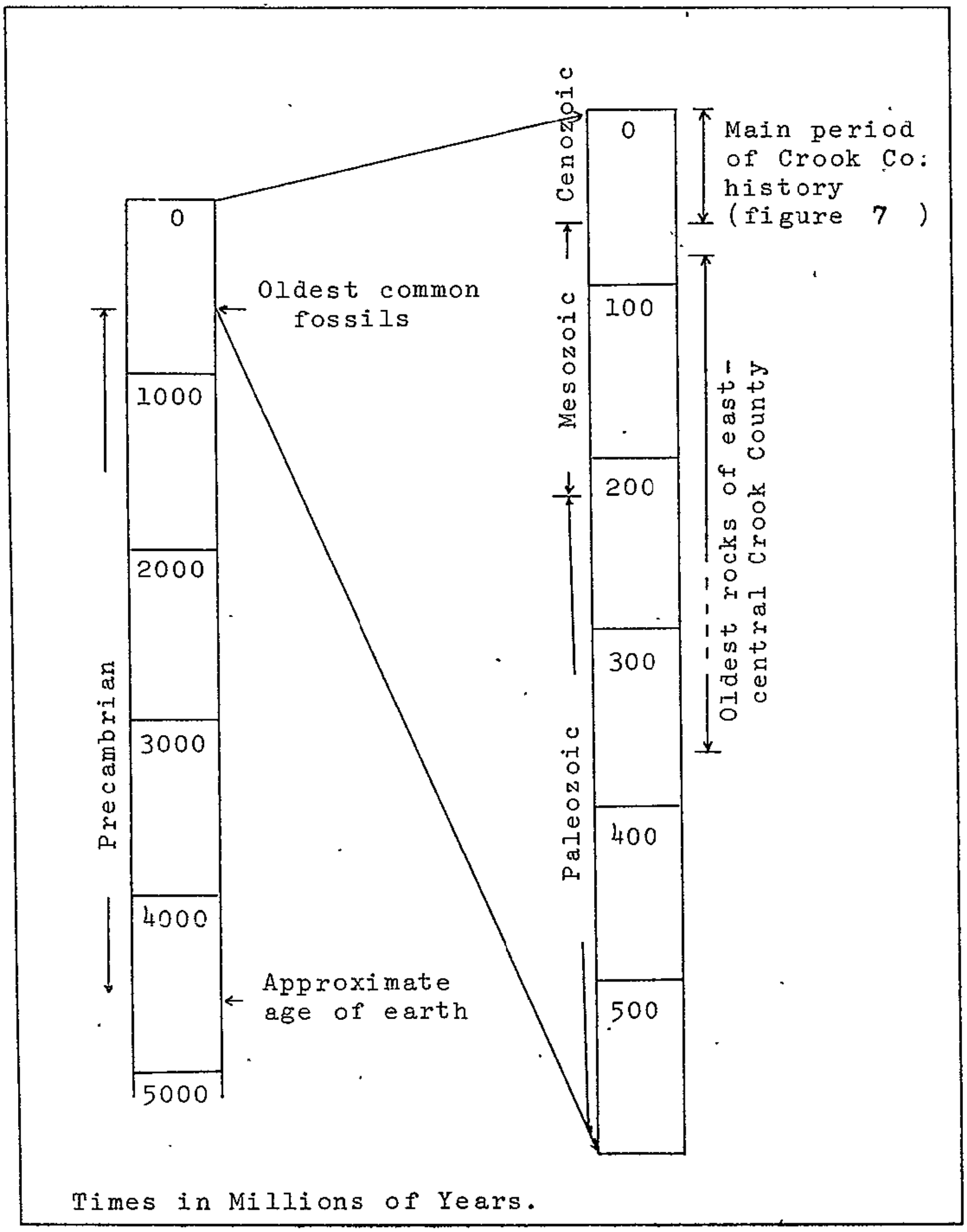

Figure 1. The place of the history of Crook County in geologic time.

material are present, but most of the area is of Mesozoic age. The rocks are largely volcanic and volcaniclastic in origin and andesitic in composition. A small area of Cretaceous marine sediments records the last time that the sea covered any part of the county.

Clarno Formation. The oldest Tertiary rocks in the county are the Clarno Formation of the Eocene age (about 37 to 46 million years ago). This unit is largely composed of volcanic flows and volcaniclastic debris, mainly of andesitic composition. The volcaniclastic component includes tuffs, breccias, and agglomerates resulting from explosive volcanic eruptions as well as deposits from rivers, debris flows, and lahars. Most of this material developed from stratovolcanoes similar to Mount Hood or the Three Sisters complex of the current crest of the Cascade Range and from the wide aprons of debris that develop around such mountains. Centers of eruption have been identified in a few places in the county and further study may locate more. Intrusive masses related to the volcanism are common in the unit. Erosion continued throughout the period when this unit was developing with the result that minor unconformities are common. The Clarno Formation is one of the most widespread in the county. It underlies the largest part of the Maury Mountains and the western portion of the Ochoco Mountains.

John Day Formation. The John Day Formation is of lower Oligocene to Lower Miocene age and is composed of tuffs and welded tuffs of silicic composition. These were derived from eruptions of volcanic centers west of the county, perhaps in the vicinity of the Cascade Range. The welded tuffs are present only in the western portion of the county. These tuffs accumulated above the topography present on the Clarno Formation as direct airfall ash deposits and as ash accumulations on river floodplains and in lakes. Powell Buttes, Bear Creek Butte, and Grizzly Mountain are masses of rhyolite domes and flows of this unit. The John Day Formation is exposed as a thin band around much of the Clarno outcrop in the western and central portions of the county. It is unconformable on the Clarno.

Columbia River Basalts. The Columbia River Basalts, of Miocene age, are a sequence of basalt flows that cover much of eastern Washington and northern Oregon. Crook County is near the southern limit of the unit and only a few hundred feet of basalt is present in contrast to the thousands of feet seen farther to the north. Individual flows are 50 to 100 feet thick. It rests unconformably on the underlying units. In the eastern part of the county the Columbia River Basalts rest directly on the Pre-Tertiary rocks, but in the rest of the county it overlies the John Day Formation.

Siliceous tuffs and tuffaceous sediments. After the Columbia River Basalts were deposited two basins developed in Crook County, one on the west side and one on the east. The eastern, Paulina Basin, is the older one within the county and contains materials deposited in Late Miocene and Pliocene time. These are the Mascall and Danforth Formations which are formed of siliceous tuffs and sediments and welded rhyolite tuffs.
On the west side the Prineville Basin is a reentrant of the larger Deschutes Basin. Siliceous tuffs and sediments similar to those described

above accumulated here as the Deschutes Formation. However these are younger than their eastern counterparts, being of Pliocene to Pleistocene age.

Rim basalts. Thin, late Pliocene to Pleistocene basalt flows rest on top of the older units described above. They are especially common over the Paulina and Prineville Basin materials. Numerous vent areas for these rocks are present in the county (figure 5). In places they are so young that some of the larger surface flow features have not been destroyed by weathering.

Youngest materials. The youngest geologic materials in the county are various unconsolidated deposits that have accumulated mostly in valleys and small basins. These include river and stream floodplain and terrace deposits, local lake beds and playas, and alluvial fans and pediment gravels. On valley slopes landslides, talus and colluvium are present. Airfall ash from the Cascades and Newberry Volcano are locally present over much of the county and contribute significantly to the valley fill materials. The most famous of these is the Mazama Ash produced by the eruption and collapse about 6600 years ago that resulted in Crater Lake.

Legend Format

The descriptive legent is in a digital format with a semi-hierarchial structure. Three digits are used:

First digit: Major material class.
Second digit: Minor material class.
Third digit: Material type.

The major departure from a clear hierarchy is in the first digit which is used to separate two levels. First it separates consolidated and unconsolidated materials and second it differentiates either the thickness of the unconsolidated material or the thickness of the regolith over the consolidated material. Thus the symbols "0 _ _" to "4 _ _" refer to unconsolidated materials while the symbols "5 _ _" to "9 _ _" refer to consolidated materials. In each case the lower numbers are for thicker materials, with decreasing thicknesses upward, and with the highest numbers ("4" and "9" respectively) are for materials of unknown or extremely mixed thicknesses. The sequence, with thicknesses used for Crook County is shown below:

Unconsolidated materials.
0 _ _ = Unconsolidated materials generally more than 10 feet thick.
1 _ _ = Unconsolidated materials generally less than 10 feet thick.
4 _ _ = Unknown materials of unknown thickness.

Consolidated materials.

5 _ _ = Consolidated materials with thin regolith, from 6 inches to 10 feet thick.
7 _ _ = Consolidated materials with little or no regolith, from 0 to 18 inches thick.
9 _ _ = Consolidated materials with unknown depth of regolith.

The second and third digits separate specific lithologic types. Here the digit "9" is reserved for units of unknown or mixed materials. Examples of lithologies designated by these symbols are:

009- Thick, unconsolidated valley bottom and plains materials not further differentiated.
112- Thin landslides on valley sides.
639- Thin regolith over mixed or undifferentiated silicic volcanic rocks.
742- Little or no regolith over basalt flows.

This digital legend was developed as a flexible tool for land use mapping of large areas at small scales, particularly on a photographic base and in combination with other disciplines.

The imagery interpretation reported herein is supported by geologic mapping at 1:250,000 (Williams, 1957; Brown and Thayer, 1966; Walker, Peterson, and Greene, 1967; Swanson, 1969; and Greene, Walker, and Corcoran, 1972) and parts of the county at 1:62,5000 (Waters, 1968; Waters and Vaughan, 1968A; Waters and Vaughan, 1968B; and Swinney, Waters and Miller, 1968) and at 1:96,000 (Wilkinson, 1939). These sources provide excellent material on bedrock interpretation and therefore the bedrock units can be treated with considerable confidence. Good sources of supporting information on the unconsolidated materials of the county are not available, however, with the result that the interpretations herein are more limited in some cases. Unconsolidated materials are largely surficial and thus usually can be interpreted from imagery with confidence. Finally, the thickness estimates for regolith and unconsolidated materials are based entirely on the interpretation of imagery. Since thickness is not directly visible on the imagery the interpretation is always an extrapolation. Limited field checking indicates that the data is good where checked, but caution in use is appropriate.

Structural Geology

The structural geology most readily studied on the ERTS imagery is the Tertiary structure of the last 70 million years. This history is presented in a series of maps (figures 2 to 6) on the ERTS base. Deformation has been nearly continuous during this time resulting in intersecting major folds which produce interference patterns of outcrops for the major units. These patterns are complicated by faulting which has broken the rock units. See figure 7 for a summary of events.

Structural mapping on high flight and satellite imagery has resulted in the addition of a great deal of information about fracturing in the county. However, it is often not possible to tell from the imagery alone whether there has been motion along the fracture (faulting) or has not been such motion (jointing). Thus such structural mapping involves separating features that can definitely be shown to be faults because offset units can be identified from those which cannot be so identified which may be either faults or joints. In addition study of the satellite imagery, while it certainly allows identification of fewer such features, generally shows greater continuity to the features seen than can be interpreted from the high flight imagery which is broken into many frames each covering a smaller area. These differences can be seen by comparing the high flight structural map to figure 6.

Pre-Tertiary Structure. The deformation of the oldest rocks in Crook County is complex and also on a scale too small to resolve on the ERTS imagery. Some details can be seen on the high flight imagery, but most of these features require field study at smaller scales than those used herein. Figure 2 shows the area of outcrop of these Pre-Tertiary materials in Crook County and adjacent areas. The general northeastern trend of these is a result of the participation of the older rocks in the deformation of the younger rocks as described below.

Internal Structure of the Clarno Formation. The Clarno Formation can be divided into a northern and a southern section at the Crooked River with significant structural differences between the sections (figure 3). No detailed studies of the internal structure of the unit are available for Crook County. Some basic features can be determined through the combined use of the ERTS and high flight imagery. In the northern area it is possible to trace lineaments on the ERTS imagery which show regional continuity along a northeasterly trend. THe high flight imagery allows these to be identified as fairly steeply dipping flow layering and bedding within the Clarno Formation. The continuity is difficult to see on the separate high flight photographs. On this basis, it is clear that the northern section on the unit is dominated structurally by folding on northeast trending axes. The regional continuity indicates that little or no faulting offsets these folds across their trend. These folds began to develop late in the period of deposition of the Clarno Formation in Crook County.

In the southern section no such overall, continuous features are present. Instead an abundant array of lineaments, mostly relatively short, are present in a complex pattern. These are shown in the most detail on the high flight structure map.

Study of the high flight imagery indicates that these are mostly faults or joints. It is not possible to resolve as much detail of these features on the ERTS imagery, but it is possible to interpret greater continuity to some zones. This fracture pattern continues into the John Day Formation and Columbia River Basalt adjacent to the southern section and thus is younger than all of these units.

Lineaments are also present in the southern section which prove to be bedding, from the study of the high flight imagery. Here the bedding trends more easterly than it does in the northern section, suggesting that the fold axes are not quite parallel to their attitude farther

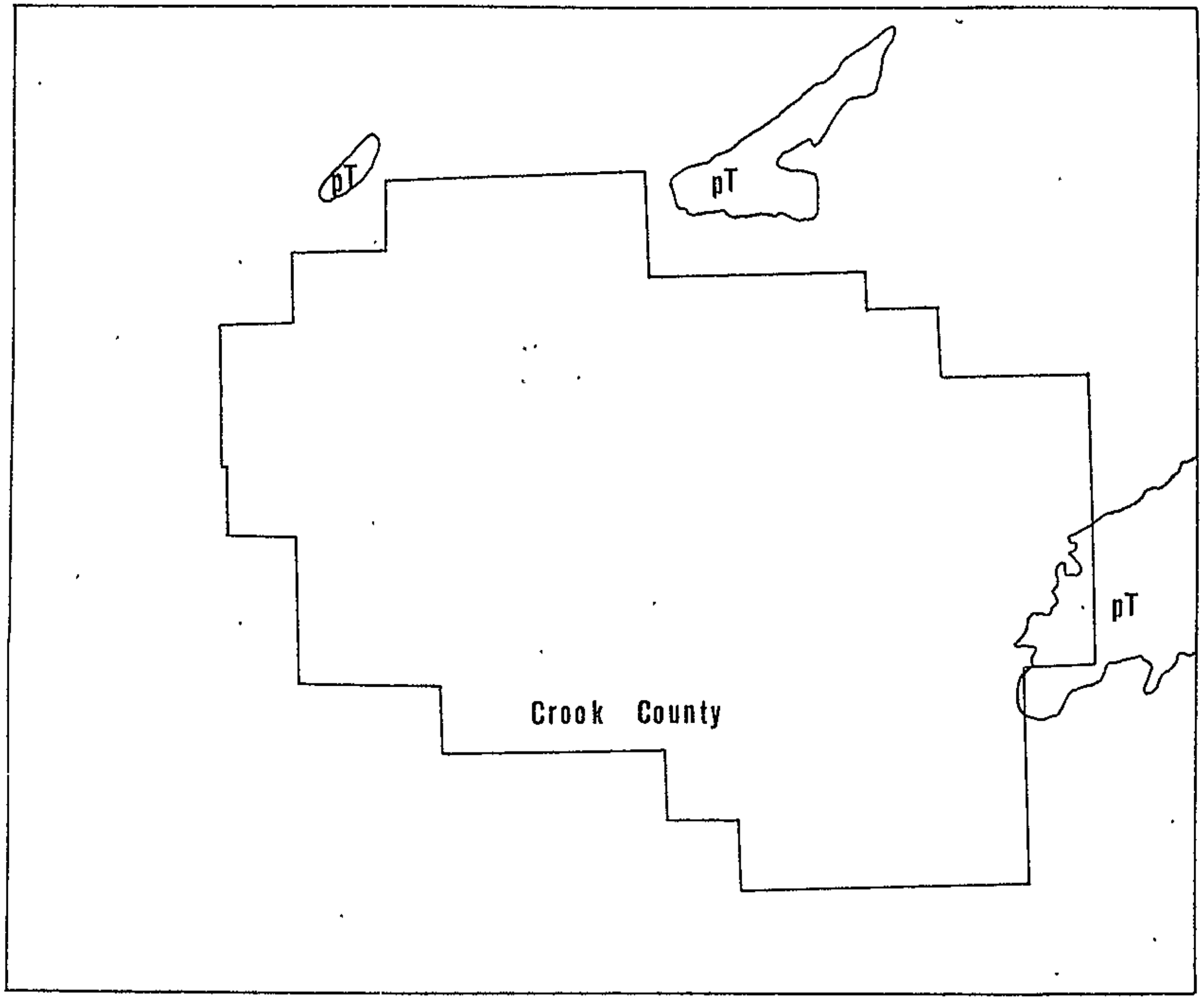

Figure 2. Areas of Pre-Cenozoic (pT) rocks in Crook County and vicinity, Oregon. ERTS fram 1076-18211.

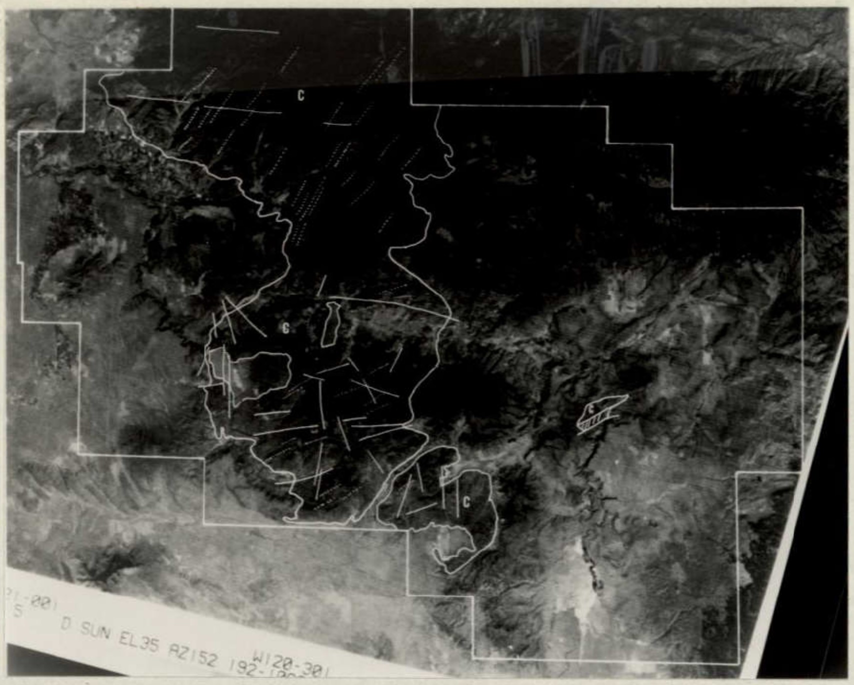

Figure 3. Structures in Clarno Formation, Crook County, on ERTS Frame 1076-18211. Dotted lines are bedding lineaments showing fold directions; solid lines are fault or joint lineaments.

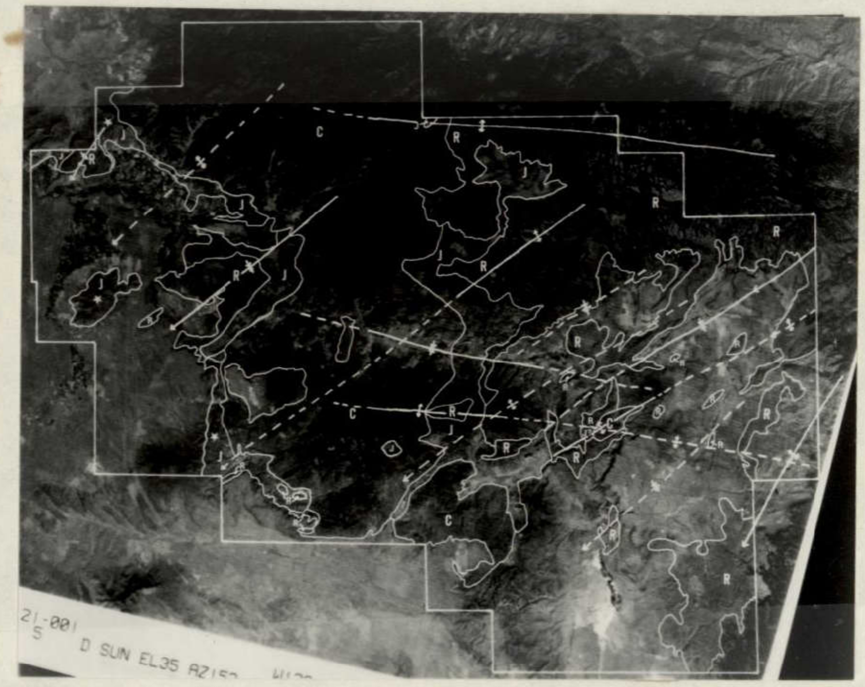

Figure 4 Interfering structures in Crook County on ERTS frame 1076-18211. C = Clarno Fm., J = John Day Fm., and R = Columbia River Basalt.

north. It is possible that faulting just north of the Crooked River is responsible for this difference, but no such faults were detected in this study.

Interference Folding. The John Day Formation and Columbia River Basin are folded on the same northeast trending axes as the Clarno Formation (figure 4). Thus this folding continued through much of Tertiary time. Each unit is deposited inconformably on the underlying one after a period of erosion during which the folding continued. Thus each younger unit is folded more gently than the underlying one. These younger folds are dramatically displayed on the ERTS imagery by the attitudes and outcrop patterns of resistant welded tuff and basalt units. Fold axes are clearly distinquished in the John Day Formation and Columbia River Basalts, but not in the underlying and more tightly folded Clarno Formation. There is significant discordance between the bedding and flow layering lineaments of the Clarno Formation discussed above and the folds of the younger units suggesting that the folds may not be perfectly identical in pattern.

In Crook County the northeast trending folds appear to have been best developed along the eastern border. Here the Pre-Tertiary basement was folded up far enough that erosion removed such material of the Clarno and John Day Formation as was deposited before the Columbia River Basalt was erupted. This is recorded by the basalts lapping directly up on the basement. This increased intensity to the east is also shown by the more closely spaced fold axes in this part of the county.

The northeast trending folds discussed above are crossed by a younger set of east-west trending structures. These are basically found as anticlines under the Ochoco and Maury Mountains and a syncline under the Crooked River Valley (figure 4). The two sets of folds interfere with each other where they intersect, in the same manner as two sets of waves on the ocean. Where two synclines meet, as in the Paulina Basin, a major depressed area results. Where two anticlines meet, as at Tower Point and Prairie Hill, major areas of high structure result. To a large degree these points of structural relief are also reflected in topographic relief where resistant basalts are present. The basalts have been relatively little affected by erosion since the folding pattern was established. This interference pattern from folding is responsible for the irregular outcrop pattern of the John Day Formation and Columbia River Basalt seen in figure 4.

Nature of the East-West Folds. The younger, east-west trending folds discussed above form the Ochoco and Maury Mountains anticlines with an intervening syncline along the Crooked River. The actual structure involved is best displayed by the block around Big Summit Prairie where a thin layer of Columbia River Basalt has preserved the form. The south limb of the fold is a gentle dip slope, slightly perturbed by the northeast trending folds. The northern limb is much steeper and is broken by en echelon normal faults down-dropped on the northern sides. Indeed, the entire pattern is more nearly that of a tilted fault block than a fold. Large lineaments similar to these faults can be identified on the ERTS imagery in the area of Clarno Formation outcrop to the west (figure 5).

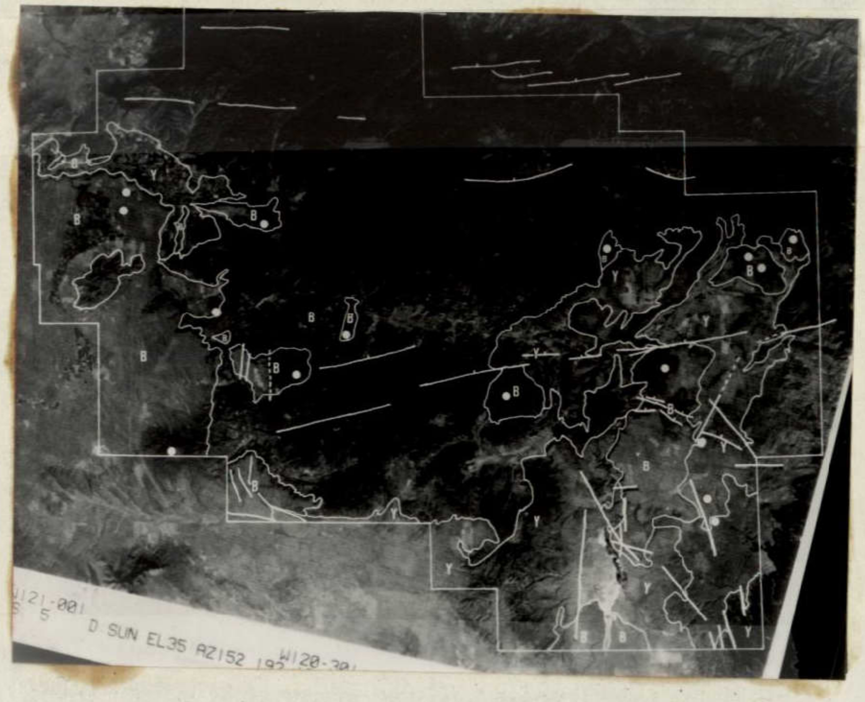

Figure 5. Youngest structures in Crook County on ERTS frame 1076-18211. B = Rim basalt and Y = other young units. Solid dots = vents for B.

Figure 6. Fault or joint lineaments in Crook County on ERTS frame 1076-18211. Dashed where less confident.

These suggest that fault control may well extend throughout the range. The Columbia River Basalts rest on weak, landslide-prone tuffs of the John Day Formation. The structural relief of the steep northern limb produces landsliding across the faults with the result that it is not possible to determine if any northward dips are structurally produced. However the overall form of a fold is produced. A similar interpretation of the Maury Mountains Anticline is also possible. Less of the Columbia River Basalt is preserved in this area than is true farther to the north so the interpretation is not as clear. However, normal faults which are down dropped on the north are present, extending west from the Paulina Basin (figure 6). Young basalt vents are aligned approximately along the faulting of the Maury Mountains Anticline. This supports an interpretation of the structure in terms of an extensional origin rather than compressional. Thus the east-west trending structures of Crook County can reasonably be interpreted as tilted fault blocks rather than simple anticlines. Whether some folding is also involved cannot be determined from the available evidence.

On the dip slope around Big Summit Prairie the joint pattern of the Columbia River Basalt is dramatically displayed. The joints are in three sets at equal angles of 120° apart. The basalt unit is only a few hundreds of feet thick and rests on very weak tuffs of the John Day Formation. The south limb of the Ochoco Anticline (or fault block) dips several degrees to the south and the basalts have slid on the weak tuffs down this slope enough to open the joint sets. Most of the joints have been deepened and widened by stream action. Locally, normal faulting, similar to that involved in creating the Ochoco Anticline occurs along the joints. Ponderosa Pine and associated plants occupy the joints while grass and sagebrush grow on the intervening scabs producing the dramatic visual effect on ERTS and other imagery. The joint sets are older than the structural events which opened them, and probably developed as cooling joints in the basalt. The process would be similar to that which develops columnar jointing but on a much larger scale.

Other Structural Features. The youngest structures in the county are faults, most of which are in the southern part of the county. Most of these are oriented about north-south (figure 5). Much of the fracturing of the Clarno Formation in the southern part of its outcrop is probably of the same age. These faults break the youngest basalts in the county and, therefore, have been active until very recently. They are probably minor continuations of the east-west extension in the Basin and Range province to the south. Time relations of fractures in the county are shown on the high flight structural map. Here those features, whether faults of joints, break geologic units younger than the Danforth Formation. Thus these features are all younger than about 5 to 6 million years old.

Many parts of the Crooked River drainage are deeply incised in canyons that have been relatively rapidly eroded in the recent past. In places the river is superimposed across pre-existing ridges of Columbia River Basalt indicating that the current drainage has eroded down from an older surface. This surface was formed by the young basalt flows and welded tuffs. Similar recent downcutting continues down the Crooked

River and Deschutes River most of the way to the Columbia River. This suggests that the entire area of eastern Oregon has been undergoing gradual regional uplift in recent geologic time.

Geologic History

Crook County has had a varied geologic history involving nearly continuous deformation. During Cenozoic time subaerial erosion has also been continuous with the result that the geologic record in the county is broken by numerous unconformities. The complex map pattern of the rock units seen in the county results from this continual interaction of erosion and deformation. These Cenozoic rocks cover almost 99% of the surface of the county, but were formed within the last 1% of geologic time (figure 1). Thus most of the geologic history of the county is fragmentary or non-existent. The better known Cenozoic history is summarized on figure 7.

The oldest rocks in Crook County are Devonian, or 350 to 400 million years old. These and other Upper Paleozoic and Mesozoic rocks are extensively exposed east of the county and are present in scattered exposures north of the county (figure 2). They presumably underly the entire county area beneath the Cenozoic units. The fragmentary exposures allow only a fragmentary history to be reconstructed. This history involves repeated invasions by the sea and deposition of marine sedimentary and volcanic rock units. The latter are mostly of andesitic composition and record marine volcanism, perhaps similar to the Indonesian island arcs of today. The last retreat of the sea was in the Cretaceous (about 100 million years ago) when an east-west trough through central Oregon was occupied. Throughout this long period of time repeated episodes of deformation folded and faulted the rocks. A long interval of erosion and deformation occurred after the Cretaceous seas retreated and before the Cenozoic history, which we know in considerable detail, began.

Andesitic volcanism resumed in the Eocene with the deposition of the Clarno Formation. During this time period we may visualize the central Oregon area as a volcanic mountain range perhaps somewhat like portions of the Cascades but with an east to northeast trend. The volcanoes were built of flows, flow breccias, debris flows and other eruptive processes. Finer grained debris from these volcanoes accumulated in a basin or basins in the area south and east of Prineville Reservoir. Lush vegetation covered the slopes reflecting warm, moist climatic conditions. Deciduous trees played a dominant role in the forests of the area in contrast to the coniferous forests of today. In the early Oligocene the rocks that had developed from these volcanoes were folded along northeast trending axes during an episode of severe deformation. In the moist climate the resulting mountains were subject to rapid erosion.

During middle and late Oligocene times a series of volcanoes developed on the present Cascade trend. Ash flows and ash falls from these volcanoes began to blanket the area of central Oregon with what would become the

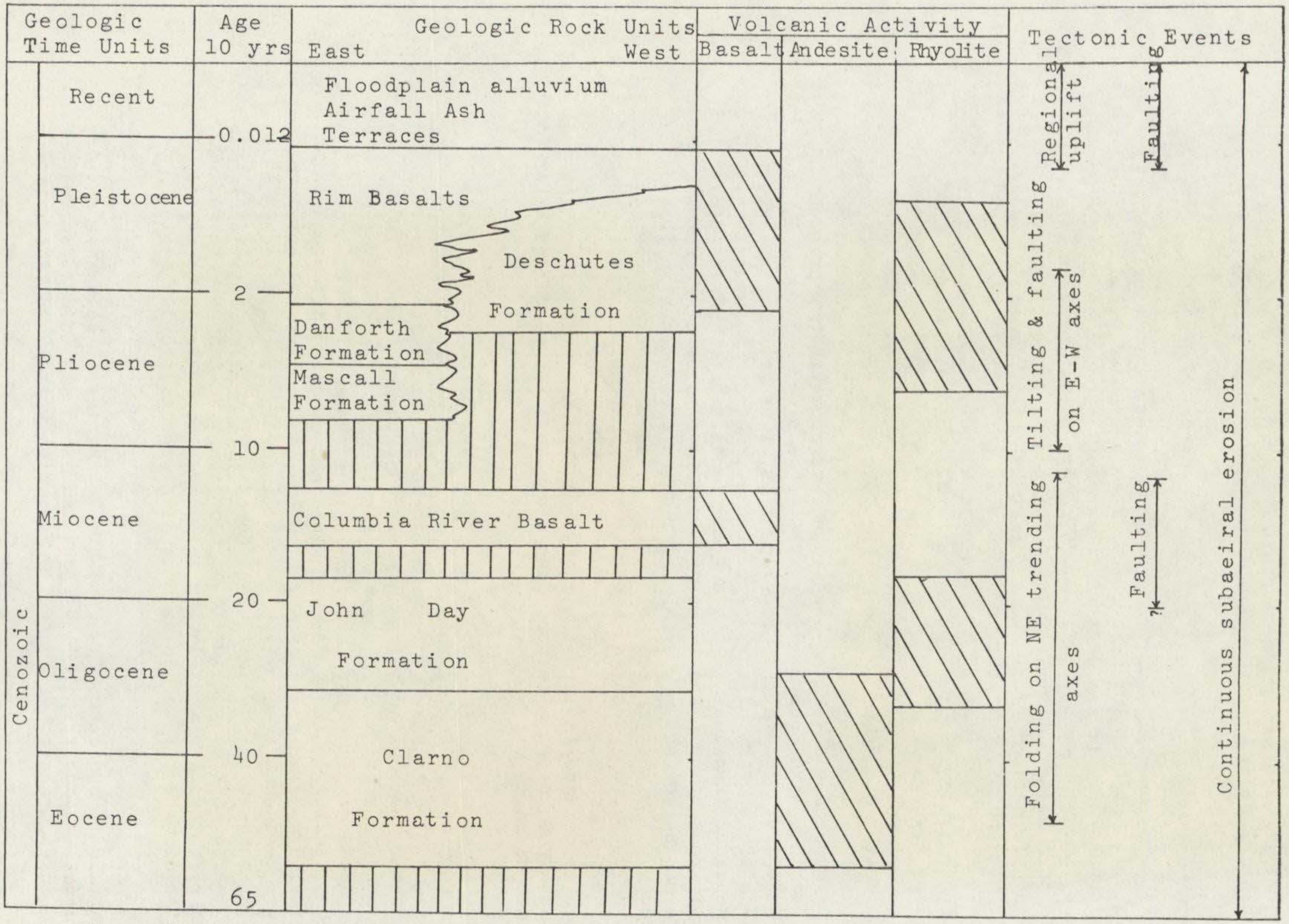

Figure 7. Cenozoic History of Crook County

John Day Formation. Locally, magma bodies made their way to the surface within the county to create small volcanic centers. These still stand as mountains at Grizzly Mountain, Powell Buttes, and Bear Creek Buttes. The ash flow units from the Cascades came into topographic lows of the western part of the county. Low areas over the entire county accumulated ash from the eruptive activity and debris from erosion of the Clarno Formation in lakes and along the flood plains of rivers and streams. The material of the John Day Formation that developed in this manner is more silicic than the andesites of the Clarno Formation indicating that the composition of the source areas had changed significantly. The climate and vegetation remain very similar in overall character to that which prevailed during the accumulation of the Clarno Formation. Deformation continued along the northeast trending axes, but much more gently so that the John Day Formation developed broad, open folds. Between the moist climate, the gentle deformation, and the generally distant volcanic activity we may suppose that a more subdued topography was present than that of the preceding Clarno times. As the topography became more gentle, deposition gradually came to an end early in the Miocene.

During the middle Miocene the area found itself on the edge of dramatic events taking place on the Columbia River Plateau to the north. Here tremendous quantities of basalt lava, the Columbia River Basalts, were issuing from fissures and ponding to cover the entire area. Crook County was part of the southern rim of this extensive basin and received a thin cover of these basalt flows over most of its area. The gentle deformation on northeast axes continued and the folds of the Columbia River Basalts are coincident with those of the John Day Formation but not quite as tight.

All three units, the Clarno Formation, John Day Formation, and Columbia River Basalt, have been faulted and jointed extensively. As many of these fractures do not extend into the younger rock units, they occurred in the Miocene and earlier but exact ages are unknown.

From the Miocene on the climate has gradually altered to become drier until the semi-arid conditions of the present prevailed. This trend was probably interupted briefly by more moist conditions during the Pleistocene ice ages.

During the Pliocene the character of deformation in the county changed. The folding on northeast axes came to an end. The new pattern was one of east-west oriented normal faulting. These faults gradually tilted up the areas of the Ochoco and Maury Mountains and let the region along the Crooked River and north of the county drop down. Where both the tilt blocks and the older folds produced downwarped structures major basins were formed. The most important of these are the Prineville and Paulina Basins. The former is an embayment of the larger Deschutes Basin to the west. Similarly, high points in the county such as Tower Point, Round Mountain, Lookout Mountain and Hash Rock are culminations produced by upwarps from both sets of structures.

The basins as produced have acted as centers of accumulation during the last part of the geologic history of the area. During the Pliocene, ash flows and associated tuffaceous sediments (the Mascall and Danforth Formation) entered the Paulina Basin from the southeast. These and locally derived sediments spread across the area as a relatively flat sheet. These materials are largely rhyolitic in composition and resemble the John Day Formation. Late in the Pliocene and into the Pleistocene basalt flows (Rim Basalts) from local vents such as Maupin Butte, and Dutchman Flat spread as a thin layer across much of the basin. Continued faulting along the east-west normal faults along the north flank of the Maury Mountains and the north edge of Twelve-mile Table broke up the level area produced by the ash flows and basalt flows and isolated the Paulina Basin from the southeastern source of rhyolitic lavas.

The Prineville Basin on the west has a similar, but more recent history. Siliceous tuffs and tuffaceous sediments (Deschutes Formation) from the Plio-Pleistocene High Cascades began to fill the area and then were covered by extensive basalt flows of Pleistocene age. This basin was never disrupted by faulting as the Paulina Basin was and remains open to the west.

The southern part of the county is adjacent to the Brothers Fault Zone, a west-northwest trending feature that forms the edge of the Basin and Range Province to the south. Considerable very young faulting along the southern edge of the county is probably related to this zone. The entire county area appears to have been subject to broad uplift during the most recent part of geologic time and probably continuing into the present. This may be a continuation of the activity along the east-west axes.

The entire county was subject to erosion following the last flows of the Rim Basalts. The major drainage lines had been established along the major downwarps and following other lines of structural and lithologic control. Near Prineville, the Crooked River flowed approximately along the eastern edge of the Rim Basalts and gradually carved a small basin northwest of the town. In the Paulina Basin, the same river cut into the level tableland. As it cut downward it encountered high areas of Columbia River Basalt, probably minor northeast trending anticlines, which slowed its rate of downcutting. Numerous small basins were formed. A period of accumulation followed during which fairly thick floodplain deposits formed along the major streams and small lakes formed in the isolated basins. Renewed downcutting left these exposed as terraces. Most recently new floodplains have formed and then been slightly entrenched. Air-fall ash from the present High Cascades is locally present in these deposits. That from Mt. Mazama, the mountain whose climactic eruption about 6600 years ago formed Crater Lake and spread ash far to the northeast, is found several feet below the surface of these most recent floodplain materials. This indicates that the most recent downcutting in the county has been during the last several thousand years.

D. SOIL-LANDSCAPES

Introduction

Forestry and agriculture support the economy of Crook County. Soils are thus a major part of the county's total resources, and a reliable record of soil distribution is considered an essential component of any county resource inventory.

Ground-truth for the soil component of this investigation was derived primarily from previous soil maps and reports dealing with the Crook County area. These maps varied from the detailed standard soil survey of the Prineville area (1), which covers approximately 11% of Crook County, to a generalized soil association map of the entire Deschutes River basin (2). Unpublished, in-service reports from Ochoco National Forest (USDA) and Bureau of Land Management (USDI) covering approximately 6% of the county were also consulted. Field work was utilized to clarify discrepencies between these various sources and to fill in obvious gaps. Further details are given in the Methodology section.

The approach taken involved delineating homogeneous segments of landscape on ERTS imagery, then describing the predominant soils associated within them. The resultant maps have been called soil-landscape maps to emphasize the importance of landforms and terrain similarity in their construction.

1:1,000,000 Map and Legend

This initial version of a soil-landscape map for Crook County is divided into 58 delineations (Figure 8) which consist of 15 described units (Table 1). Average delineation size is approximately 133 square kilometers. Agricultural potential of soils tends to decrease with increasing value of the symbol, and numbers 10 through 14 denote forested areas. With these exceptions, the choice of symbols is arbitrary. This legend, or a similar one, would apply to approximately 25 percent of Oregon.

1:250,000 Map and Legend

Figure 9 is a 50 percent reduction of the soil-landscape map which was made at a scale of 1:250,000. Approximately 157 delineations, with an average area of 49 square kilometers, are described in 23 units (Table 2). Soils occurring within each unit are listed after the description, in order of decreasing importance. To facilitate comparison of the two versions, map symbols were chosen to correspond with those used on the 1:1,000,000 map. Increased legend complexity was allowed for by adding letters to the numerical symbols. Most of the subdivisions designated by letters refer to variations in degree and direction of slope, with attendant shifts in soil dominance. Some of the delineations were made with the aid of three-band color reconstitutions, but distinct differences in tone and pattern are evident between most delineations on the red-band black and white print illustrated here (Figure 9).

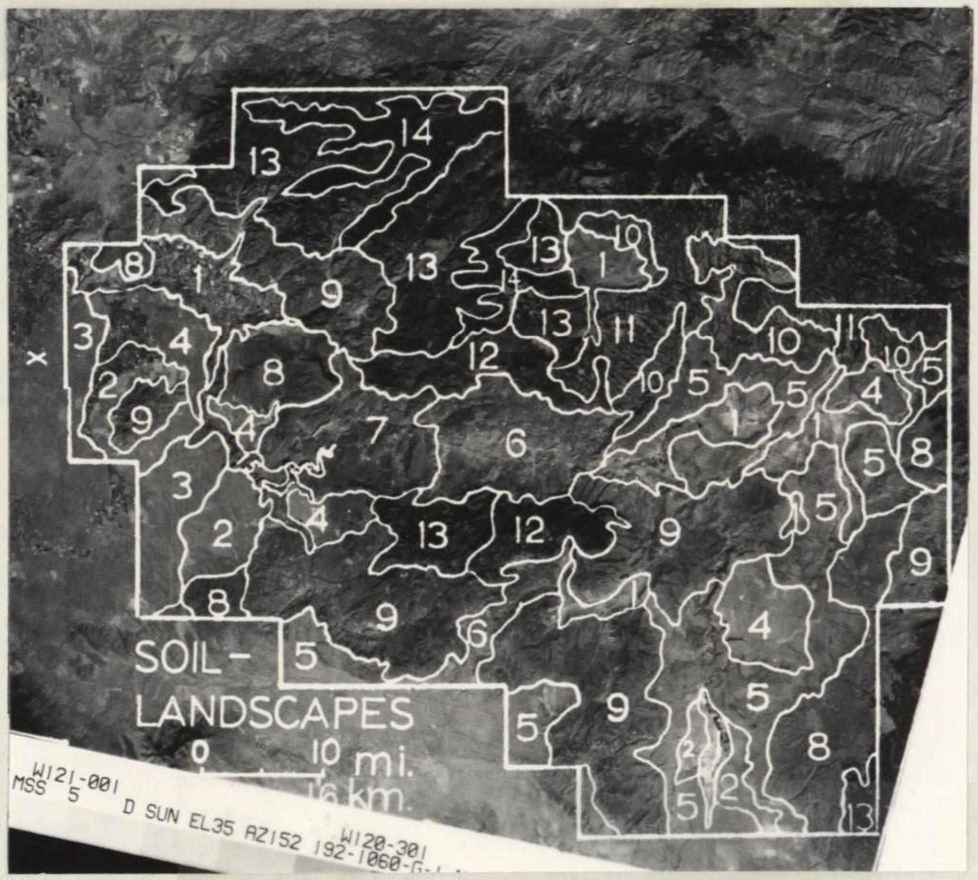

Figure 8. Soil-landscape map of Crook County, Oregon. Presented at 1:1,000,000 on ERTS 1076-18211-5. Original delineations were made on a 4, 5, and 7 band color reconstitution.

Table 1. Legend for Soil-Landscape Map of Crook County, Oregon

ERTS Frame 1076-18211 Scale 1:1,000,000

Map Symbol	Unit Description
1.	Deep and moderately deep, medium textured soils on floodplains. Alkaline soils occur in some poorly drained areas. Moderately deep, medium textured soils with strongly indurated pans predominate on terraces.
2.	Shallow and moderately deep, medium textured, gravelly soils with strongly cemented pans, on slightly dissected alluvial fans.
3.	Shallow and moderately deep, medium and coarse textured soils in nearly level and concave areas of younger lava flows. Bare rock predominates on convex portions.
4.	Shallow, very shallow and moderately deep, medium textured soils, some of which are stony, on nearly level to gently rolling older lava flows.
5.	Very shallow and shallow, stony and very stony soils, many of which have clayey subsoils, on gently rolling to nearly level volcanic plateaus.
6.	Moderately deep, shallow, and deep clayey soils, on moderately dissected, rolling terrain.
7.	Shallow and moderately deep, clayey soils in steeply rolling, dissected terrain. Moderately deep, loamy soils occur on north slopes and in concave places. Rock outcrops are common.
8.	Shallow and very shallow, stony and very stony soils, with clayey subsoils, in moerately dissected, rolling terrain.
9.	Shallow and moderately deep, stony and very stony, medium and fine textured soils predominate. Moderately deep, stone free, medium textured soils occur on some north slopes. Steeply rolling, dissected terrain predominates, and rock outcrops are common.
10.	A complex landscape consisting predominantly of very shallow, stony and very stony, sparsely vegetated soils on nearly level to rolling plateaus. Moderately deep and deep, medium textured, timbered soils occur on northern slopes and in canyons.

11. A complex landscape consisting predominantly of moderately deep and deep, medium textured, timbered soil; with sparsely vegetated, very shallow and stony soils on south facing slopes.

12. Moderately deep and deep, fine-textured, timbered soils in moderately deissected, rolling terrain, primarily above 5000 feet elevation.

13. Moderately deep and deep, medium and fine-textured, stony, timbered soils in steeply rolling, dissected terrain. South slopes may have shallow, stony soils and lack timber.

14. Moderately deep and deep, medium textured, timbered soils formed from volcanic ash over a variety of buried soils, primarily on north slopes above 4500 feet elevation.

15. Very steep, shallow, stony and rocky soils predominate. Canyons with more than 500 feet of local relief.

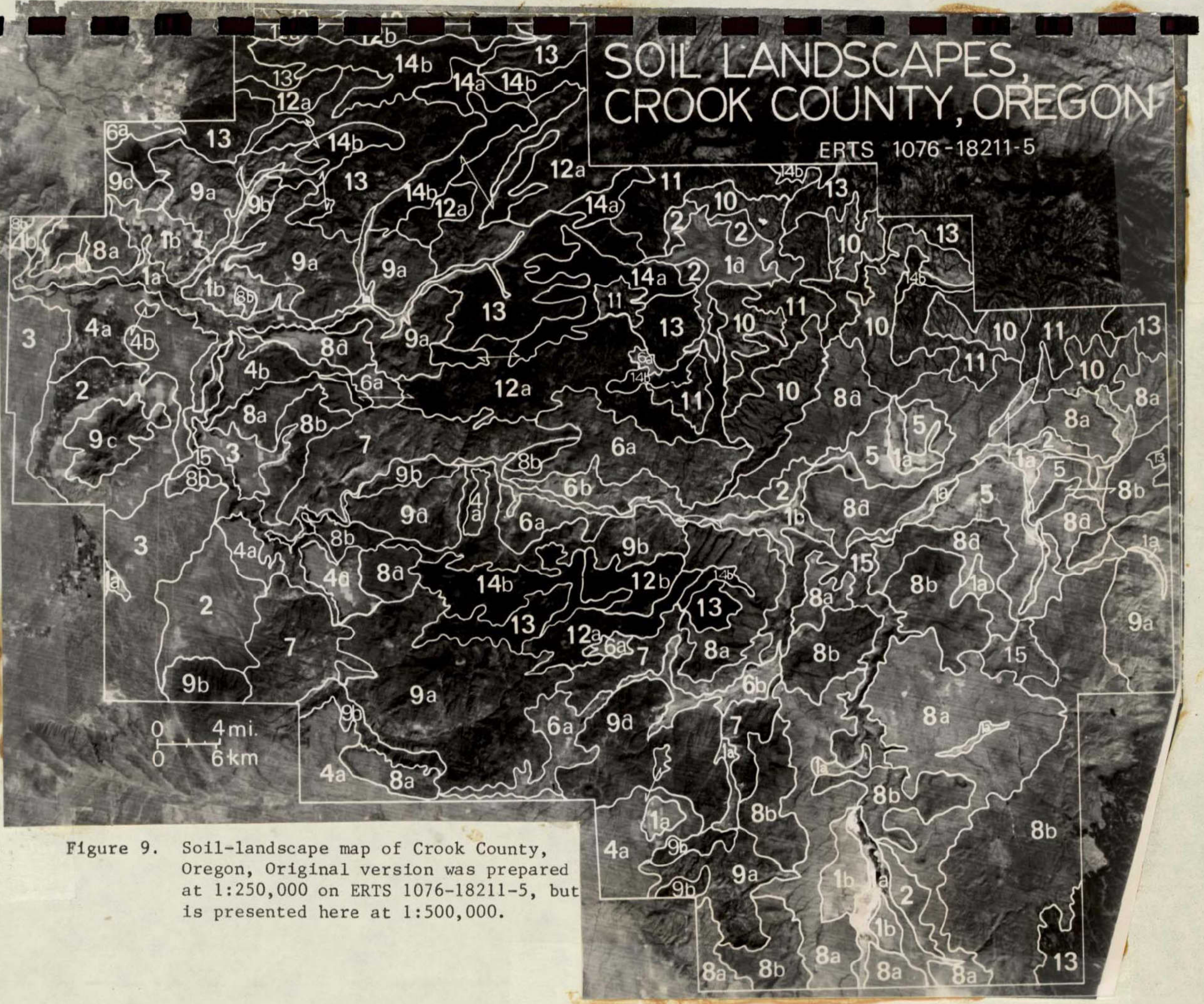

Figure 9. Soil-landscape map of Crook County, Oregon, Original version was prepared at 1:250,000 on ERTS 1076-18211-5, but is presented here at 1:500,000.

Table 2. Legend for a Soil-Landscape Map of
Crook County, Oregon

ERTS Frame 1076-18211-5 Scale 1:250,000

Map Symbol	Unit Description
1a.	Deep and moderately deep, medium textured soils on floodplains. Alkaline soils occur in some poorly drained areas. Powder loam, Courtrock sandy loam, Calabar silt loam, Damon silty clay loam, Metolius sandy loam, Crooked sandy loam, Boyce silty clay loam, Veazie sandy loam, Ontko silty clay Loam, Polly loam.
1b.	Moderately deep, medium textured soils, some of which have indurated pans, on alluvial terraces. Ochoco sandy loam, Prineville sandy loam, Hack loam, Courtrock sandy loam.
2.	Shallow and moderately deep, medium textured, gravelly soils with strongly cemented pans, on slightly dissected alluvial fans. Ayres sandy loam, Nouque silt loam, Deschutes sandy loam, Shev loamy sand, Salisbury clay loam, Gribble cobbly loam.
3.	Shallow and moderately deep, medium and coarse textured soils in nearly level and concave areas of younger lava flows. Bare rock predominates on convex portions. Deskamp loamy sand, Arron sandy loam, Deschutes loamy sand, Rockland, Gosney very stony loamy sand, Bakeoven very cobbly loam.
4a.	Shallow, very shallow and moderately deep, medium textured soils, some of which are stony, on nearly level to gently rolling older lava flows. Deschutes sandy loam, Arron sandy loam, Redmond sandy loam, Deskamp loamy sand, Gosney very stony loamy sand, Bakeoven very cobbly loam, Rockland.
4b.	As above on rolling, moderately dissected terrain. Deschutes sandy loam, Gosney very stony loamy sand, Bakeoven very cobbly loam.
5.	Shallow and moderately deep, medium textured soils in gently rolling topography formed from soft sedimentary rocks. Roba loam, Fopiano silty clay loam, Marsden silt loam.

6a. Moderately deep, shallow, and deep clayey soils, on moderately dissected rolling terrain.

Simas cobbly silty clay loam, Ginser very stony loam, Tub silt loam, Day clay, Prag very stony loam, Soft sedimentary rock.

6b. Similar to (a) but with numerous exposures of unconsolidated rock.

Simas cobbly silty clay loam, Tub silt loam, Soft sedimentary rocks, Ginser very stony loam, Day clay, Rockland.

7. Shallow and moderately deep clayey soils in steeply rolling, dissected terrain. Moderately deep, loamy soils occur on north slopes and in concave places. Rock outcrops are common.

Simas cobbly silt clay loam (shallow variant), Tub silt loam, Soft sedimentary rocks, Ginser very stony loam, Day clay, Prag very stony loam, Rockland.

8a. Shallow and very shallow, stony and very stony, loamy soils, with clayey subsoils, in moderately dissected, rolling terrain.

Ruckles very stony silt loam, Anawalt stony silt loam, Bakeoven very cobbly loam, Olson stony loam.

8b. Similar to (a) but steeply rolling.

Anawalt stony silt loam, Ruckles very stony silt loam, Lookout stony silt loam, Bakeoven very cobbly loam, Olson stony loam, Rockland.

9a. Shallow and moderately deep, stony and very stony, medium and fine textured soils predominate. Moderately deep, stone-free, medium textured soils occur on some north slopes. Steeply rolling, dissected terrain predominates, and rock outcrops are common.

Simas cobbly silty clay loam, Tub silt loam, Ginser very stony loam, Gem very stony loam, Prag very stony loam, Rarey loam, Curant silt loam, Rockland.

9b. Similar to (a) but north slopes make up more than 25% of the area.

Prag very stony loam, Tub silt loam, Rarey loam, Ginser very stony loam, Simas cobbly silty clay loam.

9c. Shallow, moderately deep and deep, stony, medium textured soils in steeply rolling and mountainous terrain underlain by rhyolite.

Searles very stony loam, Elmore very stony loam, Simas cobbly silty clay loam, Tub silt loam, Lickskillet very stony loam, Rockland, Deskamp loamy sand.

10. A complex landscape consisting predominantly of very shallow, stony and very stony, sparsely vegetated soils on nearly level to rolling plateaus. Moderately deep and deep, medium textured, timbered soils occur on northern slopes and in canyons.

    Anatone very stony loam, Klicker very stony silt loam, Hall Ranch stony loam, Tolo silt loam, Snell very stony loam.

11. A complex landscape consisting predominantly of moderately deep and deep, medium textured, timbered soils; with sparsely vegetated, very shallow and stony soils on south facing slopes.

    Klicker very stony silt loam, Anatone very stony loam, Hall Ranch stony loam, Tolo silt loam, Snell very stony loam,

12a. Moderately deep and deep, fine-textured, timbered soils in moderately dissected, rolling terrain, primarily above 5000 feet elevation.

    Hankins cobbly loam, Hankton cobbly silt loam, Boardtree gravelly loam, Yawkey gravelly loam.

12b. Similar to (a) but north slopes predominate.

    Boardtree gravelly loam, Yawkey gravelly loam, Hankins cobbly loam, Hankton cobbly silt loam.

13. Moderately deep and deep, medium and fine-textured, stony, timbered soils in steeply rolling, dissected terrain. South slopes may have shallow, stony soils and lack timber.

    Hankton cobbly silt loam, Hankins cobbly loam, Klicker very stony silt loam, Ginser very stony loam, Yawkey gravelly loam, Anatone very stony loam, Rockland.

14a. Moderately deep and deep, medium textured, timbered soils formed from volcanic ash over a variety of buried soils, primarily on north slopes above 4500 feet elevation.

    Boardtree gravelly loam, Whistler sandy loam, Yawkey gravelly loam, Hankins cobbly loam.

14b. A mixture of units 14a and 13, occurring on north and south slopes, respectively.

    Hankins cobbly loam, Hankton cobbly silt loam, Boardtree gravelly loam, Klicker very stony silt loam, Yawkey gravelly loam, Ginser very stony loam, Snell very stony loam.

15. Very steep, shallow, stony and rocky soils predominate. Canyons with more than 500 feet of local relief.

    Lickskillet very stony loam, Rockland, Bakeoven very cobbly loam, Lookout stony silt loam, Simas cobbly silty clay loam, Tub silt loam.

1:120,000 Map and Legend

NASA high-flight CIR (72-114) photography served a two-fold purpose. It contributed a vital part of the ground truth necessary for ERTS imagery interpretation and served as the base for more detailed resource maps, with which ERTS-based versions could be evaluated. The Soil-landscape map made from this high-flight photography contains approximately 220 delineations, with an average area of 35 square kilometers (App. A-4). The legend contains 32 units and is constructed in similar fashion to that used for the 1:250,000 version (App. A-5). Increased size of the legend is accounted for by attaching more lettered subdivisions to many of the numbered units. Component soils are again listed in order of decreasing importance and each mapping unit is named for the most extensive two or three soils comprising it.

Soil Groups, with Interpretations of Suitability and Limitations for Several Uses

Table 3 is an example of part of a summary table which includes interpretations for all the principal soils occurring within the described soil-landscape units, as well as an estimated percentage of each soil's extent within a given unit. Areas given for the mapped units were measured on the 1:120,000 soil-landscape map. Ratings of relative suitability and limitations for a variety of potential uses are given by individual soils and summarized by mapping unit. One or more of the main limitations are itemized for those uses which have more than slight limitations. Table 11, in the Land Resource Unit section was derived from the complete version of this compilation.

Properties and Qualities of Soils Occurring in Soil-Landscape Units

Table 4 is a portion of a summary table containing climatic data, physical characteristics, and geographic setting for soils occurring in the soil-landscape units. This sort of information, as well as field experience is used to derive the interpretations presented in Table 3.

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Footnotes for Table 3

1/ Hydrologic group: The hydrologic group ratings indicate water transmission rates through the soil. Group A soils have a high rate of water transmission and would have a low runoff potential. Goup B soils have a moderate rate of water transmission, Group C soils have a slow rate of water transmission, and Group D soils have a very slow rate of water transmission or are poorly drained.

2/ Land capability: The land capability column shows the land capability classification for each of the soil mapping units. It is a grouping, primarily for farming purposes; that shows for each soil the potential and limitations for sustained production of the common cultivated crops that do not require specialized site conditioning or site treatment. The risks of soil damage or limitations in use become progressively greater from Class I to Class VIII. Each capability class is divided into sub-classes that show the major cause of limitations: e for erosion hazard, w for wetness, s for root zone limitations, and c for climatic limitations. Class I soils have few limitations that restrict their use and are excellent for cultivated crops. Class III soils have severe limitations that reduce the choice of plants or require special conservation practices, or both. They are poor for cultivated crops. Class VI soils have severe limitations that make then unsuited for cultivation and limit their use largely to pasture, woodland or wildlife food and cover. Class VII soils have very severe limitations that make them unsuited for cultivation and that restrict their use largely to grazing, woodland or wildlife. Soils and land forms in Class VIII have limitations that prohibit their use for commercial plant production and restrict their use to recreation, wildlife, water supply and aesthetic purposes. Ratings in brackets refer to irrigation.

3/ aum = Animal unit months of carrying capacity.

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E. Vegetation/Land Use

We have made an ecologically based vegetation/land use inventory of Crook County and a special purpose inventory of subdivision development in the county outside of the Prineville area. The timber inventory conducted by the Forest Management Department will be reported in this section also, with details concerning the sampling aspects in the Experimental Applications section.

Legend Units

The major legend units interpreted and mapped on ERTS imagery (1:1,000,000 color reconstitution of 1346-18212-4, 5, 7) were 200, Water Resources; 300, Natural Vegetation; 500, Agricultural Production; and 600, Urban and Extractive Industry (Figure R-1). Brief descriptions of these follow, including subdivisions of vegetation. Pure types are described first.

- 200 - WATER RESOURCES
    - 212 - Man-Made Reservoirs and Ponds; These are artificial impoundments of water. Ochoco and Prineville Reservoirs.
- 300 - NATURAL VEGETATION
    - 315 - Meadows: These are areas where grass and grasslike plants predominate and where soil moisture contents are high throughout most of the growing season. Big Summit Prairie.
    - 325 - Shrub Steppe: The prominent species here are mostly sagebrush, including low sagebrush (*Artemisia arbuscula, A. longiloba* and *A. rigida)*, big sagebrush (*Artemisia tridentata* including subspecies *vaseyana)*, silver sagebrush *(A. cana)*, and rabbitbrush *(chrysothamnus* species).
    - 341 - Conifer Forests: Plant communities here are characterised by ponderosa pine *(Pinus ponderosa)*, douglas fir *(Pseudotsuga menziesii)*, true fir *(Abies* species) and western juniper *(Juniperus occidentalis)*.
        - 341.1 - Juniper Types: These types can be separated from other forest vegetation on dry season ERTS color reconstitutions at 1:1,000,000. Big sagebrush is the most common prominent shrub.
- 500 - AGRICULTURAL PRODUCTION: areas mapped as this unit are the irrigated croplands near Prineville and Powell Butte.
- 600 - URBAN AND EXTRACTIVE INDUSTRY: This is the city of Prineville.

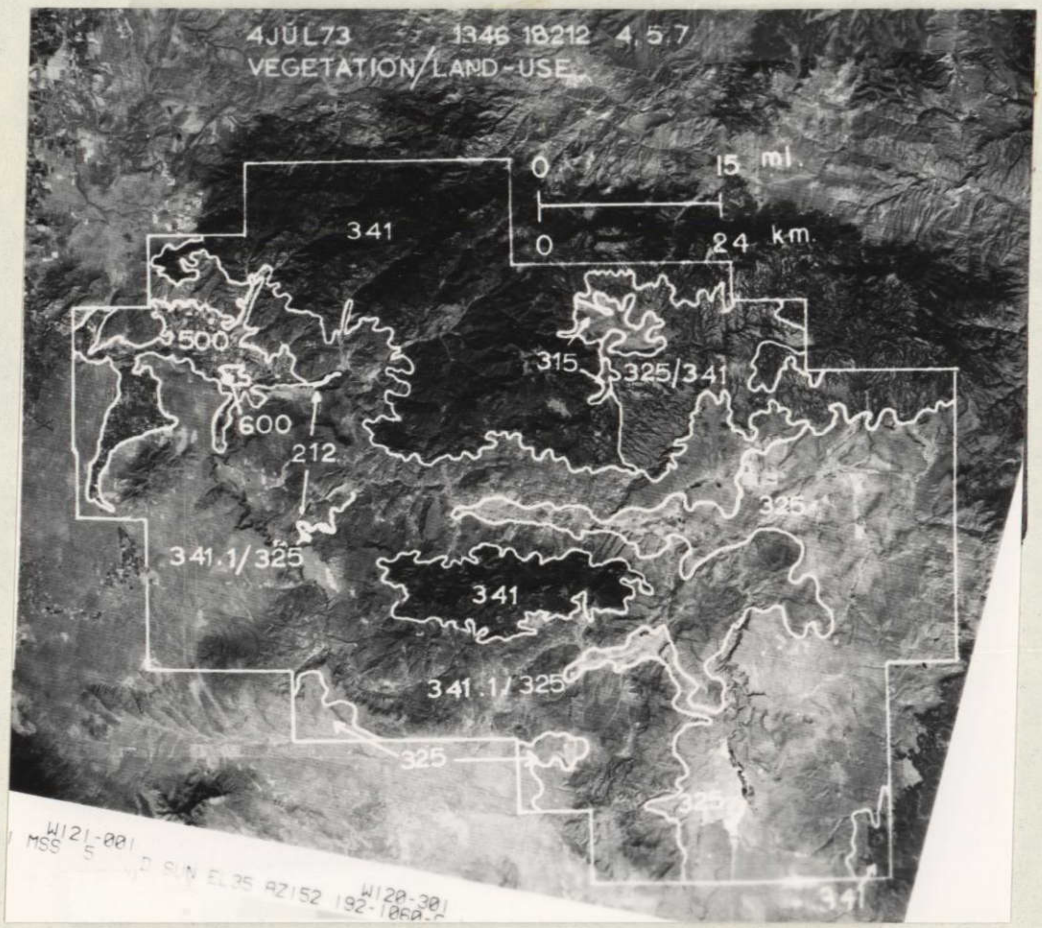

Figure 10. Vegetation/Land Use Map of Crook County on ERTS at 1:1,000,000. Mapped on 1346-18212-4, 5, 7 and 1345-18154-4, 5, 7; presented on 1076-18211-5.

Two mapping units were complexes:

325/341 - Shrub Steppe/Conifer Forest: This is basalt scabland with low sagebrush on the ridge tops and ponderosa pine in the draws.
325.1/325 - Juniper/Shrub Steppe: The juniper types occur in a mosaic with sagebrush types.

Interpretation and mapping at larger scales (1:250,000 ERTS black and white and 1:120,000 highflight color IR) further expanded the previously described units and added some new categories (Figures 11 and 12, Tables 5 and 6). The complete taxonomic legend used for the highflight mapping, 1:120,000, is contained in Appendix R-1.

Land Use Change to Recreation and Subdivision

The Environmental Remote Sensing Applications Laboratory (ERSAL) has made a survey of rural and recreational subdivisions in Crook, Deschutes, and Jefferson counties, Oregon[1/]. Subdivision activity was interpreted and delineated on color infrared highflight photography (1:120,000). Ground truth support was county records, but no comprehensive map of such activity previously existed. This inventory of 35 subdivisions in Crook County required 20 man hours and provided information not otherwise available.

We took ERSAL's map and calculated the ground area of Crook County occupied by subdivisions outside of Prineville (Table 7). Most of the subdivisions delineated are being developed in juniper or sagebrush-steppe vegetation. Three are in forested areas.

[1/] October, 1973. Rural and recreational subdivisions in Central Oregon, project report on file at ERSAL (Environmental Remote Sensing Applications Laboratory), Oregon State University, Corvallis. By David A. Mouat.

FIGURE 11

Vegetation Land-Use
Crook County Oregon
ERTS MSS 5 1076-18211
mapped at 1:250,000

Table 5. Vegetation/Land Use Mapping Units Identified on ERTS Imagery

1:1,000,000[1]	1:250,000[2]
200 Water Resources	
212 Reservoirs	212 Reservoirs
300 Natural Vegetation	
315 Meadows	315 Meadows 315/325 Meadow/Shrub Steppe 315/519 Meadow/Field Crops
325 Shrub Steppe	325 Shrub Steppe 325.1 Low Sagebrush
325/341 Shrub/Conifer Forest	325.1/341.3 Low Sage/Ponderosa Pine 325.2 Big Sagebrush
	336.11 Juniper/Low Sagebrush Savanna
341 Conifer Forest	341.1 Juniper 341.1/325 Juniper/Shrub Steppe
341.1/325 Juniper/Shrub Steppe	341.3 Ponderosa Pine 341.5 Douglas Fir 341.6 Mixed Conifer 341.7/325 Spruce-Fir/Shrub Steppe
400 Cultural Vegetation (not interpretable)	414 Grassland 414/324.3 Grass/Greasewood 414/519 Grass/Field Crops
	433 Conifer/Grass Savanna 433.1 Juniper/Grass Savanna
500 Agricultural Production	519 Undifferentiated Field Crops 519/315 Field Crops/Meadow 519.2 Irrigated Field Crops
600 Urban	(not interpretable)

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[1] Color reconstitution of 1346-18212-4, 5, 7

[2] Black and white of 1076-18211-5

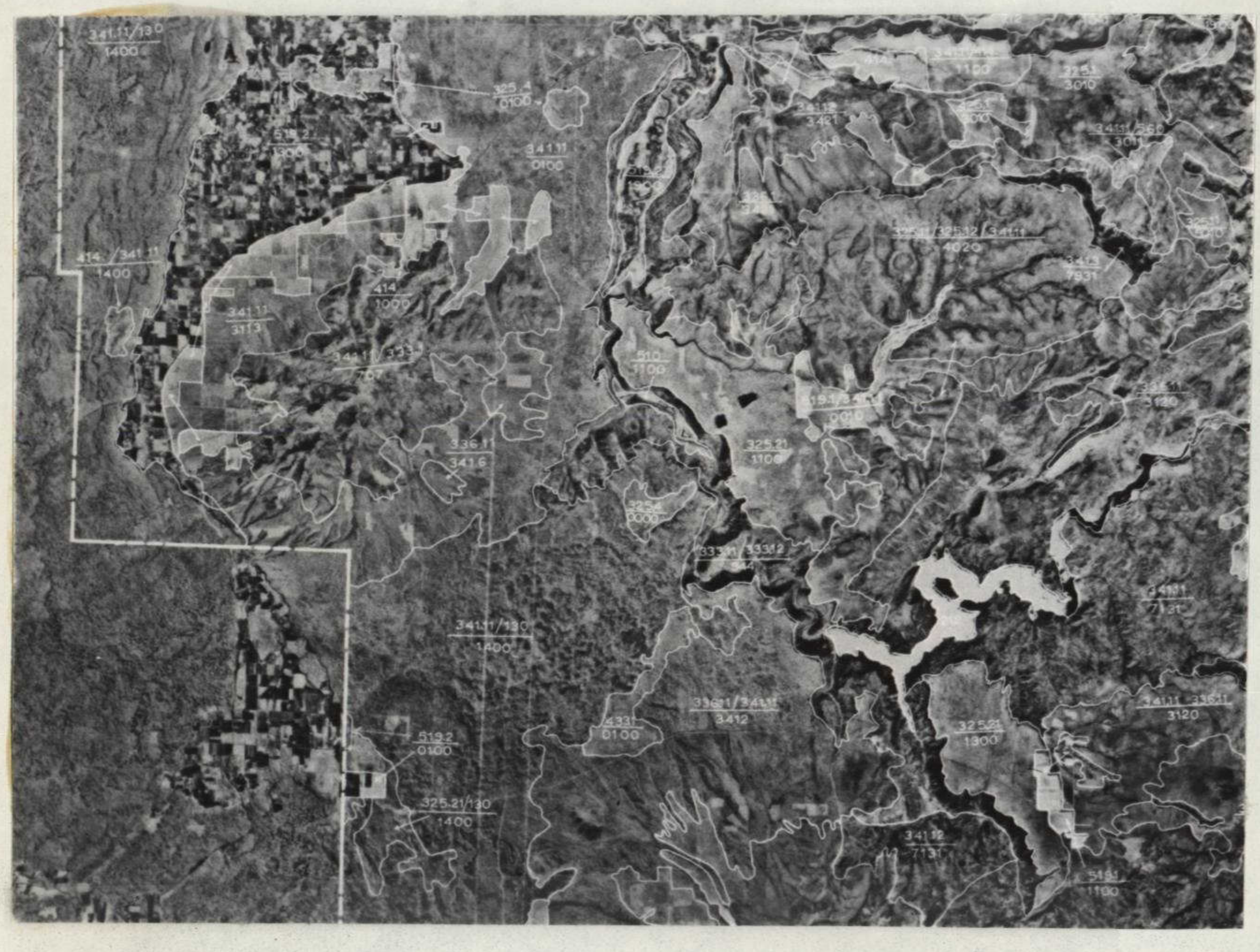

Figure 12. Vegetation/Land Use Map of Crook County on Highflight. Mapped in CIR from flight 720114 (RC-10) as 1:120,000; portion of western part of county presented on black and white photo mosaic of same imagery at 1:250,000.

Table 6. Summary of Vegetation/Land Use Mapping Units Identified on Highflight Imagery

UNITS	HECTARES	ACRES
100 Barren Land		
110 Playas	60	148
200 Water Resources		
212 Man-made Reservoirs	1,371	3,387
300 Natural Vegetation		
310 Herbaceous Types	4,681	11,567
314.3 Tall Grassland	397	981
315.2 Wet Meadow	1,042	2,572
315/325 Meadow/Shrub Steppe	1,947	4,812
315/341 Meadow/Conifer Forest	1,295	3,202
320 Shrub Types	241,157	594,613
324.3 Greasewood	2,112	5,219
325.1 Low Sagebrush	163,836	403,546
325.2 Big Sagebrush	43,324	107,055
325.2/130 Big Sagebrush/Rockland	689	1,703
325.23 Alpine Sagebrush	3,071	7,589
325.2/326.4 Big Sagebrush/Mountain Mahogany	1,423	3,517
325.3/110 Silver Sagebrush/Playa	142	352
325.4 Rabbitbrush	457	1,129
325.7 Mixed Shrub Steppe	26,103	64,503
340 Forest and Woodland		
341 Conifer Forest	192,685	476,138
341.3 Ponderosa Pine	100,361	247,999
341.3/341.5 Ponderosa Pine-Douglas Fir	49,391	122,048
341.5/341.6/341.7 Douglas Fir-True Fir	42,933	106,091
341.1 Juniper Types	256,308	633,352
341.1/130 Juniper/Rockland	23,804	58,821
341.11/333.1 Juniper/Grass	10,944	27,042
341.1/341.3 Juniper/Ponderosa Pine	322	796
341.11/336.12/325.2 Juniper/Big Sagebrush	151,798	375,099
341.1/336.11/325.1 Juniper/Low Sagebrush	69,440	171,594
400 Cultural Vegetation	13,251	32,742
414 Grassland	11,041	27,282
425.1 Overstory Clearing	1,356	3,350
433.1 Juniper/Grass Savanna	854	2,110

Table 6 (Continued).

UNITS	HECTARES	ACRES
500 Agricultural Production	38,717	95,671
510 General Field Crops	2,764	6,830
519.1 Dryland Field Crops	9,602	23,728
519.2 Irrigated Field Crops	25,976	64,188
560 Idle Land	375	925
600 Urban	884	2,184
Crook County Total Area	749,114	1,849,802

Table 7. Land Use Change to Subdivisions

Vegetation Type	Hectares	Acres
Forest	1,024	2,560
Juniper/Sagebrush	9,724	24,322
Total	10,748	26,882

F. Land Resource Units

The concept of land resource units was developed to provide land-use planners with a concise cartographic and tabular presentation of natural resource data which could be applied to help solve problems confronting counties and larger areas. ERTS imagery provides a graphic means of interpreting and depicting the areal distribution of features related to individual disciplines and is the unifying factor making it feasible to recognize and delineate unique resource combinations as land resource units.

By combining the pertinent features from geology, soils and vegetation maps, most of the resource information required for extensive land-use planning can be depicted on a single map. This approach requires some compromises, but the loss in cartographic detail is considered small compared to the advantages gained. For example, anyone using the 1:250,000 scale geology, soil landscape and vegetation maps of Crook County simultaneously must juggle with a total of approximately 75 described units. The comparable land resource map (Figure 14) uses 28 described units and shows cartographic detail which approaches an average of the three component maps. Procedure used to combine the separate resource maps is discussed in the Methodology section and will not be repeated here.

1:1,000,000 Map and Legend

The Land Resource map presented at a scale of 1:1,000,000 is divided into 13 units (Figure 13). This level of detail is a compromise between the analagous soil-landscape map (Figure 8) and the somewhat simpler maps of geology and vegetation (Figure 10). In general appearance, the Land Resource map bears a close resemblance to the soil-landscape version because the latter integrates a similar combination of factors. Descriptions of units coincide closely for all but three of the classes used on these two maps. The major difference readily apparent is that the Land Resource map is simpler cartographically than its soil-landscape analogue, since it contains only three quarters as many delineations.

In order of decreasing importance the following factors are considered in establishing the Land Resource Units: land form, soils, geology and vegetation. Interpretations have not been made specifically for units at this scale, but can be inferred from Table 10.

1:250,000 Map and Legend

On the 1:250,000 scale Land Resource map (Figure 14), 28 described units are mapped using approximately 130 delineations. Most of the units on this expanded list are subdivisions of those previously used on the smaller scale version. A brief descriptive legend is provided for this map (Table 9) as well as a set of more complete description forms (appendix L-1). On these forms physical characteristics of each Land Resource Unit appearing on the 1:250,000 version of the map are assembled on a separate sheet (Table 10).

Figure 13. Land Resource Unit map of Crook County, Oregon. Presented at 1:1,000,000 on ERTS 1076-18211-5. Original delineations were made on 1346-18212-4, 5, 7 and 1345-18154-4, 5, 7.

Table 8. Legend for a Land Resource Unit Map of Crook County, Oregon

ERTS Frame 1076-18211 Scale 1:1,000,000

Map Symbol	Unit Description
1.	Nearly level to gently sloping alluvial flood plains and terraces with deep, well-drained medium textured soils. Minor, poorly drained soils may be alkaline. Soils on terraces may be moderately deep to a cemented layer. This land is used for irrigated crops, meadowland, and homesites.
2.	Gently sloping alluvial fans, with moderately deep, medium textured soils over indurated hardpan. Vegetation is mainly big sagebrush and sagebrush-juniper. Grazing, irrigated cropland, and wildlife habitat are the main land uses.
3.	Nearly level to gently rolling, slightly dissected volcanic plains with vegetation types including low sagebrush, big sagebrush and sagebrush-juniper on shallow and moderately deep, stony, loamy soils, mostly with clayey subsoils. This land is used for grazing, wildlife habitat, dryland small grains, and irrigated cropland.
4.	Relatively young basalt flows with much rock exposed and with shallow and moderately deep loamy and sandy soils in concave positions. Vegetation is sagebrush-juniper and grazing is the main use.
5.	Rolling and gently rolling, dissected volcanic plains with shallow and very shallow, stony and very stony soils. Vegetation is low sagebrush and big sagebrush, with grazing and wildlife habitat the primary land uses.
6.	Hilly, mixed volcanic, juniper-sagebrush uplands with moderately deep and shallow, often clayey soils. This land is used for grazing, wildlife habitat and recreation.
7.	Moderately to steeply rolling, dissected mixed volcanic uplands with shallow and very shallow, stony, medium textured soils. Vegetation type is predominantly juniper and big sagebrush. Major land uses are grazing and wildlife habitat.
8.	Moderately to steeply rolling mixed volcanic terrain with shallow and very shallow, stony soils. Vegetation is low sagebrush and big sagebrush. Grazing and wildlife habitat are the main uses.
9.	Moderate to steeply rolling terrain on mixed sedimentary rock types. Relief is moderately high. Vegetation is predominantly big sagebrush and grazing is the major land use with some dryland small grain cropping in valleys.

Table 8. Continued

Map Symbol	Unit Description
10.	Steeply sloping, mountainous, mixed volcanic terrain with open ponderosa pine and scattered occurrence of other conifers, on moderately deep and shallow, medium and fine textured soils. This land is used for commercial timber, summer grazing, wildlife habitat and recreation.
11.	Moderately sloping mixed volcanic terrain with open ponderosa pine on deep and moderately deep, fine textured soils. This land is used for commercial timber, summer grazing, wildlife habitat and recreation.
12.	Steep, north slopes in mountainous terrain with mixed volcanic bedrock. Moderately deep and deep, medium textured soils predominate and support dense stands of mixed coniferous timber. Commercial timber, wildlife habitat and recreation are the primary land uses.
13.	Strongly dissected lava plateaus with low sagebrush on scablands and open ponderosa pine in the draws. The soils are very shallow and very stony in scabland areas, with moderately deep, medium textured soils on north slopes. This land is used for grazing, wildlife habitat and recreation.

Figure 14. Land Resource Unit map of Crook County, Oregon. The original version made at 1:250,000, presented here at 1:5,000,000.

Table 9. Legend for a Land Resource Unit Map of Crook County, Oregon

ERTS Frame 1076-18211-5 Scale 1:250,000

Map Symbol	Unit Description
10.	Nearly level to gently sloping floodplains and terraces; with deep, well drained soils, which are used for irrigated cropland, meadowland, and homesites. Fans and poorly drained areas occur locally.
11.	Floodplains: Locally subject to occasional flooding.
12.	Terraces: Soils are of medium texture and may be moderately deep to a hardpan.
13.	Poorly drained and alkaline soils, which are locally subject to flooding.
20.	Gently sloping alluvial fans and pediments with moderately deep, medium textured soils over an indurated hardpan. Natural vegetation is mainly big sagebrush and sagebrush-juniper. Irrigated cropland occurs where water is available, and some dryland small-grain is grown.
30.	Nearly level to rolling, slightly dissected volcanic plains, which are commonly separated from adjacent areas by a steep scarp.
31.	Shallow and moderately deep, loamy and sandy soils over basalt with juniper-sagebrush vegetation. Rangeland predominates, with some irrigated agriculture.
32.	Shallow and very shallow, loamy soils occur over welded tuff and associated sediments. Big sagebrush is the dominant vegetation, and is used mainly as rangeland.
33.	Shallow and very shallow, clayey soils occur over basalt. Low sagebrush predominates and is used mainly as rangeland.
34.	Shallow and very shallow, clayey and loamy soils occur over welded tuff. Low sagebrush and big sagebrush predominate and are used mainly as rangeland.
35.	Relatively fresh basalt flows, with well expressed micro-relief and common rock outcrops covered by moderately deep and shallow, loamy and sandy soils, some of which are stony. Juniper-big sagebrush is the principal vegetation type and rangeland is the main use.
40.	Rolling to gently rolling uplands.
41.	Slightly dissected basalt terrain with shallow and very shallow, stony soils. Vegetation type is mainly low sagebrush, and is used as rangeland.

Table 9. Continued

Map Symbol	Unit Description
42.	Slightly dissected tuffaceous sediments and welded tuffs, with shallow and moderately deep, medium textured soils. Vegetation is mainly big sagebrush with some low sagebrush. This area is used mainly as rangeland, with scattered attempts at irrigation and dryland farming.
50.	Hilly to steeply rolling, moderately to strongly dissected uplands.
51.	Tuffaceous, altered mixed volcanic rocks with shallow, moderately deep and deep clayey soils, (includes a few gently rolling areas). Low sagebrush and juniper-sagebrush are the main vegetation types. range is the main land use with local dryland agriculture.
52.	Tuffaceous volcanic rocks with shallow, very shallow and moderately deep clayey soils. Bad-land dissection and rock outcrops are common. Juniper-sagebrush and low sagebrush vegetation types predominate and are used as rangeland.
53.	Clarno formation, which consists of faulted and folded mixed volcanic rocks. Shallow and moderately deep, loamy and clayey soils predominate. Juniper-big sagebrush is the main vegetation type and rangeland is the most important use, with scattered dryland agriculture.
54.	Basalt and andesite with shallow and moderately deep, stony, loamy soils which support big-sagebrush and juniper-sagebrush vegetation types. Rangeland is the main use.
55.	Rhyolite and associated tuffaceous sediments, with shallow and moderately deep stony, loamy and clayey soils, which support low sagebrush and juniper-sagebrush vegetation types. Rangeland is the main use.
56.	Strongly folded older rocks with shallow and moderately deep loamy soils which support big sagebrush and mixed shrubs. Rangeland is the main use, with scattered dryland agriculture.
60.	Dissected, gently rolling plateau of Columbia River basalt with very shallow and shallow, stony, loamy soils and sparse cover of low sagebrush (scablands). Moderately deep loamy soils with ponderosa pine occur on dissected portions. Mixed conifers and deep soils occur on north slopes. The entire area is used as range and logging occurs locally.
61.	Scabland component predominates, making up about 70% of the unit. Big sagebrush replaces low sagebrush above 5500 ft. elevation.

Table 9. Continued

Map Symbol	Unit Description
62.	Forest component predominates, making up about 70% of the unit. Big sagebrush replaces low sagebrush above 5500 ft. elevation.
63.	Similar to Unit 62, but with more mountainous topography and a larger proportion of mixed conifers.
70.	Rolling, hilly and mountainous terrain supporting coniferous forests. Folded and faulted, mixed volcanic rocks of the Clarno formation predominate. Logging is the main use, but forest land is also grazed and serves as a watershed.
71.	Moderately sloping, open ponderosa pine forest growing on moderately deep and deep, fine textured soils. Undulating landslide topography occurs adjacent to units 62 and 63.
72.	Steeply sloping, mountainous terrain with moderately deep and shallow, loamy and clayey soils on south exposures supporting ponderosa pine, and moderately deep and deep loamy and clayey soils supporting mixed conifers on north exposures.
73.	Steep, mountainous north slopes, with moderately deep, loamy and clayey soils supporting mixed conifers.
74.	Gently rolling, rhyolite plateau, with moderately deep, loamy soils supporting dense, mixed conifers.
75.	Strongly dissected plateau of welded tuff, with shallow and moderately deep, gravelly, loamy soils which support open stands of ponderosa pine.
90.	Canyons which have greater than 500 feet of local relief, very steep slopes, and shallow, stony and rocky soils. Big sagebrush predominates with ponderosa pine on some north slopes.
91.	Landslide areas within canyons, exhibiting irregular topography and closed depressions. Moderately deep and deep, medium and fine textured soils predominate.

A summary table of interpretive ratings for several potential uses has also been compiled (Table 11).

A semi-hierarchical digital notation is used to designate Land Resource Units at this scale. The left-hand digit designates a general category, e.g. '1' for nearly level alluvial deposits, and the right-hand digit signifies a subdivision within that category, e.g. flood plains (1) versus terraces (2). Zero is used as the right-hand digit where subdivisions cannot be delineated due to small size (10) or for categories which are potentially subject to further division. In general, value of the left-hand digit increases with steepness of topography. Numbers six and seven have been used only for units which support commercial timber species. Value of the right-hand digit carries no hierarchical connotation. Elimination of the right-hand digit from map symbols should facilitate converting this map to a more generalized version, which could be portrayed at a smaller scale.

Land Resource Unit Description Forms

Table 10 is an example of the Land Resource Unit Description Forms, which contain physical and climatic information for each mapped unit. Topography, geology, vegetation and soils are briefly described. Land use and use limitations are included also. Data for each unit is assembled on a separate sheet to avoid the confusion which can result from crowded tables.

Interpretations

Table 11 contains acreage values for areas of the Land Resource Units, which were measured on the 1:250,000 scale map, as well as interpretive ratings for a number of potential uses. Soil suitability ratings are given in terms of good, fair, poor and unsuitable. Soil limitation ratings are graded slight, moderate and severe. Rock limitation ratings are termed very high, high, moderate, low and very low for risk of mass movement (landslides); and easy, fairly easy, difficult and very difficult for ease of excavation. Soil ratings for each Land Resource Unit are further subdivided into component percentages, based on data from Table 3. Data presented on Table 11 allows one to calculate the percentage (or area) of Crook County with a given relative suitability for irrigation or septic tank drain fields. For example, irrigable land in the excellent, good and fair categories totals about 15.4% of the county or 1,190 square Kilometers (460 square miles).

Table 10. Example of a land resource unit description form

Land Resource Unit 20 . Description: Alluvial fans and pediments	
Extent: 77,000 acres, 4 % of the county. Elevation: 3000 to 5000 feet	
Distribution: Western and southeastern portions of Crook County	
Climate: Ann. ppt. 9-15 in. Mean ann. temp. 46-50° F Frost free days (32°) 50-80	
Landscape and Topography: Gently sloping, slightly to moderately dissected alluvial fans and footslopes adjacent to several mountainous areas.	Geology: Poorly sorted, unconsolidated sands and gravels of alluvial fans and pediments. Material generally thick on fans and thin on pediments.
Vegetation: Predominantly juniper, shrub steppe with low sagebrush on the shallower soils, juniper or meadow intermixed with shrub steppe and Ponderosa Pine locally important on upper slopes.	Soils: Shallow and moderately deep, medium and coarse-textured, gravelly soils with a strongly cemented hardpan. Soil Landscape Units 3a & 3b
Limitations: Shallow to firmly cemented hardpan	
Land use: Predominantly irrigated field crops, range grass seedings, and a cultural juniper/grass savanna.	

Table 11. Summary of Suitability and Limitations for Rocks and Soils in Land Resource Units of Crook County, Oregon[2].

Unit	[illegible]	Area		Soil Suitability[1]				Soil Limitations[1]		Rock Limitations	
		Square Miles	Square Km	Irrigation	Topsoil	Sand and gravel	Roadfill	Septic tank drainfields	Ponds and reservoirs	Risk of Mass Movement	Ease of Excavation
10	2.	60	155	60 good 35 exc. 5 fair	60 good 40 fair	80 poor 15 fair 5 unsuit.	50 poor 30 good 20 fair	80 severe 20 slight	60 severe 30 mod. 10 slight	very low	easy
11	1.8	55	140	70 exc. 25 good 5 fair	70 fair 30 good	70 poor 25 fair 5 unsuit.	60 good 30 fair 10 poor	70 severe 30 slight	60 mod. 30 severe 10 slight	very low	easy
12	1.8	55	140	100 good	100 good	95 poor 5 fair	90 poor 5 good 5 fair	90 severe 10 slight	100 severe	very low	easy
13	.3	10	26	35 good 35 poor 30 fair	90 poor 10 fair	85 unsuit. 15 good	70 poor 30 fair	100 severe	40 slight 30 severe 30 mod.	very low	easy.
20	4.0	120	310	80 poor 20 fair	90 poor 5 good 5 poor	65 unsuit. 35 poor	60 poor 35 good 5 unsuit.	70 severe 30 mod.	95 severe 5 mod.	low	fairly easy
31	2.0	55	137	55 fair 30 poor 15 poor	50 good 45 poor 5 unsuit.	85 unsuit. 15 poor	60 poor 35 fair 5 unsuit.	100 severe	85 mod. 15 severe	very low	very difficult
32	3.0	95	246	55 fair 30 poor 15 v.poor	50 good 45 poor 5 unsuit.	85 unsuit. 15 poor	60 poor 35 fair 5 unsuit.	100 severe	85 mod. 15 severe	low	difficult
33	3.0	95	246	100 v.poor	85 unsuit. 15 poor	100 unsuit.	85 poor 15 unsuit.	100 severe	90 severe 10 mod.	very low	very difficult

Table 11. Continued.

Unit	Area			Soil Suitability 1/				Soil Limitations 1/		Rock Limitations	
	%	Square Miles	Square Km	Irrigation	Topsoil	Sand and gravel	Roadfill	Septic tank drainfields	Ponds and reservoirs	Risk of Mass Movement	Ease of Excavation
34	5.5	160	414	90 v.poor 10 unsuit.	65 unsuit. 35 poor	100 unsuit.	70 poor 30 unsuit.	100 severe	90 severe 10 mod.	low	difficult
35	3.3	100	260	40 fair 25 poor 20 v.poor 15 unsuit.	75 poor 15 unsuit. 10 good	50 unsuit. 50 poor	75 poor 15 unsuit. 10 fair	100 severe	100 severe	very low	very difficult
41	10.0	300	777	90 v.poor 10 unsuit.	65 unsuit. 35 poor	100 unsuit.	70 poor 30 unsuit.	100 severe	90 severe 10 mod.	low	very difficult
42	2.5	75	194	70 fair 30 poor	70 fair 30 poor	100 unsuit.	70 fair 30 poor	95 severe 5 mod.	80 mod. 20 severe	low	difficult
51	3.5	104	270	60 v.poor 30 poor 5 fair 5 unsuit.	85 poor 15 unsuit.	100 unsuit.	100 poor	100 severe	100 severe	mod. to high	easy
52	5.0	140	362	80 v.poor 20 unsuit.	75 poor 25 unsuit.	100 unsuit.	100 poor	100 severe	100 severe	high to very high	easy
53	13.7	410	1060	55 v.poor 20 poor 20 fair 5 unsuit.	85 poor 10 unsuit. 5 fair	95 unsuit. 5 poor	95 poor 5 unsuit.	90 severe 10 mod.	95 severe 5 mod.	mod. to high	easy to difficult
54	3.3	100	260	80 v.poor 10 poor 10 fair	60 poor 30 unsuit. 10 fair	80 unsuit. 20 poor	100 poor	90 severe 10 mod.	90 severe 10 mod.	low	difficult
55	2.0	55	140	60 v.poor 35 poor 5 fair	100 poor	85 unsuit. 15 poor	100 poor	100 poor	100 severe	mod. to low	very difficult

Table 11. Continued.

Unit	Area			Soil Suitability 1/				Soil Limitations 1/		Rock Limitations	
	%	Square Miles	Square Km	Irrigation	Topsoil	Sand and gravel	Roadfill	Septic tank drainfields	Ponds and reservoirs	Risk of Mass Movement	Ease of Excavation
56	1.5	45	116	85 v.poor 10 poor 5 fair	90 poor 10 fair	60 poor 40 unsuit.	40 poor 40 unsuit. 20 fair	100 severe	90 severe 10 mod.	mod.to	moderate
61	6.2	210	545	90 v.poor 10 poor	85 poor 15 fair	100 unsuit.	100 poor	100 severe	100 severe	low	very difficult
62	1.7	50	130	80 v.poor 20 poor	80 poor 20 fair	100 unsuit.	80 poor 20 fair	100 severe	100 severe	low	very difficult
63	2.0	56	145	80 v.poor 20 poor	80 poor 20 fair	100 unsuit.	80 poor 20 fair	100 severe	100 severe	low	very difficult
71	5.0	140	360	100 v.poor	100 v.poor	100 unsuit.	100 poor	100 severe	100 severe	high	easy to difficult
72	8.7	260	675	95 v.poor 5 unsuit.	95 poor 5 unsuit.	100 unsuit.	100 poor	100 severe	100 severe	high	easy to difficult
73	4.3	130	330	95 v.poor 5 unsuit.	90 poor 7 fair 3 unsuit.	100 unsuit.	95 poor 5 fair	95 severe 5 mod.	85 severe 15 mod.	high	easy to difficult
74	.5	12	30	85 v.poor 15 poor	85 poor 15 fair	100 unsuit.	90 poor 10 fair	85 severe 15 mod.	85 severe 15 mod.	high	very difficult
75	.5	14	36	80 v.poor 20 poor	50 fair 50 poor	100 unsuit.	50 fair 30 poor 20 good	100 severe	100 severe	low	difficult

Table 11. Continued.

Unit	Area			Soil Suitability[1]				Soil Limitations[1]		Rock Limitations	
	%	Square Miles	Square Km	Irrigation	Topsoil	Sand and gravel	Roadfill	Septic tank drainfields	Ponds and reservoirs	Risk of Mass Movement	Ease of Excavation
90	2.4	72	186	65 v.poor 25 unsuit. 10 fair	50 unsuit. 50 poor	90 unsuit. 10 poor	85 poor 15 unsuit.	100 severe	95 severe 5 mod.	very high	variable
91	.5	12	30	40 v.poor 35 poor 25 unsuit.	75 poor 25 unsuit.	100 unsuit.	100 poor	100 severe	95 severe 5 mod.	very high	mod. to easy
Total	100.0	2980	7720								

[1] Soil suitability ratings of good, fair, poor, and unsuitable are given as percent of the land resource unit for several uses. Soil limitation ratings of slight, moderate and severe are also given as percent of the unit. Good suitability or slight limitations do not require any special planning, design, or management, or there are restrictions that are easy to overcome. Fair suitability or moderate limitations have restrictions that can be overcome with planning, careful design, and good management. Poor suitability or severe limitations indicate that the use is doubtful and generally, unsound. Ratings are derived from Soil Conservation Service interpretations (OR-Soils-1) for soils given as components of soil-landscape units.

[2] This table applies only the 1:250,000 scale Land Resource Unit Map.

III. EXPERIMENTAL APPLICATIONS AND RESULTS

III EXPERIMENTAL APPLICATIONS AND RESULTS

A. Timber Inventory

The primary objective of the forestry research using the ERTS-1 imagery was to design a multi-stage sampling procedure, using ERTS-1 imagery as the data base and conventional aircraft imagery and field measurements as the succeding stages. This inventory was conducted on the Ochoco National Forest in eastern Oregon. The Ochoco National Forest consists of approximately 891,000 acres of forest lands located in Crook, Grant and Wheeler counties. The timber species included juniper, ponderosa pine, lodgepole pine, Douglasfir and true firs with some cedar and larch occurring in small areas. The forest is typical of the forest lands occurring in the eastern part of Oregon.

There were two major reasons for the selection of the Ochoco National Forest as a test site for this research. The first was that Crook County, Oregon had been selected as the primary test site area by agreement with the other disciplines involved in this multi-discipline research. Therefore, for the forestry multi-discipline research effort to be beneficial to the entire research team, the proposed forest inventory should be conducted in the general test site area. The Ochoco National Forest was selected because it contains the majority of the commercial forest lands in Crook County although the National Forest also lies in the adjoining Grant and Wheeler counties.

The second reason for selecting the Ochoco National Forest was that during 1972 and 1973, the U.S. Forest Service conducted their 10-year periodic inventory of this National Forest. It appeared that through cooperation with the U.S.F.S. this inventory information would be available which would allow accuracy and cost analysis comparison between the designed sampling procedure and the methods presently being used by the land managers.

As the first step in any sampling procedure, a data frame must be established from which all other samples will be drawn. The ERTS-1 imagery provides an excellent frame in this context, even though the frame established is of an implicit nature. This results from the inability to actually measure any concomitant variable of volume from the imagery, although some degree of stratification of the forest population is possible from tonal differentiation. The results of this stratification are presented below.

1. Stratification of forest density classes from ERTS-1 imagery

The first approach to stratification was with the use of the OSU color enhancer, an in-house constructed optical color combiner. The final image produced is 10 x 10 inches approximately 1:956,000 scale using MSS bands 4, 5, and 7 with a blue, green, and red filter respectively. Five forest density classes were used for delineation (Table 12) on this imagery and all other imagery investigated. The results of this delineation are presented in Table 13.

The advantages of this imagery include the increased image size, from 70mm, the combination of several MSS bands, and the selectivity of color combinations which highlight the areas of interest. This form of imagery is particularly advantageous when viewing ERTS imagery for the first time as it allows the researcher to investigate numerous combinations of bands and colors to determine the best combination for his area of interest. Disadvantages are primarily inherent in the machine used, rather than the imagery. They include long set-up time and limited minimal size area detection. A total for four hours were required for the set-up and delineation of the three ERTS frames required for coverage of the Ochoco National Forest with a minimum area detection of approximately eight acres.

The second approach to density class delineation was with the use of three band color composite transparencies obtained from General Electric Corporation. These transparencies are 9 x 9 inch format, approximately 1:942,000 scale using MSS bands 4, 5, and 7 with yellow, red, and blue filters respectively. Again, five density classes were used and the results are shown in Table 13.

Several advantages exist in the use of this imagery. Stereoscopic viewings of a majority of the test site area was possible due the side lap of the ERTS-1 imagery. There was less variation of apparent image density due to image variables or slight sun angle changes between frames. Minimum detection area was reduced to approximately two acres under optimum conditions. Because of the shorter set-up time required, it took only two hours for complete delineation.

There are three major disadvantages to the use of this (G.E.) imagery, all of which are the result of image procurement. These include the cost of the imagery, the long lead time of procurement and the limitations of band-filter combinations obtainable.

The third approach to density class delineation was with the use of panchromatic enlargments of the MSS band 5, with an approximate scale of 1:250,000. This imagery was tested for a small part of the test site and found unsatisfactory for forest density class delineation. These images were produced for maximum grey shade differentiation in the agricultural and other non-forested lands and result in over-exposure of the forest land areas. Although enlargement of the original image allows for a decrease in minimal area detection in non-forested lands, the lack of grey scale tonal differeniation in the forest lands defeats this advantage.

For the purposes of comparison between ERTS-1 and conventional aircraft imagery, delineation was also completed on the Color IR imagery of the Vinton packages; 70 mm imagery at approximately 1:440,000 scale. Delineation of this imagery into the five forest density classes was completed and the results are shown in Table 13. Advantages gained through the use of this imagery appear to be: 1) Minimum delineation area was reduced to approximately ½ acre due to the high resolution of the system and larger scale and 2) stereoscopic viewing of the entire test area was possible. The disadvantages of this imagery were numerous. The first was the extremely long time (14 hours) required for viewing the entire test area due to the large number of frames required. The second involved image changes between frames resulting from several factors. These include different sun angles, variation in film characteristics, both within and between flight lines and slight variation in film exposure between flight lines. All these changes required frequent cross checking between flight lines to insure continuity of delineation by the interpreter. Another disadvantage of this imagery is the changes in photo scale due to the changes in topographic displacement throughout the area.

Table 12. Forest Density Classes

Density Class	Description
I	Less than 10% stocked with commercial trees on non-stocked forest lands
II	Poorly stocked
III	Poor to medium stocked stands
IV	Medium to well-stocked stands
V	Very well stocked stands

Table 13. Results of Forest Density Class Delineation From Several Images

	Acre		
Density Class	OSU Color Enhancer	GE Color Enhancement	Vinton Color IR
I	94,618	49,002	182,551
II	225,142	237,882	181,655
III	445,918	409,835	380,041
IV	99,875	119,387	119,211
V	25,392	74,839	27,487

	Percentage		
Density Class	OSU Color Enhancer	GE Color Enhancement	Vinton Color IR
I	10.6	5.5	20,5
II	25.3	26.3	20.4
III	50.1	46.0	42.7
IV	11.2	13.4	13.4
V	2.8	8.4	3.0

For any stratification to be beneficial to the resource manager, there must be a reduction in the sampling error (standard error of the mean expressed as a percent of the mean) among stratified as compared to non-stratified plots. The separation of forested versus non-forested lands, which is easily accomplished with ERTS-1 imagery, was not considered to be of much value on the Ochoco National Forest because this separation within the forest boundary is already known. To determine the statistical gain in efficiency resulting from crown density stratification the following analysis was conducted using the interpretation results of three experienced interpreters.

Twenty plots were randomly selected in each of the five strata delineated on ERTS imagery and previously reported. These 100 plots were then located on the NASA-Ames 1/120,000 high flight color IR positive transparencies. Interpretation of the percent crown closure for each plot was then completed by all three interpreters, (Table 14).

To test the efficiency of density class delineation, the same 100 plots were then considered to be one non-stratified sample and used as the basis for comparison of gains in sampling efficiency. The results of this comparison (Table 15) showed only a slight (average 5.20%) gain in sampling efficiency when using all five forest density classes delineated on ERTS-1 imagery.

Based on a statistical analysis of the initial stratification, it appeared that we attempted stratification into too many classes and that combining certain strata would prove to be more efficient. Table 15, shows the results of several groupings of strata and their resultant gains in efficiency.

These results clearly demonstrate that the use of two strata provides the largest gain in efficiency (19.54%) over the non-stratified population. The question arises then: "What was wrong in the original five strata determined from ERTS-1 imagery?" Preliminary analysis and review indicate that three major factors influenced this problem of stratification. The first factor is that of shadow. With a 10 o'clock sun angle, north-facing slopes are in shadow and therefore appear anomalously dark on the color-enhanced imagery. The more dense forests of the region coupled with shadow on the north and west slopes caused the interpreter to overinterpret the dark tones on the color-enhanced imagery. This error was even greater when only the black and white MSS-5 band was used.

The second factor contributing to error is the lack of tonal signature distinction between forest species and brush species in this region. Because of the lack of height definition on ERTS-1 imagery, tonal signature becomes the critical defining characteristic of vegetation. Although little difficulty has been found in separating grasslands from forest lands, separation within the forest lands of trees and brush presents some difficulty.

The third factor contributing to error is the lack of proper processing of ERTS-1 imagery to produce a balanced grey scale within the image frame. It appears that the imagery received is processed for maximum total delineation of the range and agricultural lands which are primarily

Table 14 Photo Interpretation Results of Percent Crown Closure from 1:120,000 NASA-Ames High-flight Photogrammetry

Density Class (Strata)	Percent Crown Closure Statistics	Interpreters			Average
		A	B	C	A+B+C
I	$\bar{x}$ (mean)	13.0500	10.2500	7.700	10.3333
	s (standard deviation)	14.9225	11.7063	10.5536	12.3941
	$s_{\bar{x}}$ (standard error)	3.3367	2.6176	2.3598	2.7714
II	$\bar{x}$	36.0000	27.0000	23.7500	28.9167
	s	15.1830	11.4017	14.1305	13.5717
	$s_{\bar{x}}$	3.3950	2.5494	3.1596	3.0347
III	$\bar{x}$	49.7500	42.7500	39.7500	44.0833
	s	19.8994	16.7390	21.7325	19.4570
	$s_{\bar{x}}$	4.4496	3.7429	4.8595	4.3507
IV	$\bar{x}$	60.5000	55.2500	59.0000	58.2500
	s	20.7681	18.3155	18.8204	19.3013
	$s_{\bar{x}}$	4.6438	4.0954	4.2083	4.3158
V	$\bar{x}$	52.7500	53.0000	50.4000	52.0500
	s	19.2268	25.2044	26.6822	24.3711
	$s_{\bar{x}}$	4.2992	5.6358	6.4135	5.4495

Table 15 Sampling Errors and Gains in Efficiency for Non-Stratified and Various Groups of Strata

Strata Grouping	Interpreter						Average	
	A		B		C			
	$S_{\bar{y}st}$	Gain	$S_{\bar{y}st}$	Gain	$S_{\bar{y}st}$	Gain	$S_{\bar{y}st}$	Gain
Non-stratified	6.36%		6.27%		6.97%		6.53%	
Five strata	6.42%	-0.94%	5.35%	14.67%	6.81%	2.30%	6.19%	5.20%
3 Combined strata (1,2), (3,4), 5	5.94%	6.60%	5.10%	18.66%	6.04%	13.34%	5.69%	12.68%
3 Combined strata (1,2), 3, (4,5)	7.94%	-24.83%	6.94%	-10.69%	8.35%	-19.8%	7.74%	-18.47%
2 Combined strata (1,2), (3,4,5)	5.15%	19.03%	4.94%	21.21%	5.68%	18.51%	5.16%	19.54%

in the lighter shades of grey. The forested lands, imaged in darker tones are reproduced with a resulting lack of tonal separation sufficient for fully utilizing the information content of the image. (Examples: ERTS-1 Frame E-1076-18211-5 and E-1040-18210-5)

As a result of these investigations, the final stratification established as the sampling frame consisted of two strata; poorly stocked and stocked. The final stratification is shown in Figure 15.

2. Multi-stage sampling design

In the design of a multi-stage sampling procedure, consideration must not only be given to the final totals produced, but also to the variances. In multi-stage sampling, the largest component of variance occurs in the first stage of the procedure. Langley (1969) in inventorying timber volumes from Apollo 9 and high flight photography computes the variance from only the first stage, and assumes the variance of the later stages is negligible.

More important than minimizing variance in the latter stages, is the importance of avoiding bias. By using proper statistical procedures during these stages is is possible to reduce both variance and bias to a minimum. These procedures include using probability proportional to size (PPS) sample selection, stand volumes instead of individual tree volumes and ground measurement with the most accurate instruments available. Each of these will be discussed further where applicable.

The original multi-stage sampling design selected for this project contained four stages consisting of ERTS-1 imagery, two scales of NASA high flight imagery, one commercial flight and ground measurements. In multisampling, each stage consists of two levels of sampling; i.e., ERTS-1 imagery and 1:120,000 high flight imagery. Each stage is discussed below.

First Stage. The first stage of this design consists of the ERTS-1 imagery and the NASA high flight 1:120,000 imagery. On the ERTS-1 imagery, the inventory area is delineated and the imagery is interpreted for the five timber density classes discussed earlier in this report. The total area for each density class is also calculated. In each of the five strata, 20 plots are selected for further sampling based on random sampling. These plots are then located on the 1:120,000 high flight imagery and the percent of crown closure (%CC) is measured. These plots are 20¼ acres in size.

Second Stage. From the 20 plots for each strata established and measured on the 1:120,000 high flight imagery, four plots are selected in each strata using PPS sampling. PPS sampling allows concentration of study in the plots containing higher %CC without introducing bias into the sampling design. The selected plots are located on the 1:30,000 NASA high flight imagery and then subdivided into nine plots of 2¼ acres each. Each plot is measured for %CC and stand height (TH) and the concomitant variable ($\%CC \cdot (TH)^2$) is calculated. This variable has been previously found to be directly related to timber volume.

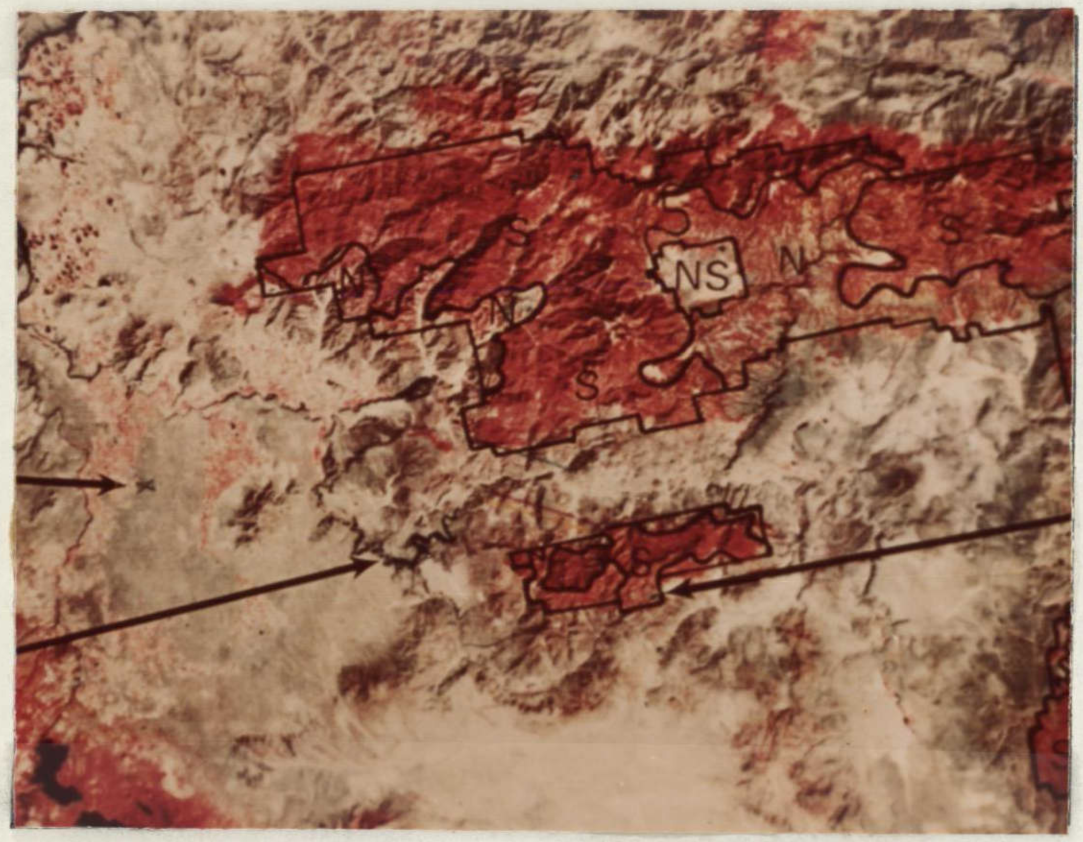

Figure 15. The majority of the Ochoco National Forest showing the final stratification of two strata. (ERTS-1 Frame No. E-1076-18211)

Third Stage. From the 36 plots established and measured for each strata in the second stage, eight plots are selected for each strata using PPS sampling. In each stage where PPS sampling is used, the sampling rule used is list sampling with replacement. The selected plots are located on the 1:5,000 commercial imagery and then subdivided into nine plots of ¼ acre each. Each plot is measured for %CC, TH and average visable crown diameter (VCD) and the concomitant Variable (%CC • $(TH)^2$VCD) is calculated.

Fourth Stage. From the 360 photo plots established and measured in the third stage, 60 plots are selected for ground measurement. Each ¼ acre plot is located in the field and every tree is measured for basal area. Sample trees are selected on each plot by PPS sampling and their total volume is measured using an optical dendrometer or a tela-relaskop. The use of these precision measuring devices allow accurate volume measurements to be completed in the field and eliminates the use of volume tables and their associated bias. By using double sampling with regression at this stage, species volumes per acre are established which are then expanded through each of the earlier stages to produce the final timber volume estimates. Expansion through each stage of the timber volume estimates are made on volume per acre basis. The use of stand volumes per acre rather than individual tree volumes removes any error in volume estimation from plot size variation which may result from differences in photographic scale caused by topographic displacement or tip and tilt.

When this original design was implemented with actual data, a major difficulty arose. The second stage of the multi-stage sampling design was to consist of photo interpretation of selected plots on NASA-Ames high flight imagery at 1:120,000 and 1:30,000 photo scales. Interpretation of 100 random plots allocated at 50 plots per strata, was completed by three experienced interpreters. On each of these 20.25 acre plots, each interpreter estimated percent crown closure - separately for both the upper and lower tree canopies for two-storied stands. From these data the next PPS subsample was selected and located on the 1:30,000 color IR positive tranparencies.

Before subdividing the 1:30,000 plots into nine subplots, each interpreter interpreted the entire plot to estimate percent crown closure again. These measurements were then used to create ratios between the percent crown closure measured on the 1:120,000 imagery and the 1:30,000 imagery. Statistically, these ratios should be about one, however, more important is consistency between the ratios among the plots. This consistency was not found in this case; for nonstocked stands, the ratios ranged from 1.111 to 15.789, while for the stocked stands, the ratios were from 0.802 to 7.857.

Review of each interpreter's results at this point showed that the ratio ranges were about the same in every case and, therefore, it could be concluded that these ratios did not result from one interpreter's errors. Critical review of the imagery showed that the error arose from the quality of imagery contained in the NASA-Ames High Flight Mission No. 72-134 at 1:120,000 photoscale. The problem is shown in the loss of detail within the shadowed areas and is probably caused by underexposure or underdevelopment of the film. The latter cause is most probably due to the lack of quality does not seriously detract from the imagery use for range and agricultural land analysis, which are primarily restricted to fairly level topography, it basically defeats any use in forest land analysis for the Pacific Northwest where forest land is primarily mountainous topography. The result of this lack of quality resulted in the removal of the 1/120,000 imagery from the multi-stage sampling design.

With the removal of the 1/120,000 imagery, the final multi-stage sampling design consisted of three stages, outlined below:

First Stage. The Ochoco National Forest was stratified into two strata poorly stocked and stocked, using a color enhanced version of ERTS-1 frames E-1076-18211-5, -6 and -7. Twenty-five plots of 20.25 acres in size were then randomly located in each strata. These plots were then located on the 1/30,000 NASA-Ames high flight imagery, Mission No. 72-134 and each plot interpreted for percent crown closure and average stand height for both the upper and lower story when both were present. From this data ten plots per strata were selected using probability proportional to size (PPS) selection for further subsampling (Figure 16).

Second Stage. Each of the ten plots selected from the first stage were then subdiveded into nine subplots of 2.25 acres in size. Each subplot was then interpreted and the percent crown closure and average stand height were recorded. From these ninety subplots per strata, twenty subplots, two per plot, were again selected using the Hartley PPS rule for further interpretation.

The twenty selected subplots per strata were located on the contractural 1/4,800 color imagery and reinterpreted for percent crown closure and stand height. Each subplot was further subdivided into nine 0.25 acre plots (Figure 17).

Third Stage. Each of the 180 quarter-acre subplots was interpreted and the percent crown closure, average stand height and average visible crown diameter for each story was recorded. From this data, twenty subplots per strata were selected and measured in the field using the procedures outlined below.

3. Field measurement of selected subplots for forest inventory

Each of the forty subplots were located in the field by marking each corner on the ground from direct photo interpretation at the site (Figure 18). After the location was verified, each tree over 5 inches diameter at breast height (dbh) was estimated within the nearest two inch diameter class and ten foot height class. This data was used to estimate each tree's volume using the Comprehensive Tree-Volume Tarif Table (Turnbill, Little and Hoyer, 1972). Because ponderosa pine is the predominant species in this area, ponderosa pine tarif access tables were used to estimate volumes for all species noted. These estimated volumes were then used to draw a two tree pps sample for each subplot for further measurement.

Figure 16. NASA Color Infrared (scale 1:30,000) Imagery Showing two 20¼ Acre plots in the Stocked Strata. (Arrow Points to Antelope Reservoir).

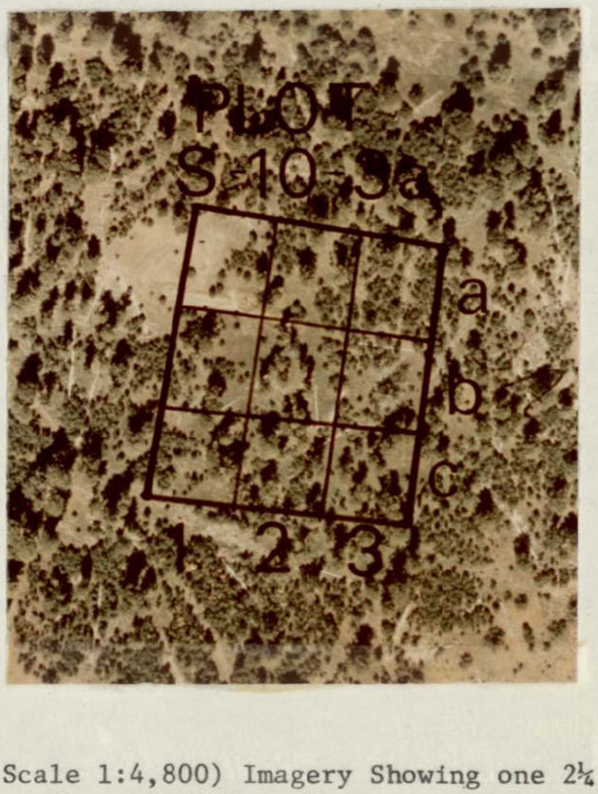

Figure 17. Color (Scale 1:4,800) Imagery Showing one 2¼ plot (S-10-3a) from plot shown in Figure 9.

4. Calculation of the final volume estimates

The following five formulas are used to expand the field measurements through each stage to calculate the average volume per acre for each strata.

a) $$VF_l = \left[\tfrac{1}{2}\sum_{m=1}^{2}\frac{V4m}{v4_m}\right] v5_l$$

where, VF_l = Actual volume of the lth 1/4 acre plot measured in the field

$V4_m$ = Actual volume of the m^{th} tree measured in the field

$v4_m$ = Estimated volume of the m^{th} tree estimated in the field

$v5_l$ = Estimated volume of the lth 1/4 acre plot estimated in the field

m = Number of trees selected for measurement in the field

b) $$V3_k = \Bigg[\frac{1}{n_5}\sum_{l-1}^{n5}\Bigg]\frac{VF_l}{v3_l}\Bigg] v3_k$$

where, $V3_k$ = corrected volume of the k^{th} 1/4 acre photo plot

$v3_k$ = photo estimated volume of the k^{th} 1/4 acre photo plot

$v3_l$ = photo estimated volume of the l^{th} 1/4 acre photo plot, selected for field measurement

n_5 = number of 1/4 photo plots selected for field mesurement

c) $$V2_j = \left[\frac{1}{n_4}\sum_{k=1}^{n4}\frac{V3_k}{v3_k}\right] v2_j$$

where, $V2_j$ = corrected volume of the j^{th} 2 1/4 acre photo plot

$v2_j$ = photo estimated volume of the j^{th} 2 1/4 acre photo plot

n_4 = number of 1/4 acre photo plots subsampled in each strata

Figure 18. Ground photograph of a typical 1/4-acre field plot in the Ochoco National Forest, Oregon.

d) $$V1_i = \left[\frac{1}{n_3} \sum_{l=1}^{n3} \frac{V2_j}{v2_j} \right] v1_i$$

where, $V1_i$ = corrected volume of the i^{th} 20 1/4 acre photo plot

$v1_i$ = photo estimated volume of the i^{th} 20 1/4 acre photo plot

$v2_j$ = photo estimated volume of th j^{th} 2/14 acre photo plot

n_3 = number of 2 1/4 acre photo plots subsampled in each strata

e) $$T = \frac{N}{n1} \left[\sum_{i=1}^{n1} \frac{V2_i}{v1_i} \right] \sum_{j=1}^{n2} v1_j$$

where T = total volume estimate of the strata

n_1 = number of 20 1.4 acre plots selected for further subsmapling

N = total possible number of 20 1/4 acre plots in the strata

$v1_j$ = photo estimated volume of the j^{th} 20 1/4 acre plot

These steps can be easily modified to calculate the volumes from different sized plots or for any species in a mixed species forest.

The variance of the estimator is found by the formula;

$$V(\hat{T}) = \frac{1}{n_1(n_1 1)} \sum_{i=1}^{n1} (V1_i \quad \overline{V1})^2.$$

5. Results of the multistage timber inventory

The results of this timber inventory of the Ochoco National Forest are shown in Table 16. Interpreters A, B, and C represent three experienced interpreters, in descending level of experience in this type of work. These interpreters used two height classes, 40 and 80 foot mid points, and limited the forest to a maximum of two stories occurring in the forest canopy on any one plot. This interpretation was completed after a one-day visit to the area which allowed limited familiarization with the local forest conditions. The results from this interpretation show average volume per acre ranging from 3,808.8 to 2,803.3 cubic feet with standard errors of means from 12.4 to 8.0 percent in the well-stocked strata.

In the poorly stocked strata, the average volume per acre range from 2,534.6 to 1,295.8 cubic feet with standard errors of the means from 15.4 to 13.8 percent. This increase in the standard errors of the means would be expected due to the increased between-plot variation experienced in the poorly-stocked strata.

After the completion of the field measurement, the most experienced interpreter of the group reinterpreted all the levels of the imagery using three height classes, 40, 80 and 120 foot mid points, and allowing a maximum of three stories occurring on any one plot. This could result in a biased answer if the interpreter remember specific field measured plots. Since this interpretation was made several months later we assumed it to be an interpretation based on a greater familiarity with the area. This would be more indicative of the results obtained at a local agency, when the work was done by persons familiar with the local situation. These results are shown under Interpreter D in Table 16. The results were an average volume of 2,221 cubic feet per acre and 1,168.6 cubic feet per acre for the well-stocked and poorly-stocked strata. The standard errors of the means were 7.2 and 15.8 percent, respectively.

Table 16. Multi-stage Inventory Results for the Ochoco National Forest, Crook County, Oregon

Interpreter	Total Vol in cu. ft.	Std. Error	Std. Error(%)	Aver. Vol/ac in cu. ft.
	Well-Stocked Strata			
A	993,470,112	5,633.4	8.0	3,463.0
B	804,221,997	5,182.4	9.2	2,803.3
C	1,092,682,632	9,582.2	12.4	3,808.8
D	637,216,987	3,235.2	7.3	2,221.2
	Poorly-Stocked Strata			
A	1,531,034,889	7,128.4	13.8	2,534.6
B	782,759,158	3,683.8	14.0	1,295.8
C	976,832,480	5,047.7	15.4	1,617.1
D	705,882,730	3,729.5	15.8	1,168.6

6. Analysis and Conclusions

The results of this multistage forest inventory clearly indicate that multistage sampling with successive levels of imagery provide a feasible method for inventorying large tracts of forest land in a timely and relatively inexpensive manner. Once the required statistical methods and computer programs were developed, approximately 5 man-days were required for photo plot layout and interpretation and 28 man-days for field measurement. A large portion of the field measurement time was spent on accurately locating the plots in the field from the 1/4,800 photos. However, this is an expenditure of time which can not be avoided whenever selected photo plots are measured in the field. On the average, this represents a total work time of 0.018 man-minutes per acre, not including image acquisition time, for the total area inventoried.

Unfortunately, we have been unable to compare the accuracy and costs of this inventory procedure with that of the USFS 1972-73 inventory since the results of the USFS inventory are not yet complete.

One major area of concern in conducting this inventory was the lack of information gained from the ERTS-1 imagery. Indications are that greater amounts of information could be gained from ERTS-1 data, especially digital data, however, this investigation was severely hampered by the delay in receiving the digital tapes. Our field work, which had to be completed during the summer months was completed before the arrival of these tapes. A more intensive stratification of the forest lands would enhance the sampling results and provide a more accurate picture of the forest lands. Further research in this area should be conducted to fully utilize the information available from ERTS-1 type imagery and data.

The new trend in forest inventory is towards a multiple-resource inventory conducted on some cyclic interval. While the reduced number of ground plots, resulting from the sampling procedure detailed above, would severely limit the amount of ancillary information gained at each field plot, this procedure could be effectively used for a periodic update of the growing stock volume within the given cyclic interval. In any area where timber volumes are the primary concern, this procedure can be utilized to gather the required informaton in an efficient and timely manner.

B. Analysis of Clearcutting Practices in Western Oregon

In reviewing the first ERTS-1 imagery of Western Oregon it was readily apparent that the clearcutting forest harvest practices in this area could be identified and potentially analyzed, especially with the use of color images. As an aid to the administration and enforcement of the Oregon Forest Practices Act of 1972, the Oregon State Department of Forestry is interested in monitoring the acreage of clearcuts made each year within the northwest and southwest regions of the state - especially the private industrial land holding. Sequential ERTS imagery offers an excellent opportunity to collect this type of information. Potential success is particularly high in the Douglas-fir forested regions of western Oregon where clearcutting blocks of 20 or more acres is the common practice.

1. Preliminary analysis

For a preliminary analysis, two areas were sampled. The Cascade sample area, 743,000 acres in the west central Cascade mounain range, east of Sweet Home, Oregon (Figure 19). A 256 dot per square inch grid was used to sample the acreage of land classes by major ownerships on a slight enlargement (1:750,000) scale) of a color composite transparency - ERTS -1 Frame E-1041-18265. The Northwest sample area consisted of ten randomly selected townships on ERTS-1 Frame E-1006-18315 (Figure 20). A 400 dot per square inch grid was used directly on the ERTS composite without enlargement.

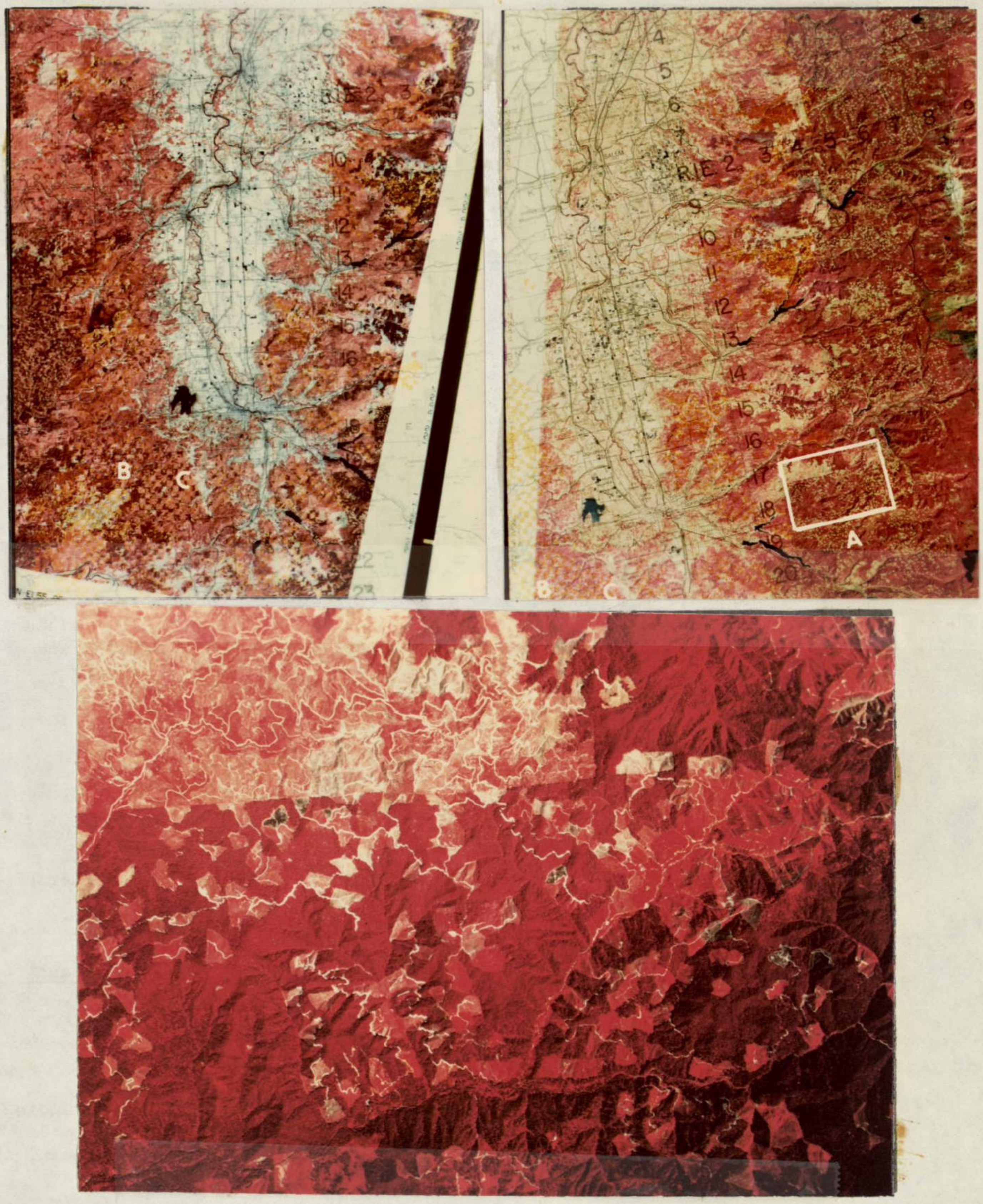

Figure 19. Comparison of diazo (upper left) and General Electric (upper right) color composites. The lower photograph is a high flight reproduction of area A showing patterns and condition of clearcut units.

Acreage Estimates for both test areas were made separately for private (Pvt.), Forest Service (U.S.F.S.), State (Ore.) and Bureau of Land Management (B.L.M.) ownerships as to: clearcut, forest, non-forest and water surface areas. Clearcuts are those areas judged by the interpreter to have supported commercial timber, been harvested and will be used for another timber crop. Areas judged to have been cleared for permanent agricultural use (valley bottoms etc.) were not counted as clearcuts in this study. Clearcuts were separated from other forest land based on the skill and judgement of the interpreter to distinguish clearcuts from the surronding timber. That is, the new crop of vegetation within the clearcut is still distinguishable from the surrounding timber. Based on a previous study, this includes clearcuts, up to 20 years in age. Burned areas were classified as forest land and not included in the clearcut acreage. In general, clearcuts in these areas are relatively easy to distinguish because of their great contrast with surrounding timber, their geometric shapes, and frequent straight sides (Figure 19).

The results of this study are summarized in Table 17 (Cascade sample area) and Table 18 (Northwest study area). These figures verify that private ownerships appear to be short of timber as evidenced by the high percent of clearcut area as compared to other ownerships. A larger sample would be necessary to get adequate regional or statewide results. For example, the Northwest sample has no U.S.F.S. land the B.L.M. shows 100% clearcut for the Cascade sample, but this amounts to only 165 acres. The state land is blue on the original map and is clearly visible in Figure 19. The B.L.M. ownership is yellow (visible in Figures 19 and 20) and the U.S.F.S. ownership was light green in Figure 19.

In Figure 19 we have included a comparison of the General Electric (G.E.) composite print ($65.00 ea.). (ERTS Frame E-1041-18265) with our relatively inexpensive diazo composite of roughly the same area (ERTS Frame E-1065-18322). The diazo technique yields superior detail of the forested areas, for example, compare the separation of conifers (dark red to black) from the hardwood and brush species (light red) in the vicinity of C in Figure 19. The contrast is much lower on the G.E. print and much of this contrast is due to the checkerboard B.L.M. ownership patterns showing through from the map. The particular bands used and their respective collars are shown below:

	Bands	Colors for each Band
Diazo	4 - 5 - 6 - 7	yellow - magenta - black - cyan
G.E.	4 - 5 - 6	yellow - magenta - cyan

Evidently the improved contrast in forest land detail is due to reproducing band 6 in black and to a lesser extent, the addition of band 7. The area just below B on the diazo reproduction is a 3 to 4 year old burn. Again, the yellow checkerboard pattern is BLM land.

Based on the success of our preliminary analysis, a third area was studied at the request of the State of Oregon Department of Forestry. This area is in southwestern Oregon and consists of five counties; Coos, Curry, Douglas, Jackson and Josephine. This area contains 8,180,480 acres (Figure 21), in

Figure 20. Location of Northwest test area, bounded by the Pacific Ocean and the Columbia and Willamette Rivers. Notice the Blue State Ownership showing through the transparency as a purple color.

Table 17 Land Use Classes by Ownership - Cascade Sample

Land Use Class	Private Acres	Private %	USFS Acres	USFS %	State Acres	State %	BLM Acres	BLM %
Clearcut	38,880	44	20,453	31	1,215	8	14,175	37
Forested	50,220	56	45,765	69	12,555	79	22,073	58
Non-forested					810	5		
Water					1,215	8	2,025	5
Total	89,100	100	66,218	100	15,795	100	38,273	100

Table 18 Land Use Classes by Ownership - Northwest Sample

Land Use Class	Private Acres	Private %	State Acres	State %	BLM Acres	BLM %
Clearcut	6,377	36	288	8	165	100
Forested	7,815	43	2,880	81		
Non-forested	3,786	21				
Water			411	11		
Total	17,978	100	3,579	100	165	100

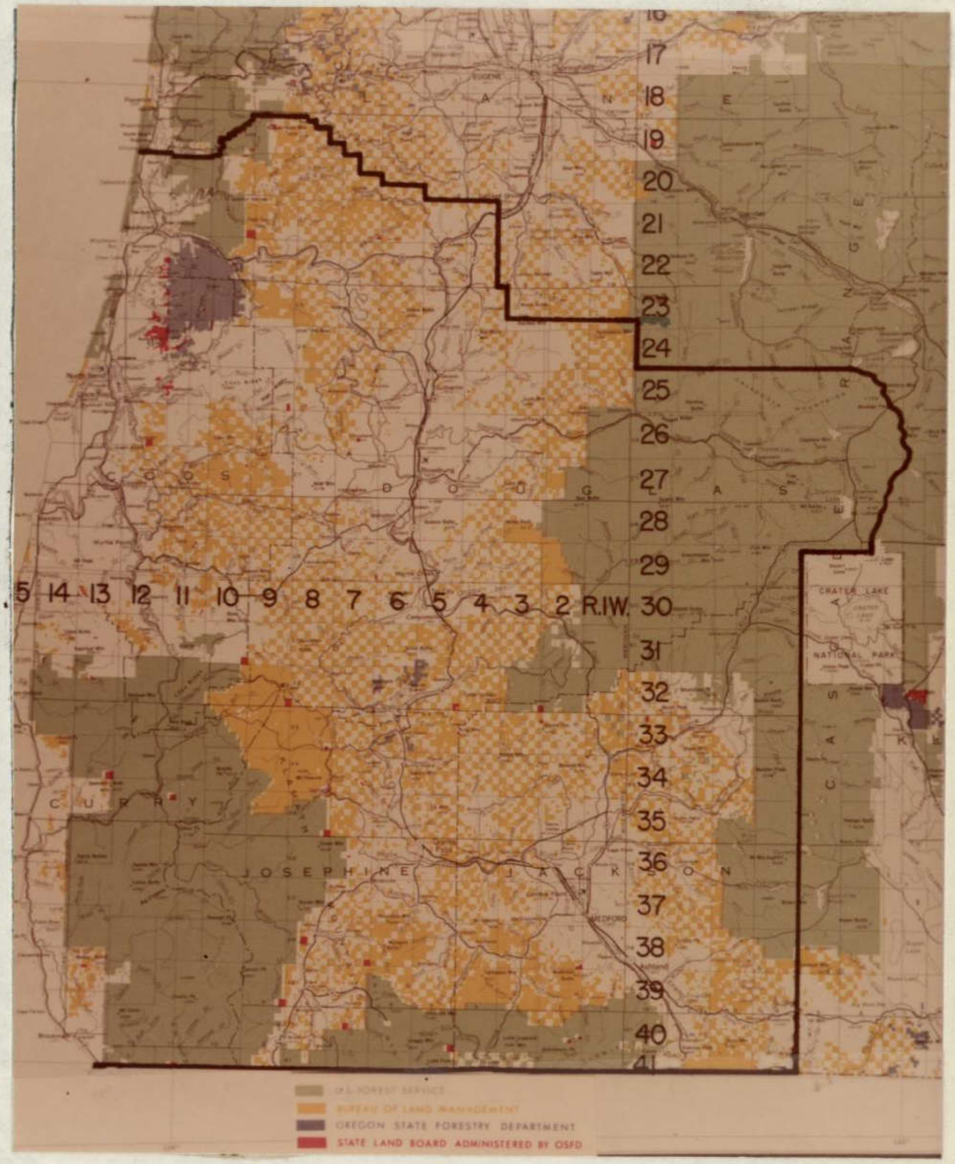

Figure 21. Land Ownership Map showing the boundaries of the southwestern Oregon Test Site and the major cities.

which ownership of the forest lands is divided between the U.S.F.S, B.L.M., the State of Oregon and private landowners (Figure 22). Within this area, there is growing concern that the stock of merchantable timer, particularly that on privately owned forest lands, is being harvested more rapidly than it is being replenished by regeneration and growth.

To analyze this area, thirty sample townships, chosen without stratification, were selected to be the sample frame. These represented 659,916 acres or 8.07 percent of the total area. Each of these townships was located on ERTS-1 color composites made from dizao films (scale 1:1,000,000) and sampled using a dot grid with an intensity of 1,156 dots per square inch. At this image scale, each dot then represents 138 acres. Before the imagery was analyzed, ownership masks were prepared for the selected townships based on the U.S.G.S. Oregon base map at 1:1,000,000 scale. The use of these masks allowed more accurate area determinations than would have been possible with manual delineation directly on the ERTS-1 imagery. As each mask was placed over the imagery, only the land in that ownership class within the selected townships could be viewed, with all the other land on the imagery blocked out (Figure 23). The only disadvantage of this method was the limitation of associative information normally available from the areas surrounding the sample townships. Since some of the smaller ownership tracts sampled were only 40 acres in size, it was necessary to remove the mask to allow reference to the surrounding area for proper interpretation.

The results of this survey are presented in Table 19, 20 and 21. Using ERTS-1 imagery, the timber harvesting activities in western Oregon are readily apparent by the contrast between the exposed soil and the dark, closed canopy of the adjacent conifers. On the ERTS-1 imagery, any high contrast feature such as a logging road of 60 foot width may show for much of its length. However, second-growth conifer stands with a large number of stems per acre often appear visually identical to old-growth stands.

Throughout most of the area, forest and non-forest lands are easily distinguishable, but in the southern section, recent clearcuts are sometimes more difficult to identify. This is because the area includes more dry vegetation habitats where the vegetation is more widely spaced. More of this area has been cleared for pastures and grazing, and frequently these areas are difficult to distinguish from recent clearcuts. One of the visible differences shown by the results in Table 19 is the differences in forest management goals and procedures between different land owners in the region. This can be seen in the differences in the percentage of clearcuts on the private and state lands. The large percentage of clearcuts in the BLM ownership illustrates the large amount of forest land, primarily the old O & C railroad grants, that exist in this area of the state. As the local counties receive fifty percent of the gross receipts from timber harvest on these lands, their economic importance can be readily seen.

This preliminary study shows that inventory of the clearcut areas in western Oregon is feasible from ERTS-1 type imagery. A mult-istage sampling procedure could be developed which would provide essential

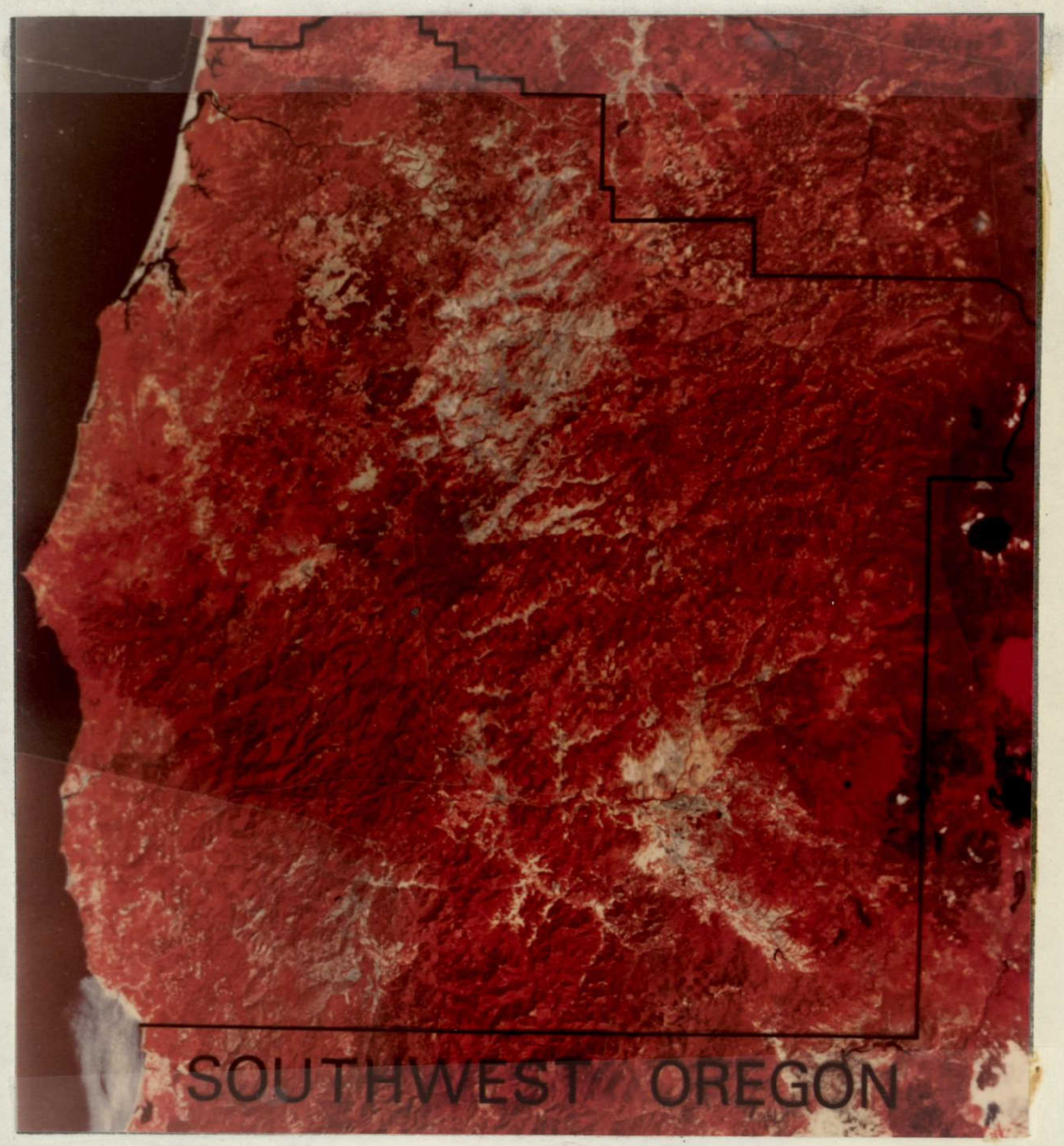

Figure 22. Color composite of ERTS-1 imagery, with ownership overlay of the southwestern Oregon Test Site.

Figure 23. Color composite of ERTS-1 showing the use of masking to outline only the U.S.F.S. ownership within the southwest Oregon Test Site.

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Table 19 Land Use Classes by Ownership - Southwest Sample

Land Use Class	Private		USFS		State		BLM	
	Acres	%	Acres	%	Acres	%	Acres	%
Clearcut	836,863	22	319,039	12	1,963	6	337,036	20
Forested	1,978,040	52	2,286,444	86	30,759	94	1,297,588	77
Non-forested	950,981	25	53,173	2	0	0	50,555	3
Water	38,039	1	0	0	0	0	0	0
Total	3,803,923	100	2,658,656	100	32,722	100	1,685,179	100

Table 20 Land Use Classes for Total Area - Southwest Sample

Land Use Class	Acres	%
Clearcut	1,494,901	18.3
Forest	5,592,831	68.4
Non-forested	1,054,709	12.9
Water	38,039	0.4
Total	8,180,480	100.0

Table 21 Total Forest Land by Ownership - Southwest Sample

Ownership	Acres	%
Private	3,803,923	46.5
USFS	2,658,656	32.5
BLM	1,685,179	20.6
State	32,722	0.4
Total	8,180,480	100.0

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information to the State Department of Forestry for the enforcement of Oregon's Forest Protection Act. One area of further investigation should be the analysis of digital data to enhance the resolution of the areas recognized and delineated as clearcut harvest areas.

C. Detection of Forest Insect and Disease Damage

One of the major potential uses expected from the ERTS-1 imagery was the detection of forest insect and disease damage occurring in large areas. Some preliminary investigations were conducted in three areas of Oregon and the results are reported below:

1. Detection of Tussock Moth damage in eastern Oregon

Northeastern Oregon is presently experiencing an epidemic of Tussock Moth affecting approximately 400,000 acres of forest land. Damage in this area ranges from light top damge to total mortality. Some areas of total mortality occur in areas in excess of 100 acres in size. Although these areas should appear detectable from ERTS-1 imagery, at this date detection from visual interpretation has not been successful. Analysis provides four major reasons for this lack of success:

a) Douglas-fir and true firs (Abies, sp.) the two primary hosts occur primarily on north facing slopes in this area. With a ten o'clock sun angle, these areas are primarily in shadow, particularly in the steep canyons of the area.

b) Throughout the area, Douglas-fir and true firs occur in medium to poorly stocked stands. Therefore, much of the image signal returned is due to the ground below the forest canopy and does not reflect the major changes in the forest canopy.

c) There is a very short period in the life cycle of the Tussock Moth when the infested trees are covered with dead needles. As the population increases, the insect then consumes the entire needle and the trees are stripped bare. Heavy wind, snow or rain can also remove the dead needles and prevent detection, especially if only the top of the trees are defoliated, leaving apparently healthy foliage near the bottom of the tree.

d) Due to budget limitations, ground truth used for this study consisted of very generalized maps from other sources, which were not comprehensive and detailed.

Detection was also attempted on digital data, however, he results were also unsuccessful. This investigation was severely limited by funds and dates of digital tape available for analysis. However, preliminary research completed in another by Dr. J. Herzog of OSU has shown a high degree of success in delineating Tussock Moth damage from digital data. It is strongly believed that this area should be investigated further, expecially in light of the socio-economic pressures which have resulted from the present epidemic infestation.

2. Detection of Mountain Pine Beetle damage in eastern Oregon

One area of investigation was to determine the detectability and identification of a known infestation of Mountain Pine Beetle in lodgepole pine on the Ochoco National Forest (Figure 24).

Figure 24. Lodgepole pine mortality caused by Mountain Pine Beetle, Ochoco National Forest, Oregon.

This area can be located on both ERTS-1 multi-band imagery and digital tape output, but only for already known infestations. At present, a definite tonal signature has not been developed for locating unknown infestations because the preliminary signatures do not allow separation of this mortality from very thick stands of true fir (Abies sp.) reproduction. Further investigation of the area on NASA highflight imagery at 1/120,000 scale and field examination, confirmed correct identification, but distinct differentiation from the true fir reproduction areas is still not possible on ERTS.

3. Detection of Poria weirii in western Oregon

Another area of investigation has been the identification and location of tree mortality casued by *Poria weirii*. This root disease affects Douglas-fir (*Pseudotsuga menziesii*) causing mortality. The disease spreads from one tree root to the next and produces characteristic circular to semi-circular patterns which are easily seen on NASA-Ames high flight imagery of 1/120,000 scale. Preliminary investigation in locating and identifying *Poria weirii* root rot areas in Douglas-fir was conducted with the cooperation of Mr. John Wear, U.S.F.S. Region Six. Initial evaluation of the potential of detection is poor, but is is recommended that further studies be completed, prior to final evaluation.

D. Change Detection in Vegetation/land Use

Since the main thrust of this project was resource inventory, we could only look at some areas of application of change detection: irrigation, development, range improvement, and field burning. We also developed the technical capability for using negative masking.

Irrigation Development

One of the prominent features on the Pendleton Frame (1039-18145-5) is the irrigation development near Boardman and Umatilla, Oregon. Individual fields are circular and range in size from 0.53 to 0.4 km (1/3 to 1/4 mile) in diameter, with the average about 0.8 km (1/2 mile). The average ground area is about 52 ha (130 acres)/circle. We counted 117 north of the Columbia River and 155 south of the river, with areas of 6084 ha (15,210 acres) and 8060 ha (20,150 acres) respectively. According to local information, all of this development has occurred in the last five years. It is apparent that changes in numbers and location of this land use feature can be readily monitored from ERTS imagery.

Range Improvement

Range improvements such as brush removal and reseeding to grass cover extensive tracts of land and usually present sharp contrasts with surrounding vegetation. We felt that this would be fruitful subject matter for change detection from ERTS and highflight imagery.

A new study was completed this year in the sagebrush grass area in central Oregon[2]. Four objectives of this project were:

(1) To determine the impact of range improvements, especially brush control and revegetation on plant community structure for several selected range locations.

(2) To determine the crown cover of three subspecies of big sagebrush *(Artemisia tridentata)* for different treatment types and ages of treatment.

(3) To use space imagery to relate and compare these improvement locations to the total range area and find the magnitude of each treatment in the study area.

(4) To evaluate relationships of three subspecies of *Artemisia Tridentata* to improvement, treatment, and composition of understory vegetation.

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[2] 31 December 1973, Progress Report for Oregon Agricultural Experiment Station Project 429 (Ecology and improvement of foothill rangeland, William C. Krueger, Assistant Professor, Rangeland Resources Program, project leader), pp. 4-8 by Roger Findley, Graduate Research Assistant, Rangeland Resources Program, Oregon State University, Corvallis, Oregon.

In order to attain Objectives 1, 2 and 4 above, measurements of vegetation were taken on 14 sampling locations during the summer of 1973. The measurements were frequency of annual and perennial vegetation, density of perennials and cover of perennials. The 14 sampling locations were located on the GI Ranch, 25 miles northeast of Hampton, Oregon; Hampton Grazing Coop at Hampton; and the abandoned settlement of Stauffer, 25 miles southeast of Hampton. Four habitat types were included in this study. They were *Artemisia tridentata* subspecies *wyomingensis/Stipa thurberiana, A tridentata* subspecies *wyomingenis/ Agropyron spicatum, A. tridentata* subspecies *vaseyana/Festuca idahoenis,* and *A. tridentata* subspecies *tridentata/Agropyron spicatum-Sitanion hustrix.* Different age classes of treatment types were also looked at for the 14 sampling locations. The treatment ages ranged from one to ten years.

To accomplish the third objective of this study (i.e., use of space imagery to find the magnitude of improvements in study area) Earth Resources Technology Satellite (ERTS) imagery (scale 1:1,000,000 color reconstitution 1004-18210-4, 5, 7) was used. This imagery allowed an overall view of the study area, but the scale proved to be too small to locate individual range improvement areas. However, subsequent mapping work on 1:250,000 ERTS indicates that some range improvements may be detectable given the appropriate season of imagery and MSS band or band combinations.

Highflight photography (NASA Flight 72-114, scale 1:120,000 color infrared) covered the study area except around Stauffer. Signatures of different known range improvement treatment types were identified on the ground and then located on these photos. Other improvement areas having the same signature were grouped according to treatment type. The approximate acreage of each improvement type was measured from the photos by the electric grid method.

The improvements involved in this work were plow-seed, spray--release, spray seed, and no treatment. Plowed areas could be distinguished from sprayed areas. However, sprayed areas could not be subdivided into spray-seed or spray-release. The plowed areas are lighter in color than the sprayed areas and have a more pronounced boundary. Variability in spray shutoff and wind drift combine to give an indistinct boundary to sprayed areas[3].

Improvement areas were located and identified on highflight photos covering the study area (except around Stauffer). These improved areas were delineated and measured by the grid dot technique. A known area was also delineated and measured on the photos. Acres per dot were calculated from the known area. The number of dots for the improved areas was then multiplied by the acres per dot factor to obtain acres of improved areas. The results obtained are shown in Table 22.

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[3] 29 August 1973. Use of highflight imagery in range improvement evaluation project. Report to ERSAL by Roger Findley.

Further work is being done on a project of similar nature in Malheur County by Mr. Findley and Kirk McDaniel, another graduate student in Rangeland Resources.

Table 22: Area included in various range improvements near Hampton, Oregon.

	Hampton Coop.		G.I. Ranch	
Treatment	Acres	Hectares	Acres	Hectares
Spray-release	2,380	952	0	0
Plow-seed	610	244	4,480	1,792
Spray-seed	12,400	4,960	6,560	2,624
Untreated	6,760	2,704	26,350	10,540
Total	22,150	8,860	37,350	14,956

Records showed the total area in the Hampton Coop is 8,192 ha (20,480 acres) versus 8,860 ha (22,150 acres) calculated. This difference amounts to about 8 percent.

Field Burning

Upon our first look at ERTS imagery of the Willametter Valley, it appeared that use of ERTS imagery for monitoring grass seed field burning was promising, particularly on color reconstitutions (bands 4, 5, 7)[4]. After consultation with the Oregon Department of Environmental Quality (DEQ), it was concluded that the greatest contribution this application of ERTS could make would be in monitoring the effectiveness of DEQ's field burning control and management program. Turn around time at present precludes use of ERTS to replace the day-to-day and month-to-month tabulation of area burned by Fire Control District.

In order to assess the feasibility of using the ERTS to monitor field burning in any sense, it was decided to compare measurements of areas burned determined from ERTS with area recorded by DEQ. Color reconstitutions of ERTS frames 1006-18315-4, 5, 7 and 1006-18322-4, 5, 7 (29 Jul 1972, 1:1,000,000) were used. Field checks could not be made due to time lag in receipt of imagery, but the images were sufficiently unique to minimize the possibility of false interpretations.

The DEQ record showed that as of 29 July 1972, 4248 ha (10620 acres) had been burned in the Willamette Valley. The ERTS determination was 4376 ha (10940 acres), a difference of about 3 percent. The DEQ record was estimated to take 100 man hours for tabulation, while the ERTS required three.

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[4] 31 March 1973. Monitoring of field burning from ERTS-1 imagery in first year projects and activities of ERSAL. Annual Progress Report to NASA, Office of University Affairs, Washington, D. C. pp. 16-19. By C. E. Poulton and D. P. Faulkner.

It was concluded that for regions of minimum cloud interference, monitoring of field burning activities could be a feasible application of the ERTS system. Whether the application would be in field burning management or in a double check on burning control program, effectiveness depends on the periodicity of the satellite and lag time between acquisition and delivery of imagery. A shorter period and time lag would be required for field burning management.

Negative Masking

A technique which we have investigated but not used extensively is that of negative masking. Essentially, the technique involves overlaying a positive transparency of one date of imagery with a negative transparency of a later date. Areas which have changed will either appear lighter or darker than the uniform background.

We have implemented this technique through use of the diazo process. We took a look at two dates of ERTS imagery on MSS band 7. Some of the changes which we could detect included fires, reservoir draw down, meadow drying, and snow melt.

Conclusion

Application of ERTS to change detection needs further in-depth investigation of specific areas and a broader perspective than reported here to fully realize the potential of the system. We feel that the applications described here are of sufficient promise to warrant continuing investigation.

E. Computer-Assisted Image Classification and Support Programs

Introduction

The two main objectives of the Computer Center were to provide computational support for the multidisciplinary investigation and to implement a computer-assisted classification system that would be available and accessable via remote terminals to users on campus and throughout Oregon. The classification package was to be implemented using existing hardware and operating system. There were no computer specialists with experience in processing digital imagery; the computer part of the investigation was started from scratch.

By working closely with coinvestigators in the natural resource area to learn their information needs and by fitting these data requirements into the available computer system, an efficient and low cost, in terms of computer expense, classification system was developed. This software is currently being used to supply information and to develop uses for digital imagery for several state and federal agencies in Oregon. In addition, the Computer Center has become a focal point for ordering and storing digital imagery, for consultation on projects contemplating the use of digital imagery, and has also been assisting in the processing of user originated classification requests.

Implementation of the Classification System

Hardware Available. A Control Data Corporation (CDC) 3300 computer, operating in a timesharing mode with as many as 60 simultaneous users, is the principal computational resource available at Oregon State University. This system services the instructional, student administrative records -- including registration and grade reports, and most of the research needs of the University. With this heavy load on a medium speed and capacity machine, it was necessary to pay particular attention to the efficient design of programs and data structures; otherwise, the digital imagery processing programs could not successfully compete, both in execution time and cost, for the avaiable computational resources.

The two hardware features found to be most valuable in processing ERTS digital imagery were hardware byte addressing, and the ease of byte array storage and access, with both features accessible at the FORTRAN level. The availability of easy and moderately rapid access disk storage was another important asset.

Remote terminals were low speed (10 characters/second) teletypewriters and there are over 200 of these available throughout the state with access to the 3300. Teletypewriters are among the most inexpensive ($700 - $1,000) remote terminals available today, particularly those that provide hardcopy, and have proven adequate for most of the computer-assisted classification operations.

Two additional peripheral hardware items were used exentsively as aids in the preparation of map bases and overlays. The first was an on-line drum plotter and the second was an off-line x-y coordinate digitizer.

Operating System Software. The operating system used on the 3300 was written at Oregon State University. In addition to batch processing and remote job entry, it features a command processor that enables the user at a remote terminal to "operate" the computer as if he were actually seated at the computer console. Another important feature is the ability to manipulate both stored and working data (disk) files easily from the remote terminal. There are cost and space limitations on the amount of data that can be stored on disk, but for most steps in the classification procedure we have found that the data required can be readily stored on disk.

Paging and Program Segmentation. A common feature on time-sharing computers is the segmentation of program code and associated data arrays into "pages". The page is a fixed number of computer memory locations, 2948 (24 bit) words on the CDC 3300. At the demand of the operating system, the contents of pages not being referenced by a specific user program are written ("swapped") onto an auxiliary storage device, usually a disk, and the freed pages are assigned to another user program requesting memory. This demand paging, also called "virtual memory", requires careful attention to both program structure and the data arrays referenced by a program in order to keep page swapping at an acceptable level. The preferred situation is to have a program compact enough to remain resident in memory, i.e., a one or two page program, and the worst case is to have a procedure that requires a new page reference with each data value used. The requirements for efficient program operation in a paging system does not place an excessive burden on the programmer, but does require a knowledge of the paging strategy and the data array storage arrangement.

In designing our classification system we found that one scan line or parts of it made natural and convenient data records and furthermore, when doing a classification, there are distinct steps in the procedure that make a modular series of programs possible. For example, after an investigator selects a training site, there is usually a break before a classification is done; thus three program modules -- selection, statistics, selection adjustments are possible. The linkage between the modules is the temporary storage on disk of the output from one module as input for the next program. Furthermore, machine code copies of the program modules can also be stored on disk, and loaded by a single word command. By using modular programs and by taking advantage of the linearly stored intensity values in a scan line, it is possible in almost all programs to keep the size at one or two memory pages. During some workshop sessions, we have had 10-12 terminals accessing data files and program modules without degrading the overall computer system performance when the total number of computer users was 35-40.

File Structure. For tape files of digital imagery, two strips (180 pixels and 2340 scan lines) of reformatted digital imagery are stored on one magnetic tape with a file mark between the strips.

For disk files the 25 x 100 N. mile strips are subdivided into 128 pixel (512 bytes) strips. These 128 pixel sub-strips were selected to be compativle with the width of the computer printer line, i.e., 128 characters plus a four digit scan line number. Also, a scan line number and 64 characters will fit on a teletypewriter line which enables a convenient split of the 128 character sub-strip. The number of scan lines in a 128 pixel sub-strip is variable, but usually less than 750.

User costs minimization. In looking to the foreseeable future, there was no indication that the local processing of digital imagery would be anything other than a shoestring operation in terms of both funding and hardware. Therefore, the computer software was written to conform to a low cost operation. No important or necessary features were excluded, but there are no frills; options that were attractive but not required were skipped.

Program Modules For Computer-assisted Classifications

Reformatting and error summary. Prior to use in a classification the digital imagery received from NASA or EROS was rewritten into a format better suited for the local computer system. While only parts of a tape (25 x 100 N. mile strip) may be processed, a full tape is usually unpacked and rewritten. As a result of data compression during the reformatting, two strips (tapes) can be written on one 2400-foot tape and thus reduce the original tape storage requirements by a half.

The reformatting/error summary program module includes the NASA supplied annotation data and generates a 23-word file identication record. This file identification record is used to identify the imagery source in succeeding processing steps and it may be altered or updated in indicating the current processing phase.

Using table-lookup the original 7-bit intensity values are compressed to a 6-bit value (character). These 6-bit characters are stored four to a computer word, and the words interleaved by band. By storing four characters per word, data references and access times can be reduced in many operations; it requires the same number of machine cycles (time) to reference and move a word as it does to reference and move a single character.

During the reformatting a check is made for missing data, data outside the allowed ranges, and for tape parity errors. A printed record of any errors is produced. Other features of the error/summary routines have been described in earlier reports.

All of the main program modules have been written in FORTRAN; however, in the unpacking routines we have found that coding parts of the program in assembly language has reduced cost and time; thus, two versions of the routine are available. Our current minimum cost for reformatting is about $50 per tape.

Additional programs have been developed for use during the unpacking phase. One is used to generate, correct, or update the identification record which preceeds each data file. Another will output the original and/or reformatted data in octal or decimal format. A third compares two files word for word and lists any discrepencies.

Sub-strip selection. In most applications for interactive, on-line processing selected sub-sets of a digital imagery scene, usually stored on magnetic tape, are transferred to disk file. The program module developed for this purpose has the following options: interleaved or single band output the starting and ending scan lines may be specified as are the starting and ending pixels, and the compilation of a frequency distribution and histogram.

Printer-produced grayscales, training site selection, statistics, and classification program modules. Program modules to produce grayscales, to select training sites, to compute statistics, and to classify digital imagery have been developed by the Computer Center or by co-investigators in Electrical Engineering. These program modules have been described and examples of their usages shown in earlier reports. In general, the programs are conversational and user-oriented, and they are based on the file structure and hardware features detailed in the preceeding sections; altered versions have been implemented to aid in software development or in error checking. To simplify the selection of geographic sites or areas, modifications have been made which use the input from visual display terminal or from digitized (off-line) x-y coordinates.

One feature we have found useful is a carefully selected, single character printer grayscale rather than a multiple character overstrike. The single strike is faster and less costly and is sufficient in most uses.

Data Display Routines

Early in the ERTS-1 project it became apparent that line printer grayscales were inadequate to represent the detail available in digital classifications and to present the information on a suitable base and scale. The latter point, map bases and scale, are especially important when dealing with user agencies. Thus we have found that different users want the same information shown in a different format, but we have also found the first requirement is the need to reference a range-township grid.

A computer-driven drum plotter and an off-line x-y coordinate digitizer were available and, using well documented examples of thematic mapping as a guide, some simple presentations of digital imagery were made. Examples of scaled and plotted imagery superimposed on range-township grid have been included in some of our previous reports.

An additional example of scaled and plotted imagery is shown in Figure 25. The data is from scene 1-452-18082, and depicts at a scale of about 1:40,000 a part of Malheur Lake Waterfowl Refuge in central Oregon. The horizontal arrows, each representing a pixel, indicate open water, and the vertical arrows represent marsh vegetation and wet lands. Several versions of the plotted imagery have been produced; the partially completed example shown was plotted in three colors on acetate for an overlay on an aerial photo mosaic.

If viewed from about three feet at a 30 degree angle above the paper, the plot is a partial three-diminsion perspective.

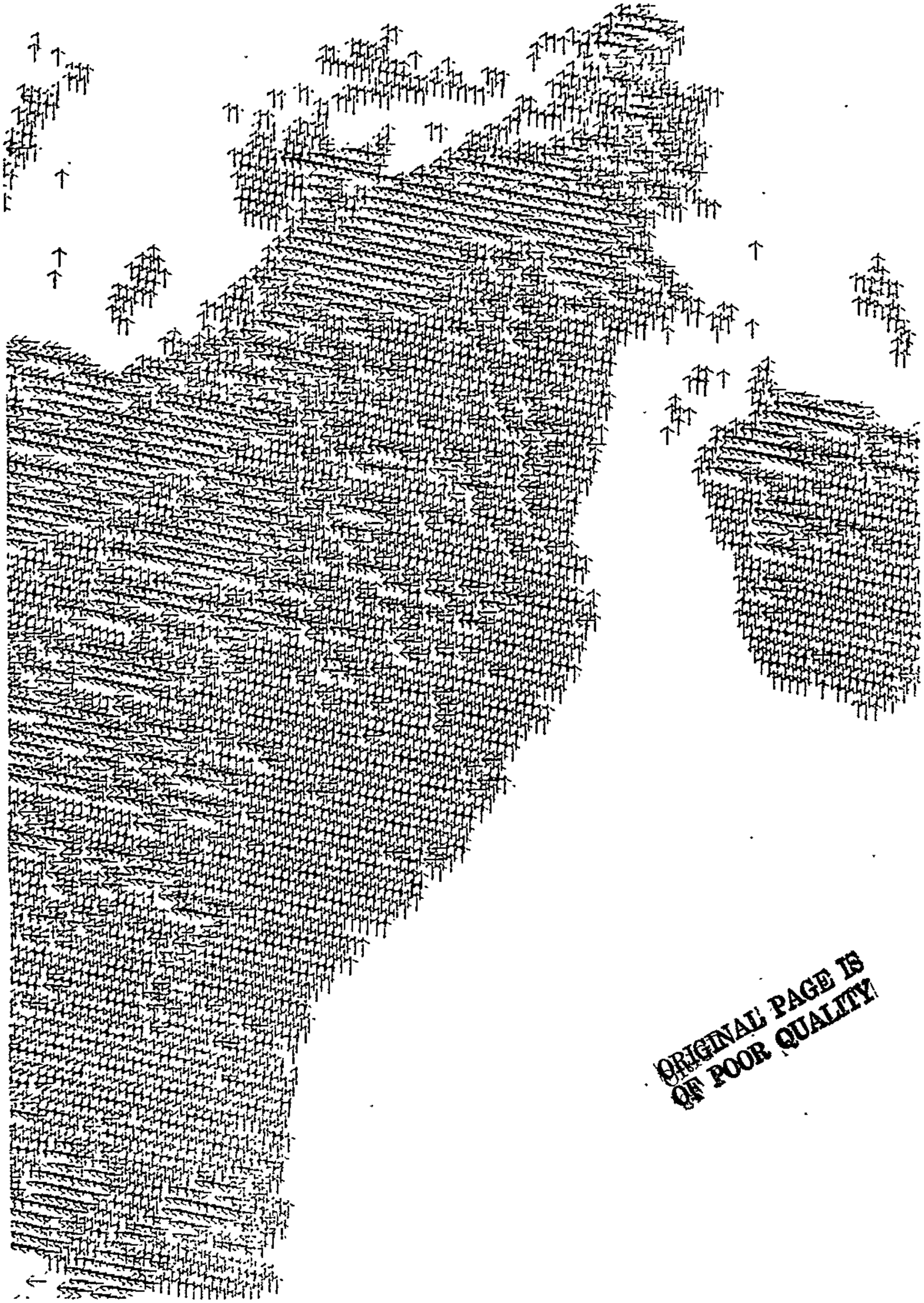

Figure 25. Part of Malheur Lake in central Oregon. Scale: approx. 1:40,000. → = open water. ↑ = marsh and wet lands. Scene ID 1-458-1882.

Another example of computer produced plotting and scaling is shown in Figure 26. Here the scale is 1:12,000 (1" = 1000') and an overlay showing a part of a computer classification has been made for an orthophotograph taken in June 1972. Centered in the photograph is a clearcut, still being worked when photographed, which is surrounded by a heavy Douglas Fir stand. On the overlay the scan lines (from scene 1-006=18322) have been scaled and rotated to match the ground tract; also the section corners and some ownership points, digitized off-line and maintained as separate file, have been drawn by the machine. At this scale a pixel is about 0.25 inches square, and the displacement of a pixel unit on the boundaries in any direction produces obvious misregistrations in the classification; thus, the matching of the base map (photo in this case) and the imagery is well within one pixel. The scale factors were not determined in this area, but were available from a similar scene about 40 miles away.

In Figure 26 only the heavy conifer or the bare soil classes were plotted; however, the delineation, based primarily on ownership lines, between the mature timber and the earlier cuts now regrowing is excellent.

The plotting of individual pixels as has been shown here is costly and probably of limited value on the long term. Additional work needs to be done on delineating boundaries of similar groups and then matching these boundaries to ancillary information. Nevertheless, we feel that the approach taken here is a necessary and instructive first step.

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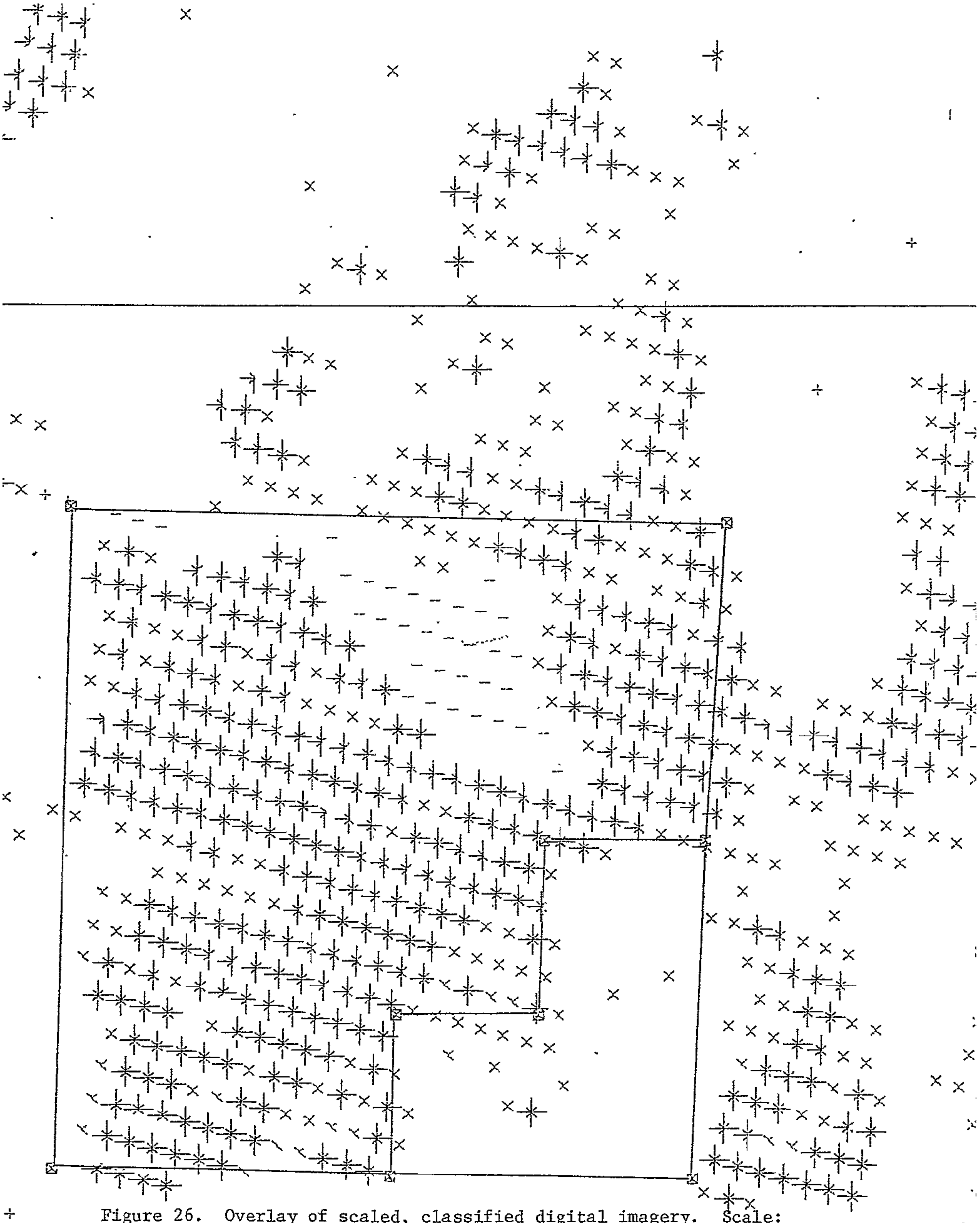

Figure 26. Overlay of scaled, classified digital imagery. Scale: 1:12,000 (1" = 1000'). † = dense Douglas fir; – = bare soil (clearcut); x = medium density Douglas fir stand. Scene 1-006-18322

Computational Support for the ERTS-1 Multidiscipline Investigation

Unfortunately, the computational support of the co-investigators in our ERTS-1 project was late in reaching an operational state and some of the anticipated applications were not made. The delays in obtaining digital imagery and a longer than expected time to obtain ground truth data reduced the amount of digital classification. Some digital imagery was used by most of the coinvestigators and all of them became familiar with the potentials and problems of this information source. Reports on the results of digital interpretations have been reported earlier or are contained in the appropriate discipline section.

Follow-on Compute-rassisted Classification Projects

An objective of our ERTS-1 investigation was to develop a digital imagery processing system that would be available for use throughout Oregon or the Pacific Northwest. We feel this objective has been accomplished.

Projects involving extensive Computer Center participation and funded by the named agencies have been undertaken for the U.S. Geological Survey, the Corps of Engineers, U.S. Wildlife Service, and Bonneville Power Administration. Additional studies and projects using digital imagery almost exclusively, including one to train about 25 personnel from state agencies in Idaho, Oregon, and Washington, are being planned.

Project COVEDS. A major project undertaken following the ERTS-1 investigation has been a COordinated VEgetation Digital Study--COVEDS--with the active participation of the following agencies:

U.S. Forest Service
Bureau of Land Management
Oregon State Forestry Department
Oregon Wildlife Commission
U.S. Wildlife Service
U.S. Corps of Engineers

Several other state and federal agencies are participating or have expressed interest to a lesser degree. Funding has been on a hand-to-mouth basis and the largest amount expended by any agency has been $3000.

The study area is a 60 mile long, 40 mile wide strip running inland from the central Oregon coast. As indicated in the title, the prime objective is to determine the level of discrimination that can be made using digital imagery in the heavy and diffuse vegatation of the coastal region. Also several of the participants are interested in a detailed inventory of estuaries in the region.

One feature of this study was intended to test the availability and usefulness of ground truth or information that is currently utilized and cataloged by user agencies. Therefore, all test site descriptions and verifications are handled by the participating agencies' personnel.

The results to date have been satisfactory. Separation of clearcuts, hardwoods, brush, and conifers into several levels of cover has been accomplished. For example, conifers (Douglas Fir) has been assigned to at least four age/ stocking levels. The ability to make finer distinctions has been limited by the lack of adequate training or verification sites.

While the recorded information currently available for the agencies is usually inadequate for ground truth, we have found no problem in training or instructing field personnel in the approach used to obtain supplementary data. The one item found to be most readily available and valuable in this study has been excellent photographic coverage.

The study is continuing as funds can be scrounged, and the next major problem is that faced sooned or later by anyone supplying information extracted from digital imagery--exactly what is needed and how can the agencies best use it to meet their information needs.

Cost Accounting

The computer Center has established an ERTS support project as a part of its accounting system. Since the Center is required to operate on a self-sustaining basis, charges are made in proportion to the computational resources used. Current ERTS support activities include maintaining a magnetic tape library of digital imagery; providing consultation on the applicability of digital imagery in solving a problem, on computer costs, and on program usage; mmaintaining, documenting or providing documentation, and modifying software routines; and running programs for users. These activities are classed as overhead and not chargeable to a specific user funded project.

Therefore, the purpose of the cost accounting is not to determine the cost effectiveness of ERTS data in comparison with some other information source, but to determine the level of support, on a nonprofit basis, that can be sustained by generated income.

While the accounting has been in effect for only a short period, it will suffice to say that only about 50% of the incurred expenses are being recovered.

At the end of a year the cost/income data will be analyzed and the level of support and/or the charges adjusted accordingly.

F. Computer Processing of ERTS Digital Data

Introduction

This report documents the activity of the Electrical and Computer Engineering component of the Oregon State University Multidiscipline research proposal. This group subsequently contrived the name PIXEL (Pictorial Information Extraction and Enhancement Laboratory) and will be referred to as such in the body of this report.

PIXEL was charged with two primary responsibilities; one development and the second application oriented.

1) Develop a core of computer programs and utility routings suitable for the analysis of ERTS MSS data.

2) Demonstrate the feasibility of using automatic data processing to aid and assist other members of the multidisciplinary team.

The following initial specifications were closely followed in developing a complete processing system called PIXSYS for use with ERTS data.

1) The PIXSYS system must be capable of operating within the limitations imposed by a shared medium scale digital computer (CDC 3300) similar to what would be available on most university computing centers. Specifically no unique hardware or dedicated processors were to be used.

2) The PIXSYS system was to be readily usable by investigators with a minimum of programming background. It was to be easy to use and operate in a natural question and answer interactive made from a typical remote computer terminal.

3) All programs were to use standard FORTRAN IV. This would allow other investigators to readily modify the program for application at other sites.

4) PIXSYS was to be highly modular to allow modification and extension of capability.

A complete description of PIXSYS is included in the appendix in the form of a short overview paper "An Automatic Classification System for ERTS Digital Data" and "PIXSYS A Users Manual" which is the current documentation for PIXSYS.

A second series of short papers describes the cooperative activity between PIXEL and a wide variety of state, federal, and private organizations, to establish the credibility of ERTS data for natural resource managment. In several instances the activity was performed with the assistance of one or more of multidisciplinary team participants.

The following criteria were used in selecting application oriented programs:

1) The research objective must include a component which examines the feasibility of utilizing ERTS data in a unique application.

2) The results of the activity must be applicable to other "similar" situations.

3) The cooperating organization must make a commitment of personnel and in some instances financial assistance to the project.

4) The project must be of sufficient importance, either cost/benefit or research.

Based on these criteria the following investigations were performed.

1. Big Summit Prairie

Objective - Determine the feasibility of using ERTS data to prepare vegetation maps of natural plant communities typical of the high desert country of the Western United States.

Procedures - Big Summit Prairie, a 200 square mile region in Oregon was selected as a test region. Ground vegetation experts using computer "gray scale" maps selected test sites for the PIXSYS classifier. PIXEL research assistants applied an early version of PIXSYS to produce vegetation classifications. Several modifications and test site evaluations were required before satisfactory results were obtained.

Significant Results - Ten natural vegetation species were classified and mapped by computer. The classes included water, sagebrush (four types), grasses, mixed conifers (trees), and Ponderosa pine. Ground truth indicated very good agreement. The results cannot be completely quantified since ground coverage of the 200 square mile test area was not possible.

Importance of Results - Natural plant communities, being highly non-homogeneous, present unique automatic classification problems. The success of this project suggests that satellite data may be used to manage the extremely large regions of natural vegetation. This vegetation is of great economic importance as grazing land and recreational land. It may be used as one component of a comprehensive environmental impact statement.

2. Mt. Washington, Belknap Crater

Objective - Evaluate the effectiveness of using ERTS data and PIXSYS processing to classify major geologic structures.

Procedure - The Mt. Washington region of the Oregon Cascades was selected as an experimental site. Cooperating with Dr. Robert Lawrence of the Multidisciplinary team test sites for lava from three distinct eruptions from Belknap crater were selected. Additional test sites for water resources and a recent (1967) major forest fire were included.

Significant Results - Three types of lava were distinguished. The burn area was classified. Water resources were accurately mapped. Areas of forest "clear cut" logging were delineated.

Importance of Results - The results obtained were primarily of scientific importance in understanding the geology of the region. Although not primary objectives the study indicated that brush and/or timber regrowth could possibly be monitored from satellite. This result has very large economic and environmental potential.

3. Salishan Spit

Objective - Evaluate the effectiveness of using satellite data for monitoring beach erosion and estuary conditions.

Procedure - In the winter of 1972, a group of vacation homes on Salishan Spit on the Oregon Coast were threatened by severe beach erosion. Several homes were destroyed. A breach in the Spit threatened to greatly alter the status of Siletz Bay and the Siletz River estuary. ERTS data was used to pictorially portray the water/land interface. A poster/display was created describing the activity and results.

Significant Results - ERTS resolution was found to be too coarse to monitor the subtle effects of beach erosion. PIXSYS processing delineated several features within the Siletz estuary. Shoaling patterns in the mouth of the bay were observed.

Importance of Results - The results indicated that shoaling in bays, rivers, and estuaries could be monitored by satellite. These results were presented to the Army Corps of Engineers which is currently sponsoring additional research in this area.

4. Unity Reservoir

Objective - Determine the feasibility of monitoring water acreage from satellite data.

Procedure - Unity Reservoir in Central Oregon was selected as a typical small but economically important reservoir. Proper water management is essential for irrigation and recreational activity in the region. Using PIXSYS water acreage was determined.

Significant Results - Satellite data can be used to monitor water acreage with great precision.

Importance of Results - Satellite surface surveys have great potential in accurately determining the water budget for whole regions. This information is accurate and cost effective compared to fixed wing aircract photography.

The following activities were initiated using NASA funds but completed using other sources of funding. Their economic and environmental importance warrants their inclusion of this report.

5. Tussock Moth

Objective - Evaluate the feasibility of using ERTS data to provide managment data for detecting, delineating, and monitoring insect defoliation in timber resources.

Procedure - With cooperating personnel from the Oregon State Department of Forestry and Boise Cascade Corporation, twenty-six test sites were established in Northeast Oregon. These comprised three stocking densities (crown closure) and four degrees of moth damage. PIXSYS was used to classify a three hundred square mile region. The resuls were evaluated using trained (Boise Cascade) personnel and low elevation aerial photography.

Significant Results - Tussock moth damage was accurately delineated for three degrees of infestation. Thus far only the 100% crown cover timber stands have been investigated. The computer results graphically show the degree of damage and calculate the total acreage infected.

Importance of Results - Nearly a million acres of forest land are now defoliated by Tussock moth. Total economic/recreational impact is enormous. To our knowledge this is the first demonstration that vegetation stress can be determined from satellite data. These results strongly suggest the tremendous cost/benefit impact of using satellite data for timber resource management.

6. Rhea Creek

Objective - Determine the feasibility of separating irrigated vs.non-irrigated agricultural land.

Procedure - A test region adjacent to Rhea Creek in Central Oregon was investigated. Water right maps were provided by the State Engineer's Office.

Significant Results - Inconclusive. Adequate ground truth was not available.

Importance of Results - Prudent allocation of irrigation water is essential to optimize agricultural production. Satellite data may provide data for the monitoring of irrigation and the enforcement of water rights.

7. Columbia River

Objective - Evaluate the feasibility of using satellite data to monitor shoaling and determine water depth in the Columbia River.

Procedure - With the cooperation of the U.S. Army Corps of Engineers, "super pictures" (multi-spectral enhancements of water features) were prepared for 80 miles of the Columbia River. Test sites were selected and water depths determined from survey maps. PIXSYS was used to classify the water based on water depth.

Significant Results - a principal component data transformation (super picture) offers an excellent method to enhance selected low contrast features. Shoals up to about ten feet in depth were accurately portrayed. The pictorial results offer a viable alternate to aerial photography.

Importance of Results - Dredging in the Columbia River is a multi-million dollar operation. Satellite data introduced the possibility of monitoring sediment transport and shoal build-up on a repetitive basis. This will have economic impact on optimizing the dredging and disposal operations in the river.

G. Automatic Pattern Recogition Experiments in Vegetation/land Use

Upon receipt of the first digital products from NASA, we worked with our co-investigators in Electrical Engineering and the Computer Center in developing a vegetation classification. The first step was to select an area in which there was enough diversity in plant communities to assure at least a broad classification and also an area where additional vegetation information would be desirable. Using these criteria, an area in the Ochoco Mountains known as Big Summit Prairie was selected. An additional area, between Ochoco and Prineville reservoirs, was chosen to assess whether training sets could be transferred.

Big Summit Prairie

Using ~1:30,000 color infrared imagery (NASA 72-134, 24" fl) of Big Summit Prairie (Crook County, Oregon), the vegetation occurring on the prairie (privately owned) and the surrounding forest fringes (public) was mapped in detail. Ground truth samples were made to determine actual make up of mapping units and to check type line accuracy.

Using ERTS digital data from frame 1021-18151-5 (13 Aug 1972) a gray scale print out was produced. Sample plots (for training sets) were established for computer mapping of the prairie and surrounding forests and scablands. This was done by using vegetation type mapping on NASA high flight (Acc. No. 72-134, ~1:30,000, CIR transparency, 24" fl, 9" x 18" format) and overlaying it on the gray scale printout using a zoom transfer scope. Test sets were chosen for water, ponderosa pine forest, sagebrush scabland, and wet meadow vegetation. Statistical analysis of each class was computed and a classification using all four ERTS bands was generated. This classification matched the photo interpretation mapping closely but left much of the area unclassified.

While this work was being conducted, additional ground truth data were collected at Big Summit Prairie. New and more refined training classes (Table 23 were located on topographic maps and NASA highflight (72-134 ~1:30,000). These training classes were located on the gray scale printout in the same manner as was previously used. Statistics were calculated for each class. This analysis showed there was no significant difference between each member of four pairs of the classes (Table 23). Consequently, each of these class pairs was combined into a single class. One class (bare ground) was found to have a great amount of variance and was broken into two classes which were significantly different (1. -lava, and 2. -other rock).

The second classification was based on the ten classes resulting from the statistical analysis. This classfication was run with no threshold, so all resolution elements were classified. This classification was analyzed using a zoom transfer scope and overlying the NASA highflight (No. 72-134, ~1:30,000) on the printout. Close correlation was found between the photo interpretive mapping and the computer classification. Upon making this comparison, it was decided that the mixed conifer class more closely represented ponderosa pine stands, which were dense and had greater crown closure, as the mixed conifers were of very limited

Table 23: Classes Used in Computer Classification of MSS Digital Data from Big Summit Prairie.

Statistical Analysis	Second Classification
Water	Water
Stiff Sagebrush Scabland *Artemisia rigida*	Low Sagebrush Scabland
Low Sagebrush Scabland *A. arbuscula*	
Pine/Fescue *Pinus ponderosa/Festuca idahoensis*	Pine
Pine/Mt. Mahogany *P. ponderosa/Cercocarpus ledifolius*	
Mixed Conifer *Abies* spp.	Mixed Conifer
Silver Sagebrush *Artemisia cana*	Big Sagebrush
Big Sagebrush *A. tridentata*	
Forbs *Wyethia* spp.	Forbs
Forbs *Lomatium* spp.	
Moist Meadows *Juncus* & *Carex* spp.	Moist Meadows
Riparian *Salix*, *Alnus*, & meadow spp.	Riparian
Bareground	Lava Rock

distribution in the area and in very small patches. Also, the riparian class more closely represented a density class of ponderosa pine as the riparian vegetation occurred as narrow stringers associated with the pine. Misclassification was noted along class boundaries where broad ecotones exist. No assessment was made of omission-commission errors because of the arbitrariness of type boundary locations in ecotonal areas at the highflight scale (~1:30,000).

Additionally, ERTS frame 1040-18210 (1 Sep 1972) was selected for classification to determine if the training sets from one date of imagery could be transferred to another for the same area (Big Summit Prairie). A classification printout based on these previously used training sets was generated. This classification was not as accurate as the first when compared to the mapping of like units in highflight 72-134 (~1:30,000). These classification errors may be attributed to phenological changes, changes in sun angle and errors in location of the training sites on the digital imagery between dates. The communities most consistently classified in the multidate digital data were pine *(Pinus ponderosa)* moist meadows *(Juncus* and *Carex* spp.), big sagebrush, *(Artemesia cava and Artemesia tridentata)*, and low sagebrush scabland *Artemesia cava* and *A. rigida)*.

Prineville Reservoir

Using the same ERTS scene (1040-18210), another site for computer classification was selected, the area between the Ochoco and Prineville Reservoirs. Selection was based on a need for intensive information within this area due to subdivision development pressures within a fragile ecosystem.

A classification of the area was based on the training sets which were used in the Big Summit Prairie area. Some of the vegetation types did not occur in both places (Table 24). However, an accurate classification did not result from the use of the training sets for vegetation types in Big Summit Prairie which do occur near Prineville Reservoir. The juniper sagebrush lands *(Juniperus occidentalis/Artemisia* spp.) were classified as pine types *(Pinus ponderosa)*. Also, pine types were classified as mixed conifer (apparently due to shadow on north slopes "looking" like dense forest). Change in scene date and transfer of training sets from one ecological zone to another (pine zone to juniper sagebrush zone) seem to account for the errors. Changes in soil color (dark to light) and degree of vegetative cover (to more sparse) seem particularly relevant.

Due to the gross errors in the classification, training sites within the test area were selected from the highflight 72-134 (~1:30,000) photography and transferred by zoom transfer scope to the digital imagery as accurately as possible. Classes selected were: low sagebrush scablands *(Artemisia rigida* and *A. arbuscula)*, juniper/sagebrush *(Juniperus occidentalis/Artemisia* spp.), pine *(Pinus ponderosa)* and water.

The first run classification using these training classes was very poor due to a programming error. Subsequent classification produced more promising results. Accuracy of classification of the water and

Table 24: Performance of Training Sets Transferred from Big Summit Prairie to Prineville Reservoir Area.

Big Summit Prairie Training Sets	Occurrence[1] at Prineville Reservoir	Prineville Reservoir Classes[2]
Water	+	Water
Low Sagebrush Scabland	+	Low Sagebrush Scabland
Pine	+	Juniper-Sagebrush
Mixed Conifer	-	Pine
Big Sagebrush	-	
Forbs	-	
Moist Meadows	-	
Riparian	-	
Lava	-	
Rock	-	

---

[1] + = did occur; - = did not occur.

[2] This column indicates into which Big Summit Prairie class the Prineville Reservoir area classes were placed.

pine was highly reliable but juniper/sagebrush and low sagebrush scablands were confused with no consistent misclassifications. The latter classes are areas of very sparse vegetation in which the exposed soils contribute an overwhelming amount of reflectance to the image's spectral signature. therefore, since the soils are of very nearly the same color, these two classes overlap, which accounts for classification errors.

Conclusion

Vegetation types can apparently be separated and identified at levels of greater detail and complexity by computer analysis of ERTS digital (MSS) data than by visual interpretation of ERTS imagery. Lending support to this conclusion is the need we found to use ~1:30,000 high resolution aerial photography in order to select and locate training sets in the digital data. We feel that with more experience using the computer classification system, selection of appropriate dates of data, and further development of techniques for training set selection, more specificity in plant community identification can be attained.

H. Computer Classification of ERTS Data for Soil Association Mapping

Where correlation between distribution of soils and vegetation is very good, distinctive plant communities can be used as indicators of particular groups of soils. Where adjacent plant communities are strongly, contrasting and exhibit sharp boudaries, ERTS digital data can approach its theoretical resolution potential. All three of these conditions are met in that portion of the Ochoco National Forest which occurs in northeastern Crook County, Oregon.

The top section of Figure 27 shows a 50 square kilometer portion of the Big Summit Prairie test area (black and white reproduction of NASA Flight 72-114 CIR). Light areas are sagebrush "scabland", with shallow and very shallow, stony and very stony soils. Stippled dark areas are forests of pine and mixed conifers, which grow on moderately deep and deep, loamy soils. The smooth, dark area in the upper left-hand corner is a moist meadow, with poorly drained soils. The lower half of Figure 27 is a comparable portion from a computer classification of MSS digital data, for vegetation in the Big Summit Prairie area (III-G). Pine and mixed conifer symbols have been darkened. The letter "M" represents wet meadow. Other symbols depict various kinds of sagebrush, forbs and bare ground.

Except for vertical compression introduced by the print-out format, agreement between these two images is quite good. Where scan lines run parallel to vegetation boundaries, delineations only a single element wide are resolved. Where scan lines cut across vegetation boundaries, marginal error seldom exceeds two elements in width. Comparison of delineated areas, measured by the grid counting method revealed that the average discrepancy in class area was only 11 percent, between the two images.

This example illustrates that under optimum conditions computer classification of ERTS digital data can be used to delineate and measure soil associations at scales as large as 1/25,000. Similarly favorable soil-vegetation correlations are estimated to exist in approximately 3.7 percent of Oregon.

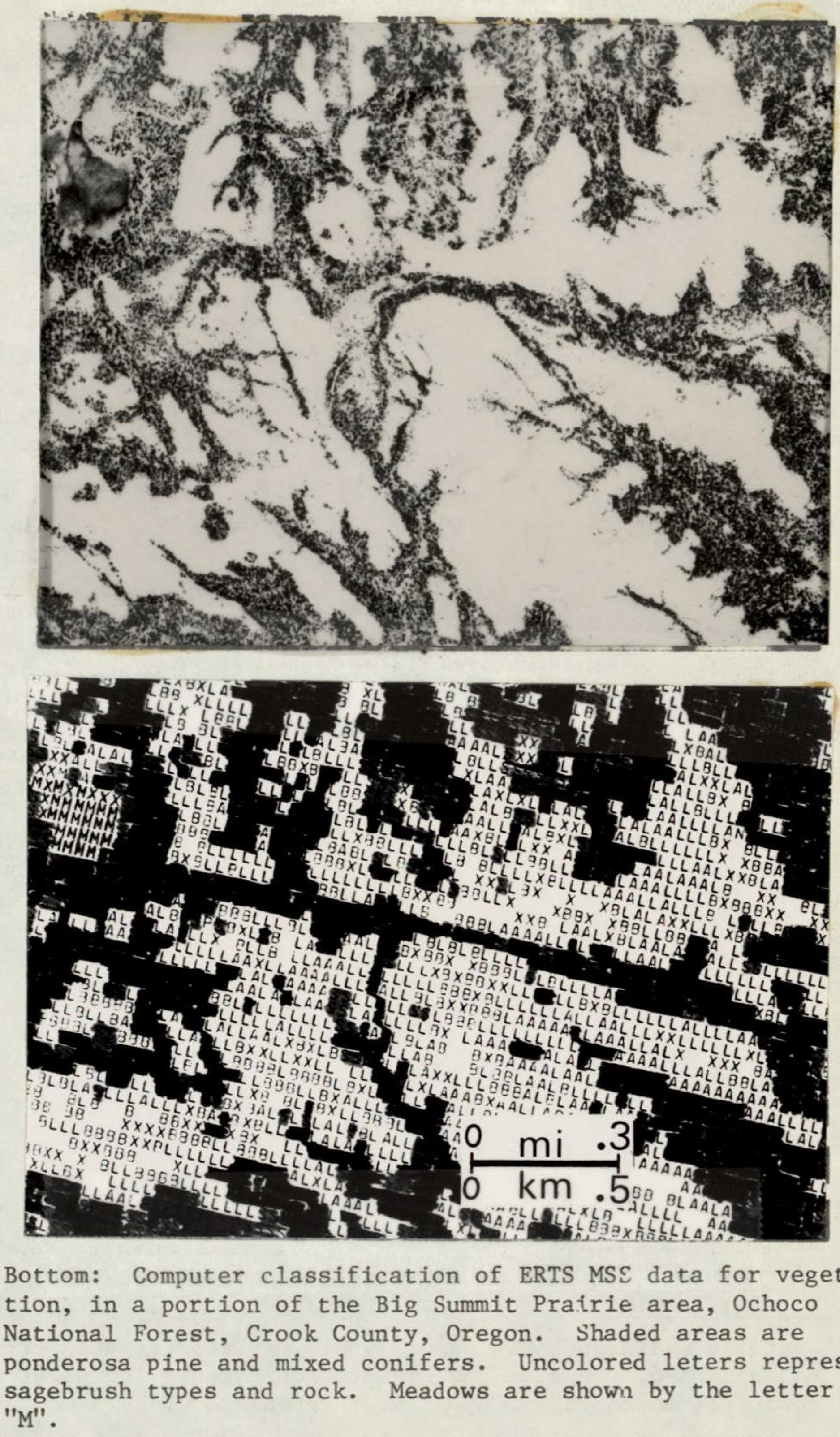

Figure 27. Bottom: Computer classification of ERTS MSS data for vegetation, in a portion of the Big Summit Prairie area, Ochoco National Forest, Crook County, Oregon. Shaded areas are ponderosa pine and mixed conifers. Uncolored leters represent sagebrush types and rock. Meadows are shown by the letter "M".

Top: The same area depicted on NASA Flight 72-114, CIR. Distribution of vegetation and soil associations correlates very well here. This computer vegetation map can thus be used to make a soil association map, at a scale which approaches 1:25,000, by defining the soils which occur under each vegetation type.

I. Regional Soil Colors Recorded on ERTS Imagery of the Columbia Basin, Oregon

Direct observation of soil colors on remotely sensed imagery is commonly confounded by vegetation or a wide range of agricultural practices. Regional variation in soil color is thus not readily demonstrated using aerial photography. Widespread use of a wheat-fallow rotation in the Columbia Basin of Oregon and Washington offers a striking exception to this general condition. Agricultural practices and soil parent material are nearly uniform across a transect receiving average annual precipitation ranging from 9 to 18 inches. North and east of Pendleton, Oregon, topography is sufficiently gentle that shadows do not complicate image interpretation. Pronounced seasonal rainfall distribution insures that soils are uniformaly dry in early fall.

Figure 28 is a portion of ERTS frame 1075-18150-5, 6 October 1972, showing a 30 mile east-west transect across this area. The light rectangles are stubble fields of wheat already harvested. Gray rectangles are bare fallow fields. Darkening of the gray tones toward the east (right side of the figure) corresponds generally with soil colors described from the area, and quite closely with content of organic matter in the plow layer. Color of surface soil in this area is influenced primarily by content of organic matter. The linedrawing above this ERTS excerpt is a slightly generalized version of a soil association map for the same area (1). Soil name, dry surface color, and organic matter content of a representative surface soil are given for each delineation (2).

Under favorable conditions, ERTS imagery can show regional changes in soil color and, by inference, soil organic matter content as well. Data of this sort are valuable for resource evaluation of remote areas.

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[1] Umatilla drainage basin general soil map report, with irrigable areas. Appendix 1-6, Oregon's long-range requirements for water. State Water Resources Board 1969. By J. A. Norgren and G. H. Simonson.

[2] Soil survey of the Umatilla area, Oregon. U. S. Department of Agriculture, Series 1937, No. 21, 1948. By W. G. Harper

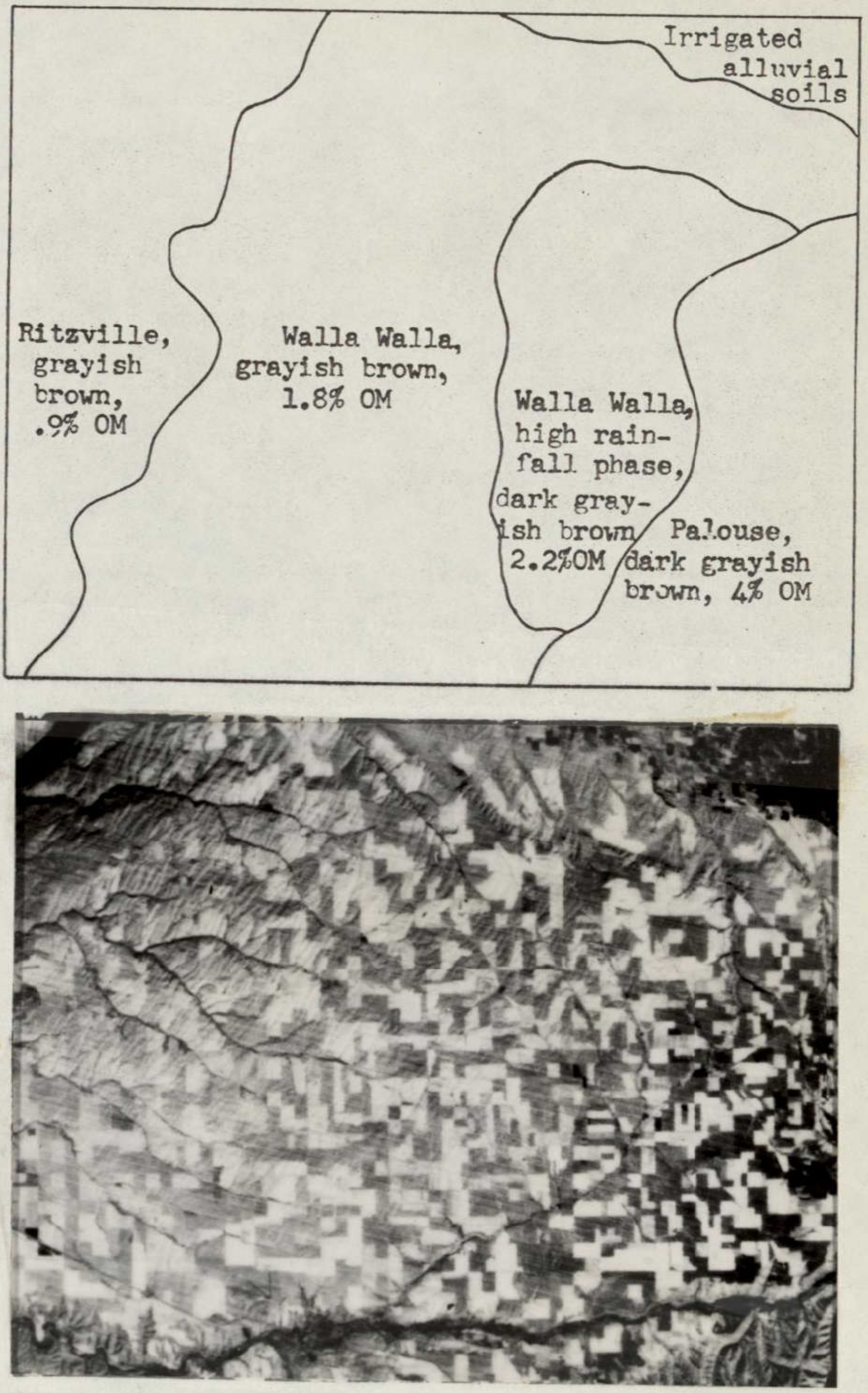

Figure 28. Bottom: An excerpt from ERTS 1075-18150, band 5, which shows a 48 km east-west transect across the gently rolling, wheat-fallow region of the Columbia Basin, just north and east of Pendleton, Oregon. Light rectangles are wheat stubble. Gray tones represent fallow fields. Darkening of gray tones toward the right corresponds to the known trend in surface soil colors and organic matter content.
Top: Generalized portion of a soil association map for the same area, showing soil name, dry surface color and representative organic matter contents for each delineation.

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IV. COMPARATIVE EVALUATIONS

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IV COMPARATIVE EVALUATIONS

A. Comparison of ERTS-1 Imagery and NASA Highflight Photography

Throughout the duration of this research project, several forms of imagery have been used as data sources. These include ERTS-1 imagery in both 70mm and 9" x 9" format, individual panchromatic scenes and various color enhanced scenes; and NASA U-2 highflight imagery, scale 1/120,000 and 1/30,000 color infrared and 1/4,000,000 Vinten package imagery. Although there might be a tendency to compare "apples and oranges" in comparing space and highfligh imagery, it is fully realized that these two types of imagery are not designed to replace each other, but rather complement one another. However, some comparative analysis has been made and the results are provided below.

1. Scale versus detectable detail

As was fully and logically expected, review of the ERTS-1 imagery reflects the fact that smaller scales of imagery contain lesser amounts of detectable and identifiable finite detail. However, it is also noted that smaller scale imagery, such as ERTS-1, contains broadbased detail which has gone undetected and not identified in the past. Therefore, the question of which imagery is "best" depends to a large extent on the subject matter of study. This becomes a management decision which must be based on the results of research conducted in relation to each individual subject matter.

Analysis can be made, however, of the use of different scales of imagery from the same source. ERTS-1 imagery used in this research consisted primarily of two scales; 1:1,000,000 and 1:250,000.

Vegetative type mapping of the southwest portion of Crook County at a scale of 1:250,000 on a black and white print of band 5 proportionately increased the detail of the type lines along the "edge" of a type as compared to a similay 1:1,000,000 imagery. Types too small or intricate to be delineated at the previous scale could not be indicated as separate types. As previously complexed, on a scale of 1:1,000,000 few of the areas could be further simplified because of the low contrast differences between the intricately associated types. The greatest advantage of the increased scale was the increased accuracy of delineations.

The mapping of soil-landscapes required a combination of interpretations of visible boundaries from ERTS imagery, delineation of like soil areas through tonal patterns, and indirect inferences from land forms and vegetative indicators. Identity of soil profile types and characteristics of component soils in each defined soil-landscape unit was based on field descriptions and observations, and an existing general soil map for the area. Mapping at a scale of 1:250,000 allowed somewhat greater separation of smaller areas and recognition of a few additional sub--units, based on soil patterns and topographic differences.

In mapping of bedrock geology on both scales of ERTS imagery, the boundaries of identifiable units were drawn utilizing image difference as a major criterion for delineation. Units were identified largely on the basis of information available on existing geologic maps.

In a number of instances on both scales, serious questions were raised on the accuracy of delineation and identification of a unit drawn on the geologic map. In such instances attempts were made to overcome the potential inaccuracies. It was felt, therefore, that the ERTS imagery allowed the interpreter to question the validity of prior geologic mapping.

The units chosen to categorize the bedrock geology of the county, as mapped on the imagery, represent compromise among units described on the geologic maps. In most cases they represent an amalgamation of similar specific units into broader groupings. It was felt necessary to group together bedrock units that were indistinguishable on the ERTS imagery. The extensive John Day and Clarno formations were combined on the 1:1,000,000 imagery. From the standpoint of their effects on land use and their relative interpretability on the imagery, it was felt that their being considered together was a logical decision.

Macrorelief classes were mapped at both scales, primarily from ERTS image interpretation, without field checking. One of the purposes of the mapping exercise was to determine the facility with which skilled photo interpreters could interpret macrorelief without ground truth assistance. The ultimate purpose of macrorelief mapping is to give users, county planners, resource managers, and environmental investigators an accurate appraisal of a region's topographic texture.

For the purpose of forest density class delineation, scale was not a limiting factor. As with the vegtative type mapping, the larger scale imagery provided smaller minimum area delineation, however, density class mapping was completed on 1:1,000,000 scale color enhanced imagery.

2. Information per frame

ERTS-1 Imagery. One of the pleasant surprises resulting from ERTS-1 imagery has been the amount of information which is contained in each frame. Oregon is fortunate in that its geographical location has resulted in much of the state being covered by stereo imagery resulting from the sidelap of each succeeding orbit. Where stereo coverage has not been complete, the use of two images of the same scene, approximately six months apart, has produced a "false" stereo resulting from the shadow differences. This has proved very successful in the mapping of topographic features.

The major advantage of the ERTS-1 imagery is, of course, the large area represented by each frame. This has allowed, for the first time, continuity of large area structures to be identified and delineated. Although the most striking examples of this are seen in the field of geology, in both the studies of lineaments and faults, and general structural geology, this continuity is also seen in the study of vegetative mapping. Although the "big picture" aspect of ERTS-1 imagery has been deservingly publicized, it is also important to note the level of small finite detail involved in the continuity research results.

Extensive use of color enhanced multiband ERTS-1 imagery has been made by all disciplines involved in the current research program and this imagery is generally classed as far superior to the single band, panchromatic imagery. We have used color enhanced imagery from our own color enhancer, from NASA and commercial firms and from our diazo film processing. This latter process has proven to be highly successful, in both time and expense involved. Whatever the source, the use of both multiband and multiseasonal color composites greatly increase the interpretation of the data available on the ERTS-1 imagery. This has been especially true for interpretation of the forested lands, where on the single band images (particularly MSS-band 5), the dark images prevent successful interpretation.

Highflight imagery. The amount of data present on the two major highflight formats, 1/120,000 and 1/30,000 scales, was found to be dependent upon the area in question. The major problems experienced in the use of this data were the results of the quality of imagery received and are discussed in a subsequent section. In general, the amount of data presented from these sources were as to be expected, and sufficient evaluation of this type of data can be found in the present literature.

B. Analysis of Image Quality

1. ERTS-1 Imagery

Oregon contains a large amount of forested lands and because of its economic dependence on forest products, applications of ERTS-Type imagery to forest management is an area of major concern to many local agencies. In reviewing the numerous ERTS-1 imagery received during the duration of this research, one major fault has been experienced throughout this time frame. It appears that the imagery received is processed for maximum tonal delineation of the range and agricultural lands which are primarily represented by the midrange grey scale tones. The forested lands, imaged in the darker grey scale tones are reproduced with a resulting lack of tonal separation sufficient for fully utilizing the information content of the image frame. (Examples: ERTS- Frame E-1676-18211-5 and E-1040-18210-5.)

Since the primary objective of the ERTS-1 satellite is basic research in applications, this lack of balanced grey scale has reduced the successful evaluation of the potential use of ERTS in forestry applications. This shortcoming has been overcome to a great extent by the use of multispectral, color-enhanced images, but when the results of single band image interpretation are being reviewed for range and agricultural land uses, a question arises about the potential use for forestry that is being lost in the processing of the imagery.

Four different forms of multispectral color-enhanced imagery have been used in this research project. These four forms are NASA produced, General Electric produced, in-house optical color-enhanced and diazo-film sandwiches. While all of these forms have proven satisfactory, the diazo-film form has proven the most successful for several reasons. In addition to the obvious factors of expense and time of production, four major advantages of the diazo film sandwiches are: (1) Gives a quick-look capability of examining recently acquired imagery to aid in deciding if more intensive evaluation is needed; (2) Gives the investigators the capability of giving special emphasis to desired bands to emphasize features of particular interest simply by varying exposure time or multi-layering of the diazo film from the band of interest; (3) Makes possible the comparison of multidate imagery in color to give maximum information on seasonal variations to aid in deciding upon further evaluations and comparisons as well as additional products required; and (4) Enables investigators to make quicklook evaluations of change, either seasonal or cultural, on multidata imagery by the technique of negative masking.

2. NASA-Ames highflight imagery

Review of two NASA highflights of the Oregon area, Mission No. 72-114 flown for Oregon State University and No. 73-119 flown for the USGS, both at 1/120,000 photo scale, show that serious quality control problems exist in the production of this scale imagery. The imagery from Mission No. 72-114 shows severe lack of detail in shadowed areas of each frame. Although lack of shadow detail is a common problem in the use of color

IR imagery, the severity of this problem in the two missions listed above has resulted from two sources which can be corrected in future missions. The imagery from Mission No. 72-114 has been underdeveloped resulting in darkness throughout the frame and lack of color balance. The imagery from Mission No. 73-110 shows severe vignetting of each frame which results from either using a panchromatic camera with color film or underexposure of the film in a proper camera. In both missions described above, proper quality control can correct the problem sources and provide imagery which can be used to its fullest potential.

The 1/30,000 scale, 9 x 18 inch format color IR imagery taken during Mission No. 72-134 (HR732) is an excellent example of color IR imagery which can be fully utilized. This imagery has been successfully used for species identification, insect damage location, and accurate measurement of photo inventory characteristics of the forest lands in the test area. Imagery of this quality even at the 1:120,000 scale can provide a successful intermediate step between ERTS-1 imagery and actual on-the-ground measurements, essential to the success of the ERTS program for any form of multistage sampling procedure.

One other form of NASA highflight data that has been analyzed was the Vinten color IR imagery, approximate scale 1/440,000. The use and evaluation of this imagery has been detailed in Section III-A-1 of this report and need not be further reviewed.

C. Soil-Landscape and Land Resource Mapping on ERTS Imagery

Introduction

The wide range of climatic, geological and botanical conditons present within its boundaries, makes Crook County, Oregon a more favorable site to test the potential of ERTS-1 imagery for mapping soil resources than some of the more uniform areas in which similar studies have been made. Precipitation ranges from 20 cm to 60 cm, generally varying with elevation. Vegetation varies from sparse shrub-steppe at lower elevations; through dense, mixed shrubs; shrub-juniper; and open ponderosa pine; to dense, mixed coniferous forests at higher elevations. Geologic diversity includes unconsolidated deposits of recent alluvium and volcanic ash; weathered, clayey tuffaceous deposits; a variety of hard volcanic flows; and intensely folded, deeply dissected older rocks.

Agriculture is concentrated at the western end of Crook County. Tonal variations visible on ERTS imagery for most of the county are thus due to natural conditions, and might logically be expected to correlate with variation in soils, vegetation or geology. Where vegetation is very sparse, reflectance of soils and rocks is recorded directly on ERTS imagery. Examples of this sort are ephemeral lake beds, alkaline alluvium and scattered areas of badland topography; all of which occur in southeastern Crook County and exhibit high reflectivity.

Throughout most of the county, kinds of soils must be inferred from a combination of vegetation and topography. The most widespread contrast afforded by vegetation is that between coniferous forests (dark) and the much lighter sagebrush species, which are adjacent and at somewhat lower elevations. Soil associations occurring within these contrasting types of vegetation are consistently different and can be reliably delineated on ERTS-1 imagery, provided that the pattern is coarser than its resolution capability (Section III-I).

Soil differences within each of these major vegetation types can also be distinguished, but with greater effort and less reliability. For instance, ponderosa pine stands occur on groups of soils distinct from those supporting larch, firs and Douglas fir. Separation of these vegetation types, however, is complicated by topographic variables. Shadowed north slopes supporting ponderosa pine can be mistaken, both visually and by computer, for mixed conifers (Section III-F).

Patterns resulting from topography are as important as tonal differences due to vegetation change for indicating a particular soil-landscape. Since shadows tend to emphasize topographic features, relatively low sun elevation offers an advantage for image interpretation with respect to soils. Late dry season imagery was therfore considered optimum for showing soil landscapes in Crook County. Early dry season, i.e. high sun elevation, imagery was considered best for interpretation of vegetation (Section IV-E).

Effect of Scale and Kind of Imagery on Map and Legend Complexity

In this comparison of highflight photography versus ERTS imagery for resource inventory purposes, the objective was not to achieve maximum cartographic detail, but to convey the pertinent resource characteristics of the area under consideration to potential users in an easily understood form. With respect to types and scales of imagery utilized, the aim was to make the best use of contrasts visible on each of them for delineating natural resource features. The resulting cartographic detail is determined mainly by contrasts in color, tone and pattern visible at a given scale. The relationship between legend complexity and map detail is summarized in Figure 29. Number of delineations increases proportionately to the numerical value of the scale. Number of described units increases more slowly, so that each mapping unit is repeated many more times on larger scale versions than on those of smaller scale. In other words, the larger scale maps appear relatively more detailed than their respective legends imply.

Effect of Scale and Kind of Imagery on Accuracy of Area Measurement

A strict comparison of relative accuracy among the soil-landscape maps produced at all three scales is not feasible because definition of some units was allowed to change as visible resolution increased. However, one estimate of agreement between the more detailed and more generalized maps can be obtained by comparing the respective areas of analagous mapping units at the three scales used (Figure 30). Average discrepancy in areas measured for similar units between the 1/120,000 scale airphoto version and the 1/250,000 ERTS version is 7 percent. Where the difference in scale is greater, the disagreement in measured area is also larger. Units mapped at a scale of 1/1,000,000 on ERTS imagery differ by an average of 21% from corresponding units mapped on highflight airphotos at a scale of 1/120,000. Comparable average discrepancy between the larger and smaller scale versions on ERTS imagery was about 12% and 18% for the land resource unit and soil-landscape maps respectively.

Doubling the scale at which a resource inventory map is made does not have a proportionate affect on its accuracy in terms of area measurement. Conversely, reducing the map scale by a factor of two may only result in a ten percent change in acreage measurements.

Aerial Photography

The much finer resolution of the highflight photography permits more accurate placement of boundaries than does the ERTS imagery. Such a high degree of accuracy is probably not necessary for resource inventory purposes. In fact, this high a degree of precision is fruitless to attempt except for maps printed on a precise, planimetric base. Such is not generally the case with maps of this sort.

A disadvantage presented by the detail visible on highflight photography is that users of general maps made on such photographs may be tempted to apply them to on-the-ground resource management. Such missapplication could only lead to frustration, and eventual disillusion.

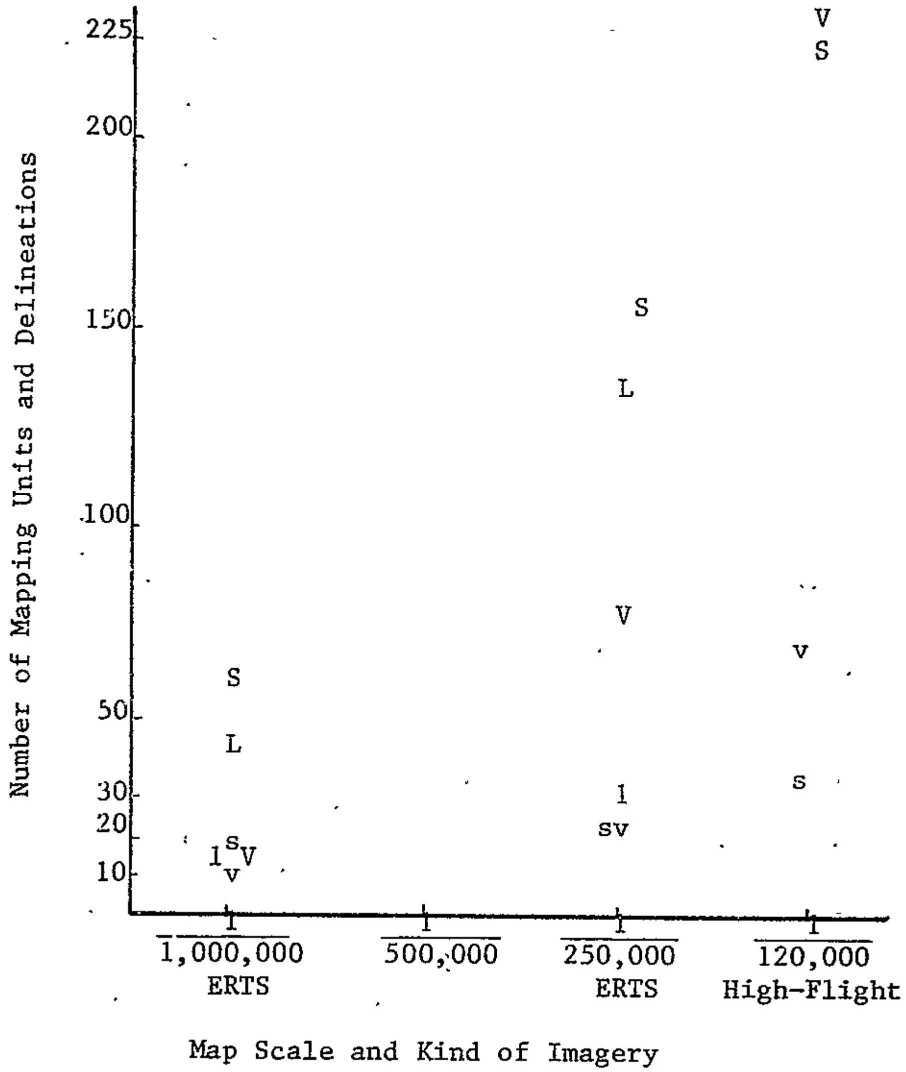

Figure 29: Graph showing relationships between the nature and scale of imagery versus number of mapping units (v, s and 1) and delineations (V, S, and L) for vegetation, soil-landscape and land resource maps, respectively of Crook County, Oregon.

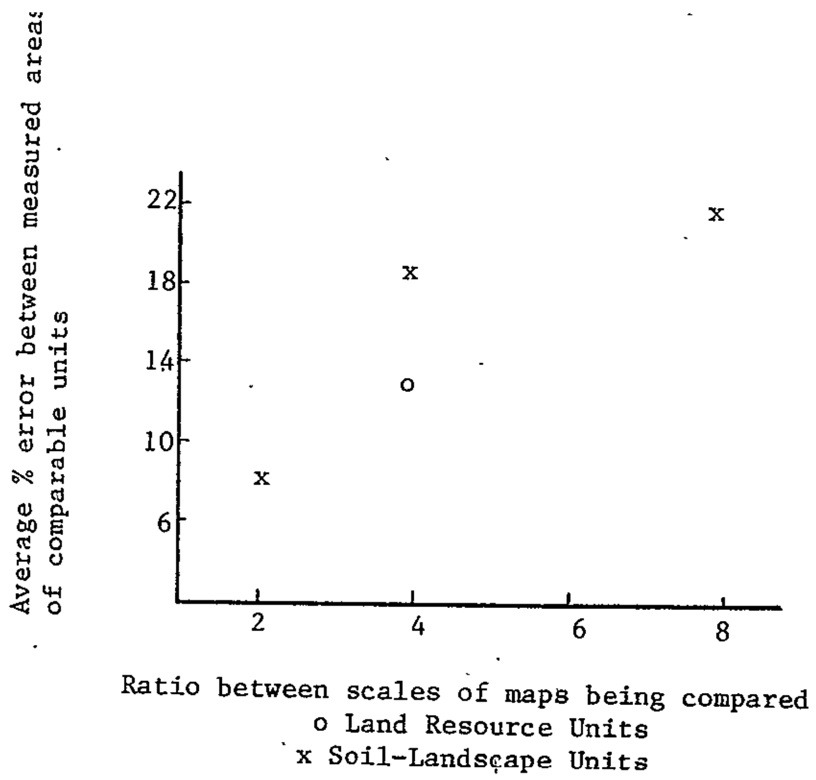

Figure 30: Average percent error in measured area of comparable units depicted on soil-landscape maps and land resource unit maps made at scales of 1:120,000 (NASA hi-flight photography), and on ERTS-1 imagery at scales of 1:1,000,000 and 1:250,000.

The limited resolution of ERTS imagery has an advantage for presenting land resource information because it encourages a broad perspective.

Conclusion

For the conditions present in Crook County, ERTS imagery is well suited to determining the size and distribution of natural resource areas. It is even better suited as a means of graphically portraying the distribution of these areas. The wide range of choices offered by multi-band and multi-data options much more than compensates for the limited resolution of ERTS imagery. Maximum contrast between types of resource areas can be obtained by careful selection of imagery date and band combinations. For Crook County conditions, late summer or eary fall, 4, 5, 7 band color resonstitutions provided the best discrimination between the widest variety of land resource units. Red-band imagery of similar date was next in order of preference. Considering differences in printing expense, the red-band black and white prints are perhaps the most economical map base for publication. Individual 6 and 7 band imagery was superior for distingishing different kinds of topography, but minimized effects of vegetation too much to be valuable over the whole county. In areas where vegetation is not an important component of local resources relative to topography, the near-infrared bands may well provide the best means of both discrimination and presentation. Green-band imagery was far less discriminating of natural resource features than the other three bands, in Crook County.

D. Color Reconstitutions of ERTS for Interpretation and Identification of Vegetation/land Use

Early on, with receipt of the first black and white ERTS imagery, we felt color was much more suitable for our purposes. This feeling was confirmed when the first color reconstitutions arrived from NASA-Goddard. However, delivery was slow and uncertain. We investigated other sources, but the quality didn't match the NASA product and delivery time wasn't much better.

Through contact with the General Electric Company, we did have the opportunity to evaluate different band combinations for identifying various vegetation/land use subjects. This was helpful, because then we heard about diazo. We checked into the diazo process and found it promising in relation to time, material cost, and quality. ERSAL was fortunate to purchase an Ozalid machine at reasonable cost and train an excellent technician.

Multispectral Band Combinations

Working through the color laboratory at General Electric, we had the following three color reconstitutions made of frame 1076-18211 (by a dye transfer process producing color separation negatives): bands 4, 5, 7; 4, 5, 6; and a band 4, 5, 7, with band 7 at half power. We did the half power band 7 experiment because of having noticed the very high intensity saturation of red color in most of the standard 4, 5, 7 band reconstitutions made by NASA. We tried the bands 4, 5, 6 reconstitution because of a feeling that use of the infrared band that fell across the rapid change area in the infrared response curve may contain unique kinds of information lost in or less evident from, the band 7 reconstitution.

As compared to the 4, 5, 7 full power reconstitution, the half power on band 7 almost completely loses recognition of the juniper woodland areas, gives a strong bluish cast to the juniper types and to the sagebrush steppe. It strongly enhances the agricultural areas by contrast with the surrounding rangland, where agricultural crops are either still green from irrigation, fields plowed or burned, or fields harvested and covered by cereal, grass, or hay stubble with little bare soil surface showing through.

Some native meadow and hay areas seem to be enhanced with a more vivid pink by the half power band 7 treatment. The demarcation between ponderosa pine and mixed forest communities with the surrounding juniper woodland and sagebrush steppe is very strongly enhanced by the half power band 7 treatment. Because of the strong blue hues, the feeling of relief may be enhanced by the half power band 7 treatment. This may be a disadvantage for vegetational interpretation on northwesterly facing slopes because of sun angle in relation to these slopes. They appear darker blue to purple in the half power band 7 treatment than in the full power band 7. Because the red saturation is reduced in half power band 7 treatment, it appears that the hardwood-conifer contrast may be enhanced in this treatment.

Because of the darker blues in the half power band 7 treatment, it may be that differences in rock type show less well than on the full power color reconstitution of bands 4, 5, and 7.

The half power band 7 treatment doesn't seem sensitive to picking up initial growth stages on grass vegetation in the steppe region or in the agricultural crop area where one would expect initiation of growth in winter wheat, for example.

Similarly, the full power bands 4, 5, 7 treatment seems to be only fair for detecting the initial flush of green growth on winter annual grasses and cereal grains. There is too much similarity between the pink tones of the juniper and the pink from the initial flush of herbaceous vegetation growth.

With bands 4, 5, 6, however, it appears that greater sensitivity may be achieved for detecting the initial flush of growth on winter annuals. Still, however, the differentiation between juniper types and greening annuals is difficult.

It also appears on the 4, 5, 6 reconstitution that the juniper types are less easy to delineate than on the full power 4, 5, 7. Juniper delineation is difficult but reasonably possible on full power 4, 5, 7. It is impossible on the half power 7, and very difficult except where juniper stand density is very high, on 4, 5, 6.

Bands 4, 5, 6 seem to give better contrast on many agricultural crops than does 4, 5, 7. Fallow or burned fields show equally well on 4, 5, 6 as 4, 5, 7, full power, but not quite as contrasty as on the half power 7 treatment. The ecotone between the conifer forest types and the sagebrush steepe and juniper is most strongly enhanced by the 4, 5, 6 combination, but it appears more difficult to differentiate the moderately dense ponderosa pine from the very dense mixed conifer stands with the 4, 5, 6 treatment.

It is difficult to say which of the two full power treatments, 4, 5, 7, and 4, 5, 6, is best for differentiation among the shrub-steppe types. Our present judgment favors the 4, 5, 7 full power treatment. The contrast between dry grasslands and shrub-steppe vegetation may be enhanced, however, by the 4, 5, 6 treatment and they are very strongly enhanced by the 4, 5, 7 half power treatment. For example, the contrast between dry grass meadows with the vegetation matured and surrounding sagebrush steppe is very vividly portrayed by the 4, 5, 7 half power treatment.

Diazo Process

ERSAL's Ozalid machine and the services of their technician were available for our use. By using Diazo projection film in yellow, magenta, and cyan on MSS band 4, 5, and 7 respectively, we have been able to produce false color infrared reconstitutions in 70 mm and 9" x 9" formats.

We have done considerable mapping on these products and find them of good to excellent quality for photo interpretation and delineation at these scales. Some of the most interpretable color reconstitutions that we have are Diazo. There are several advantages of these inexpensive and quickly produced reconstitutions:

(1) Gives a quicklook capability of examining recently acquired imagery to aid in deciding if more intensive evaluation is needed;

(2) Gives the investigators the capability of giving special emphasis to desired bands to emphasize features of particular interest simply by varying exposure time or multi-layering of the Diazo film from the band of interest;

(3) Makes possible the comparison of multi-date imagery in color to give maximum information on seasonal variations to aid in deciding upon further evaluations and comparisons as well as additional products required; and

(4) Enables investigators to make quick-look evaluations of change, either seasonal or cultural, on multi-date imagery by the technique of negative masking.

Problems encountered with the Diazo process of producing reconstitution products have been minimal. The variables which were most troublesome were the varying density of the positives for each band and obtaining accurate registration when "sandwiching" the various bands into a final product. Both of these problems were minimized by the technician becoming familiar with the machine's capability and operation and maintaining accurate records of exposure times and relative densities of the film.

To date, 70 mm color products have been made of several frames for use as lantern slides. Greatest emphasis has been placed on producing 9" x 9" color reconstitutions at a scale of approximately 1:1,000,000 of suitable quality for photo interpretation and mapping of resources. Color enlargements of the Diazo products have proven satisfactory also.

This process gives us a wide latitude for experimentation in attempting to produce images which will emphasize specific resource features. One such attempt has been the addition of band 6 exposed with black film to give emphasis to old growth forest and clear cuts.

Conclusions

Our experience to date has been that bands 4, 5, 7 give the color reconstitution most suitable for general vegetation mapping. Our results suggest, however, that band 6 should be retained in the system of color reconstitutions for specific interpretive purposes. Also the capability for manipulating the intensity of a particular band *(a la GE)* appears valuable in special problems.

Visual comparison of Diazo products with similar products from NASA and several commercial sources indicate that the resolution may be slightly degraded with Diazo. However, we rate our Diazo as only slightly inferior, if not equal to the NASA products. The concensus of the local users is that the advantages of quick (45 minutes to an hour) and inexpensive reproduction outweight whatever degradation of resolution there is. In this way, we can have the added information of the color product available virtually as soon as we receive the ERTS black and white positive transparencies.

E. Multidate, Multiband Comparison of ERTS for Vegetation/land Use Mapping

The first objective here for Crook County was to delineate, interpret, and compare the workable mapping intensities and accuracy of ERTS to the highflight mosaic and ground truth. Since we used the mosaic as the representation off ground truth, we made all comparisons with mapping on the highflight mosaic.

In addition, we wanted to check image identification repeatability, especially over time (multidate). Some aspects of change detection are implicitly included here, although this subject is covered in another section of the report.

Approach

Selection of scene dates and spectral bands. The scenes used in mapping the vegetational resources were selected to represent the seasonal differences of most vigorous growth (spring) vs. mature and dormant vegetation (summer or fall). Selection was based on a quick look analysis of all available imagery affording complete coverage of the test site county. Diazo color reconstitutions (bands 4, 5, 7) were made of all scenes free of obscurances such as clouds, snow or smog, and were of good resolution, showing sharp differences in contrasting image subjects. To obtain the greatest seasonal differences desired, the spring coverage of 11 May 1973 was used because of its overall red appearance indicating maximum vegetation growth. 4 July 1973 was selected for dry season coverage because of the lack of red color in the areas where the herbaceous vegetation was predominant and should have been matured and have minimal green foliage.

MSS bands 4, 5, and 7 were selected for evaluation as single bands in black and white. MSS band 6 was not used because of its great similarity to band 7.

Mapping. Mapping (1:1,000,000) on the ERTS imagery was done on black and white transparencies for the single bands and Diazo color transparencies for the false color infrared. For complete coverage of the test site (Crook County), it required one scene adjacent to the south in the same flight path and two adjacent scenes in the flight paths adjacent to the east (Table 25). All mapping possible was done using a mirror stereoscope to take advantage of the stereo coverage afforded by the ~40 percent side lap of the adjacent flight paths' scenes.

The same mapping guidelines as were used in the highflight mapping were applied. The legend used was the same as used in the highflight mapping (Appendix R-1) because of its hierarchical arrangement allowing the user to apply higher legend levels to achieve the generalization required by the ERTS scale, but remain compatible with the highflight mapping for comparative purposes.

Having completed the highflight mapping and generalized it to the ERTS scale, the photo interpreter was sufficiently familiar with the

Table 25: ERTS Imagery Used for Multiband, Multidate Comparisons[1]

Scene Name	Number	Date
Ochoco	1292-18220	11 May 1973
Fort Rock	1292-18222	11 May 1973
John Day	1309-18160	28 May 1973[2]
Wagontire	1309-18163	28 May 1973
Ochoco	1346-18212	4 July 1973
Fort Rock	1346-18215	4 July 1973
John Day	1345-18154	3 July 1973
Wagontire	1345-18160	3 July 1973

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[1] Single bands 4, 5, 7 and diazo color reconstitutions, 4, 5, and 7 were used for each scene.

[2] For these two scenes, John Day and Wagontire, this was the date nearest to 11 May which was clear and gave full coverage of Crook County.

image-subject relations and locations in the test site that mapping on ERTS products was a matter of being able to detect the type boundaries of those subjects meeting the mapping criteria. If a subject was not contrasting enough to be delineated, the subject area in which it was included was generalized to a higher hierarchical legend level or complexed as appropriate.

In mapping on the ERTS images, if an image-subject could be delineated, i.e., a contrast difference detected, it was identified. Identifications were based on familiarity with the previous mapping rather than on any imagesubject relationship. Repeatability of identifying image subjects is indicated if that image-subject is delineated. The degree of identifiability of an image-subject is indicated by the coincidence of the type lines and degree of generalization or complexing within the delineation as compared to the ground truth standard.

Ground truth standard. Upon completion of the highflight mapping, the overlay was photographically reduced to the ERTS scales and generalized by complexing or combining and identifying that subject at a higher hierarchical legend level (Figure 31). Additionally, some contrasting image-subjects which were too small to meet our mapping criteria were delineated on the generalized map. This was done to determine if these particular contrasting image-sujects could be detected, although they were too small to map. Fourteen mapping units were identified as the standard (Table 26). This generalized photo reduction was used for comparing the ERTS mapping by overlaying the individual ERTS maps upon it.

Evaluations of comparisons. Eight criteria of evaluation (in reference to the standard) were used: (1) number of mapping units; (2) detectability of unit; (3) degree of "purity" of comparable mapped unit; (4) image contrast; (5) coincidence of type lines; (6) number of units identified correctly; (7) number of errors of commission; and (8) number of errors of omission. Numerical codes were established for each criterion to make the evaluations more straight forward (Table 27), and a score sheet was devised (Figures R-6, 8). The procedure used was as follows:

(1) Identify the imagery mapped on the score sheets.
(2) Determine the number of mapping units.
(3) Overlay the ERTS map and the standard map on a light table.
(4) For each standard mapping unit, determine whether there is a comparable unit mapped on the ERTS, its degree of purity, coincidence of type lines, and errors if any, using numerical codes.
(5) Overlay the ERTS scene transparency and the standard map on the light table.
(6) For each standard mappin unit, determine if it is detectable in the scene and the degree of contrast with adjacent images, using numerical codes.

Following the evaluation of all date/band combinations considered, the scores for each criterion (map characteristics) were summed over mapping units. Thus, a profile or vector of score sums was created to characterize each ERTS map (Table 28). Considering each ERTS map, as

Table 26: Map Units Identified on the Ground Truth Base.

Map Unit	Legend Unit (Appendix R-I)
1	519.2
2	341.1
3	341.3
* 4	341.6
5	341.3/325.1
* 6	510/315
7	325
8	325.2
* 9	433.1
*10	433
11	315/325
*12	325.1
13	341.71
14	212

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* Those units which appear on the generalized high flight map but not expected to be mapped at ERTS scales because of intricacies of type boundaries or size of units. They were delineated here to determine if they are detectable on ERTS imagery.

Table 27. Evaluation Standards for Comparing Vegetation/ Land Use Mapping on ERTS with the Ground Truth Base.

Number of Mapping Units

Tally of the number of mapping units on a map made from ERTS imagery.
0-14

Detectability of Mapping Units

Can standard mapping units be detected on ERTS imagery?
0 = No
1 = Yes

Purity of Mapped Type

The ERTS map is examined to determine whether mapped types comparable to the standard units were delineated and the degree of purity of such units is rated. For this evaluation, the standard units are considered to be pure.
0 = None: no comparable mapped type delineated.
1 = Complex: combination of two standard units or of generalizations of standard units.
2 = General: a legend unit at a more general level in the hierarchy which includes the standard unit, e. g., 341 contains 341.3.
3 = Pure: mapped type is the same as standard unit.

Image Contrast

On ERTS imagery, the contrast of areas bounded by typelines of standard units with adjacent areas.
0 = None: no contrast can be detected.
1 = Poor: differentiation very difficult.
2 = Fair: some study is required to separate adjacent types.
3 = Good: type differentiation is sharp and easily determined.

Type Line Coincidence

Matching of the ERTS mapping with the standard map. Type lines which form new complexes of standard units are not considered.
0 = None: no coincidence of type lines, usually where no comparable unit was mapped.
1 = Poor: variations greater than 1/8", comparable mapped type.
2 = Fair: variations generally less than 1/8" with few variations up to 3/16".
3 = Good: variations generally less than 1/16" with few variations up to 1/8".

Table 27
Continued

Errors

Errors of commission, omission, and the number of correctly identified mapping units are noted. Errors are identified in the following form:

Error/Unit
Error: 0 = Omission
C = Commission

Unit: If error = 0, the incorrect identification is noted.
If error = C, the correct identification is noted.

Table 28. Comparison of Vegetation/Land Use Mapping on ERTS (1:1,000,000) with Ground Truth Standard.

Score Sums Per Criterion

Criterion	Standard	July[1/] 4,5,7	July 5	May 4,5,7	July 4	May 5	July 7	May 7	May 4
No. Map Units	14	7	7	7	7	6	5	5	4
Detectable	14	14	14	14	14	14	12	12	13
Comp. Map Unit	42	26	25	22	24	22	20	21	18
Image Contrast	42	37	35	33	34	28	25	25	25
Coincidence	42	18	16	17	15	11	14	10	8
Correct	14	2	1	2	1	1	2	2	1
Com. Error	0	12	11	11	10	11	12	11	13
Om. Error	0	12	11	11	11	12	14	11	13
Distance[2/] from Standard		36.6	38.4	39.3	39.4	45.3	46.1	47.2	51.3

[1/] Month/MSS bands, 1973 ERTS-1 imagery, May = scene number 1292-18220, July = scene number 1346-18212.

[2/] Euclidean distance, considering each date/band combination as a point in map characteristic coordinate space.

well as the standard map, to be a point in map characteristic coordinate space defined by its vector of score sums, the Euclidean distance of each ERTS map from the standard map was calculated: $D_{js} = [\Sigma (S_i - X_i)^2]^{1/2}$. D_{js} is an expression of the difference between the jth ERTS map and the standard, S; S_i are the sums of the standard scores for the map characteristics, and X_i are the sums of scores for the map characteristics for the jth map, $i = 1, 2, \ldots, 8$. The vectors were then ordered according to increasing distance from the standard vector. Thus, the ERTS maps may be ranked according to similarity to the ground truth standard (increasing distance equivalent to decreasing similarity, Table 28).

Results and Discussion

Ranking of the maps indicates that the one made on the color composite of the 4 July 1973 ERTS scene was most similar to the ground truth standard. This map is presented in Figure 32, and its scores in Figure 33. For comparison, the least similar map, from the 11 May 1973 ERTS scene band 4, is presented in Figure 34, with its scores in Figure 35.

While the color reconstitution of the July scene apparently yields the best vegetation map for a single date of imagery, observations made during this investigation indicate that other date/band combinations have advantages for identifying particular features. For example, July/band 5 is optimum for separating agricultural areas from the natural vegetation, and July/band 7 is best for identifying water resources (Table 29).

Repeatability of image identification varies with the feature. Identification of some features was very consistent throughout the frame in the optimum date/band combination (phenologic and other directional, temporal changes contribute to the optimization of a date/band combination for a particular feature), e.g., water resources, forest, and agricultural areas. In the more sparsely vegetated areas, juniper and shrub-scrub types, difficulties arise, however. In Crook County, there is juniper on rolling basaltic uplands, giving a more or less uniformly dark signature. There is also juniper on lower lying, more level terrain, mantled in pumice and giving a lighter signature. The confounding thing is that there are sage-brush types which give signatures nearly identical to each of the juniper signatures. These were the areas we had to ground check to be sure of our identification.

Conclusions

We conclude that, in general, dry season (e.g., July) ERTS imagery is best for mapping vegetation/land use. Further, we conclude that color reconstitutions are much better than single bands (MSS) except for particular features such as water or water influenced features (band 7). The optimum date of dry season imagery will vary from year to year depending upon when drying of herbaceous vegetation commences. In 1973, it was earlier than in 1972, for example. The 27 July 1972 scene (1004-18210-4, 5, 7) of Crook County is very comparable to the 4 July 1973 scene.

Figure 31. Vegetation/Land Use Ground Truth Base. Generalized from highflight mapping at 1:120,000, presented on 1346-18212 at 1:1,000,000.

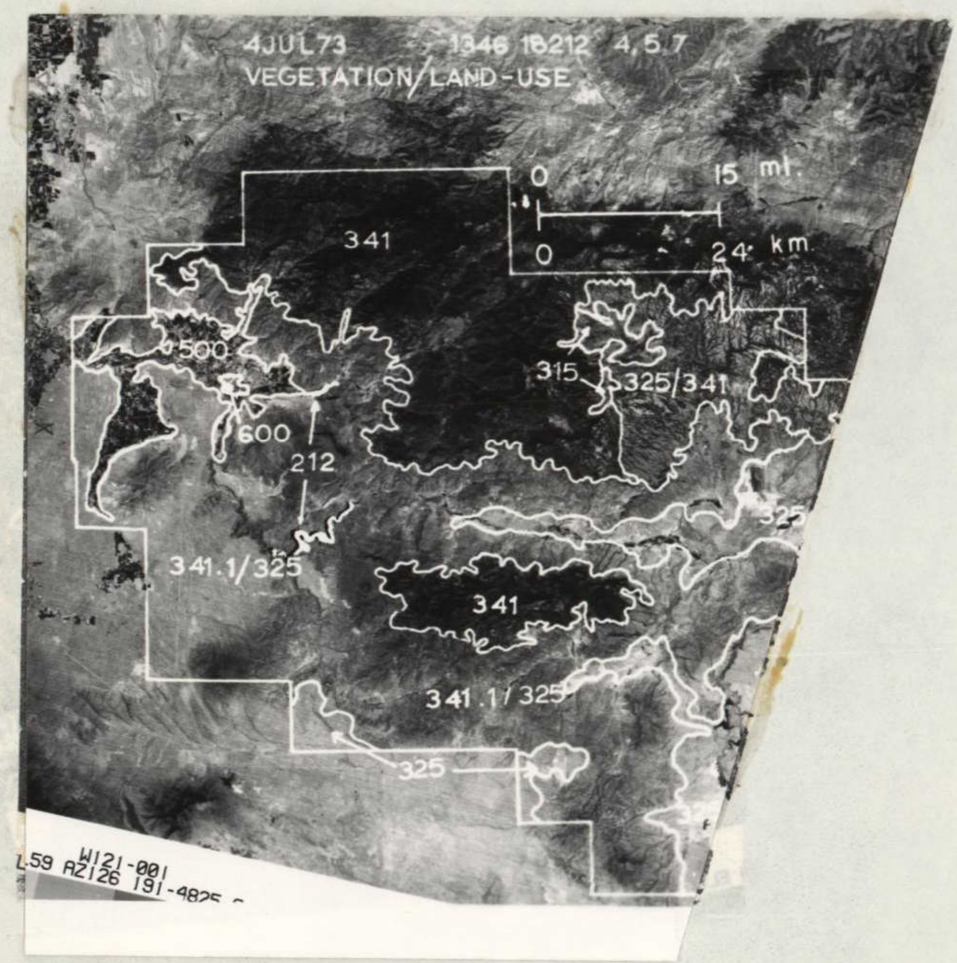

Figure 32: "Best" ERTS map. Made on 1346-18212-4, 5, 7 and presented on 1346-18212-5 at 1:1,000,000.

Standard	Detectable	Comparable Mapped Type	Image Contrast	Type Line Coincidence	Error/Unit	
1	1	2	3	3	None	
2	1	1	2	2	C/6 C/7	C/8 C/9
3	1	2	3	2	0/11	C/4 C/10 C/13
4	1	2	2	1	0/3	
5	1	2	3	2	C/7 C/12	
6	1	0	3	0	0/2 0/7	
7	1	3	2	2	0/2 0/5	C/6 C/8
8	1	2	2	1	0/2 0/7	
9	1	1	2	0	0/2	
10	1	2	3	0	0/3	
11	1	3	3	2	C/3	
12	1	1	3	0	0/5	
13	1	2	3	0	0/3	
14	1	3	3	3	None	

Figure 33. Score Sheet for "Best" ERTS Map

Type of Imagery: ERTS, diazo color reconstitution, positive transp.

Frame #: 1346-18212-4,5,7 Scale: 1:1,000,000

Number of Mapping Units: 7

Figure 34: "Worst" ERTS map. Made and presented on 1292-18220-4 at 1:1000,000.

Standard	Detectable	Comparable Mapped Type	Image Contrast	Type Line Coincidence	Error/Unit
1	1	2	3	2	0/2
2	1	1	2	1	C/1 C/3 C/5 C/6 C/7 C/8 C/9 C/11 C/12
3	1	2	2	2	0/2 C/4 C/7 C/10 C/13
4	1	2	2	0	0/3
5	1	0	2	0	0/2
6	1	0	2	0	0/2
7	1	1	1	0	0/2 0/3
8	1	1	2	0	0/2
9	1	1	1	0	0/2
10	1	2	1	0	0/3
11	1	1	1	0	0/2
12	0	0	0	0	0/2
13	1	2	3	0	0/3
14	1	3	3	3	None

Figure 35. Score Sheet for "Worst" ERTS Map

Type of Imagery: ERTS, black and white positive transparency

Frame #: 1292-18220-4 Scale: 1:1,000,000

Number of Mapping Units: 4

Table 29. Summary of Most Identifiable Features for Single MSS Bands

Date/Band	Features
July/4	Agriculture vs. Natural Vegetation - Good
	Forest vs. Juniper/Shrub-Scrub - Good
	Land Form - Good.
July/5	Agriculture vs. Natural Vegetation - Optimum
	Forest vs. Other Natural Vegetation - Very Good
	Meadow vs. Forest - Good
	Water Resources - Very Good
July/7	Water Resources - Excellent
	Agriculture vs. Natural Vegetation - Excellent
May/4	Very Poor for Anything
May/5	Agriculture - Fair
	Water Resources - Fair
May/7	Agriculture vs. Natural Vegetation - Very Good
	Water Resources - Very Good

Some features can be consistently identified, such as water resources forest, and agricultural land. Others, such as juniper and shrub-scrub types, have so much apparent variability that is confounded with non-corresponding variation in soil surface characteristics that they are difficult to separate at times, let alone identify correctly.

V. APPENDIX A: RESOURCE INVENTORY LEGENDS

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Appendix A-1

DIGITAL LITHOLOGY LEGEND FOR CROOK COUNTY, OREGON

0_ _ =UNCONSOLIDATED MATERIALS, generally with thicknesses greater than 10 feet.

00_ =Relatively thick valley bottom and plain materials.

000 =Relatively thick floodplain alluvium. Varies from coarse gravels derived from lava flows, welded tuffs, and intrusive rocks to fine-grained material derived from erosion of tuffs and tuffaceous sediments (see 030, 730, and 720). The coarser materials are mainly found in major drainage lines and the finer material is common in many of the upper drainages. Some of the finer material has accumulated since the deposition of the Mazama Ash some 6600 years ago, as this ash layer can be found several feet below the surface of many of the flood plains.

001 =Relatively thick terrace alluvium. Includes silt, sand, and gravel terraces of the Prineville Basin and fine-grained terraces of the Paulina Basin. The Prineville terraces are up to 300 feet thick and consist primarily of beds of silt and clay alternating with thin beds of sand and gravel. A stratum of gravel ranging between 10 and 30 feet thick at the base of the unit is the most productive ground-water source in the area (Robinson and Price, 1963). These gravels are mined at the terrace scarp. The terrace surface is prime irrigable agricultural land.

002 =Relatively thick bajada and alluvial fan gravels. Poorly sorted clastic debris deposited at slope bases by streams, mudflows, debris flows, and sheet floods. Materials derived from local bedrock. Mode of formation indicates continuing debris flow and sheet flood hazard, usually related to cloudbursts.

009 =Relatively thick, but otherwise undifferentiated valley bottom and plain materials. Typically used to include alluvium, terrace, and alluvial fan complexes in smaller valleys.

01_ =Relatively thick valley side materials. In Crook County these units are used only where distinctive and significant slope deposits are present. Colluvium, saprolite, and other simple slope materials are indicated as regolith over bedrock types (see 6_ _, 7_ _, and 9_ _).

012 =Relatively thick landslides. Both active and inactive landslides are shown wherever distinctive scarps and hummocky topography indicate their presence. No attempt at distinction is included. The most common landslide pattern involves an erosion resistent rock overlying a weak tuffaceous unit such that erosion of the latter undercuts the former and slabs of the resistent rock collapse onto and slide with the underlying material. Many of these slides result from rimrock situations where thin basalt flows overlie tuffs and tuffaceous units. One particular caution is important in using this unit on the 1:120,000 high flight photomap. Those landslides shown within the unit 624 are difficult to interpret with confidence at the scale of imagery used. The unit itself is subject to rapid creep on all slopes resulting in a topography for which it is difficult to accurately distinguish distinct slides from the surrounding actively creeping slopes.

013 =Relatively thick talus and scree. Used here for slopes developed on basalts and covered by coarse rock fragments. The fragments are angular, usually derived by frost action, and in many cases have been moved down slope by periglacial creep processes. Stone stripes are commonly present. Many of these slopes are still actively forming.

02_ =Relatively thick lacustrine (lake) and marine materials.

020 =Relatively thick lake beds. Developed in isolated basins in the eastern portion of the count. Largely fine-grained materials derived by erosion of tuffs and tuffaceous sediments (see 030, 720, 730).

021 =Relatively thick evaporite and playa deposits. Playa deposits in undrained depressions occupied by intermittent lakes.

03_ =Relatively thick aeolian materials.

030 =Relatively thick air-fall ash accumulations. Much of the county surface is mantled by geologically recent air-fall ash from volcanic activity in the High Cascades and Newberry Volcano. The most famous of these is the great pumice eruption of Mt. Mazama (Crater Lake) some 6600 years ago. This loose material is an important source of slope wash in the county. Where the deposits are sufficiently large they are mapped. The largest deposits are in depressions such as on the surfaces of very recent lava flows and on lee (NE facing) slopes.

1_ _ =UNCONSOLIDATED MATERIALS, generally with thicknesses less than 10 feet.

10_ =Thin valley bottom and plain materials

100 =Thin floodplain alluvium. See 000 for detailed description. West of Powell Buttes includes area of very thin alluvium over basalt that is irrigated and used agriculturally.

105 =Thin coarse clastic sediments. Used for various pediment gravels found locally throughout the county. These never exceed a few feet in thickness. The gravels may or may not be locally derived. In the southeastern corner quartzite gravels, presumably of Pre-Tertiary origin (690) are present. Generally the pediment gravels are well to moderately well sorted and rounded.

11_ =Thin valley side materials. Refer to 01_.

113 =Thin talus and scree. See 013 for detailed description.

12_ =Thin lacustrine and marine materials.

121 =Thin evaporite and playa deposits. See 021 for detailed description.

13_ =Thin aeolian materials.

130 =Thin air-fall ash accumulations. See 030 for detailed description.

4_ _ =UNCONSOLIDATED MATERIALS of unknown thickness.

40_ =Valley bottom and plain materials of unknown thickness.

400 =Floodplain alluvium of unknown thickness. See 000 for detailed description.

402 =Bajada and alluvial fan gravels of unknown thickness. See 002 for detailed description.

409 =Undifferentiated valley bottom and plain materials of unknown thickness. See 009 for detailed description.

41_ =Valley side materials of unknown thickness. Refer to 01_.

412 =Landslides of unknown thickness. See 012 for detailed description.

413 =Talus and scree of unknown thickness. See 013 for detailed description.

42_ =Lacustrine and marine materials of unknown thickness.

421 =Evaporite and playa deposits of unknown thickness. See 021 for detailed description.

6__ =CONSOLIDATED MATERIALS with thin regolith, from 6 inches to 10 feet thick.

60_ =Clastic sedimentary rocks with thin regolith.

602 =Poorly consolidated tuffaceous sediments with thin regolith. Mostly fine- to medium-grained lake and floodplain deposits formed by the reworking of freshly fallen ash but including some clastic debris from older rocks. Locally includes conglomerate lenses deposited as channel gravels. Detritus is mainly of andesitic and dacitic composition. Generally accumulated in valleys and basins eroded in older units. In the Prineville Basin of the western part of the county this unit correlates with the Dalles, Deschutes, and Madras Formations described further to the west (Hodge, 1942; Williams, 1957; Waters, 1968; Swanson, 1969; and Taylor, 1973). In this area the material varies from 0 to 300 feet thick and is Middle (?) Pliocene to Pleistocene in age. In the Paulina Basin and along the South Fork of the Crooked River this unit correlates with the clastic portions of the Mascall and Danforth Formations (Merriam, 1901; Monte, 1939; and Davenport, 1971). Here the unit is 0 to 700 feet thick and is Upper Miocene to Pliocene in age.

62_ =Intermediate volcanic rocks with thin regolith.

620 =Andesitic and dacitic tuffs and tuffaceous sediments with thin regolith. These are relatively easily eroded andesitic pyroclastic rocks found principally in the Crooked River Valley east of Prineville Reservoir and along Bear Creek south of the Reservoir. The erodibility of the unit may have contributed to the location of these major drainages. The rocks were probably deposited on the flanks of major stratovolcanoes similar to Mt. Hood of today and on broad aprons adjacent to such volcanoes by streams, sheet wash, debris flows, avalanches, and slurry floods. Local lake deposits included, as well as direct air-fall ash and coarser fragmental deposits. In places numerous flows and local welded tuffs included (see 624). The original glass found in the matrix of the rocks has been altered to clay minerals with the result that the unit forms generally unstable slopes on which soil creep processes are active. All rocks designated by this symbol are considered correlative with the Clarno Formation of Eocene to Lower Oligocene age (Merriam, 1901; Swanson, 1969; and Oles and Enlows, 1971).

621 =Basaltic and andesitic vent rocks with regolith. A small area of altered basalt and andesite cinders, scoria, bombs, and spatter southeast of Prairie Hill and east of Lost Creek considered a vent area for John Day Formation material in the vicinity (Waters, 1968; Swanson, 1969).

622 =Andesitic flows with thin regolith. Locally indicated within units 620 and 720 of the Clarno Formation as Clarno flows (Waters, 1968). Shown south of Prairie Hill as part of the John Day Formation (Swanson, 1969). In the vicinity of Gerry Mountain indicates thin, commonly platey, locally scoriaceous andesite and dacite (?) flows of Pliocene (?) age (Walker, Peterson, and Greene, 1967).

624 =Mixed andesitic flows and fragmental rocks with thin regolith. Mostly flows and coarse, non-sorted to poorly sorted volcanic breccias. Unit includes small amounts of tuffaceous material similar to unit 620. Minor intrusive bodies are common. Composition of most of the flows is basaltic andesite to andesite. The material was mostly erupted from straovolcanoes and shield volcanoes. Flows typically have top and basal breccias and platey or columnar interiors. The volcanic breccias originated by debris flows, flow breccias, and similar processes. They consist of angular to subrounded fragments in a matrix either of material similar to the clasts or of ash. The breccia layers are up to several tens of feet thick. Much of the unit has been altered and clay minerals produced from devitrifying glass are common. Generally forms unstable slopes. Landslides in which relatively intact flow blocks move on tuffaceous material are common, but relatively difficult to distinguish on high flight imagery from stable dip slopes (see 012). Unit correlates with the Clarno Formation (Merriam, 1901; and Swanson, 1969). Most of the unit is probably the Lower Clarno of Oles and Enlows (1971) which is largely of Eocene age, 37 to 46 million years old (Enlows and Parker, (1972).

63_ =Silicic Volcanic rocks with thin regolith.

630 =Silicic tuffs and tuffaceous sediments with thin regolith. This unit includes fine-grained, water laid tuffs, lapilli tuffs, and tuffaceous claystone with lesser amounts of coarser tuffaceous material. These are colorful rocks in shades of buff, red, and green. Much of the unit is altered from original glass to clay minerals, zeolites, and other secondary materials. Rocks rich in altered glass are bentonitic and slopes formed on these materials tend to be very unstable, especially under rimrock basalts and other relatively rigid materials. These rocks are also easily eroded, particularly where vegetation is

sparse. They were produced by direct deposition from ash falls; redeposition of ash falls by wind, shallow streams, and sheet wash; and deposition in shallow ponds. They correlate with the John Day Formation of middle Oligocene to early Miocene age, 32 to 25 million years old (Merriam, 1901; Swanson, 1969). The unit makes up the dominant part of the John Day Formation in the eastern two-thirds of the county and a significant portion of it elsewhere. A small portion of the unit near Rocky Butte may be correlated with either the Clarno Formation or the John Day Formation (Swanson, 1969).

631 =Silicic vent rocks with thin regolith. Dacitic to rhyolitic dikes, plugs, and related shallow intrusives associated with volcanic centers at Hampton Buttes. Includes some related flows and flow breccias and grades laterally into rhyodacite welded tuff in a few locations. Age Pliocene, Pleistocene, and Recent (?).

632 =Silicic flows with thin regolith. Associated with intrusive centers of John Day Formation at Grizzly Mountain, Powell Buttes, and Bear Creek Buttes, where the rocks are mostly rhyolite and dacite flows, with domes and small near surface intrusive bodies. They are mostly light grey to red, dense, and show planar flow banding. In the northern portion of the county around Rooster Rock, Hash Rock and Wildcat Mountain they are rhyolite flows, commonly with lithophysae. These rocks are unconformabe on the Clarno and may be basal John Day Formation (Swanson, 1969) or Upper Clarno Formation (Oles and Enlows, 1971).

633 =Silicic welded tuffs with thin regolith. Densely welded portions of rhyolite ash-flow tuffs that are resistent rimrock and cuesta formers in the county make up this unit. Such rocks are deposited by volcanic eruptions of the glowing avalanche, or nuee ardente, type. Many of these are extremely widespread units that form excellent time markers in the county. Units of a variety of geologic ages are included. The oldest are exposed in the western half of the county, where they make up a significant portion of the John Day Formation (Peck, 1969; Waters and Vaughan, 1968; and Robinson, 1973). Most of these ash flows were probably erupted from vents located west of the county. The prominent cuestas north of Prineville Reservoir are of these rocks. Just north of Ochoco Reservoir the small area of 633 is subject to debate as to whether it is a rhyolite flow (632) or a rhyolite welded tuff (633) (Taylor and Robinson, personal communication, 1973). At least three welded tuffs of the Mascall and Danforth Formations (Davenport, 1971) occupy the area from Paulina Basin to the southern edge of the county. In this area the resistent welded tuffs occur as nearly flat lying rimrocks and tablelands. Each of the three welded tuffs is a single cooling unit deposited during a single volcanic

episode. The single layers average 30 to 40 feet thick, but locally may reach as much as 200 feet thick. They were deposited in a structural basin in the southeastern portion of the county. The most widespread unit is the Rattlesnake ignimbrite which is about 6 million years old The other two are found along canyons and in fault scarps and have ages of about 9 and 16 million years (Davenport, 1971).

639 =Undifferentiated silicic rocks with thin regolith. Used in the John Day Formation for small areas with both welde tuffs and non-welded tuffs and tuffaceous sediments that cannot be separated even diagramatically at the scales used here.

64_ =Basaltic volcanic rocks with thin regolith.

640 =Basaltic vent materials with thin regolith. These are vent rocks for unit 642 which principally form low shield volcanoes, lava domes, and cinder cones. Include considerable amounts of basaltic cinders and scoria, blocks, bombs, and basaltic agglomerate. Most such as Grass Butte, Alkali Butte, and Arrow Wood Point are of Pliocene (?) to Pleistocene age. At Round Mountain and adjacent O'Neill Butte, similar vent materials of Clarno age are present.

642 =Basaltic flows with thin regolith. Two major groups of massive erosion resistent basalts are present in the county. The older ones belong to the Columbia River Group of Middle Miocene age, or about 14 to 18 million years old (Swanson, 1969). These are 50 to 100 foot thick, columnar jointed, olivine-bearing basalt flows. Flow direction indicators who that many flows came from vents to the east and northeast, probably in the Monument dike swarm. The Columbia River Group lavas are 250 feet thick at Lookout Mountain, 625 feet thick on the North Fork of the Crooked River 1 mile upstream from the mouth of Rough Canyon Creek, and 410 feet thick in the Maury Mountains (Waters, 1961). They are extremely prone to sliding on the underlying John Day tuffs. The extensive pattern of open joints in the Ochoco Mountains is sliding of the basalts down their own dip slope on these underlying tuffs. These lavas are correlated with the Picture Gorge basalt member of the Columbia River Group. Between the Ochoco and Prineville Reservoirs, however, the stratigraphic relations are uncertain. South and east of the Paulina Basin, around MacKay Butte and Powell Mountain, Brown and Thayer (1966) describe a marginal facies in which basalt flows

are interbedded with other materials. The second major group of basalt flows is much younger than those of the Columbia River Group. These are 10 to 30 foot thick olivine basalt flows in which columnar jointing is generally more poorly developed than in Columbia River Group basalts. They are of Late Pliocene to Pleistocene age (Swanson, 1969). McBirney and Sutter (1974) report dates of 3.36 and 5.67 million years for basalts of this group. Numberous vents (640) are present in the county which were sources for these flows. In general these flows form units less than 100 feet thick, but locally where they fill previously eroded canyons much thicker sections are developed. The flows rest on top of the Danforth and Deschutes Formations in most places. Near the dam for Prineville Reservoir some interbedding with the underlying tuffs occurs. In general these flows closely follow the contours of an older topography in the county that has been altered by both deformation and the intrenchment of the major drainages.

66_ =Coarse grained intrusive rocks with thin regolith.

664 =Silicic intrusive rocks with thin regolith. See 964 for detailed description.

69_ =Combined units with thin regolith.

690 =Pre-Tertiary rocks with thin regolith. This unit combines mixed older rocks at the eastern end of the county that are not separately mapped. A wide range of clastic sedimentary, volcaniclastic, and volcanic rocks with minor limestones are present. Ages range from Devonian to the Cretaceous. All of these units are greatly deformed.

692 =Mixed welded tuffs and tuffaceous sediments of the Danforth and Mascall Formations with thin regolith. See 633 and 602 for detailed descriptions of the units combined.

7__ =CONSOLIDATED MATERIAL with little or no regolith, up to 18 inches thick.

70_ =Clastic sedimentary rocks with little or no regolith.

702 =Poorly consolidated tuffaceous sediments with little or no regolith. See 602 for detailed description.

72_ =Intermediate volcanic rocks with little or no regolith.

720 =Andesitic and dacitic tuffs and tuffaceous sediments with little or no regolith. See 620 for more details. Unit 720 includes areas of essentially bare bedrock that have been rapidly eroded in recent times. Badland topography

is common. Probably contribute significantly to reservoir turbidity and to recent valley alluvium (cf. 730). Unit 620 can become like 720 through poor management practices.

73_ =Silicic volcanic rocks with little or no regolith.

730 =Silicic tuffs and tuffaceous sediments with little or no regolith. See 630 for more detailed description. This unit includes those areas where intensive erosion has stripped the soil and, commonly, produced badland topography. The most recent alluvium on some floodplains probably derives from these areas (see 000) and much of the material that causes reservoir turbidity may be produced by continuing activity. Unit 630 has the potential to become this way if the vegetation is removed, especially on steeper slopes.

732 =Silicic flows with little or no regolith. Rhyolite flow west of Pilot Butte. Included in the John Day Formation.

733 =Silicic welded tuffs with little or no regolith. See 633 for detailed description.

74_ =Basaltic volcanic rocks with little or no regolith.

742 =Basalt flows with little or no regolith. This unit designates the youngest basalt flows of the county. Although the surfaces have been weathered to broken rock fragements and detailed flow features have been obscured, large flow features like pressure ridges and tumuli are still recognizable. Undrained depressions are common and normally contain relatively thick accumulations of air-fall ash from eruptions of Mt. Mazama and other Cascade volcanoes, but these areas are too small to map at the scales used in most cases.

76_ =Coarse grained intrusive rocks with little or no regolith.

763 =Intermediate intrusive rocks with little or no regolith. See 963 for detailed description.

_ =CONSOLIDATED MATERIALS with unknown thickness or regolith.

92_ =Intermediate volcanic rocks with unknown thickness of regolith.

922_ =Andesite flows with unknown thickness of regolith.

93_ =Silicic volcanic rocks with unknown thickness of regolith.

933 =Silicic welded tuffs with unknown thickness of regolith. See 633 for detailed description.

96_ =Coarse grained intrusive rocks with unknown thickness of regolith.

963 =Intermediate intrusive rocks with unknown thickness of regolith. Mostly plugs, dikes, and irregular intrusive bodies of basaltic andesite and andesite identical to most lavas in unit 624. Some may be younger than the Clarno Formation, but most are probably of similar age.

964 =Silicic intrusive rocks with unknown thickness of regolith. Plugs and irregular intrusive bodies of rhyolite. May be vents for unit 632 in the north-central area of the county. May be of either Clarno or John Day age or both.

Appendix A-2

Geology
Crook County Oregon
ERTS MSS 5 1076-18211
Scale app. 1:250,000
by Robert Lawrence

Appendix A-3

Brief Glossary of Geologic Terms

Agglomerate: An assemblage of coarse, angular, and fragmental volcanic material.
Andesite: A volcanic rock of intermediate composition, see attached figure.
Anticline: An uparching fold in rock layers.
Ash flow: A turbulent blend of unsorted, mostly fine-grained pyroclastics and high temperature gas ejected explosively from a fissure or crater.
Basalt: A volcanic rock of mafic composition, see attached figure.
Cinder cone: A conical hill formed by the accumulation of cinders and other scoriaceous volcanic ejecta, normally of basaltic or andesitic composition.
Colluvium: A general term for any loose, incoherent, and heterogeneous mass of soil material or rock fragments chiefly deposited by slope processes.
Dacite: A volcanic rock of Intermediate composition see attached figure.
Dome (volcanic): A steep-sided, rounded extrusion of highly viscous lava squeezed out of a volcano and forming a dome-shaped mass at the vent.
Fault: An earth fracture along which the sides have moved with respect to one another.
Flow breccia: An angular, fragmental mass of volcanic rock that is formed simultaneously with the movement of the lava flow by the break up of early cooled crust.
Geologic time scale: A chronologic arrangement of geologic events presented in terms of geologic-time units, see figures 1 and 7.
Ignimbrite: The rock formed by the deposition and consolidation of ash flows (see tuff and welded tuff).
Joint: An earth fracture along which the sides have not moved with respect to one another.
Lahar: A volcanic mudflow triggered by an eruption and carrying hot pyroclastic debris.
Mafic: Said of an igneous rock rich in one or more of the ferromagnesian, dark-colored minerals and, hence, low in SiO_2.
Magma: Naturally occurring molten rock material within the earth; becomes lava when extruded.
Mudflow: A general term for a mass movement landform, process, and deposit characterized by a flowing mass of earth material and water possessing a high degree of fluidity during movement.
Normal fault: A fault with a steep (60^{o}) dip in which the overhanging block has moved down with respect to the underlying block.
Plug: A vertical, pipelike body of magma that represents the conduit to a former volcanic vent.
Pumice: A light-colored, vesicular, glassy volcanic rock usually of rhyolite composition.
Pyroclastic: Said of fragmental volcanic rocks.
Quaternary: A subdivision of cenozoic time including the Pleistocene and Recent.

Regolith: A general term for the entire layer of unconsolidated material, of whatever origin, overlying bedrock at the earth's surface.

Rhyodacite: A volcanic rock of composition intermediate between rhyolite and dacite, see attached figure 5-8.

Rhyolite: A volcanic rock of silicic composition, see attached figure 1-8.

Saprolite: A soft, clay-rich soil formed by in place decomposition of igneous or metamorphic rocks.

Scoria: A volcanic rock filled with holes formed where lava hardened around trapped gas bubbles.

Shield volcano: A broad, low volcano built by flows of very fluid basalt.

Silicic: Said of silica-rich igneous rock or magma; generally implies over 65% SiO_2 un the rock composition.

Stratovolcano: A volcano that is composed of alternating layers of lava and pyroclastic material.

Syncline: A downarching fold in rock layers.

Tertiary: A subdivision of Cenozoic time extending from the Eocene to the Pliocene, see figure 7.

Tuff: A compact pyroclastic deposit of volcanic ash and dust that may contain up to 50% fine-grained sediments.

Tuffaceous: Said of sediments containing up to 50% tuff.

Unconformity: A substantial break in the geologic record; normally implies a period of uplift and erosion between the times of deposition of adjacent rock layers.

Welded tuff: A pyroclastic rock that has been indurated by the action of retained heat, weight of overlying material, and hot gases.

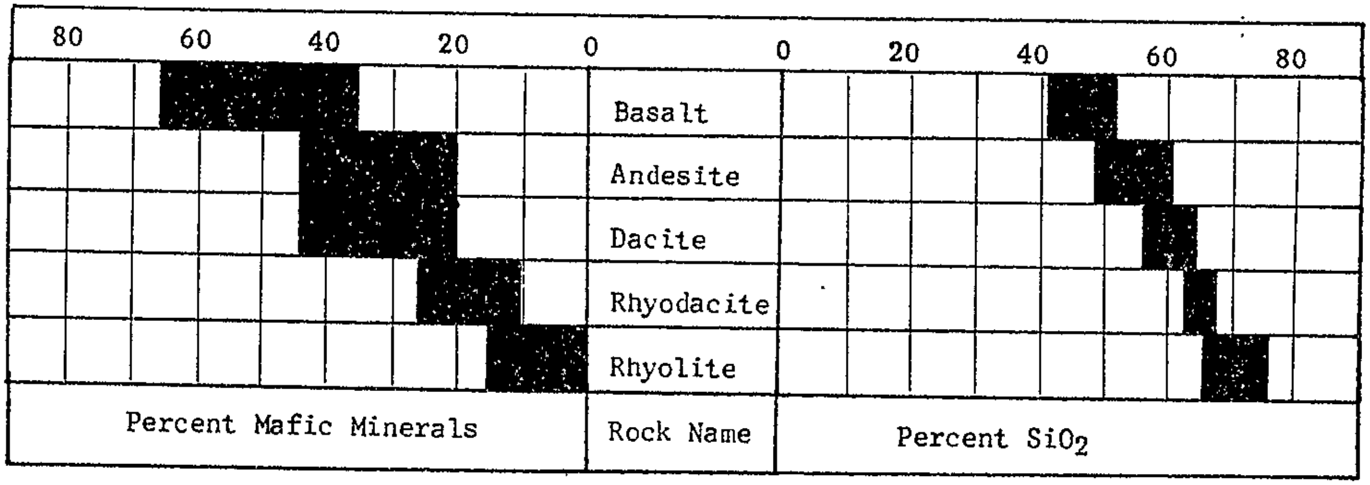


Figure 1 Appendix A3. Compositional variations of some typical volcanic rocks.

Appendix A-4

Legend for Soil-Landscape Map of

Crook County, Oregon

NASA Flight 72-114

1:120,000

Soil Association, Description, and Component Soils

Symbol

1a. Powder-Courtrock Association: Deep and moderately deep, medium textured soils on floodplains. Alkaline soils occur in some poorly drained areas.

Powder loam, Courtrock sandy loam, Metolius sandy loam, Veazie sandy loam, Polly loam.

1b. Calabar-Damon Association: Poorly and somewhat poorly drained, medium and fine textured soils, some of which are alkaline.

Calabar silt loam, Damon silty clay loam, Crooked sandy loam Boyce silty clay loam, Ontko silty clay loam.

2. Ochoco-Prineville Association: Moderately deep, medium textured soils, with partially cemented pans, on old alluvial terraces.

Ochoco sandy loam, Prineville sandy loam, Hack loam, Courtrock sandy loam.

3a. Ayres-Nouque Association: Shallow and moderately deep, medium textured, gravelly soils with strongly cemented pans, on slightly disected alluvial fans.

Ayres sandy loam, Nouque silt loam, Deschutes sandy loam, Shev loamy sand, Salisbury clay loam, Gribble cobbly loam.

3b. Ayres-Nouque Association (dissected): Similar to 3a, but moderately to strongly dissected.

4a. Deschutes-Arron-Redmond Association: Shallow, very shallow and moderately deep, medium textured soils, some of which are stony, on nearly level to gently rolling older lava flows.

Deschutes sandy loam, Arron sandy loam, Redmond sandy loam, Deskamp loamy sand, Gosney very stony loamy sand, Bakeoven very cobbly loam, Rockland.

4b. Deschutes-Gosney Association: Similar to 4a, but on rolling, moderately dissected terrain.

Deschutes sandy loam, Gosney very stony loamy sand, Bakeoven very cobbly loam.

4c. Deschutes-Redmond Association: Shallow and moderately deep, medium and coarse textured soils in nearly level and concave areas of younger lava flows. Bare rock predominates on convex portions.

Deschutes sandy loam, Redmond sandy loam, Bakeoven very cobbly loam, Rockland.

4d. Deskamp-Arron-Gosney Association: Similar to 4c, but bare rock predominates.

Deskamp loamy sand, Arron sandy loam, Gosney very stony loamy sand, Rockland, Deschutes loamy sand.

5. Roba-Fopiano Association: Shallow and moderately deep, medium textured soils in gently rolling terrain formed from soft sedimentary rocks.

Roba loam, Fopiano silty clay loam, Marsden silt loam.

6a. Ruckles-Anawalt Association: Very shallow and shallow, stony and very stony soils, many of which have clayey subsoils, on gently rolling to nearly level volcanic plateaus.

Ruckles very stony silt loam, Anawalt stony silt loam, Bakeoven very cobbly loam, Olson stony loam.

6b. Anawalt-Ruckles-Lookout Association: Similar to 6a, but on rolling, somewhat dissected topography.

Anawalt stony silt loam, Ruckles very stony silt loam, Lookout stony silt loam, Bakeoven very cobbly loam, Olson stony loam, Rockland.

6c. Anawalt-Ruckles-Rarey Association: Similar to 6a, but on steeply rolling, dissected topography.

Anawalt stony silt loam, Ruckles very stony silt loam, Rarey loam, Rockly very cobbly loam, Bakeoven very cobbly loam, Rockland.

7a. Simas-Ginser-Tub Association: Moderately deep, shallow, and deep clayey soils, on moderately dissected rolling terrain.

Simas cobbly silty clay loam, Ginser very stony loam, Tub silt loam, Day clay, Prag very stony loam, Soft sedimentary rocks.

7b. Simas-Tub-Soft Sedimentary Rock Association: Similar to 7a, but with numerous exposures of unconsolidated rock.

Simas cobbly silty clay loam, Tub silt loam, Soft sedimentary rocks, Ginser very stony loam, Day clay, Prag very stony loam Rockland.

8a. Anawalt-Merlin Association: Shallow and moderately deep clayey soils in steeply rolling, dissected terrain. Moderately deep, loamy soils occur on north slopes and in concave places. Rock outcrops are common.

Anawalt stony silt loam, Merlin very stony loam, Rarey loam.

8b. Venator-Izee Association: Shallow, moderately deep and deep, medium textured soils on rolling terrain of strongly folded older rocks.

Ventor shaly loam, Izee shaly loam, Rarey loam, Utley shaly loam.

8c. Ventor-Izee-Rarey Association: Shallow and moderately deep, medium textured soils on steeply rolling to hilly terrain of strongly folded older rocks.

Venator shaly loam, Izee shaly loam, Rarey loam, Utley Shaly loam.

9a. Simas-Tub-Ginser Associaton: Shallow and moderately deep, stony and very stony, medium and fine textured soils predominate. Moderately deep, stone-free, medium textured soils occur on some north slopes. Steeply rolling, dissected terrain predominates, and rock outcrops are common.

Simas cobbly silty clay loam, Tub silt loam, Ginser very stony loam, Gem very stony loam, Prag very stony loam, Rarey loam, Curant silt loam, Rockland.

9b. Prag-Tub-Rarey Association: Similar to 9a, but north slopes make up > 25% of the area.

Prag very stony loam, Tub silt loam, Rarey loam, Ginser very stony loam, Simas cobbly clay loam.

9c. Searles-Elmore-Simas Association: Shallow, moderately deep and deep, stony, medium textured soils in steeply rolling and mountainous terrain underlain by rhyolite.

Searles very stony loam, Elmore very stony loam, Simas cobbly silty clay loam, Tub silt loam, Lickskillet very stony loam, Rockland, Deskamp loamy sand.

10. Anatone-Klicker-Hall Ranch Association: A complex landscape consisting predominantly of very shallow, stony and very stony, sparsely vegetated soils on nearly level to rolling plateaus. Moderately deep and deep, medium textured, timbered soils occur on north slopes and in canyons.

Anatone very stony loam, Klicker very stony silt loam, Hall Ranch stony loam, Tolo silt loam, Snell very stony loam.

11. Klicker-Hall Ranch-Anatone Association: A complex landscape consisting predominantly of moderately deep and deep, medium textured, timbered soils; with sparsely vegetated, very shallow and stony soils on south facing slopes.

Klicker very stony silt loam, Anatone very stony loam, Hall Ranch stony loam, Tolo silt loam, Snell very stony loam.

12a. Hankins-Hankton Association: Moderately deep and deep, fine-textured. timbered soils in moderately dissected, rolling terrain, primarily above 5000 feet elevation.

Hankins cobbly loam, Hankton cobbly silt loam, Boardtree gravelly loam, Yawkey gravelly loam.

12b. Boardtree-Yawkey-Hankins Association: Similar to 12a, but north slopes predominate.

Boardtree gravelly loam, Yawkey gravelly loam, Hankins cobbly loam kankton cobbly silt loam.

13a. Hankton-Hankins-Klicker Association: Moderately deep and deep, medium and fine-textured, stony, timbered soils in steeply rolling, dissected terrain. South slopes may have shallow, stony soils and lack timber.

Hankton cobbly silt loam, Hankins cobbly loam, Klicker very stony silt loam, Ginser very stony loam, Yawkey gravelly loam, Snell very stony loam, Anatone very stony loam, Rockland.

13b. Hankton-Klicker-Ginser Association: Similar to (13a), but south slopes predominate.

Hankton cobbly silt loam, Klicker very stony silt loam, Ginser very stony loam, Snell very stony loam, Anatone very stony loam, Rockland.

13c. Hall Ranch-Daxty Association: Shallow and moderately deep, gravelly, loamy soils on a strongly dissected plateau.

Hall Ranch stony loam, Daxty very stony loam, Anatone very stony loam.

14a. Boardtree-Whistler Association: Moderately deep and deep, medium textured, timbered soils formed from volcanic ash over a variety of buried soils, primarily on north slopes above 4500 feet elevation.

Boardtree gravelly loam, Whistler sandy loam, Yawkey gravelly loam, Hankins cobbly loam.

14b. Hankins-Hankton-Boardtree Association: A mixture of units 14a and 13b.

Hankins cobbly loam, Hankton cobbly silt loam, Boardtree gravelly loam, Klicker very stony silt loam, Yawkey gravelly loam, Ginser very stony loam, Snell very stony loam.

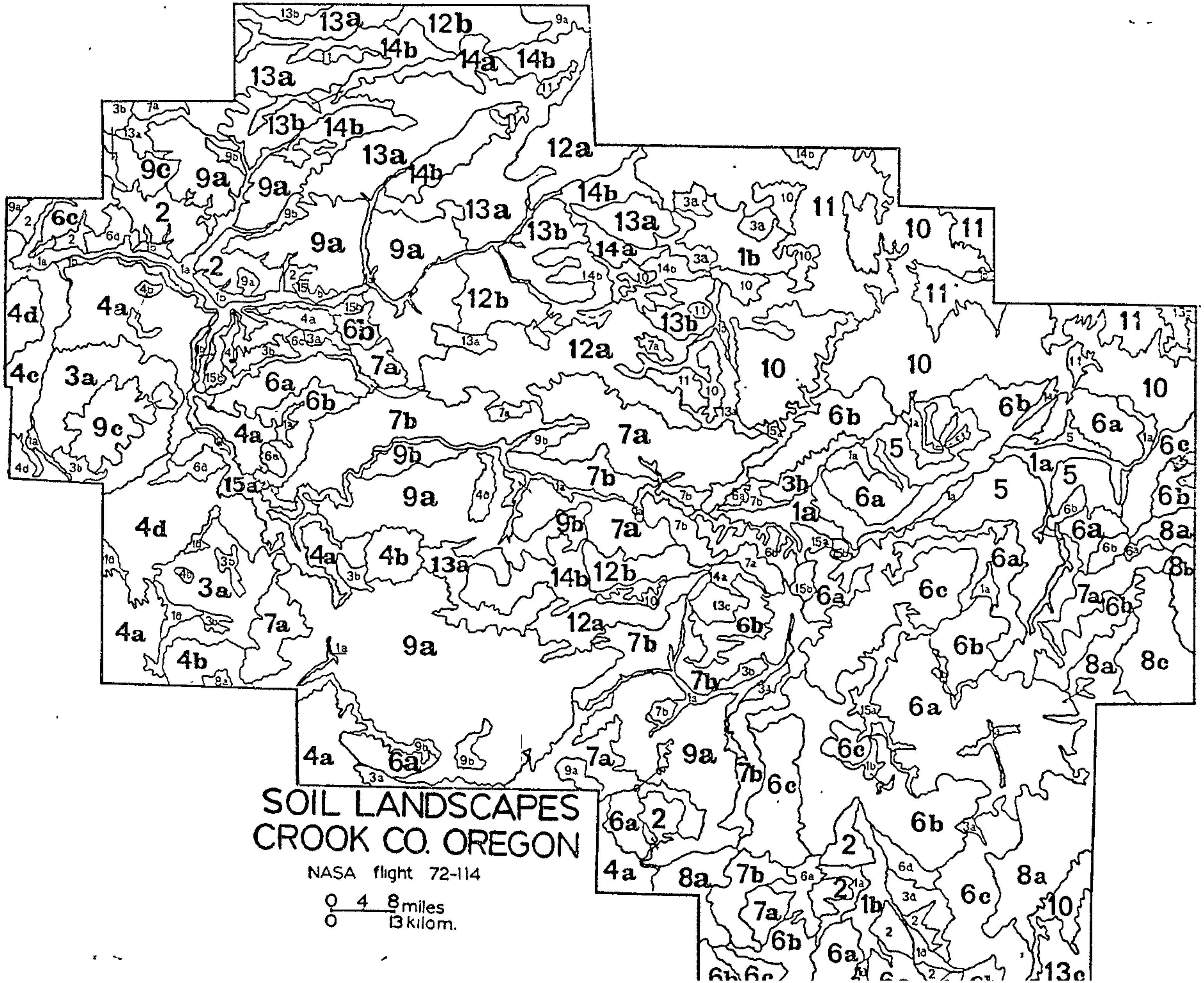
15a. Lickskillet-Rockland Association: Very steep, shallow and moderately deep, stony and rocky soils predominate. Canyons with more than 500 feet of local relief.

Lickskillet very stony loam, Rockland, Bakeoven very cobbly loam, Lookout stony silt loam, Simas cobbly silty clay loam, Tub silt loam.

15b. Simas-Tub-Rockland Association: Similar to 15a, but includes areas of more gentle relief resulting from landslides.

Simas cobbly silty clay loam, Tub silt loam, Rockland, Lookout stony silt loam, Gem very stony loam.

Component soils are listed in order of decreasing importance.



SOIL LANDSCAPES CROOK CO. OREGON

NASA flight 72-114

Appendix A-6

VEGETATION/LAND-USE LEGEND

Crook County

(From ERSAL Legend)

100 - BARREN LAND - Land areas supporting little or no vegetation or where vegetation growth is severely limited by climatic and geomorphologic patterns.

- 110 - PLAYAS, DRY, OR INTERMITTENT LAKE BASINS - Dry or intermittently moist lake basins regardless of whether the basin is volcanic or sedimentary; or whether a basement rock is variously covered by clastic sediments.
- 130 - ROCKLANDS - Any bare bedrock outcrops usually having elevated relief patterns and lichen and moss vegetation with generally scattered vascular plant development.
- 180 - MAN-MADE BARRENS - Non-vegetated areas that can historically be documented to have come directly or indirectly into existence due to human action.

200 - WATER RESOURCES - Ground surface areas covered by natural or man-made water areas. Streams, lakes, reservoirs, snow and ice cover, canals, aqueducts, and other water bodies lacking surface vegetation are classed here.

- 210 - PONDS, LAKES, AND RESERVOIRS - Man-made and naturally impounded freshwater bodies without a readily observable current.
  - 211 - NATURAL LAKES AND PONDS - Naturally occurring bodies of freshwater.
  - 212 - MAN-MADE RESERVOIRS AND PONDS - Reservoirs and ponds are artificial impoundments of water.
- 220 - WATER COURSES - Natural and man-made flowing water including rivers, creeks, canals, ditches, and aqueducts. The boundary between flowing water courses and standing water is arbitrarily defined as a straight line across the mouth of a stream.
  - 221 - NATURAL WATER COURSES - Rivers, creeks, and other flowing water courses.
  - 222 - MAN-MADE WATER COURSES - Canals, ditches, aqueducts, and other artificial water courses.
- 230 - SPRINGS, SEEPS, AND WELLS - Natural and artificial freshwater source areas. These are generally mapped as point data.
- 290 - UNDIFFERENTIATED COMPLEXES OF WATER RESOURCES

VEGETATION/LAND-USE LEGEND - Crook County

300 - NATURAL VEGETATION - Vegetation consisting mainly of native species. These areas may be in varying successional stages due to historical or current use and treatment. The management objective is to maintain a cover of native vegetation in contrast to selected or cultivated species.

310 - HERBACEOUS TYPES - That vegetation (annual, biennial, or perennial) which is predominently herbaceous including any or all grasses, grass-like plants, forbs, and non-vascular or vascular cryptogams. Other growth forms of vegetation may be present but they are subordinate in terms of aspect.

314 - GRASSLAND, STEPPE, AND PRAIRIE - Any land area which has grass as the predominent vegetation. Tall-grass prairies, short-grass prairies, desert grasslands, palouse grasslands, bunchgrass, and steppe grasslands are all included in this category.

314.1 - TUSSOCK GRASSES OR BUNCH GRASSES *(Agropyron, Sporobolus, Aristidas)* - Areas which have a physiognomic aspect of bunch grass prominent type. The most common grasses which may be found within this type are *Agropyron spicatum* (Bluebunch wheatgrass) and *Festuca idahoensis* (Idaho fescue). A wide variety of other grasses may occur with these or be dominant. Usually these types are on upland sites.

314.3 - TALL GRASSLANDS *(Elymus cinereus)* - These grasslands are characterized by such species as *Elymus cinereus* (Giant wildrye). The aspect is of large bunchgrass 3 to 6 feet tall. Usually these types are found on bottomlands with deeper soils and more effective moisture, and may be associated with such species as *Artemisia tridentata* (Big sagebrush) or *Sarcobatus vermiculatus* (Black greasewood) in more saline areas.

315 - MEADOWS - Areas in which species of Gramineae or Cyperaceae (and related families) predominate and where soil moisture contents are high through most of the growing season.

315.1 - DRY GRAMINACEOUS MEADOWS - Meadows which support such characteristic grasses as *Poa* spp. (Bluegrasses), and *Festuca* spp. (Fescue). Due to seasonally dry conditions and better drained soils, these areas do not support the more mesic *Carex* spp. (Sedges) and *Juncus* spp. (Rushes). These types most commonly are found along streams and in forest openings.

NATURAL VEGETATION (Meadows, cont.)

315.2 - WET MIXED GRAMINACEOUS - These meadows are characterized by species of Gramineae (Grasses), Juncaceae (Rushes), and Cyperaceae (Sedges). These types are found on bottomlands which may be seasonally inundated and may experience late season drying of short duration.

316 - GRAMINACEOUS MARSHES - Areas where water is standing on the land surface much of the time either on a seasonal or daily basis. Water mixing occurs so that stagnation generally does not occur and the vegetation is dominantly grasses.

317 - TULE MARSHES - Areas as in 316, but with species of Juncaceae (Rushes), Cyperaceae (Sedges), Typhaceae (Tules), or other aquatic and sub-aquatic angiosperms as the dominant vegetation.

319 - UNDIFFERENTIATED COMPLEXES OF HERBACEOUS TYPES

320 - SHRUB-SCRUB TYPES - All types of shrubs or scrubby plants are the prominent vegetation. These usually form a closed layer so that the herbaceous layer is completely subordinate. The herbaceous vegetation is highly variable but can be important.

324 - HALOPHYTIC SHRUB - Salt tolerant shrubs occurring as the prominent species mostly in playas, alkali flats, and other soils with high salt content. This category includes such genera as *Atriplex* (Saltbrush), *Eurotia* (Winterfat), *Grayia* (Hopsage), and *Sarcobatus* (Greasewood).

324.3 - GREASEWOOD *(Sarcobatus* inc. *S. baileyi)* [Bailey's Greasewood] - Type found on saline-alkaline areas. Usually in bottomlands which are poorly drained. Commonly associated species are: *Artemisia tridentata* (Big sagebrush), *Dictichlis stricta* (Alkali saltgrass), *Elymus cinereus* (Giant Wildrye), and *Sitanion hystrix* (Bottlebrush squirreltail). Normally there is a high percentage of bare ground in the more alkaline conditions.

325 - SHRUB STEPPE - *Artemisia* (Sagebrush), *Chrysothamnus* (Rabbitbrush), *Purshia* (Bitterbrush), *Cowania* (Cliffrose), and other shrubs occurring as the prominent species associated with grasses and other herbs in the understory.

NATURAL VEGETATION (Meadows, cont.)

325.1 - LOW SAGEBRUSH - Includes any of the species of low sagebrush: *Artemisia arbuscula* (Low sagebrush), *A. longiloba* (Longlobe sagebrush), or *A. rigida* (Stiff sagebrush). These types are usually found on rolling or flat uplands. They may have very stony or scabby to stony soil surfaces. The aspect of the community is of low growing shrub but may have a grass species equally abundant. Most commonly associated grasses are *Agropyron spicatum* (Bluebunch wheatgrass), and *Festuca idahoensis* (Idaho fescue), to the more xeric *Sitanion hystrix* (Bottlebrush squirreltail) and *Poa sandbergii* (Sandberg's bluegrass).

325.11 - *ARTEMISIA ARBUSCULA-A. LONGILOBA/AGROPYRON SPICATUM-FESTUCA IDAHOENSIS* (Low sagebrush-Longlobe sagebrush/Bluebunch wheatgrass-Idaho fescue) - Usually found on stony or very stony (scabby) shallow soiled uplands. Sites are on ridge tops or exposed slopes. More mesic sites normally support Idaho fescue.

325.12 - *ARTEMISIA RIGIDA/POA SANDBERGII* (Stiff sagebrush/Sandberg's bluegrass) - (Scablands.) Type occurs on exposed, very shallow, very stony soils (scabby) on uplands. High percentage of the soil surface is stone covered and there is wide spacing between shrubs and low percentage of herbaceous cover.

325.2 - BIG SAGEBRUSH TYPES *(Artemisia tridentata, A. tripartita)* [Big sagebrush, Threetip sagebrush] - The big sagebrush types occur on a wide variety of sites and deep soiled bottomlands along streams. There is a wide variety of species associated with hhe big sagebrush types. The most common shrubs are *Chrysothamnus* spp. (Rabbitbrush), and *Purshia tridentata* (Antelope bitterbrush); in more xeric sites, grasses are *Agropyron spicatum* (Bluebunch wheatgrass), *Stipa* spp. (Needlegrasses), *Poa* spp. (Bluegrasses), and *Festuca idahoensis* (Idaho fescue) on more mesic sites.

325.21 - *ARTEMISIA TRIDENTATA/AGROPYRON SPICATUM* (Big sagebrush/Bluebunch wheatgrass) - (Xeric uplands.) This type occurs on rolling uplands which have adequate soil depth to support big sagebrush or on the somewhat protected slopes and drainages. Commonly associated shrubs are *Chrysothamnus* spp. (Rabbitbrush) and *Purshia tridentata* (Antelope bitterbrush). The big sagebrush always dominates the aspect of the community although it may be very sparse on the xeric sites. Commonly associated grasses are *Agropyron spicatum* (Bluebunch wheatgrass), *Stipa* spp. (Needlegrass), *Sitanion hystrix* (Bottlebrush squirreltail), *Poa sandbergii* (Sandberg's bluegrass), and *Festuca idahoensis* (Idaho fescue), which is usually most prominent on more mesic sites which also may have *Purshia tridentata* (Antelope bitterbrush).

325.22 - *ARTEMISIA TRIDENTATA/FESTUCA IDAHOENSIS* (Big sagebrush/Idaho fescue) - (Mesic north slopes.) This type occurs on the more mesic north slopes. The *Artemisia tridentata* (Big sagebrush) may be very sparse and give the site an aspect near that of a grassland. The *Festuca idahoensis* (Idaho fescue) may have a high percentage of ground cover.

325.23 - *ARTEMISIA TRIDENTATA* SUBSP. *VASEYANA* (Alpine sagebrush) - (High Altitude.) This big sagebrush type is found on high altitude sites or those which are more mesic than the prior types. Commonly *Festuca idahoensis* (Idaho fescue) is associated with this type but in the areas where snow remains late into the spring and summer, there may be few grasses and the herbaceous layer may be mostly annual forbs.

325.24 - *ARTEMISIA TRIDENTATA*/TALL GRASS-*ELYMUS CINEREUS* (Big sagebrush /Giant wildrye) - These types are usually found on deep soiled flat bottomlands. They are characterized by the *Elymus cinereus* (Giant wildrye) and *Artemisia tridentata* (Big sagebrush). Many of the sites may be of saline-alkaline conditions and be associated with halophytic shrubs and related vegetation.

325.3 - SILVER SAGEBRUSH TYPES *(Artemisia cana)* - These *Artemisia cana* types are usually found around the perimeter of playas which may be seasonally inundated. These types may have no other species associated or have such species as *Juncus* spp. (Rushes), *Carex* spp. (Sedges), *Sitanion hystrix* (Bottlebrush squirreltail) and annual forbs.

NATURAL VEGETATION (Shrub-Steppe, cont.)

325.4 - RABBITBRUSH DOMINANT TYPES *(Chrysothamnus)* - These types are found on the same kinds of sites as the *Artemisia tridentata* (Big Sagebrush) types. Associated species remain the same but annual grasses and forbs and perennials such as *Sitanion hystrix* (Bottlebrush squirreltail) may be more prominent.

325.7 - MIXED SHRUB-STEPPE *(Artemisia, Purshia, Symphoricarpos, Amelanchier* [Sagebrush, Bitterbrush, Snowberry, Serviceberry], but always with *Artemisia)* - The more mesic upper elevations of the shrub-steppe. Flora is rich and usually a wide variety of species. Commonly is associated with *Festuca idahoensis* (Idaho fescue).

326 - SCLEROPHYLLOUS SHRUB - Shrublands with leathery-leaved evergreen species adapted to xeric and mediterranean environments occurring as the dominant vegetation. This category includes chaparral *(Quercus, Arctostaphylos, Ceanothos, Cercocarpus* [Oak, Manzanita, Ceanothos, Mountain mahogany]).

326.4 - CURLLEAF MOUNTAIN MAHOGANY *(Cercocarpus ledifolius)*- These types are found on sites which are marginal or ecotonal between *Pinus ponderosa* (Ponderosa pine) forest types and *Artemisia* (sagebrush) shrub-steppe types. They may be found on north slopes and uplands which are more mesic than the surrounding shrub steppe or within the marginal pine forest types. Most commonly *Festuca idahoensis* (Idaho fescue) is found within these sites. *Purshia tridentata* (antelope bitterbrush) and *Juniperus occidentalis* (Western juniper) are also common.

330 - SAVANNA-LIKE TYPES - Any area covered by vegetation of any two major life forms with the species in the subordinate layer being prominent in aspect.

333 - CONIFEROUS TREE OVER HERB - Coniferous tree species over herbaceous vegetation.

333.1 - JUNIPER OVER GRASS - A savanna-like type in which the herbaceous layer is most prominent and the *Juniperus occidentalis* (Western juniper) is widely scattered. The grasses may be any of those found in the shrub-steppe areas.

NATURAL VEGETATION (Savanna-like types, cont.)

333.11 - *JUNIPERUS OCCIDENTALIS/AGROPYRON SPICATUM* (Western juniper/Bluebunch wheatgrass) - The most xeric of the *Juniperus occidentalis* (Western juniper)/grassland savanna-like types. Sites are usually located on uplands. The grasses within the type are characterized by *Agropyron spicatum* (Bluebunch wheatgrass) but may be any of the species found in the shrub-steppe areas such as *Stipa* spp. (Needlegrass), *Poa* spp. (Bluegrass), *Koeleria cristata* (Prairie junegrass), and *Sitanion hystrix* (Bottlebrush squirreltail).

333.12 - *JUNIPERUS OCCIDENTALIS/FESTUCA IDAHOENSIS* (Western juniper/Idaho fescue) - These types are more mesic sites at higher elevations or on protected slopes. *Festuca idahoensis* (Idaho fescue) is always the most prominent grass.

NATURAL VEGETATION (Savanna-like types, cont.)

336 - CONIFEROUS TREE OVER LOW SHRUB - Coniferous tree species over a low shrub layer.

336.1 - JUNIPER OVER SHRUB - A savanna-like type in which the shrub layer is most prominent. Shrubs may be any of those found in the shrub steppe areas such as *Artemisia* spp. (sagebrush), *Purshia tridentata* (Antelope bitterbrush), and *Chrysothamnus* spp. (Rabbitbrush).

336.11 - *JUNIPERUS OCCIDENTALIS* (Western juniper)/ LOW SAGEBRUSH - Savanna-like types in which the prominent shrub may be any of the species included in the low sagebrush group - *Artemisia arbuscula* (Low sagebrush), *A. longiloba* (Longlobe sagebrush), and *A. rigida* (Stiff sagebrush). Common grasses are *Agropyron spicatum* (Bluebunch wheatgrass), *Poa* spp. (Bluegrass), *Sitanion hystrix* (Bottlebrush squirreltail) and *Festuca idahoensis* (Idaho fescue). Sites are usually located on uplands and exposed areas.

336.12 - *JUNIPERUS OCCIDENTALIS/ARTEMISIA TRIDENTATA* (Western juniper/Big sagebrush) - Savanna-like type in which *Artemisia tridentata* (Big sagebrush) is the prominent shrub. Other common shrubs are *Chrysothamnus* spp. (Rabbitbrush), and *Purshia tridentata* (Bitterbrush). This type is found on rolling uplands and low lands.

340 - FOREST AND WOODLAND TYPES - The tree layer forms the dominant vegetational feature. This layer often forms a closed canopy over a variety of subordinate vegetation types.

341 - CONIFER FORESTS - Forested areas dominated by any Coniferales or Taxales.

341.1 - JUNIPER TYPES - *Juniperus occidentalis* (Western juniper) is the prominent tree species within this type. *Artemisia tridentata* (Big sagebrush) is most often the prominent shrub. Other shrubs which are common are *Purshia tridentata* (Antelope bitterbrush), which may be prominent or coprominent with *A. tridentata* (Big sagebrush), *Chrysothamnus* spp. (Rabbitbrush), and *A. arbuscula* (Low sagebrush). Characteristic grasses are *Agropyron spicatum* (Bluebunch wheatgrass), *Festuca idahoensis* (Idaho fescue), *Poa sandbergii* (Sandberg's bluegrass), and *Stipa thurberiana* (Thurber's needlegrass)

NATURAL VEGETATION (Forest and Woodland types, cont.)

341.11 - *JUNIPERUS OCCIDENTALIS/ARTEMISIA TRIDENTATA/ AGROPYRON SPICATUM* (Western juniper, Big sagebrush/Bluebunch wheatgrass) - These types are the more xeric of the *Juniperus occidentalis/ Artemisia tridentata* (Western juniper/Big sagebrush) sites. The grasses found in these types are characterized by *Agropyron spicatum* Bluebunch wheatgrass), *Stipa* spp. (Needlegrass), *Sitanion hystrix* (Bottlebrush squirreltail), and *Poa sandbergii* (Sandberg's bluegrass). *Festuca idahoensis* (Idaho fescue) may be found in the shelter of the *Juniperus occidentalis* (Western juniper). These types are found on level to sharply rolling upland and may be stony to very stony.

341.12 - *JUNIPERUS OCCIDENTALIS/ARTEMISIA TRIDENTATA/ FESTUCA IDAHOENSIS* (Western juniper/Big sagebrush, Idaho fescue) - These types are the most mesic of the *Juniperus occidentalis/ Artemisia tridentata* (Western juniper/Big sagebrush) types and are characterized by *Festuca idahoensis* (Idaho fescue). These types are found on moister sites, most commonly protected north slopes. Usually the *Artemisia tridentata* (Big sagebrush) has low cover value.

341.3 - PONDEROSA PINE - The *Pinus ponderosa* (Ponderosa pine) types are associated with a wide variety of other tree species from *Juniperus occidentalis* (Western juniper), the most xeric, to *Pseudotsuga menziesii* (Douglas fir), and *Abies* spp. (Fir), which are the most mesic. Shrubs associated with the *Pinus ponderosa* (Ponderosa pine) types range from the xeric *Artemisia* spp. (Sagebrush), *Purshia tridentata* (Antelope bitterbrush), and *Cercocarpus ledifolius* (Curlleaf mountain mahogany) to the more mesic such as *Ceanothus spp.* (Ceanothus), *Symphoricarpos* spp. (Snowberry), and *Arctostaphylos* spp. (Manzanita). Common herbaceous vegetation is *Agropyron spicatum*, (Bluebunch wheatgrass), *Festuca idahoensis* (Idaho fescue), *Calamagrostis rubescens* (Pinegrass) and *Carex Geyeri* (Elk sedge). These types are found on uplands and hilly to mountainous terrain where moisture is adequate. A few isolated stands may be found in protected areas such as north slopes.

IATURAL VEGETATION (Forest and Woodland types, cont.)

341.31 - *PINUS PONDEROSA-JUNIPERUS OCCIDENTALIS* (Ponderosa pine Western juniper) - Within these types, either of the major tree components may be prominent or they may share prominence. As effective moisture increases, the *Pinus ponderosa* (Ponderosa pine) becomes more prominent. These are the more mesic of the *Pinus ponderosa* (Ponderosa pine) types and may be found on foothills between the dense forests and the shrub steppe. Common shrubs are *Artemisia* spp. (Sagebrush), *Purshia tridentata* (Antelope bitterbrush), and *Cercocarpus ledifolius* (Curlleaf mountain mahagony). Characteristic grasses are *Agropyron spicatum* (Bluebunch wheatgrass) and *Festuca idahoensis* (Idaho fescue).

341.32 - *PINUS PONDEROSA-PSEUDOTSUGA MENZIESII* (Ponderosa pine-Douglas fir) - These are the more mesic of the *Pinus ponderosa* (Ponderosa pine) types and are usually found at higher elevations in the mountains near the true fir types or on more protected sites such as north slopes within the forest. Characteristic shrubs are *Symphoricarpos* spp. (Snowberry), *Arctostaphylos* spp. (Manzanita), and high elevation *Artemisia* spp. (Sagebrush). Commonly associated herbaceous species are *Calamagrostis rubescens* (Pinegrass) and *Carex Geyeri* (Elk sedge).

341.4 - LODGEPOLE PINE TYPES - These *Pinus contorta* (Lodgepole pine) types are found in mountainous areas at higher elevations in basins and along stream channels, where there is a cold air drainage effect. These types also occur in disturbed areas such as burns. Commonly associated species are *Vaccinium* spp. (Huckleberry), *Calamagrostis rubescens* (Pinegrass), and *Carex* spp. (Sedges).

341.5 - DOUGLAS FIR TYPES - The *Pseudotsuga menziesii* (Douglas fir) types are more mesic than the *Pinus ponderosa* (Ponderosa pine) types and are usually found at higher elevations or in protected sites, but they are more xeric than the true fir types. Commonly, other tree species such as *Pinus ponderosa* (Ponderosa pine), *Larix occidentalis* (Western larch), and *Abies* spp. (Fir) are included. Characteristic understory is *Festuca idahoensis* (Idaho fescue), *Calamagrostis rubescens* (Pinegrass), and *Carex* spp. (Sedges).

NATURAL VEGETATION (Forest and Woodland types, cont.)

341.6 - MIXED CONIFER TYPES - These types are composed of a mixture of species of which there are none being clearly prominent. Species which are included are *Abies* spp. (Fir), *Pseudotsuga menziesii* (Douglas fir), and *Pinus ponderosa* (Ponderosa pine). These types are found on sites above the *Pseudotsuga menziesii* (Douglas fir) types which are more mesic due to elevational differences or more protected areas.

341.7 - SPRUCE-FIR TYPES - These types are found near alpine areas along the upper elevational extent of the forest zone or areas which are much more mesic than previous types due to topographic conditions. *Picea* spp. (Spruce) and *Abies* spp. (Fir) are characteristic of the type.

341.71 - *ABIES LASIOCARPA* (Subalpine fir) - The *Abies lasiocarpa* types are found at higher elevations bordering alpine openings. These sites usually have snow cover from early fall to late spring. Commonly the adjacent open areas have *Artemisia tridentata* var. *vaseyana* (Alpine sagebrush).

400 - CULTURAL VEGETATION - This class provides for the culturally introduced and intensively managed vegetations where the management objective is essentially maintainance of a permanent stand subsequently managed and manipulated through ecological rather than agronomic principles. The class is designed primarily to provide for seeded range and the planted forest where the intention is permanency of stand e.g., grass seedings in a shrub steppe land or savanna land and planted coniferous forests in a hardwood forest area. Removal of woody overstory species on potential rangeland, range seedings and clear-cut forests allowed to revert to natural successional patterns are classed in the appropriate 300 category. These types are treated as seral vegetation. If, however, such areas were additionally planted to exotic species not initially natural to the site and managed to maintain the exotic species or altered physiognomic aspect, they would then be classed under the appropriate 400, Cultural Vegetation, category.

410 - CULTURAL HERBACEOUS TYPES - Grasslands, marshes, swamps, and any other herbaceous vegetation that has been directly influenced by human activity such as seeding, spraying, etc., but subsequently managed on an ecological basis to maintain the culturally created herbaceous type.

414 - CULTURAL GRASSLAND, STEPPE, AND PRAIRIE - Any land area dominated by grass vegetation as a result of direct influence of man regardless of prior vegetative cover i.e., grass, shrub, forest, etc. The vegetation may be a result of seedings, spray-release, mechanical treatment, etc.

CULTURAL VEGETATION (Cultural Herbaceous Types, cont.)

419 - UNDIFFERENTIATED COMPLEXES OF CULTURAL HERBACEOUS TYPES

420 - CULTURAL SHRUB-SCRUB TYPES - Shrub-scrub vegetation that has been directly affected by human activity with the resulting shrub-scrub physiognomic type being managed on an ecological basis to maintain the shrub-scrub type.

425 - CULTURAL SHRUB-STEPPE - *Artemisia* (Sagebrush), *Chrysothamnus* (Rabbitbrush), *Purshia* (Bitterbrush), and other shrubs occurring as the prominent species associated with grasses and other herbs in the understory. The grasses may be native or introduced species. This type may result from clearing an overstory of trees such as *Juniperus occidentalis* (Western juniper), spray seed in which the shrubs are reestablished or introduced, etc.

425.1 - CLEARING OF OVERSTORY SPECIES - These types include mechanical removel of overstory such as *Juniperus occidentalis* (Western juniper) by fire or other cultural practice resulting in a shrub-steppe physiognomic type consisting of the species previously associated with the overstory.

430 - CULTURAL SAVANNA-LIKE TYPES - Any area covered by vegetation of any two major life forms with the species in the subordinate layer being prominent in aspect. This savanna-like appearance is a result of direct influence of man upon the vegetation.

433 - CONIFEROUS TREE OVER HERB - Coniferous tree species over herbaceous vegetation.

433.1 - JUNIPER OVER GRASS - A savanna-like type in which the herbaceous layer is most prominent and the *Juniperus occidentalis* is widely scattered. The savanna-like aspec may be due to removal of the shrub species by cultural means. The grasses may be any of those found in the shrub-steppe area or introduced species.

490 - UNDIFFERENTIATED CULTURAL VEGETATION TYPES

500 - AGRICULTURAL PRODUCTION - Land areas managed by agronomic principles. Any land areas or structures and facilities that are directly related to intensive agricultural practices. Agricultural lands are those which are characterized by the relatively constant manipulation by man of the vegetation and microenvironment and the general control of placement and growth of vegetation. Vegetation growth is essentially of an annual or short rotation basis.

VEGETATION/LAND-USE LEGEND - Crook County

AGRICULTURAL PRODUCTION (cont.)

510 - FIELD CROPS - Cereals, grains, forage, drugs, spices, fiber crops, and other field crops which are the dominant land use.

511 - CEREAL AND GRAIN CROPS - All cultivated grains and cereals such as wheat, oats, rye, corn, sorghum, and rice.

512 - FORAGE CROPS - Non-grain and cereal feed crops such as legumes (alfalfa and clover), grasses (timothy, ryegrass, etc.), and root crops that are cropped for animal feed or in seed production are included in this category.

514 - DRUG, FLAVORING AND SPICE CROPS - Any crops grown for spice (cinnamon, cloves, nutmeg, pepper), flavoring (vanilla, ginger), or drug (*Papaver*, *Cannabis*, etc.) production.

519 - OTHER UNDIFFERENTIATED FIELD CROPS

519.1 - DRYLAND FIELD CROPS - Agriculturally cropped areas which depend upon natural moisture throughout the growing season. Usually cultural practices are used which help conserve non-growing season moisture.

519.2 - IRRIGATED FIELD CROPS - Agriculturally cropped areas which rely upon artificial means of supplying growing season moisture to the crops. Usually more intensely managed with a greater variety of crops and higher production per unit area.

540 - PASTURE - Any land area seeded and harvested exclusively by grazing as an annual crop, short term ley, or a permanent pasture. Any evidence of harvesting for hay puts the area in the field crop category.

541 - HERBACEOUS PASTURE - Grasses, legumes, and other herbaceous vegetation utilized only for grazing purposes.

560 - NON-PRODUCING FALLOW, TRANSITION, OR IDLE LAND - Fallow, plowed (or variously worked) and leached cropland, including harvested fields; included here are abondoned or idle croplands, fields, and pastures as well as entrapped lands.

561 - FALLOW CROPLAND - Seasonally idle cropland or in early stages of seedbed preparation.

562 - PLOWED CROPLAND - Land recently harvested and plowed to begin preparation for another season of planting without remaining in an idle condition for any growing season.

AGRICULTURAL PRODUCTION (Non-producing Land, cont.)

564 - HARVESTED STUBBLE FIELDS - Agricultural lands recently utilized for crop production and still not plowed (including harvested land open to grazing).

590 - UNDIFFERENTIATED AGRICULTURAL PRODUCTION

600 - URBAN AND EXTRACTIVE INDUSTRY - Those lands which have been altered by man for living, manufacture, transportation, recreation, and other related activities. Much of the land area is covered by structures making up cities towns, institutions, mining operations, power production facilities, and transportation facilities.

610 - RESIDENTIAL - Single and multiple unit dwellings including secondary structures, driveways, and landscaped areas. Sparse residential land use should be included in with that land use category of which they are an integral part.

620 - COMMERCIAL AND SERVICES - Areas used predominantly for the sale, storage, and handling of products and services. Suburban and city shopping centers, warehouses, waste-disposal areas, office buildings, parking lots, and intensively developed resort sites are examples of this category.

640 - INDUSTRIAL - All types of light manufacturing and industrial parks to heavy manufacturing. Light industries concentrate on finishing, assembling, designing, and packaging products while heavy industries require more or less large amounts of raw materials such as metal ores, timber, and other materials. These heavy industry sites are usually associated with concentrations of raw materials, transportation facilities, power sources, and waste products.

650 - TRANSPORTATION, COMMUNICATIONS AND UTILITIES - Highways and railways make up the two basic transportation means that require stationary routings visible on remote sensing images. Facilities related to all transportation types are included in this category (sea ports, airports, railroad terminals, bus terminals, highways, roads, etc.). Resource transportation facilities that are non-mobile themselves are included in this category (oil pipeline, gas, electricity, and airwave facilities).

660 - RESOURCE EXTRACTION - Surface and subsurface mining facilities are included in this category. Areas of reserves and future operations are included in other land use categories. Gravel, earth, clay, oil, coal, metals, and gas are examples of resource types.

URBAN AND EXTRACTIVE INDUSTRY (Resource Extraction, cont.)

661 - SANDAND GRAVEL - Pits, processing and crushing sites as well as those sites identified for use as gravel or sand extraction sites.

665 - CHEMICAL, FERTILIZER, AND NON-METALLIC MINERALS - Sulfur, phosphates, borates, salts, and other non-metallic mineral mining facilities.

670 - OPEN SPACE AND RECREATIONAL FACILITIES - Land areas in intensive or low intensity use may be included in this category. Activities and facilities requiring significant land area that is the dominant or the major prerequisite to the activity itself are included in this category. Parks, ski areas, golf courses, cemeteries, and other open lands are included in this category.

671 - DESIGNATED NATURAL OPEN SPACE - Natural areas set aside expressly for educational, research, or scenic purposes with very little in the way of improvement facilities for recreation.

672 - STATE PARKS -

900 - OBSCURED LAND - Land areas obscured by wind-born particles, vapors, or smog.

SPECIES NAMES WITHIN GENERA

Genus	Species	Common Name
ABIES		Fir
	lasiocarpa	Subalpine fir
AGROPYRON		Wheatgrass
	spicatum	Bluebunch wheatgrass
AMELANCHIER		Serviceberry
ARCTOSTAPHYLOS		Manzanita
ARISTIDAS		Threeawn
ARTEMISIA		Sagebrush
	arbuscula	Low sagebrush
	cana	Silver sagebrush
	longloba	Longlobe sagebrush
	rigida	Stiff sagebrush
	tridentata	Big sagebrush
	tridentata vaseyana	Alpine sagebrush
	tripartita	Threetip sagebrush
ATRIPLEX		Saltbrush
CALAMAGROSTIS		Reedgrass
	rubescens	Pinegrass
CAREX		Sedges
	Geyeri	Elk sedge
CEANOTHUS		Ceanothus
CERCOCARPUS		Mountain mahogany
	ledifolius	Curlleaf mountain mahogany
CHRYSOTHAMNUS		Rabbitbrush
COWANIA		Cliffrose
CYPERACEAE		Sedge family
DICTICHLIS		Saltgrass
	stricta	Alkali saltgrass
ELYMUS		Wildrye
	cinereus	Giant Wildrye
EUROTIA		Winterfat

SPECIES NAMES WITHIN GENERA

Genus	Species	Common Name
GRAMINEAE		Grass family
GRAYIA		Hopsage
JUNCACEAE		Rush family
JUNCUS		Rushes
JUNIPERUS		Juniper
	occidentalis	Western juniper
KOELERIA		Junegrass
	cristata	Prairie junegrass
LARIX		Larch
	occidentalis	Western larch
PICEA		Spruce
PINUS		Pine
	ponderosa	Ponderosa pine
POA		Bluegrass
	sandbergii	Sandberg's bluegrass
PSEUDOTSUGA	menziesii	Douglas fir
PURSHIA		Bitterbrush
	tridentata	Antelope bitterbrush
QUERCUS		Oak
SARCOBATUS		Greasewood
	baileyi	Bailey's greasewood
	vermicularus	Black greasewood
SITANION		Squirreltail
	hystrix	Bottlebrush squirreltail
SPOROBOLUS		Dropseed
STIPA		Needlegrass
	thurberiana	Thurber's needlegrass
SYMPHORICARPOS		Snowberry
TYPHACEAE		Tule family
VACCINIUM		Huckleberry

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PLANT LIST BY COMMON NAMES

Common Name	Genus	Species
Alkali saltgrass	DICTICHLIS	stricta
Alpine sagebrush	ARTEMISIA	tridentata vaseyana
Antelope bitterbrush	PURSHIA	tridentata
Bailey's greasewood	SARCOBATUS	baileyi
Big sagebrush	ARTEMISIA	tridentata
Bitterbrush	PURSHIA	
Black greasewood	SARCOBATUS	vermicularus
Bluebunch wheatgrass	AGROPYRON	spicatum
Bluegrass	POA	
Bottlebrush squirreltail	SITANION	hystrix
Ceanothus	CEANOTHUS	
Cliffrose	COWANIA	
Curlleaf mountain mahogany	CERCOCARPUS	ledifolius
Douglas Fir	PSEUDOTSUGA	menziesii
Dropseed	SPOROBOLUS	
Elk Sedge	CAREX	Geyeri
Fescue	FESTUCA	
Fir	ABIES	
Grass family	GRAMINEAE	
Greasewood	SARCOBATUS	
Giant wildrye	ELYMUS	cinereus
Hopsage	GRAYIA	
Huckleberry	VACCINIUM	

PLANT LIST BY COMMON NAMES

Common Name	Genus	Species
Idaho fescue	FESTUCA	idahoensis
June grass	KOELERIA	
Juniper	JUNIPERUS	
Larch	LARIX	
Longlobe sagebrush	ARTEMISIA	longloba
Low sagebrush	ARTEMISIA	arbuscula
Manzanita	ARCTOSTAPHYLOS	
Mountain mahogany	CERCOCARPUS	
Needlegrass	STIPA	
Oak	QUERCUS	
Pine	PINUS	
Pinegrass	CALAMAGROSTIS	rubescens
Ponderosa pine	PINUS	ponderosa
Prairie junegrass	KOELERIA	cristata
Rabbitbrush	CHRYSOTHAMNUS	
Reedgrass	CALAMAGROSTIS	
Rush family	JUNCACEAE	
Rushes	JUNCUS	
Sagebrush	ARTEMISIA	
Saltbrush	ATRIPLEX	
Saltgrass	DICTICHLIS	
Sandberg's bluegrass	POA	sandbergii
Sedge family	CYPERACEAE	
Sedges	CAREX	

PLANT LIST BY COMMON NAMES

Common Name	Genus	Species
Serviceberry	AMELANCHIER	
Silver sagebrush	ARTEMISIA	cana
Snowberry	SYMPHORICARPOS	
Spruce	PICEA	
Squirreltail	SITANION	
Stiff sagebrush	ARTEMISIA	rigida
Subalpine fir	ABIES	lasiocarpa
Threeawn	ARISTIDAS	
Threetip sagebrush	ARTEMISIA	tripartita
Thurber's needlegrass	STIPA	thurberiana
Tule family	TYPHACEAE	
Western juniper	JUNIPERUS	occidentalis
Western larch	LARIX	occidentalis
Wheatgrass	AGROPYRON	
Wildrye	ELYMUS	
Winterfat	EUROTIA	

Land Resource Unit 10   Description: Flood Plains and Terraces

Extent: 38,400 acres, 1.8 % of the county. Elevation: 3000 to 5000 feet

Distribution: Along streams, in central and eastern portions of Crook County

Climate: Ann. ppt. 9-16 in.   Mean ann. temp. 45-49° F   Frost free days (32°) 50-80

Landscape and Topography:
Nearly level to gently sloping flood plains, terraces and alluvial fans, in valleys too small to allow their separation at this scale.

Geology:
Thick, unconsolidated silts, sands, and gravels of valley bottoms. Frequently contains groundwater supplies. Locally includes fine sediments from shallow lakes.

Vegetation:
Predominantly shrub steppe intermixed with meadow, with low sagebrush on shallow soils on locally higher areas, and with scattered patches of juniper.

Soils:
Deep and moderately deep medium textured soils on flood plains and terraces. Alkaline and poorly drained soils may occur in concave areas.

Soil Landscape Units 1a, 1b, & 2**

Limitations: Flood hazard, poor drainage and alkalinity

Land use:
*(Natural vegetation considerably altered) Field crops intermingled with meadow and cultural grassland, with some extensive areas of field crops.

*Definition of land use for purposes of this inventory. WTP, Rangeland Resources.
**Soil Landscape Units given are for the 1/120,000 scale version.

Land Resource Unit 11 Description: Flood Plains

Extent: 35,200 acres, 1.8 % of the county. Elevation: 2800 to 4200 feet

Distribution: Along streams in western and southeastern Crook County

Climate: Ann. ppt. 9-16 in. Mean ann. temp. 45-49° F Frost free days (32°) 50-80

Landscape and Topography: Nearly level to gently sloping flood plains. Micro-relief is due to changes of stream channel location during floods.	Geology: Thick, unconsolidated silts, sands, and gravels, of current flood plains. Subject to occasional local flooding. Frequently contains groundwater supplies.
Vegetation: Shrub steppe, with giant wild rye and sedges or rushes in wet areas.	Soils: Deep and moderately deep medium textured soils on flood plains. Alkaline and poorly drained soils may occur in concave areas. Soil Landscape Units 1a & 1b

Limitations: Flood hazard, poor drainage and alkalinity (in local areas)

Land use:
Predominantly field crops and meadows intermingled with many of the crops under irrigation.

Land Resource Unit 12 Description: Terraces

Extent: 35,000 acres, 1.8 % of the county. Elevation: 3000 to 4500 feet

Distribution: In major valleys of western and southeastern Crook County

Climate: Ann. ppt. 9-16 in. Mean ann. temp. 45-49° F Frost free days (32°) 50-80

Landscape and Topography: Nearly level to gently sloping terraces, along margins of major valleys. Some terraces are dissected by numerous, steep-walled gullies.	Geology: Thick, unconsolidated silts, sands, and gravels of valley bottoms. Good groundwater source. Gravel mined at terrace scarp.
Vegetation: Predominantly shrub steppe with juniper intermixed and with some extensive areas of big sagebrush.	Soils: Medium textured soils, which are moderately deep to a cemented hardpan. Soil Landscape Unit 1b

Limitations: Moderate depth to hardpan

Land use:
Predominantly irrigated field crops and extensive areas of range grass seedings with inclusions of patches of greasewood in some locations.

Land Resource Unit 13 Description: Poorly drained, and alkali areas

Extent: 6,400 acres, .3 % of the county. Elevation: 2900 to 4200 feet

Distribution: Southeastern Crook County, near headwaters of South Fork of Crooked River

Climate: Ann. ppt. 9-12 in. Mean ann. temp. 44-50° F Frost free days (32°) 50-80

Landscape and Topography:
Nearly level and slightly concave areas in major valleys.

Geology:
Thick, unconsolidated muds and silts with alkaline soils. Subject to flooding.

Vegetation:
Meadows and field crops intermingled with greasewood and salt grass.

Soils:
Medium and moderately fine-textured soils which are somewhat poorly drained. Alkaline areas are common.

Soil Landscape Unit 1b

Limitations: Flood hazard, alkalinity, poor drainage, low permeability

Land use:
In addition to field crops, range grass seedings with patches of greasewood intermingled.

Land Resource Unit 20 Description: Alluvial fans and pediments

Extent: 77,000 acres, 4 % of the county. Elevation: 3000 to 5000 feet

Distribution: Western and southeastern portions of Crook County

Climate: Ann. ppt. 9-15 in. Mean ann. temp. 46-50° F Frost free days (32°) 50-80

Landscape and Topography:
Gently sloping, slightly to moderately dissected alluvial fans and footslopes adjacent to several mountainous areas.

Geology:
Poorly sorted, unconsolidated sands and gravels of alluvial fans and pediments. Material generally thick on fans and thin on pediments.

Vegetation:
Predominantly juniper, shrub steppe with low sagebrush on the shallower soils, juniper or meadow intermixed with shrub steppe and Ponderosa Pine locally important on upper slopes.

Soils:
Shallow and moderately deep, medium and coarse-textured, gravelly soils with a strongly cemented hardpan.

Soil Landscape Units 3a & 3b

Limitations: Shallow to firmly cemented hardpan

Land use:
Predominantly irrigated field crops, range grass seedings, and a cultural juniper/grass savanna.

Land Resource Unit 31   Description: Basalt plains, with moderately deep loamy and sandy soils.

Extent: 34,000 acres, 1.8 % of the county. Elevation: 3000 to 4500 feet

Distribution: Western and southwestern Crook County

Climate: Ann. ppt. 9-12 in.   Mean ann. temp. 47-50° F   Frost free days (32°) 50-80

Landscape and Topography: Nearly level to gently rolling, older lava flows, which are largely covered by a thin mantle of wind-transported silt, sand and volcanic ash.	Geology: Hard basalt lava flows less than about 6 million years old. Individual flows 10 to 30 feet thick. Entire set of flows usually less than 100 feet thick. Locally, ancient vents from which the flows issued are present.
Vegetation: Predominantly juniper and juniper/low sagebrush savanna with areas of big sagebrush.	Soils: Shallow, very shallow and moderately deep, medium textured soils, some of which are stony. Soil Landscape Unit 4a

Limitations: Shallow and moderately deep to rock

Land use:
Grazing and irrigated field crops, where water is available.

Land Resource Unit 32 Description: Welded tuff plains with shallow loamy soils

Extent: 61,000 acres, 3.2 % of the county. Elevation: 3000 to 5000 feet

Distribution: South-central Crook County

Climate: Ann. ppt. 9-12 in. Mean ann. temp. 47-50° F Frost free days (32°) 50-80

Landscape and Topography:
Nearly level to gently rolling volcanic plateaus.

Geology:
Hard welded tuff with associated soft sedimentary materials. Welded tuffs generally form cliff-bounded rimrocks with sediments underneath.

Vegetation:
Predominantly juniper with areas of big sagebrush.

Soils:
Shallow, very shallow and moderately deep, medium textured soils, some of which are stony.

Soil Landscape Unit 4a

Limitations: Depth to rock

Land use: Range grass seedings.

Land Resource Unit 33 Description: Basalt plains with shallow clayey soils

Extent: 61,000 acres, 3.2 % of the county. Elevation: 4500 to 5000 feet

Distribution: Southeastern Crook County

Climate: Ann. ppt. 9-12 in. Mean ann. temp. 47-50° F Frost free days (32°) 50-80

Landscape and Topography:
Nearly level to gently rolling volcanic plateaus.

Geology:
Hard basalt lava flows less than 6 million years old. Ancient vents from which the flows issued are locally present. Individual flows 10 to 30 feet thick. Entire set of flows usually less than 100 feet thick.

Vegetation:
Predominantly low sagebrush with areas of other kinds of shrub steppe and of juniper.

Soils:
Shallow and very shallow, stony and very stony, loamy soils with clayey subsoils.

Soil Landscape Unit 6a

Limitations: Depth to rock, stoniness and texture

Land use:
Grazing

Land Resource Unit 34   Description: Welded Tuff Plains with shallow, clayey and loamy soils

Extent: 102,000 acres, 5.4 % of the county. Elevation: 4000 to 5000 feet

Distribution: Southeastern Crook County

Climate: Ann. ppt. 9-12 in.   Mean ann. temp. 47-50° F   Frost free days (32°) 50-80

Landscape and Topography: Slightly dissected, gently rolling volcanic plains.	Geology: Hard welded tuff with associated soft sedimentary materials. Welded tuffs generally form cliff-bounded rimrocks with sediments underneath.
Vegetation: Predominantly shrub steppe with some areas of low sagebrush and juniper/low sagebrush savanna.	Soils: Shallow and very shallow, stony and very stony, soils with clayey subsoils. Soil Landscape Units 6a & 6b

Limitations: Depth to rock, stoniness, and texture

Land use:
Grazing

Land Resource Unit 35	Description: Fresh basalt mixed with loamy and sandy soils of varying depth
Extent: 64,000 acres, 3.4 % of the county.	Elevation: 3000 to 4000 feet
Distribution: Western Crook County	
Climate: Ann. ppt. 9-12 in. Mean ann. temp. 47-50° F	Frost free days (32°) 50-80
Landscape and Topography: Younger lava flows, which retain pronounced microtopography. Bare rock is common on convex areas.	Geology: Hard, fairly fresh basalt lava flows retaining many irregular features of the original flow surface. Individual flows 10 to 30 feet thick. Rock exposures common. Younger than units 31 or 33, perhaps 1-2 million years old.
Vegetation: Juniper on the rock outcrops.	Soils: Shallow and moderately deep, medium and coarse-textured soils, in nearly level and concave areas. Soil Landscape Units 4c & 4d
Limitations: Common rock outcrops, and limited soil depth	
Land use: Grazing, range grass seedings on interspersed soil.	

Land Resource Unit 41 Description: Rolling and gently rolling basalt upland

Extent: 192,000 acres, 10 % of the county. Elevation: 3500 to 5000 feet

Distribution: Western and eastern Crook County

Climate: Ann. ppt. 10-16 in. Mean ann. temp. 45-50° F Frost free days (32°) 50-80

Landscape and Topography: Moderately dissected, rolling and steeply rolling volcanic plateau.	Geology: Hard lava flows from 14 to 18 million years old (Columbia River Basalt). Individual flows are 50 to 100 feet thick with well developed columnar jointing. Total thickness of unit is several 100 feet. Landsliding on underlying tuffs is common at margin of unit.
Vegetation: Predominantly low sagebrush with areas of juniper, other kinds of shrub steppe.	Soils: Shallow and very shallow, stony and very stony soils with clayey subsoils. Soil Landscape Units 6a & 6b

Limitations: Depth to rock, and stoniness

Land use:
Grazing

Land Resource Unit 42 Description: Rolling and gently rolling upland of soft volcanic sediments

Extent: 48,000 acres, 2.5 % of the county. Elevation: 4000 to 4500 feet

Distribution: Eastern Crook County, near Paulina

Climate: Ann. ppt. 10-13 in. Mean ann. temp. 45-50° F Frost free days (32°) 70-90

Landscape and Topography:
Gently rolling and rolling terrain rising gradually from flood plains to rimrocks which bound the adjacent plateaus.

Geology:
Soft sedimentary materials with associated hard welded tuff. Welded tuffs generally form rimrocks with sediments underneath.

Vegetation:
Predominantly low sagebrush with areas of other kinds of shrub steppe and juniper.

Soils:
Shallow and moderately deep soils over soft sedimentary rocks.

Soil Landscape Unit 5

Limitations: Moderately slow permeability

Land use:
Grazing, with some reseeded range and local irrigated crops.

Land Resource Unit 51 Description: Somewhat dissected, hilly to steeply rolling, soft volcanic sediments

Extent: 67,000 acres, 3.5 % of the county. Elevation: 3500 to 5000 feet

Distribution: Central Crook County

Climate: Ann. ppt. 10-14 in. Mean ann. temp. 45-49° F Frost free days (32°) 50-100

Landscape and Topography: Moderately dissected, rolling and steeply rolling terrain.	Geology: Soft volcanic sediments and tuffs, mostly altered to clay minerals. Easily eroded. Clays expansive and prone to landsliding. North of Prineville Reservoir includes hard, resistant welded tuff layers. Mostly John Day Formation.
Vegetation: Predominantly juniper, some shrub steppe, and some Ponderosa Pine at higher elevations.	Soils: Moderately deep, shallow, and deep clayey soils. Soil Landscape Unit 7a

Limitations: Slow and very slow permeability, poor foundation stability

Land use:
Grazing

Land Resource Unit 52 Description: Strongly dissected, hilly to steeply rolling soft volcanic sediments

Extent: 90,000 acres, 4.7 % of the county. Elevation: 3500 to 5000 feet

Distribution: Central and southern Crook County

Climate: Ann. ppt. 10-14 in. Mean ann. temp. 45-49° F Frost free days (32°) 50-100

Landscape and Topography:	Geology:
Steeply rolling, strongly dissected terrain with common exposures of soft sedimentary rocks.	Soft volcanic sediments and tuffs. Mostly somewhat less altered than 51. Easily eroded, with badland topography locally developed. Includes material from several different geologic formations.
Vegetation:	**Soils:**
Juniper on side slopes and ridges.	Shallow and moderately deep, clayey soils. Moderately deep, loamy soils occur on north slopes. Soil Landscape Unit 7b

Limitations: Steep slope, fine texture and poor foundation stability in some places

Land use:
Intermingled range grass seedings, field crops and meadow in the bottoms.

Land Resource Unit 53 Description: Hilly to steeply rolling Clarno volcanic flows, breccias, and sediments

Extent: 262,000 acres, 13.8 % of the county. Elevation: 3000 to 5000 feet

Distribution: Western Crook County

Climate: Ann. ppt. 10-18 in. Mean ann. temp. 45-50° F Frost free days (32°) 50-100

Landscape and Topography:
Steeply rolling, dissected terrain, with commor small rock outcrops.

Geology:
Volcanic flows, breccias, and sediments of the Clarno Formation. Flows are mostly very hard, while sediments may be soft. Much clay mineral alteration. High landslide potential.

Vegetation:
Predominantly juniper with some areas of shrub steppe intermixed and Ponderosa Pine, Douglas Fir, or mixed conifer at higher elevations.

Soils:
Shallow and moderately deep, stony and very stony, medium and fine-textured soils predominate.

Soil Landscape Unit 9a & 9b

Limitations: Slope, stoniness and depth

Land use:
Grazing

Land Resource Unit 54 Description: Hilly to steeply rolling basalt and andesite

Extent: 64,000 acres, 3.3 % of the county. Elevation: 4500 to 5500 feet

Distribution: Southeastern and southwestern Crook County

Climate: Ann. ppt. 12-16 in. Mean ann. temp. 45-49° F Frost free days (32°) 50-100

Landscape and Topography: Moderately dissected, hilly to steeply rolling.	Geology: Hard lava flows. Thick, columnar jointed basalt flows around MacKay Butte. Platy, jointed andesite flows and a silicic vent around Gerry Mountain.
Vegetation: Predominantly shrub steppe including areas of low sagebrush and big sagebrush with areas of juniper and with some Ponderosa Pine at higher elevations. Idaho fescue is the most important grass.	Soils: Shallow, very shallow and moderately deep, stony and very stony, loamy soil with clayey subsoils. Moderately deep medium-textured soils occur on some north slopes. Soil Landscape Unit 8a

Limitations: Slope, depth and stoniness

Land use:
Grazing

Land Resource Unit 55 Description: Hilly to steeply rolling rhyolitic flows

Extent: 35,000 acres, 1.8 % of the county. Elevation: 3500 to 5500 feet

Distribution: Higher elevations in western Crook County

Climate: Ann. ppt. 9-12 in. Mean ann. temp. 45-50° F Frost free days (32°) 50-100

Landscape and Topography: Moderately to strongly dissected, hilly to steeply rolling.	Geology: Hard rhyolite flows and domes in western Crook County. Probably old volcanoes (John Day Formation).
Vegetation: Predominantly either low sagebrush or juniper, depending on location.	Soils: Shallow, moderately deep and deep, medium-textured soils. Soil Landscape Units 9c & 7a

Limitations: Slope, stoniness and depth

Land use:

Grazing, with localized small grain in small valleys.

Land Resource Unit 56 Description: Hilly to steeply rolling, folded and faulted older rocks

Extent: 29,000 acres, 1.5 % of the county. Elevation: 4500 to 5500 feet

Distribution: Eastern edge of Crook County

Climate: Ann. ppt. 13-16 in. Mean ann. temp. 43-47° F Frost free days (32°) 30-60

Landscape and Topography:

Geology:
Severely folded and faulted older rocks of eastern Crook County. All Pre-Tertiary (>70 million years) in age. A wide range of clastic sedimentary, volcaniclastic, and volcanic rocks is present as well as minor amounts of limestone.

Vegetation:
Same as Unit 54

Soils:
Shallow and moderately deep, medium-textured, stone-free soils predominate.

Soil Landscape Units 8b & 8c

Limitations: Slope and depth

Land use:
Grazing, with dryland small grain locally in small valleys.

Land Resource Unit 61 Description: Dissected, rolling to gently rolling Columbia river basalt scabland

Extent: 134,000 acres, 7 % of the county. Elevation: 4000 to 5500 feet

Distribution: Northeastern Crook County

Climate: Ann. ppt. 16-20 in. Mean ann. temp. 45-49° F Frost free days (32°) 40-80

Landscape and Topography:
Gently rolling and nearly level plateaus which are moderately dissected, and rolling plateaus which are strongly dissected.

Geology:
Hard lava flows from 14 to 18 million years old (Columbia River Basalt). Individual flows are 50 to 100 feet thick with well developed columnar jointing. Total thickness of unit is several 100 feet. Landsliding on underlying tuffs is common at margin of unit.

Vegetation:
Predominantly low sagebrush on the scabby ridges with Ponderosa Pine and Douglas Fir in the draws.

Soils:
Very stony, shallow and very shallow soils, with low sagebrush. Moderately deep loamy and clayey soils support Ponderosa Pine.

Soil Landscape Units 10 & 11

Limitations: Depth and stoniness

Land use:
Grazing, with scattered logging.

Land Resource Unit 62 Description: Dissected, rolling to gently rolling Columbia river basalt plateau

Extent: 32,000 acres, 1.6 % of the county. Elevation: 4500 to 7000 feet

Distribution: Northeast Crook County

Climate: Ann. ppt. 16-25 in. Mean ann. temp. 44-47° F Frost free days (32°) 40-80

Landscape and Topography:
Rolling and gently rolling plateau, which is dissected by numerous small, forested canyons.

Geology:
Hard lava flows from 14 to 18 million years old (Columbia River Basalt). Individual flows are 50 to 100 feet thick with well developed columnar jointing. Total thickness of unit is several 100 feet. Landsliding on underlying tuffs common at margin of unit.

Vegetation:
Predominantly Ponderosa Pine with mixed conifer at higher elevations or on north slopes and low sagebrush intermixed on the scabby ridges.

Soils:
Shallow and moderately deep, loamy and clayey soils under timber with very shallow and stony soils on broad ridges.

Soil Landscape Unit 11

Limitations: Depth, stoniness and slope

Land use:
Logging and grazing.

Land Resource Unit 63 Description: Dissected, rolling to mountainous Columbia river basalt plateau

Extent: 36,000 acres, 1.9 % of the county. Elevation: 5000 to 7000 feet

Distribution: Northeastern Crook County

Climate: Ann. ppt. 18-25 in. Mean ann. temp. 44-47° F Frost free days (32°) 40-80

Landscape and Topography:
Rolling and mountainous terrain which is mostly timbered but has common openings, especially on south slopes.

Geology:
Hard lava flows from 14 to 18 million years old (Columbia River Basalt). Individual flows are 50 to 100 feet thick with well developed columnar jointing. Total thickness of unit is several 100 feet. Landsliding on underlying tuffs common at margin of unit.

Vegetation:
Predominantly Ponderosa Pine with either Douglas Fir or subalpine fir/shrub steppe at higher elevations.

Soils:
Moderately deep and deep, loamy and clayey soils.

Soil Landscape Units 13a, 13b & 11

Limitations: Depth, slope and stoniness on south aspects; slope on north aspects

Land use:
Logging and grazing

Land Resource Unit 71 Description: Somewhat dissected, moderately sloping forested upland, on mixed volcanic rocks of the Clarno formation

Extent: 90,000 acres, 4.7 % of the county. Elevation: 4000 to 5500 feet

Distribution: Northern and central Crook County

Climate: Ann. ppt. 16-25 in. Mean ann. temp. 43-45° F Frost free days (32°) 20-60

Landscape and Topography:
Moderately dissected rolling and hilly terrain, with occasional small rock outcrops.

Geology:
Volcanic flows, breccias, and sediments of the Clarno Formation. Flows are mostly very hard, while sediments may be soft. Much clay mineral alteration. High landslide potential.

Vegetation:
Predominantly Ponderosa Pine, mostly on south slopes, Douglas Fir at higher elevations or on gentle north slopes, and mixed conifer on steeper north slopes.

Soils:
Moderately deep and deep, fine-textured soils.

Soil Landscape Units 12a & 12b

Limitations: Clayey subsoil

Land use:
Logging with some grazing
Cultural Ponderosa Pine/grass savanna (brush removed).

Land Resource Unit 72 Description: Steeply sloping, forested mountainous terrain on mixed volcanic rocks of the Clarno formation

Extent: 166,000 acres, 8.7 % of the county. Elevation: 3500 to 6000 feet

Distribution: Northern and central Crook County

Climate: Ann. ppt. 18-25 in. Mean ann. temp. 43-45° F Frost free days (32°) 20-60

Landscape and Topography:
Steeply sloping, forested, terrain, with occasional rock outcrops.

Geology:
Volcanic flows, breccias, and sediments of the Clarno Formation. Flows are mostly very hard, while sediments may be soft. Much clay mineral alteration. High landslide potential.

Vegetation:
Predominantly Ponderosa Pine, mostly on south slopes, Douglas Fir at higher elevations or on gentle north slopes, mixed conifer on steeper north slopes, and a small amount of juniper at lower elevations at the north edge of the county.

Soils:
Moderately deep and shallow, loamy and clayey soils on south exposures; similar but deeper soils occur on north exposures.

Soil Landscape Units 13a, 13b, & 14b

Limitations: Slope and stoniness

Land use:
Logging, with some grazing

Land Resource Unit 73 Description: Steep, mountainous, heavily forested north slopes on mixed volcanic rocks of the Clarno formation

Extent: 83,000 acres, 4.4 % of the county. Elevation: 3500 to 6000 feet

Distribution: North-central Crook County

Climate: Ann. ppt. 18-25 in. Mean ann. temp. 40-45° F Frost free days (32°) 20-60

Landscape and Topography:
Steep, mountainous terrain with north slopes predominating. Rock outcrops are common, but not large.

Geology:
Volcanic flows, breccias, and sediments of the Clarno Formation. Flows are mostly very hard, while sediments may be soft. Much clay mineral alteration. High landslide potential.

Vegetation:
Predominantly mixed conifer on the steep north slopes, Douglas Fir on gentler north slopes, with a small amount of Ponderosa Pine at lower elevations.

Soils:
Moderately deep and deep, loamy and clayey soils.

Soil Landscape Unit 14b

Limitations: Slope and rock outcrops

Land use:
Timber production, recreation and watershed

Land Resource Unit 74 Description: Gently rolling rhyolite plateau

Extent: 7,700 acres, .4 % of the county. Elevation: 5000 to 6000 feet

Distribution: Northern Crook County

Climate: Ann. ppt. 20-25 in. Mean ann. temp. 40-43° F Frost free days (32°) 20-60

Landscape and Topography:
Gently sloping and nearly level, heavily forested plateau, with scattered meadows.

Geology:
Hard rhyolite flows.

Vegetation:
Mixed conifer.

Soils:
Moderately deep and deep loamy soils predominate.

Soil Landscape Unit 14a

Limitations: Low temperature

Land use:
Timber production, recreation and grazing in mountain meadows

Land Resource Unit 75 Description: Strongly dissected welded tuff plateau

Extent: 9,000 acres, .5 % of the county. Elevation: 4500 to 5000 feet

Distribution: Southeast corner of Crook County

Climate: Ann. ppt. 16-20 in. Mean ann. temp. 45-47° F Frost free days (32°) 50-80

Landscape and Topography:
Nearly level to gently rolling ridges separated by small canyons.

Geology:
Hard welded tuff with associated soft sedimentary materials. Welded tuffs generally form cliff-bounded rimrocks with sediments underneath.

Vegetation:
Ponderosa Pine, Idaho fescue and elk sedge.

Soils:
Shallow and moderately deep, gravelly, and stony, loamy soils.

Soil Landscape Unit 13c

Limitations: Depth and coarse fragments

Land use:
Timber production, grazing and water supply

Land Resource Unit 90 Description: Canyons

Extent: 46,000 acres, 2.4 % of the county. Elevation: 3000 to 4500 feet

Distribution: Western and central Crook County

Climate: Ann. ppt. 9-18 in. Mean ann. temp. 46-50° F Frost free days (32°) 50-100

Landscape and Topography:
Very steep slopes with common rock outcrops. Local relief averages 500 feet or more.

Geology:
Canyons, mostly with basalt of welded tuff rimrock and softer material below. Near Prineville Reservoir entirely excavated in basalt.

Vegetation:
Predominantly sagebrush with Ponderosa Pine intermixed on deeper soils at higher elevations, other kinds of shrub steppe intermixed at lower elevations, with juniper on rock outcrops and steep rocky slopes at lower elevations, and riparian vegetation (not identified or mapped).

Soils:
Shallow and very shallow stony and rocky soils predominate.

Soil Landscape Unit 15a

Limitations: Steep slope, rock outcrops and stoniness

Land use:
Grazing

Land Resource Unit 91 Description: Landslide areas associated with canyons

Extent: 7,700 acres, .4 % of the county. Elevation: 3000 to 4500 feet

Distribution: Western and central Crook County

Climate: Ann. ppt. 9-16 in. Mean ann. temp. 48-50° F Frost free days (32°) 80-100

Landscape and Topography:
Irregular, hummocky terrain, with common closed depressions, usually adjacent to a steep canyon wall.

Geology:
Landslide areas associated with canyons. Generally result when rimrock blocks collapse on softer underlying materials.

Vegetation:
These occur in areas mapped as juniper but may have other vegetation more abundant locally.

Soils:
Moderately deep and deep, loamy and clayey soils. Large boulders may be common locally.

Soil Landscape Unit 15b

Limitations: Unstable, with very irregular microrelief

Land use:
Grazing

VI. APPENDIX B: SEPARATE PAPERS IN GEOLOGY

Appendix B-1

LARGE SCALE TEAR FAULTING AT THE NORTHERN TERMINATION OF THE BASIN AND RANGE PROVINCE IN OREGON

Robert D. Lawrence

Abstract

The pattern of faulting in southeast Oregon is interpreted in terms of four major zones of right lateral tear faulting which separate blocks broken by normal faulting. The total amount of east-west extension is considered to decrease in the block north of each tear fault zone. The right lateral offset results from the decrease in extension. Extension essentially dies out across the Vale and Brothers fault zones which are thus considered the northern limit of the Basin and Range Province. The greatest offset is apparently recorded on the Eugene-Denio zone by the displacement of the eastern edges of the Sierra Nevada and Idaho Batholiths. The Eugene-Denio and Mt. McLoughlin zones offset the Pleistocene to Holocene trend of the High Cascades by 10 to 20 km in a right lateral sense. The Brothers fault zone is regarded as of special interest because both ends of the fault are interpreted to be exposed at the surface.

Introduction

Much discussion of the characteristics of faulting in the Basin and Range Province of western North America has resulted in general agreement that these structures are the surface expression of overall east-west extension of the province during Late Cenozoic time. The total amount of extension involved remains uncertain with published estimates ranging from 50 km to 200 km across the center of the province (Hamilton and Meyers, 1966; Stewart, 1971; Thompson and Burke, 1974). These figures suggest strain rates for the province between 10^{-16} and 10^{-15}/sec. For the Dixie Valley area Thompson and Burke (1973) give an average spreading rate over the last 15 million years of 0.4 cm/yr and a greater rate of about 1.0 cm/yr over the last 12,000 years. These results are comparable to those calculated for the whole province. To date little attention has been focused on the manner in which this motion terminates to the north. The present paper offers one hypothesis on this question.

The structural pattern of Oregon was studied on red band (Band 5) and infrared band (Band 7) satellite imagery recorded by the ERTS-1 (Earth Resources Technology Satellite). Figure 1 is a black and white mosaic of fall 1972 band 5 imager illustrating the proposed hypothesis. It shows a series of west-northwest trending tear fault zones with postulated right-lateral strike slip displacement separating areas of normal faulting. More extension is suggested for successively more southerly areas of normal faulting, culminating somewhere in central Nevada in the 50 to 200 km maximum cited above. The difference in net motion between zones is accommdated by offset on the intervening tear faults. Thus four identified tear fault zones cut through southeast Oregon and form the transition between the main Basin and Range extension province of Nevada and the largely unfaulted Columbia River Plateau of north-central Oregon and southeast Washington.

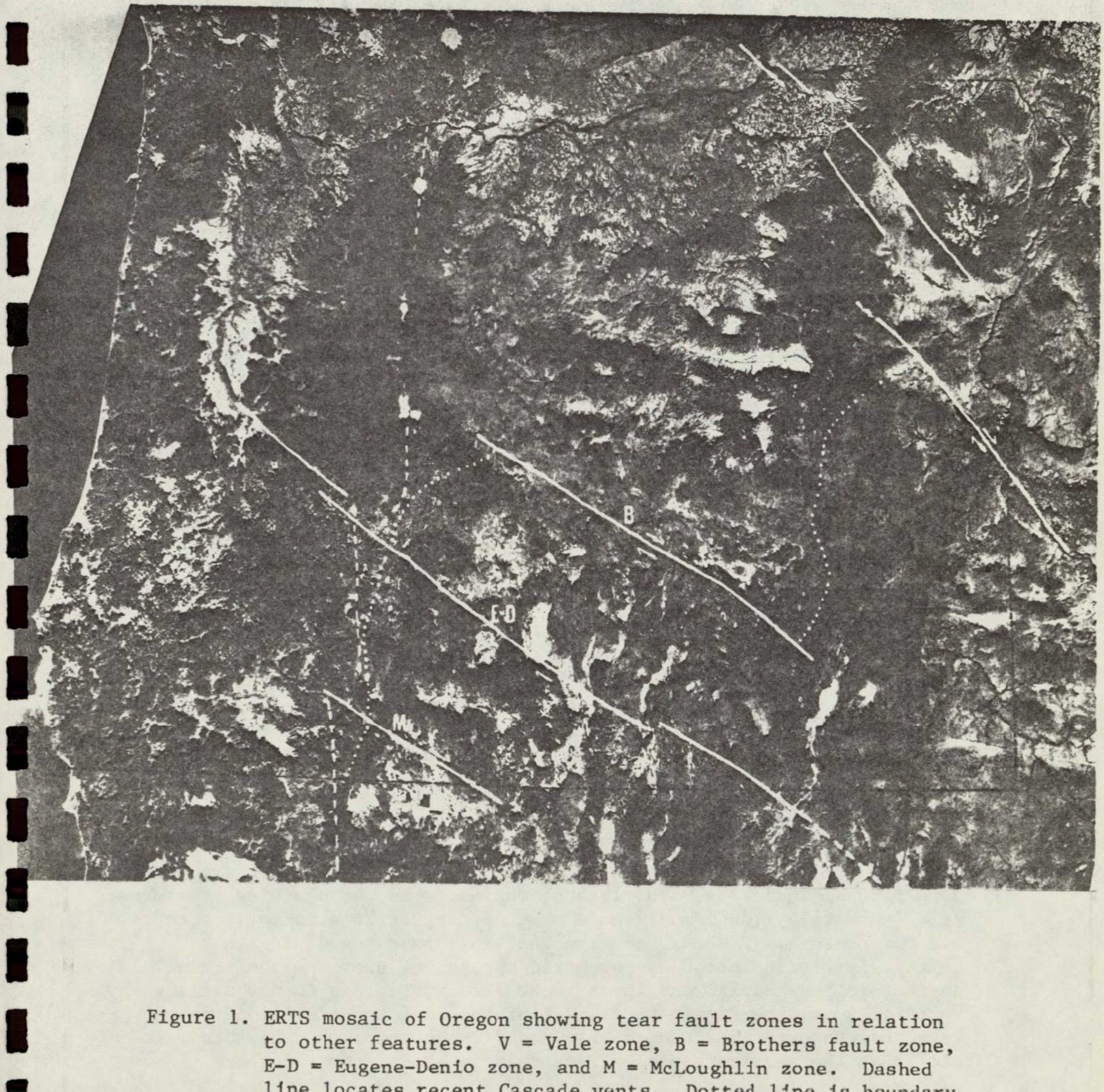

Figure 1. ERTS mosaic of Oregon showing tear fault zones in relation to other features. V = Vale zone, B = Brothers fault zone, E-D = Eugene-Denio zone, and M = McLoughlin zone. Dashed line locates recent Cascade vents. Dotted line is boundary of Basin and Range Province.

The Tear Fault Zones

Four zones extending west-northwest across much of Oregon are suggested as tear fault zones. Of these the Brothers fault zone has been named and briefly described (Walker, 1969 and Higgins and Waters, 1967). Informal names proposed herein for the other zones are the Vale zone and Eugene-Denio zone, shown by Walker (1973), and the Mt. McLoughlin zone, parts of which are described by Pease (1969). The four zones are nearly parallel, and all break rocks of Pliocene or younger age. If faulting began at the same time as Basin and Range faulting in general, it has continued for the last 15 to 17 million years (Noble, 1972; Christiansen and Lipman, 1972).

The Brothers Fault Zone. The clearest relationships occur along the Brothers fault zone which extends about 300 km along a N60°W trend across central Oregon. This zone has a distinct east end at the Steens fault, one of the largest normal faults in Oregon. East of the Steens fault, normal faults of the Basin and Range type extend further north into the state until they are largely terminated against the Vale fault zone. West of the Steens fault, normal faults largely end against the Brothers fault zone. North of this zone, recent deformation has largely involved folding and faulting on east-west and northwest trends (Walker, 1973; Brown and Thayer, 1966). Thus the area north of the Brothers fault zone may be considered nearly stable in an east-west direction, while the area south of it shows extension in this direction. As the Steens fault extends across the end of the Brothers fault zone, this end of the system can be considered fixed during at least the most recent history of the system. The result of these considerations is that the area south of the system must move west with respect to that to the north (Figure 2), producing a right-lateral tear fault. The amount of offset should increase from east to west along the fault. Unfortunately the western end of the fault occurs in very young rocks and is obscured by Holocene ash from Newberry Caldera so that such effects are not recorded.

The details of the Brothers fault zone support the preceding interpretation. The zone is made up of a series of discontinuous en echelon fractures trending about N40°W. Many of these are apparently short normal faults, 10-20 km long, with intervening minor horsts and grabens. Less abundant faults, about 5 km long, trend about N30°E. This pattern is the same as that of strike slip shear zones on many scales. The detailed analysis of such structures by Tchalenko (1970) suggests that the en echelon fractures are Riedel shears and the shorter fractures are conjugate Riedel shears. The acute angle between the trend of the en echelon fractures (N40°W) and that of the overall shear zone (N60°W) indicates right lateral motion. The throughgoing fractures, call P shears by Tchalenko, where most of the strike slip motion occurs are not present. P shears are the last to appear suggesting that relatively little motion has occurred across the Brothers fault zone. As the Brothers fault zone is in rocks almost all less than 6 million years old, and the strain rate south of the zone is herein considered less than that for the central Basin and Range Province, the total strain at the surface could be less than is needed for a P shear

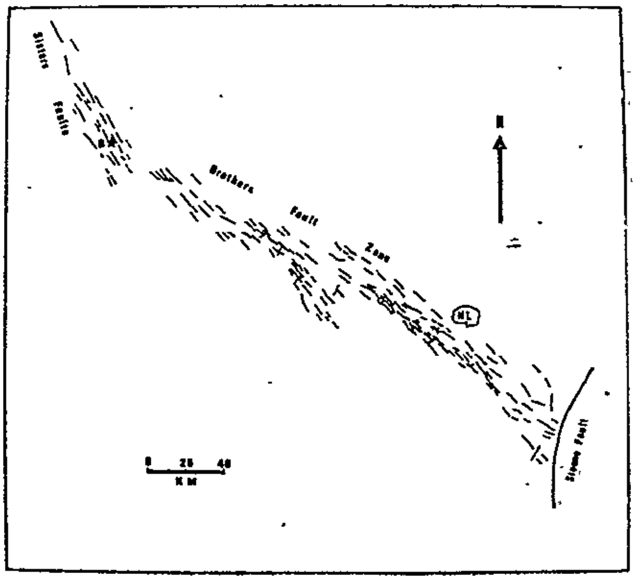

Figure 2. The Brothers fault zone as an en echelon set of fractures along a right lateral shear zone (mapped on ERTS imagery). B = Bend and HL = Harney Lake.

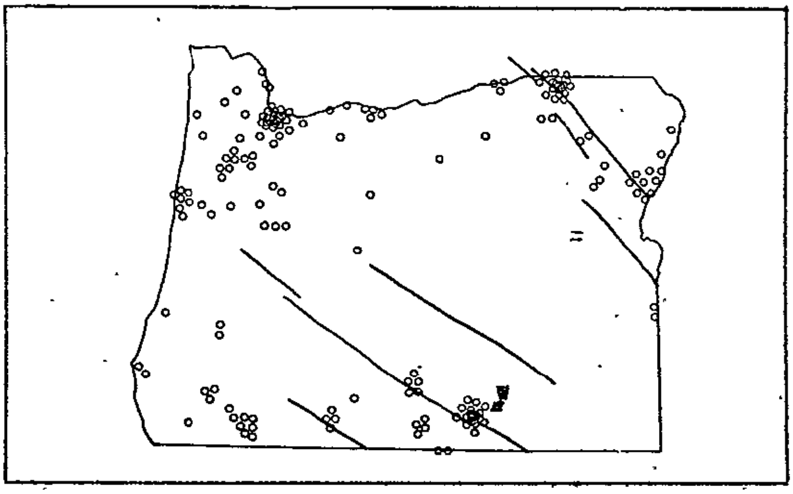

Figure 3. Earthquake epicenters in Oregon, 1841-1970 (after Couch and Lowell, 1971). W = Warner Valley swarm.

system. The presence of a concentration of volcanic vents along the zone supports the notion that it is a relatively deep seated, fundamental tectonic feature, in spite of relatively limited visible offset. These vents become younger from east to west (Walker, 1974). If volcanism is concurrent with motion, this suggests that motion on the zone has also migrated from east to west.

The Vale Zone. As noted above, normal faults extend north through the Owyhee Uplands east of the Steens fault. This area of extension ends mainly at the Vale zone. The location of this zone is based on the consistent linear trend of Willow Creek and of portions of the Snake River in Idaho, on parallel lineaments in the mountains to the west, and on termination of abundant normal faults at these features. The zone trends about N50-55°W. Heat flow data of Bowen and Fisher (personal communication, 1974) show a sharp drop across it. In Idaho, Basin and Range faulting extends farther to the north. Thus the Vale zone is relatively short. The amount of right-lateral motion involved in this zone is presumed to be quite small (a few kilometers?) as the area of extension is narrow. Similar motion may continue on the faults extending from Walla Walla across the southern Wallowa Mountains to the Snake River. First motion results from an earthquake in the southern Wallowa Mountains (Couch and Whitsett, 1969) are consistent with right-lateral motion.

The Eugene-Denio Zone. Another band of fractures extends across most of Oregon about 100 km southwest of the Brothers fault zone. East of the 121st meridian much of this band has been mapped by Walker (1974). The overall zone trends N55-60°W and individual fractures trend about N50°W. The individual fractures are not interconnected and most are less than 10 km long. The en echelon pattern is less clear than on the Brothers fault zone, but has the same implication of right lateral motion. The zone has been mapped through the Cascade Range as a series of lineaments. Many of these cross drainage divides without deflection indicating structural control. The High Cascade volcanic trend has about 10 to 20 km of right lateral offset across the zone. At least two discontinuous offsets of the zone itself are present (Figure 1).

This zone is associated with major changes in the Basin and Range pattern. The Summer Lake, Lake Abert, and Klamath Marsh basins and associated faults terminate against the zone. The Warner Lake basin is constricted and slightly offset by the zone. The Pueblo and Pine Forest Ranges and associated basins are offset along the zone. Similar disturbances of the Basin and Range pattern can be traced on ERTS imagery to the southeast across much of Nevada. A maximum estimate of the displacement along this zone may be derived from Taubeneck (1971) who estimates that as much as 80 km of offset in the alignment of the Idaho and Sierra Nevada batholiths has been accomplished by normal faulting, dike intrusion, and right lateral faulting since the end of the Oligocene. The Eugene-Denio zone is located properly to produce a significant part of this motion.

The Mt. Mcloughlin Zone. The southwestern zone is similar to the Eugene-Denio zone in character. It includes many fractures interpreted as right-lateral fractures by Pease (1969). Individual fractures of the zone trend about N45°W and the overall zone trends about N50-55°W, with the same implication as in each of the two zones to the north. At Mt. McLoughlin this zone offsets the High Cascade trend about 15-20 km in a right lateral sense. This zone does not obviously extend far into Nevada as does the Eugene-Denio zone.

Basin and Range Faulting in Oregon

The physiographic expression of the Basin and Range faulting in Oregon changes dramatically across the Eugene-Denio zone (Figure 1). North of the zone, many fault scarps such as Walker Rim, Winter Rim, Abert Rim and Warner Rim are little modified by erosion. The volcanic uplands of the ranges probably retain nearly the surface formed by the most recent lava flows. The flat surfaces are clearly marked by numerous fractures of lesser offset. Thus the area north of the Eugene-Denio zone retains the features of a lava plain broken by block faulting but otherwise little modified. South of this zone, in most of the major ranges the original volcanic surfaces have been destroyed by erosion. Many fault line scarps are present where weathering and erosion have produced scarp retreat. Only locally do unaffected faults occur. Locally the contrast is related to changes in attitude and rock type across the zone which make erosion earier and more rapid to the south. The consistent contrast suggests, however, that major faults appeared earlier, perhaps by several million years, south of the zone than north of it. While such an age contrast cannot be demonstrated from existing data it is suitable to the hypothesis of this paper. Since significant strain must precede faulting, the greater total strain proposed for the area south of the Eugene-Denio zone would lead to earlier faulting than would occur north of the zone.

Studies of the seismicity of the Basin and Range Province in Oregon are consistent with the concepts developed herein. Oregon has generally lower seismicity than the surrounding region, both in earthquake frequency and magnitude. Earthquake epicenters from 1841-1970 (Couch and Lowell, 1971) are plotted on Figure 3 along with the tear fault zones suggested in this discussion. Within the Basin and Range Province most of the seismicity occurs along or south of the Eugene-Denio zone. The greatest concentration is the Warner Valley earthquake sequence which coincides with one of the discontinuities in the zone. The lack of earthquakes north of this zone is interpreted as a result of the lower strain rate. First motion studies of the Warner Valley earthquake sequence (Couch and Johnson, 1968) indicate normal faulting on approximately north-south trends for 8 shocks and either right lateral faulting on west-northwest trends or left lateral faulting on north-northeast trends for 2 shocks. The right lateral result fits the trend of the Eugene-Denio zone. As the sequence is located where both kinds of fault (normal and tear) are postulated to occur, these first motion results fit readily with the interpretation offered.

The most detailed study of the Basin and Range faulting in Oregon is that of Donath (1962) in the Summer Lake area, which clearly identified two major fault trends: about N20-30°E and N30-40°W. Donath interpreted this rhombic pattern as due to north-south compression that produced a conjugate set of vertical strike slip faults. More recent block faulting was considered to have produced the vertical offsets. He indicated that most of the exposed faults were vertical or nearly vertical in attitude. If this is correct no extension occurs on the faults. This is in marked contrast to relations for the Basin and Range Province as a whole where similar rhombic patterns are produced simultaneously with extension (Thompson and Burke, 1974). The interlocking pattern of fault traces and irregular distribution of offsets were interpreted by Donath as evidence that all of the recent motion for which there is evidence is dip slip. No offset markers or other evidence except the conjugate pattern could be found which demonstrated an earlier episode of strike slip motion.

The pattern studied by Donath can be traced over the entire region on the ERTS-1 imagery. This imagery clearly shows that the same pattern is present throughout the area between the Brothers fault zone and the Eugene-Denio zone. The major basins and rim faults are mostly related to the northeast-trending fault set, Winter Rim being the most conspicuous exception. The northwest-trending set is largely expressed as somewhat smaller fractures that cut the uplifted blocks. This is also the set that curves continuously into the en echelon fracture sets of the tear fault zones in a reversed "S" pattern (Figure 4). As noted by Donath, neither set consistently offsets the other and the pattern of fault traces that results is everywhere very angular and irregular so that the faults are interlocked. The motion on both sets is mainly dip slip. Thus simultaneous motion is implied not only between the two Basin and Range fault sets, but also between these and the tear fault zones, but none is present within the intervening blocks. Thus it seems necessary to seek a new mechanical explanation for the rhombic pattern to replace Donath's hypothesis. Such a new explanation must produce the several sets of fractures simultaneously and with the same pattern of motion as currently exists.

High Cascade Interactions

The crest of the Oregon Cascades is a series of Pleistocene to Holocene volcanoes (mostly less than 1 million years old) and associated lava flows that occupy a down dropped block similar to many other volcano-tectonic depressions (Allen, 1965; Taylor 1973, and personal communication). Within these features the recent vents form north-trending linear features on the scale of the ERTS-1 imagery. Two of the tear fault zones discussed above offset this trend in a right lateral sense about 10 to 20 km. These offsets are the only known measure of the amount of offset on the tear fault zones. It indicates that the total strain in each segment has decreased by about the same amount across each zone since the High Cascade trend was established. However, the Eugene-Denio zone is the one that extends a great distance into Nevada suggesting that it is a particularly important feature in comparison to the less extensive Mt. McLoughlin zone. Thus it is equally reasonable to extrapolate a greater offset on this zone into the past.

Table 1. Examples of effect of tear fault zones on Basin and Range parameters.

	Location	$\dot{\varepsilon}$ x 10^{-16}/sec	Total extension	% strain
Example 1	Between Eugene-Denio and Brothers Fault Zones	0.3	10 km	1.2
	Between McLoughlin and Eugene-Denio Zones	0.9	30 km	4
	South of McLouglin Zone	.3	50 km	6
Example 2	Between Eugene-Denio and Brothers Fault Zones	0.3	10 km	1.2
	Between McLoughlin and Eugene-Denio Zones	1.1	40 km	5
	South of McLoughlin Zone	1.3	50 km	6
Example 3	Between Eugene-Denio and Brothers Fault Zone	0.7	25 km	3
	Between McLoughlin and Eugene-Denio Zones	2.1	75 km	9
	South of McLoughlin Zone	2.6	100 km	12

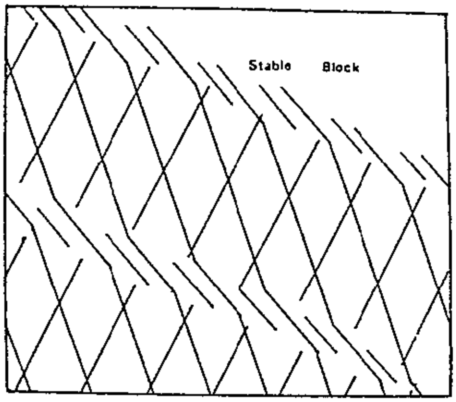

Figure 4. Idealized pattern of faulting for tear faults with intervening extensional zones in southeastern Oregon.

Using typical values for the strain rate and total strain in the central Basin and Range Province for the area south of the Mt. McLoughlin zone, illustrative examples can be calculated to show the effect of the tear fault zones under various assumptions (Table 1). In the first example an arbitrary 20 km decrease in total extension across each zone and a 50 km minimum figure for the amount of Basin and Range extension have been used. In the second and third examples the maximum offset has been placed on the Eugene-Denio zone with equal, lesser offsets on the Mt. McLoughlin and Brothers fault zones. In the third example the total extension has been increased to 100 km. Recalling that Thompson and Burke (1973) have shown that Basin and Range strain rates are variable with time, it should be clear that these calculated examples serve largely to illustrate the step-down effect on strain rate here suggested for the area. The numberous assumptions inherent in obtaining the results forbid treating them as conclusions.

The Brothers fault zone appears to merge with the eastern faults of the High Cascade depression (Figure 2). The apparent lack of offset across the High Cascades indicates that relatively little displacement has taken place along the Brothers fault zone. Such motion as has occurred in the last few million years must appear as extension of the High Cascades depression and, possibly, as spreading under the Deschutes Basin. The interconnection is made by a gradual deflection of faulting to a N35°W trend from the N60°W trend of the zone. This deflection takes place on a series of small normal faults through the Deschutes Basin (informally, the Sisters fault zone). The individual fractures of this zone are parallel, rather than en echelon in pattern. The Sisters fault zone culminates in the Green Ridge fault which trends about N25°W. At Green Ridge the faults are clearly the bounding structure of the volcano-tectonic deprssion of the Cascade crest (Taylor, personal communication).

A similar interaction between Basin and Range features and the High Cascade depression occurs where the Klamath graben extends under Crater Lake. Here normal faulting of the Basin and Range Province merges directly with the volcano-tectonic depression.

Recalling the earlier discussion of the role of the Steens Fault in addition to the reflections on the Sisters fault zone above, the writer interprets the Brothers fault zone as terminated at each end in a transition to normal faulting. This implies that one has here the rather rare possibility of studying the actual ends of a large fault zone. At the Steens Fault, a normal fault crosses and abruptly truncates the Brothers fault zone. Motion on the Steens fault has continued at least as long as on the Brothers fault zone. On the other hand a gradual transition takes place to the Sisters fault zone, where motion is quite young and may have developed since the initial activity of the Brothers fault zone. In each case, however, the termination is exposed for study at the surface, unlike most major faults and fault zones which disappear under more recent cover or are otherwise concealed.

Discussion and Conclusions

Large displacements due to right lateral motion are also described along the Walker Land and Death Valley-Furnace Creek Zones of southwestern Nevada (Nielsen, 1965; Stewart, Albers, and Poole, 1968). However, most of this motion is of pre-Miocene age and only a few tens of kilometers are related to Basin and Range activity. The Oregon tear fault zones, in contrast, are Miocene to Recent features and are on about a 20° different trend. Thus these features are probably not directly related to one another.

The Basin and Range Province in Oregon is believed to terminate in a series of right lateral tear fault zones along which the total extension and extensional strain rates decrease progressibely northward. Extension essentially ceases at the northern edge of the province along the Vale and Brothers fault zones. The rhombic pattern of normal faulting in the region results from the interaction of extension in blocks between the fault zones and the right lateral strike slip motion along the zones. The net offsets on individual tear fault zones are estimated to be in the range of a few tens of kilometers, with about 80 km as a maximum.

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Appendix B-2

COMPUTER CLASSIFICATION OF ERTS-1 DIGITAL DATA FOR INFORMATION ON GEOLOGY AND FORESTRY

Robert D. Lawrence and James H. Herzog

Abstract

Computer classifications into 7 and 10 classes of two areas in central Oregon of interest to geology and forestry demonstrate the extraction of information from ERTS-1 data. The area around Newberry Caldera was classified into basalt, rhyolite obsidian, pumice flats, Newberry Pumice, ponderosa pine, lodgepole pine and water classes. The area around Mt. Washington was classified into 2 basalts, 3 forest, 2 clearcut, burn, snow, and water classes. Both also include an unclassified category. Significant details that cannot be extracted from photographic reconstitutions of the data emerge from these classifications, such as moraine locations and paleo-wind directions. Spectral signatures for the various rocks are comparable to those published elsewhere.

Introduction

The ERTS-1 Satellite was launched by NASA in July 1972 into a 500 mile sun synchronous orbit. The satellite is equipped with a variety of sensors which for the first time allow scientists and engineers to freely experiment with the potential of high quality digital data procured from a stable space platform. The primary data collection device on board the satellite is multi-spectral scanner which accepts reflected ground radiation in four distinct bands: green (0.5 -0.6 μm), red (0.6 - 0.7 μm), infrared (0.7 - 0.8 μm), and infrared (0.8 - 1.1 μm), and infrared (0.8 -1.1 μm). The optics of the satellite scan across the surface of the earth in direction perpendicular to the flight path. A vertical raster is provided by the forward motion of the satellite Each frame of ERTS data covers 100 by 100 nautical miles. The ground resolution of each digital datum is approximately 1.16 acre. ERTS data can be used to reconstitute photograph-like imagery for each band or some combination of bands, to produce a spectral signature for each individual earth resolution element or to produce a classification map based on signature types. The photographic product has been widely discussed and used according to conventional and exotic photointerpretation techniques. The latter two products are the result of some form of computer analysis of the digital data.

Rowan (1972) has published spectral signatures for some common rocks and minerals. He finds that spectral response depends largely on the iron content of the material. Vincent (1973) has applied this approach to ERTS data for iron deposits in Wyoming. Areas of recent volcanism in central Oregon (Figure 1) provide an opportunity to examine the spectral response of rocks of varied composition, texture, and iron content in this study. Rhyolite obsidian, rhyolite ash and basalt flows are present that are young enough (less than a few thousand years old) to produce rather pure signatures. These can be compared with the

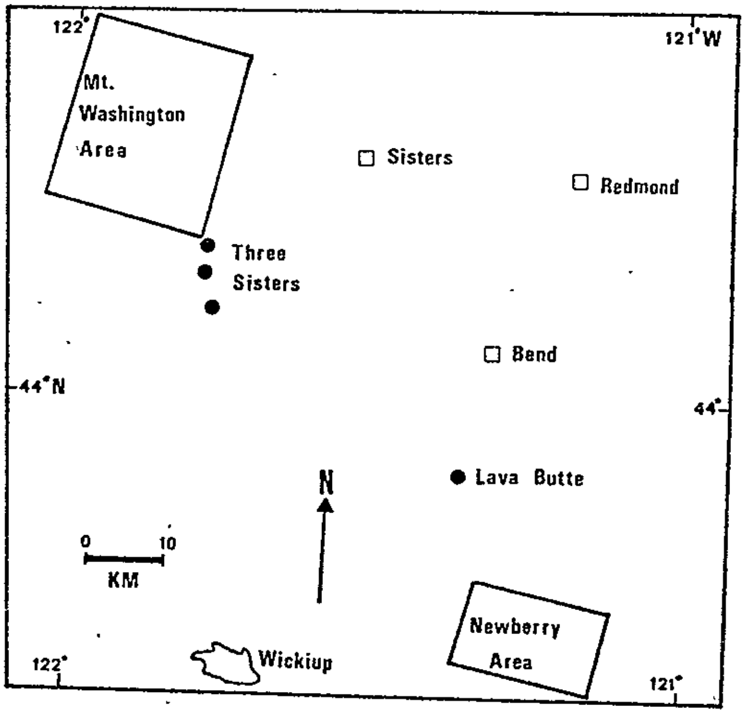

Figure 1. Location map for areas used in digital classifications.

signatures of progressively older rocks. that are increasingly altered and vegetated.

Computer classifications of ERTS data have been produced by a number of workers, mostly utilizing user supplied training sets. Successful classifications have differentiated types of agricultural croplands (Bauer and Cipra, 1973, Baumgardner and Dillman, 1973), and broad natural area categories (Kirvida and Johnson, 1973; and Thomson and Roller, 1973). All of these efforts and others of a similar nature have concentrated on the extraction of land use and vegetational information. Similar classifications of two volcanic areas of central Oregon described below were performed with training sets selected by a geologist. These classifications display both gross and detailed geologic information content and considerable forest information as well. A similar effort in an area of sedimentary rocks is reported by Melhorn and Sinnock (1973).

Study Areas

The two study areas selected for the present effort are in central Oregon (Figure 1) where young volcanic rocks are exposed at the surface. The Newberry area covers the crest of Newberry Volcano, a young caldera developed around the central vent of a large basaltic shield volcano (Higgins, 1973). Very recent rhyolitic obsidian flows, less than 1720 ± 250 years old, are present on the floor of the caldera (Higgins, 1969) and recent basalt flows (radiometric age unknown) are present on the flanks of the volcano. Older rhyolite domes and ash and basaltic cinder cones are also abundant. Much of the area is blanketed by Newberry (1720 years old) and Mazama (6500 years old) pumiceous ash. The Mt. Washington area centers on Belknap Crater and Mt. Washington. Basalt flows of various young ages (1500 to 4000 years) erupted from Belknap Crater, North Sister, and other vents in the area (Taylor, 1968, and personal communication, 1974). Both areas have extensive forest covers where the very young rocks are not exposed. The greatest variety of forestry interest is in the Mt. Washington area. Details on the geology used in the following discussion of these two areas rely heavily on the work of Higgins and Taylor.

Classification

Classification is the process in which a set of rules is used by a computer to assign each ground resolution element to one of several classes. As in the case of a human photointerpreter, classification extends results obtained in local, knownregions to surrounding, unknown regions. Either classification maethod requires the use of selected characteristics. The photointerpreter commonly uses color or tone, texture, and shape to identify similar regions. In computer classification the magnitudes of the four pieces of spectral information are used as characteristics. It is assumed that two regions on the earth which are identical will have identical or very similar sets of numbers (spectral signatures). Regions which differ should have different signatures.

Computer classification eliminates the repetitious judgement of a human operator and increases the detail of the classification. Because of the magnitude of the data, a human operator could not possibly individually evaluate and classify the approximately 7.5 million ground resolution elements of an ERTS scene. However, extensive interaction with a human interpreter is still required as the "ground truth" requirements are very similar to those of photointerpretation. Known examples of the classes selected for classification must be identified for the computer as training sets. The computer abstracts the mean and standard deviation of each of the four spectral measurements for all elements in each training set.

For each of the classes (1, 2, ..., i) the computer constructs a prototype vector,

$$F_i = \begin{bmatrix} f_{ia} \\ f_{ib} \\ f_{ic} \\ f_{id} \end{bmatrix}$$

where a, b, c, and d indicate the four spectral bands. Each element of this vector is the mean of the corresponding training set for that class. Classification of the unknown vectors is performed based on the euclidean distance between the unknown vector and each of the prototype vectors. Each unknown vector, F_x, is constructed from the four data of a given resolution element, such that

$$F_x = \begin{bmatrix} f_a \\ f_b \\ f_c \\ f_d \end{bmatrix}$$

and a set of D_i calculated against the prototype vectors as,

$$D_i = (f_{ia} - f_a)^2 + (f_{ib} - f_b)^2 + (f_{ic} - f_c)^2 + (f_{id} - f_d)^2.$$

The threshold value, T_i, for each class is defined by the human operator. This value is included in order to allow a "none of these" classification if the distance is larger than that expected for a given class. Now D is the minimum value of the set of D_i and

if $D \leq T_i$, F_x is assigned to class i,

if $D > T_i$, F_x is assigned to "none of these".

Tables I and II show the values of band means and thresholds for the prototype vectors used in the two classifications discussed herein.

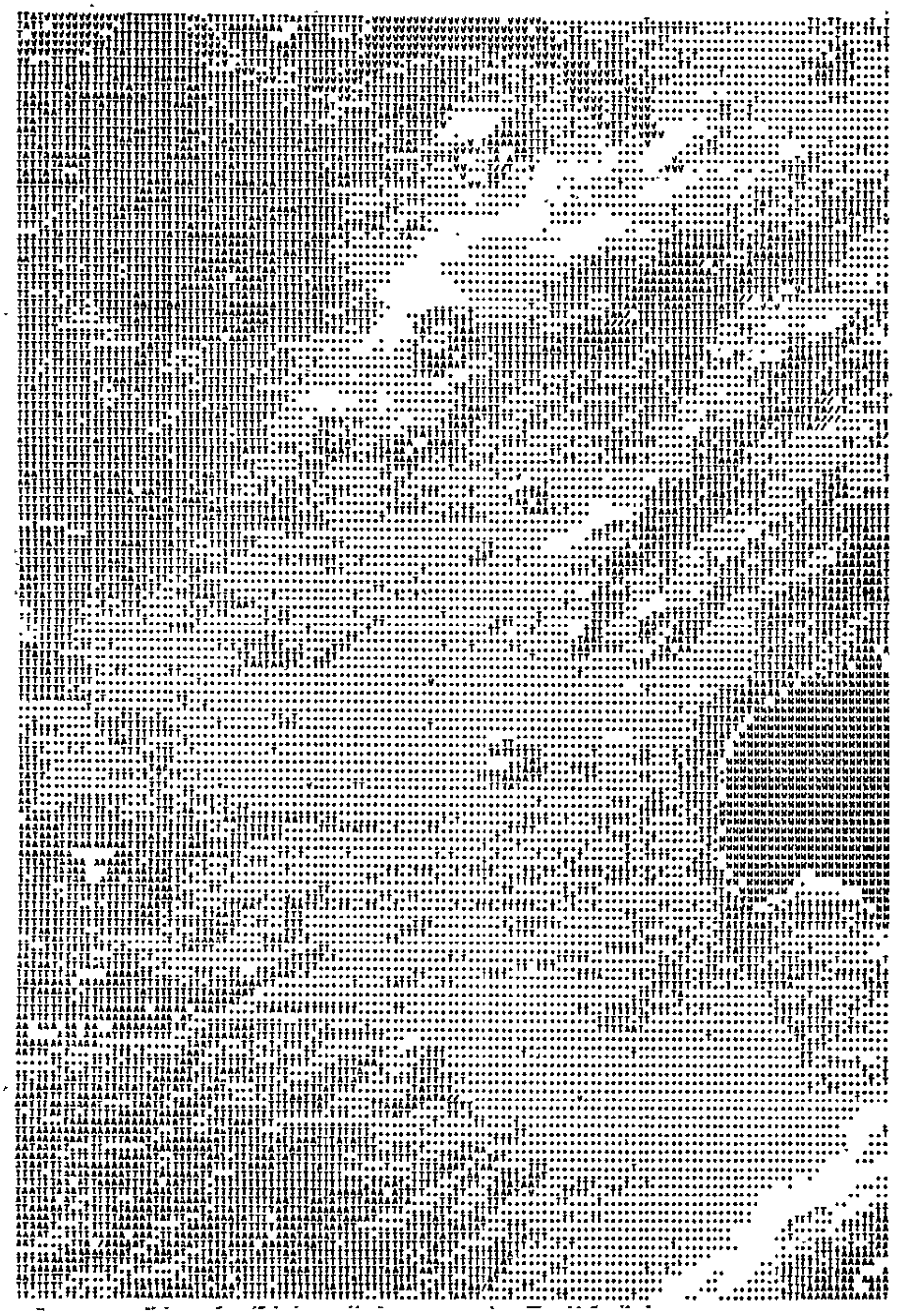

Plate I. Computer classification of the Newberry Area of ERTS-1 frame 1076-18213, 7 October 1972 (see Table I for coding). (left half)

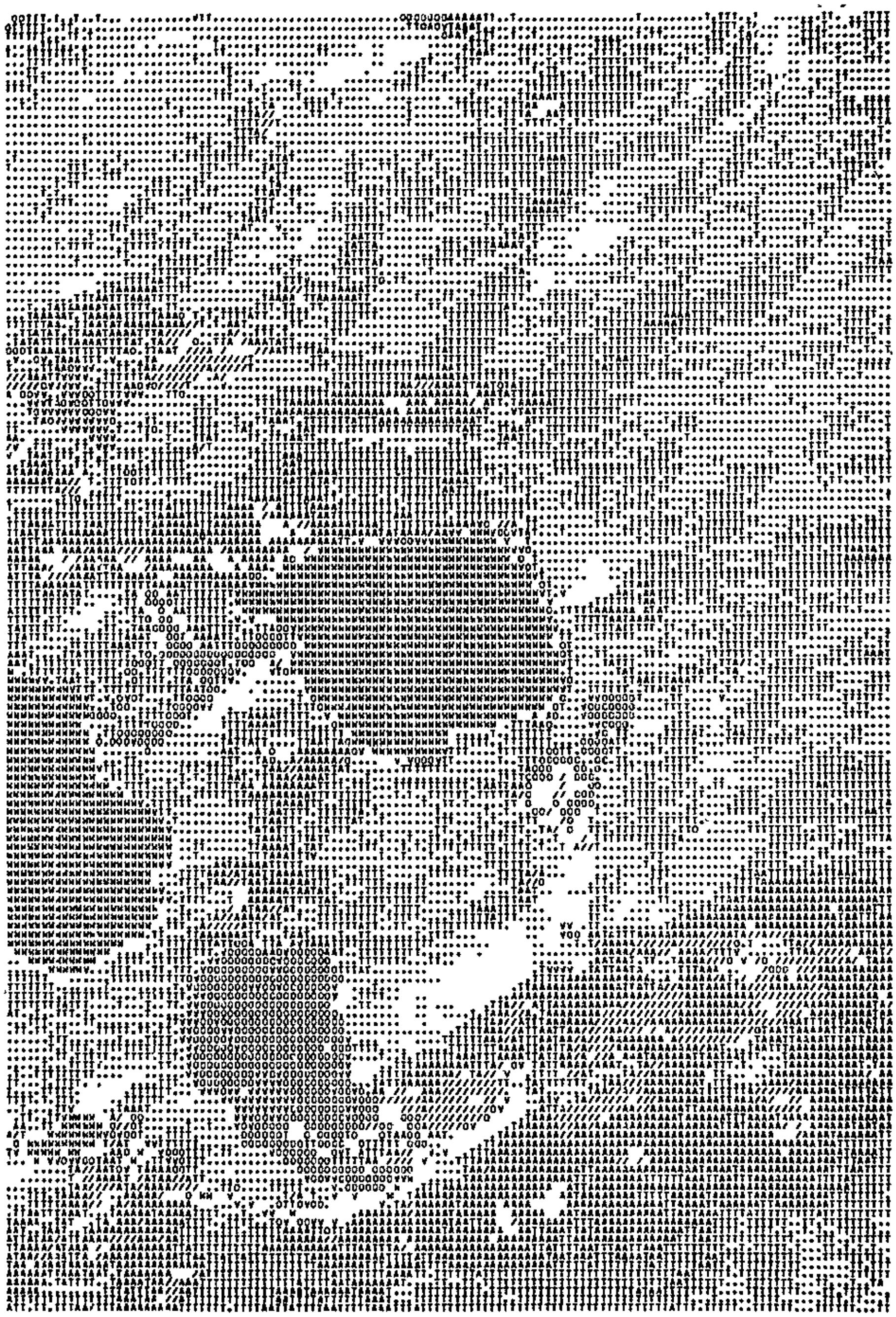

Plate I. Computer classification of the Newberry Area of ERTS-1 frame 1076-18213, 7 October 1972 (see Table I for coding). (right half).

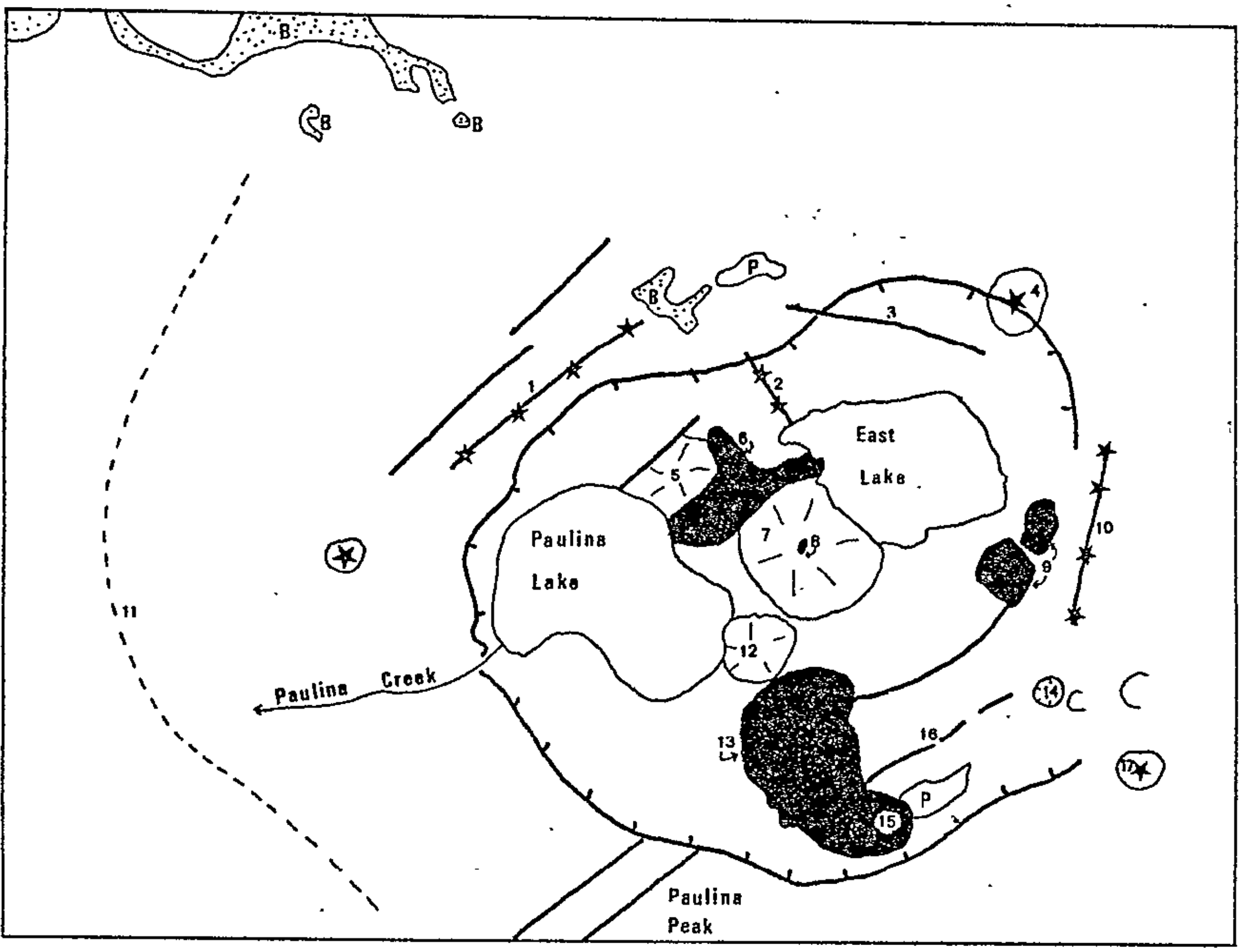

Figure 2. Interpretation of Classification of the Newberry Area

Number Symbols

1 Red Slide Conder Cones
2 East Lake Fissure
3 Deep Valley Fault
4 Sheeps Rump Cinder Cone
5 North Pumice Cone
6 North Obsidian Flow
7 Central Pumice Cone
8 Obsidian flow in vent of Central Pumice Cone
9 East Lake Obsidian Flows
10 Chain Craters on East Rim Fissure
11 Boundary: Lodgepole Pine to east/Ponderosa Pine to west
12 Little Crater Tuff Ring
13 Big Obsidian Flow
14 The Blowout
15 Plug Dome of Big Obsidian Flow
16 Rhyolite ridge
17 Sand Hill Cinder Cone

Letter and Pattern Symbols

B & dots	Basalt flows
P	Pumice flats
Stars	Cinder Cones (locations diagramatic along fissures 1 and 10)
Heavy lines	Faults and fissures
Solid	Obsidian flows

Table I. Statistics on Newberry Classification

Class	symbol	Acres	%	Band Means				Threshhold
				4	5	6	7	
Bare basalt flow	V	721	2	8.14	5.66	4.99	3.98	4.00
Bare rhyolite obsidian	D	885	2	10.94	9.01	7.43	5.71	15.00
Pumice flats	I	610	1	14.54	14.50	14.89	13.31	40.00
Newberry Pumice in SE (south slopes elsewhere)	A	5,287	12	9.29	7.50	11.41	12.65	14.00
Ponderosa Pine forest (open)	T	17,446	39	7.80	4.50	8.51	9.86	20.00
Lodgepole Pine forest (dense)	.	15,008	34	7.81	4.79	6.82	7.55	4.00
Water	W	2,282	5	6.93	2.13	1.11	1.00	5.00
Unclassified		2,007	5					
Total		44,246	100					

Results

The computer classifcations of the two areas are shown in Plates I and II (portions of ERTS frames 1076-18213 and 1041-18265, respectively) with the color coding presented on Tables I and II. Eight classes are used on the Newberry area classification and eleven classes on the Mt. Washington area classification. These classifications have been evaluated through the use of published geologic maps and RB-57 high flight imagery (NASA Flights 72-114 and 73-106). The brief class denotations listed on Tables I and II represent the character of the training sets used. In some cases the actual class is more varied. Plates I and II are, therefore, evaluated in two different manners. First, they are treated as simple automatic classifications of the data and classification accuracy is evaluated both subjectively and quantitatively. Second, they are treated from the perspective of a photointerpreter and information is extracted from variations that are treated as classification errors in the first approach. This second method allows information details to be extracted from the data that are either impossible or extremely difficult to see on the photographic ERTS imagery, and are also beyond the ability of the automatic classifier to decipher. Thus we find that the maximum information is extracted from ERTS data by a combination of machine and human interpretation. Figures 2 and 3 are interpretive overlays drawn from the automatic classifications showing some of the significant features that are present on them. Reference to these figures will clarify much of the discussion that follows. Areas used to evaluate the classifications quantitatively were determined by planimeter from maps and aerial photographs. Particularly for the smaller areas this method may involve as much or more error as the digital determination.

Newberry Lithologic Classes. Four classes based on lithology are used in the Newberry classification. These are bare basalt, bare rhyolite obsidian, pumice flat, and Newberry pumice. The first three of these are quite successful; the last proves to be a poor class. For the three good classes a comparison of the area classified to that measured is shown on Table III. The two larger classes reflect results for the entire classification, while the smaller ones are for selected areas. The apparent precision of the results for the obsidian flows is the result of rather numberus, but mutually compensating errors of commission and omission. However, the areas of the bare obsidian flows are all identified and blocked out, including even the very samll one in the vent of the Central Pumice Cone (8 on Figure 2). The omission errors result in less than the total flow area being identified, while the commission errors are mostly single points scattered widely over the remainder of the classification. This is an excellent example of the role of the threshold value. Lowering the threshold will increase the relative number of omission errors, while raising the threshold will increase the relative number of commission errors. Either represents a departure from the overall precision of the statistical result. This level of statistical success is not possible with the basalt flow and pumice flat classes. In these cases most of the errors are of commission. For example, an edge effect occurs along water such that a single resolution element which covers about half water and half land will be classified as basalt. Likewise, scattered forest on obsidian is

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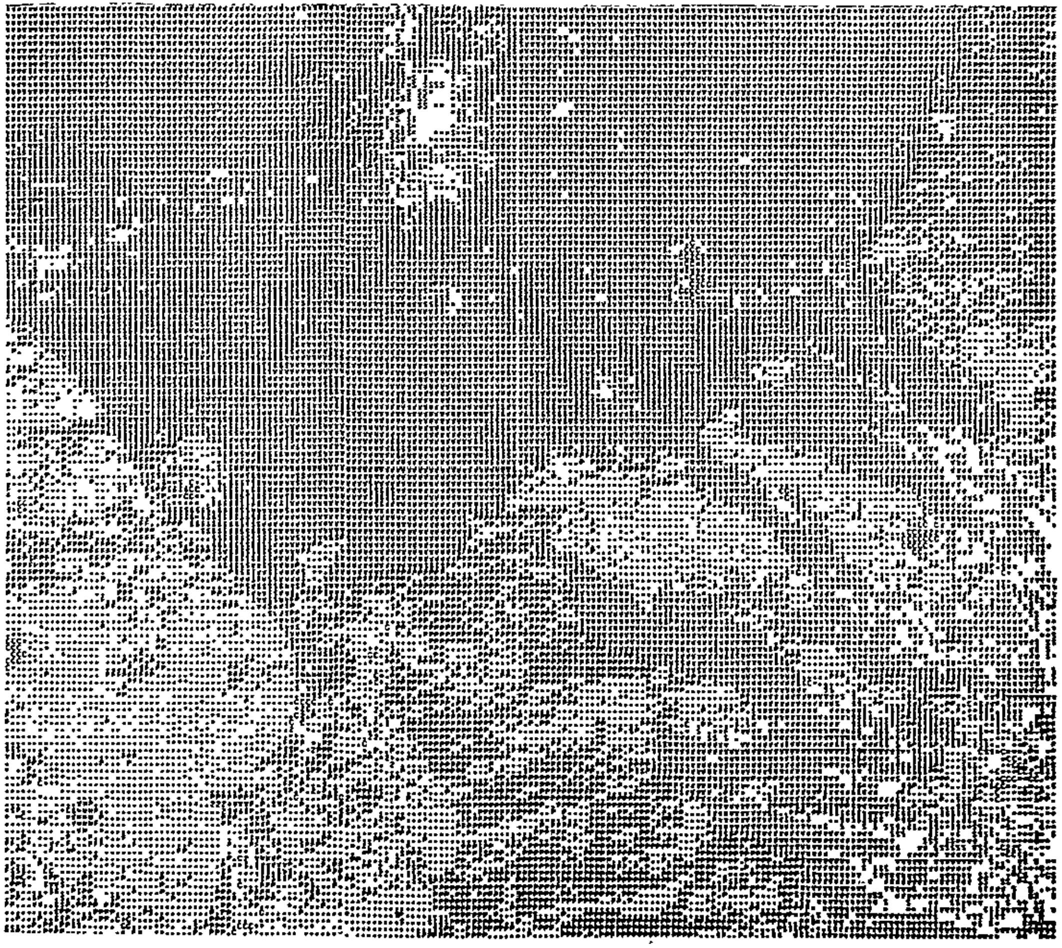

Plate II. Computer classification of the Mt. Washington area of ERTS-1 frame 1041-18265, 2 Sept. 1972 (see Table II for coding) (Lower right 1/4).

Plate II. Computer classification of the Mt. Washington area of ERTS-1 frame 1041-18265, 2 Sept. 1972 (see Table II for coding) (Lower left 1/4).

Plate II. Computer classification of the Mt. Washington area of ERTS-1 frame 1041-18265, 2 Sept. 1972 (see Table II for coding) (Upper right 1/4).

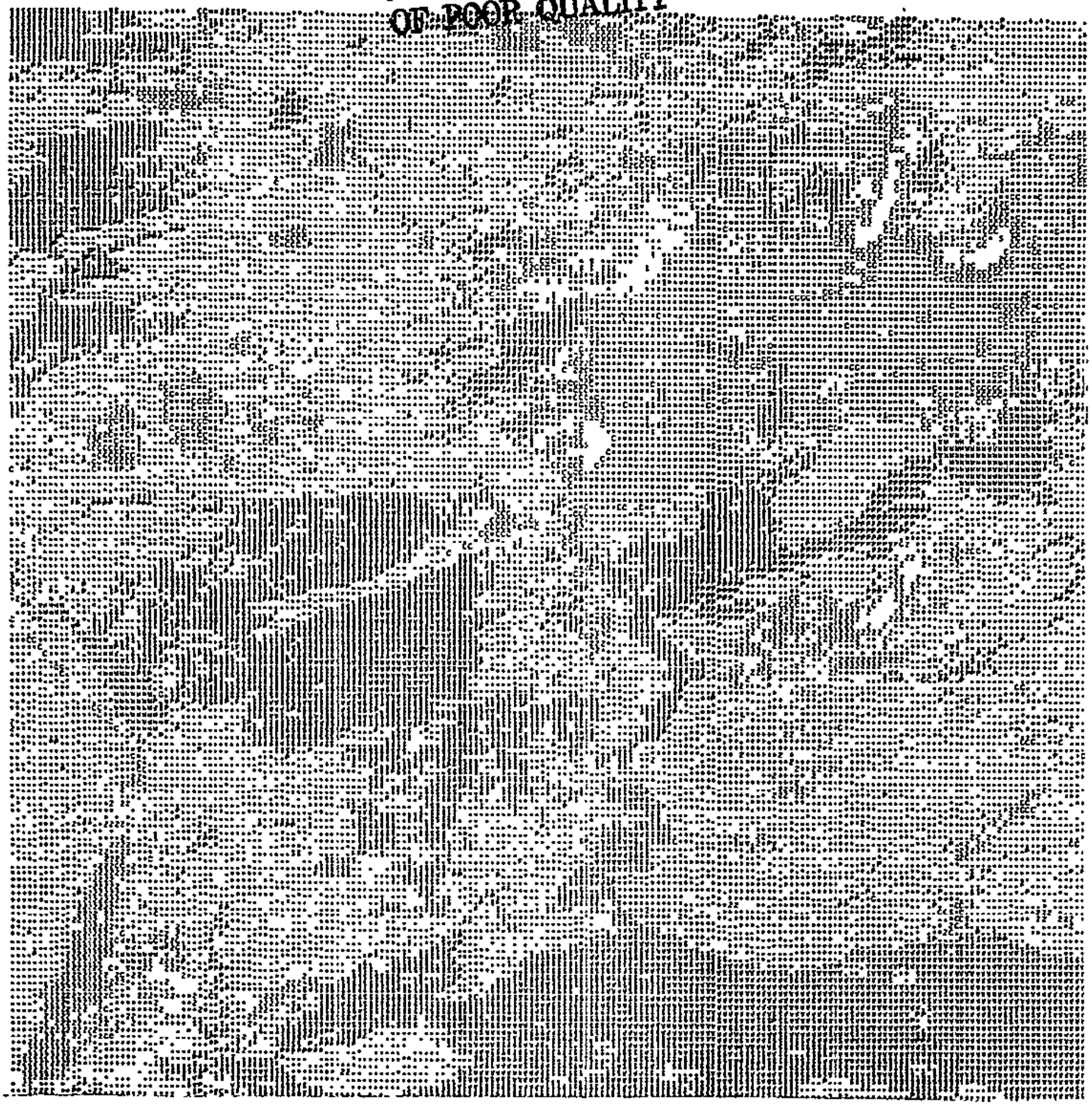

Plate II. Computer classification of the Mt. Washington area of ERTS-1 frame 1041-18265, 2 Sept. 1972 (see Table II for coding) (Upper-left 1/4).

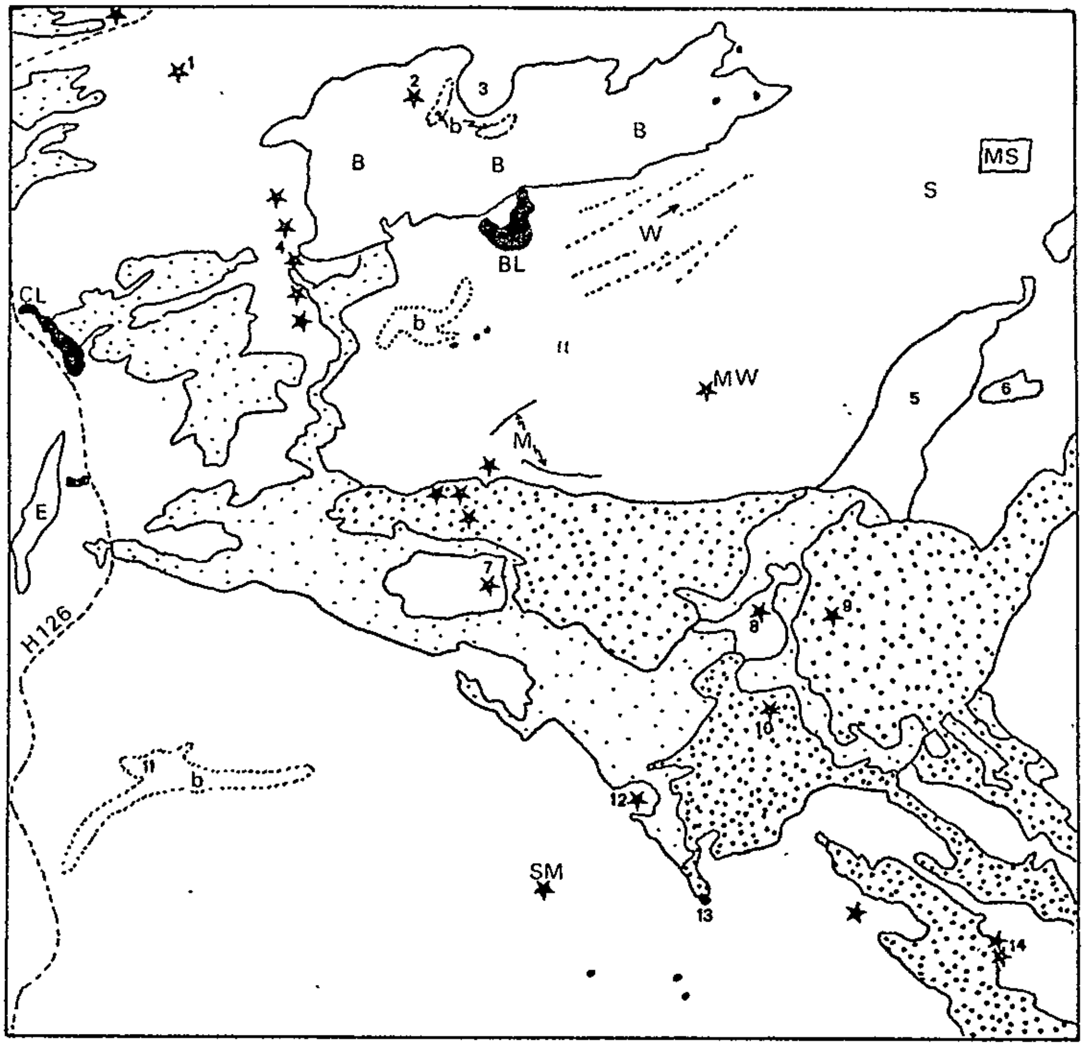

Figure 3. Interpretation of Classification of the Mt. Washington Area.

Legend for Figure 3

Interpretation of Classification of the Mt. Washington Area.

Letter Symbols

CL	Clear Lake	H126	Highway 126
BL	Big Lake	M	Morainal ridges from Mt. Washington
MW	Mt. Washington	W	Wind direction by ash dunes
SM	Scott Mountain	E	Classification error
B	Area of Hoodoo Burn	b	Brushy areas of interest
S	Area of selective cutting of Ponderosa Pine forest	MS	Mostly cut block within area S

Pattern Symbols

Stars	Volcanic vents - all exactly located
Light dots	Older basalt lava flows
Heavy dots	Younger basalt lava flows
Solid	Lakes

Number Symbols

1	Nash Crater	8	Belknap Crater
2	Hoodoo Butte	9	Little Belknap Crater
3	Hayrick Butte	10	South Belknap Crater
4	Sand Mountain Cones	11	Anderson Creek flow with brush cover
5	Old Belknap flow with brush cover	12	Twin Craters
6	Small burned area	13	Hand Lake
7	Inaccessible Cone	14	Four-in-one Cone

Table II. Statistics on Mt. Washington Classification

Class	Symbol	Acres	%	Band Means				Threshhold
				4	5	6	7	
Younger Basalt	V	16551	12.4	8.89	6.23	5.55	4.54	10.00
Older Basalt	$	14417	10.8	8.84	6.41	8.77	9.19	12.00
Water	W	418	0.3	7.66	3.21	2.17	1.22	7.00
Forest 1 - Mixed	.	47688	35.7	8.24	4.99	10.06	12.21	10.00
Forest 2 - Douglas Fir or Ponderosa Pine	+	17283	12.9	8.12	4.63	13.19	16.50	6.00
Forest 3 - Lodgepole Pine	P	13164	9.9	7.65	4.59	8.47	9.90	12.00
Clearcut 1 - Little revegetation	C	5982	4.5	10.87	9.94	14.43	16.74	18.00
Clearcut 2 - Brushy revegetation	2	3872	2.9	10.30	7.72	17.32	21.41	21.00
Snow	S	322	0.2	41.76	43.05	37.76	28.10	70.00
Burn	=	7257	5.4	11.52	10.26	11.94	12.18	13.00
Unclassified		6678	5.0					
Total		133,632	100.0					

classified as basalt. In each case, a subclass of significant size is present which has the same spectral signature as basalt. The small area of basalt within the classification, less than a square mile, makes these effects particularly significant. Thus although the total area classified as basalt is 24% greater than the measured area of basalt flows, when only a single flow is measured it is significantly underclassified (compare the two basalt entries on Table III). The results for the pumice flats are probably similar except that the classification is nearly correct for isolated areas. The degree of commission error is difficult to evaluate, however, because the very small areas of open pumice are not readily distinguished on the available photography. The class created on the thick deposits of Newberry Pumice in the southeastern part of the classification is not highly successful as a unique lithologic class. This is largely because most of the classification is blanketed by pumice with varying densities of forest cover so that the intended class is not unique. Thus most highly illuminated south slopes are included in the Newberry Pumice class.

Mt. Washington Lithologic Classes. Almost the entire area is underlain by basaltic flow materials in various stages of weathering. Two very successful basalt classes were developed which separate the most recent flows. The younger basalt lava flows are mostly bare rock with lichen and scattered blackberry, margarita, and other bushes. The older basalt lava flows have scattered trees in addition to the vegetation just mentioned. This corresponds very closely with the separation of flows that are less than 3000 years old by radiocarbon dates and flows that are greater than 3000 years old (Taylor, 1968). The primary error in the age distinction is that one of the younger flows from Belknap extends west across highway 126, but the more moist climate on this western slope has resulted in sufficient weathering and revegetation to change the classification. Much the same effect occurs on the older flows results in their being classed as forest. The kind of commission errors discussed under the Newberry lithologic units are not important in this area where basalt flows make up over 20% of the total classification. While this age distinction is visible on color infrared reconstitutions of the area, a photointerpreter cannot map the boundary as well as it is done here by computer.

Water Classes. Water is present on both classifications and snow on the Mt. Washington classification. These are very successful classes. Even very small lakes (for example, 13 on Figure 3) and snow patches are correctly classified. Quantitative comparisons are within 1% (Table III). The omission errors on the Newberry classification are largely accounted for by the basalt edge effect discussed above.

Forest Classes. In general both stand density and tree species are significant in defining spectral signatures in the 5 forest classes. Thus the species names attached to the forest classes are not dependable beyond the original training set locations. In the Newberry area the distinction between the ponderosa pine and lodgepole pine classes holds along the west slope (11 on Figure 2) but stand density probably controls much of the variation within the caldera. In the Mt. Washington area Forest-3 is a mixture of lodgepole pine and true fir stands. Forest-1 is a class that includes some of each of the other two. No quantitative

Table III. Quantitative Comparison of Selected Classes

Class	Area (acres)		Error %
	Classified	Measured	
Newberry Lithologic Classes			
Rhyolite obsidian flows	877	870	0.8
Bare basalt flows	721	588	24
Single basalt flow	77	128	-40
Single pumice flat	117	111	5
Water Classes			
Newberry lakes	2220	2600	-15
Big Lake (Mt. Washington)	196	185	0.6
Burn and Clearcut Classes			
Hoodoo Burn	5480	5180	6
Clearcuts (total of 6)	248	224	11

evaluation of these classes is available. However, one significant classification error (E on Figure 3) is known to occur where a rather large area of forest is misclassified as brush. The first classes are based on very small spectral differences in the infrared bands (see Tables I and II), which largely do not show on the photographic reconstructions. In addition to distuinguishing different forest stands, these classes allow one to interpret details not otherwise possible. Thus, on the Newberry classification, Paulina Creek and other elements of the radial drainage of the volcano show up through this class distinction. Most of the faults and fissures (Figure 2) are also distinguished in this manner. On the Mt. Washington classification the wind direction recorded by linear ash duens is reflected in the forest class distinctions (W on Figure 3). No training sets were taken in the northeastern corner of the Mt. Washington classification where selectively logged ponderosa pine is present. Some suggestion that a distinct class would have been possible is given by the combination of brush and Forest-2 that results from the classes used.

Burn and Clearcut Classes. The Mt. Washington area has been clearcut on the west side and selectively logged on the northeast. Training sets selected from these clearcuts are separated into younger and older clearcuts on the basis of ground observations and air photo interpretation. The resulting classes are found to be accurate within about 10 percent, but the figure must be treated with caution because the areas of the individual clearcuts measured are small enough to approach the accuracy of the planimeter and probably involve considerable internal error. The age distinction is correctly maintained in the classification. The younger clearcuts are only a few years old and have little vegetation present. In 1967 a large forest fire created the Hoodoo Burn (B on Figure 3) in the northern part of the area. The resulting class is within 6% of the measured value (see Table III).

Both burn and clearcut classes establish signatures for grass, brush, and other forms of low vegetation. Thus they classify more than the specific features of interest. From a thorough interpretation of these low vegetation classes many important features can be distinguished (cf. Figure 3) such as areas of alpine vegetation on Belknap Crater, North Sister, and other peaks, numberous cinder cones and other volcanic vents, moraines from Mount Washington, two areas of older lava flows, and selectively logged areas in the northeast corner of the classification. A small number of clearcut areas are classed as burn suggesting that they may have been slash burned in about 1967. A small forest fire scar (6 on Figure 3) is classed as Clearcut-1 indicating that burns can be separated on the basis of age.

Photointerpreters perspective. Additional details, not readily apparent from the classes used, can be interpreted from the classifications (Figures 2 and 3). Some of these are readily apparent on the photographic imager, but others are not. The computer program that we used fails as soon as geometric shape becomes important. Thus conical cinder cones and linear fractures cannot be classified although they are readily visible on the photographic imagery. The shading effects that make them visible on the imagery defeat the computer program. They can, however, be interpreted from the classifications. Figure 2 shows numberous

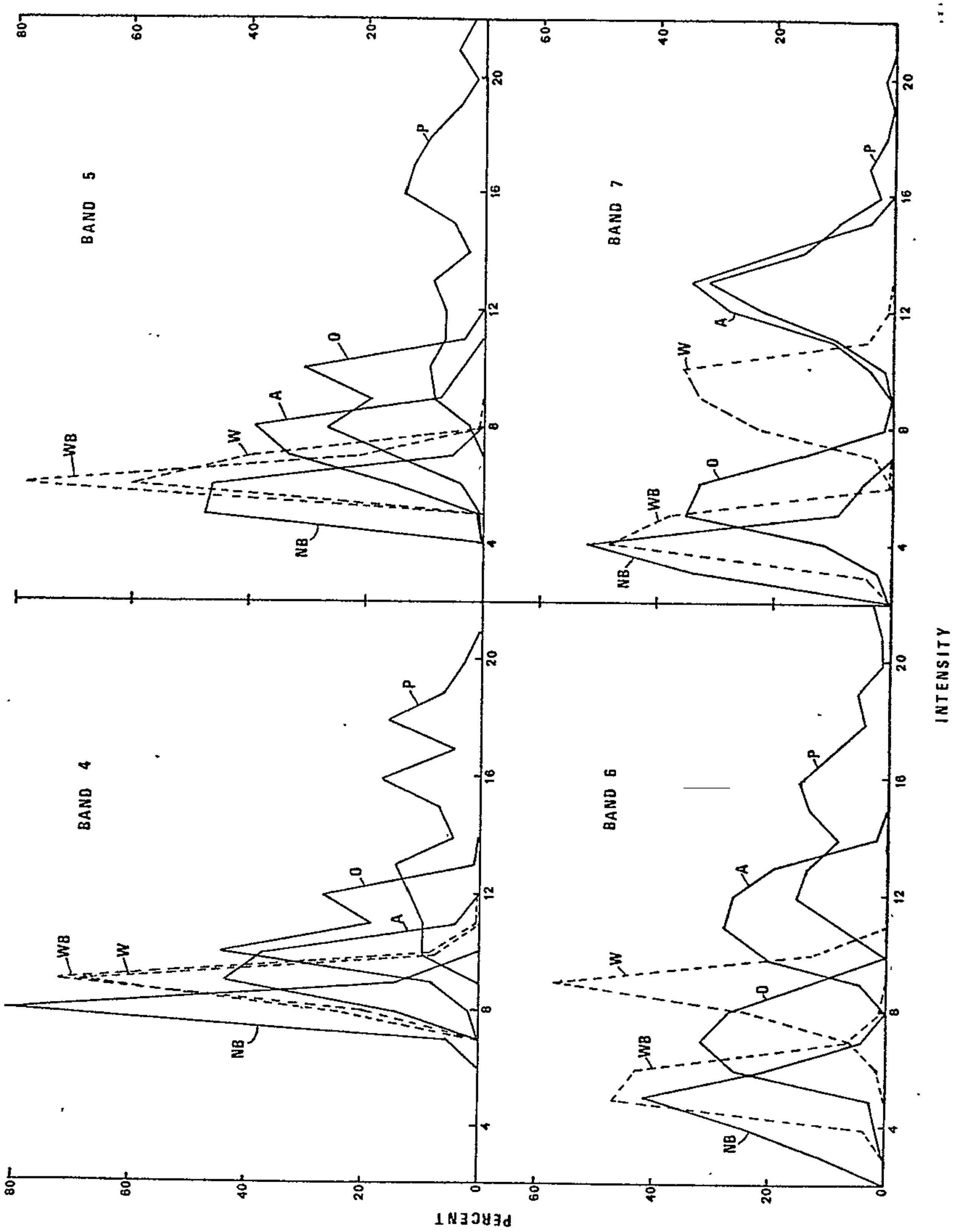

Figure 4. Spectral responses and class separation for materials of geologic interest (P= pumice flats, O= obsidian, A= Newberry Pumice, NB= Newberry basalt, WB= Mt. Washington younger basalt, and W= Mt. Washington older basalt).

faults and both cinder cones and some other volcanic vents. In general the cinder cones show up as a multiclassified area with one of the clear cut classes, the burn class, or the Newberry pumice class recording the bare area near the crest. On the Mt. Washington classification other special features that can be seen, but are difficult or impossible to see on the imagery are U.S. Highway 126, morainal ridges west of Mt. Washington, and the orientation of linear ash dunes which record the wind direction at their time of deposition.

Spectral Response. Details of spectral response will be considered only for the geologic materials as these are most unique to this investigation. The means and thresholds used for all 16 classes of the two areas are given on Tables I and II. As our program does not yet collect statistics for the entrie area classified, the data used are from the trainings sets selected for each class. As such they represent the purest examples of each class available. Variation in spectral response and class separation for materials of geologic interest are shown on Figure 4. Of these the two basalts (NB and WB) are very similar classes, being bare rock of an aa surfaced flow with only widely scattered shrubs as vegetation, and their spectral response is very similar. The older basalts (w) with scattered tree regrowth in the Mt. Washington area differ only in the two infrared bands. The rhyolite obsidian flows (O), which have extremely blocky surfaces, differ from the basalts largely by having slightly higher reflectances in all bands. The Newberry ash (A) and pumice flat (P) materials are quite similar substances with relatively high reflectances. Both are fragmental, vesicular rhyolitic material from explosive eruptions. The pumice flats are topographic flat areas covered with pumice and relatively little vegetation. Somewhat more forest is present in the ash areas and most of the surface is sloping. The reflectance spectra produced by the ERTS data are interesting to compare to laboratory data discussed by Rowan (1972). He shows that basalt has a decrease in reflectance in the near-infrared while rhyolite has an increase in the same range. This corresponds to the results for basalt and for pumice and ash, but differs from those for obsidian. Since the published spectra are for crushed samples, surface texture is probably important in the variation shown by the obsidian.

Discussion and Conclusions

Classifications of two areas in central Oregon into 8 and 11 classes demonstrate the value of a user oriented and inexpensive program for utilizing ERTS-1 data. The classifications are evaluated both directly and from the perspective of a photointerpreter, and significant information is obtained in each manner. ERTS spectral signatures are established for the various lithologic classes. Costs of the classification system used here are low once the NASA data is reformated for the local system. Gray scales and training set selection for a large area such as the Mt. Washington classification are around $100-150 in computer time and the classifications themselves about $20. Usually the classification is performed 2 or more times with different thresholds and classes so that the entire effort may come to less than $200 or about $.002/acre. Indirect costs such as ground truth acquisition, operator time, etc. are not available as this classifcation was not made with an overall intent to evaluate cost effectiveness.

Acknowledgements

The research discussed herein was partially supported by NASA Contract NAS 5-21831. Assistance in acquisition and evaluation of ground truth data by Glen Miller and Dave Mouat of the OSU Environmental Remote Sensing Applications Laboratory is gratefully acknowledged. Critical reading by Dave Paine and Ralph Shay significantly improved the manuscript.

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VII. APPENDIX C: SEPARATE PAPERS IN COMPUTER APPLICATIONS

Appendix C-1

ERTS DIGITAL TECHNOLOGY APPLICATIONS FOR OREGON'S NATURAL RESOURCES

Linda Yamanuha, Roy C. Rathja and James H. Herzog

Abstract

The tremendous task of monitoring the earth's natural resources through conventional means has proved to be not only costly and inefficient but often times inadequate at best. With the launching of the Earth Resources Technology Satellite (ERTS) by the National Aeronautics and Space Administration (NASA) in 1972, methods involving computer techniques in pattern recognition have opened new avenues for resource monitoring at potentially lower costs, greater efficiency and reliability and with the added capability of repeated coverage.

The Pictorial Information Extraction and Enhancement Laboratory (PIXEL) working in conjunction with various experts in their field have to date undertaken projects ranging from geologic mapping to the monitoring of insect damage in forested areas. This paper focuses on the classification of natural plant communities using satellite data.

Introduction

The ERTS I Satellite was launched by NASA in July 1972 into a 500 mile sun synchronous orbit. The satellite is equipped with a variety of sensors which for the first time allow scientists and engineers to freely experiment with the potential for high quality digital data procured from a stable space platform.

The primary data collection device on board the satellite is multispectral scanner which accepts reflected ground radiation in four distinct bands: green (0.5 -0.6 μm), red (0.6 - 0.7 μm), infrared (0.7 - 0.8 μm), and infrared (0.8 - 1.1 μm).

The optics of the satellite scan across the surface of the earth in a direction perpendicular to the flight path. A vertical raster is provided by the forward motion of the satellite. Each frame of ERTS data covers 100 by 100 nautical miles. The ground resolution of the digital data is approximately 1.125 acres.

The variety of applications of this data to land use classification and natural resource inventory is very large. This paper will consider the problem of classifying natural vegetation communities.

Big Summit Prairie is located in the high desert country of central Oregon approximately 100 miles northeast of Bend, Oregon. The region of approximately 100 square miles contains a diverse assortment of sages, grasses, trees, and water resources. This area is typical of many portions of the Western United States in which large acreages must be managed with respect to timber production, cattle grazing, mineral production, and recreation.

Satellite observation offers a cost effective means of obtaining data relevant to the management of these regions. The repeated coverage every 18 days allows the possibility of monitoring seasonal changes in these natural resources.

The research described in this paper represents a coordinated activity between experienced personnel in natural resource and vegetation management and the PIXEL (Pictorial Information Extraction and Enhancement Laboratory) group at Oregon State to test the feasibility of digital classification of several communities of natural vegetation.

Big Summit Prairie

Big Summit Prairie, at a mean elevation of 4500 feet, contains the following predominant vegetation communities.

Shrub Dominant Vegetation

a) Artemisia rigida/Poa secunda - Tri folium macrocephalum. Rigid sagebrush scattered with Sandberg's bluegrass and big headed clover in understory.

b) Artemisia arbuscula/Poa secunda - scabland sagebrush dominant with Sandberg's bluegrass in understory.

c) Artemisia cana - Hoary Sage on old flood - plains with many weedy forbs.

d) Artemisia tridentata/Festuca idahoensis - Big sage with Idaho foscue as dominant understory. Some scattered Purshia tridentata.

Forest Vegetation

e) Abies grandis/Calamagrostis rubescens - Mixed Conifer, Grand Fir, White Fir, Douglas Fir, Western Larch.

f) Pinus Ponderosa/Festuca idahoensis - Cerocarpus ledifolius - Scattered Ponderosa Pine with a fringe of Mountain Mahogany.

g) Pinus Ponderosa/Festuca idahoensis - Scattered Ponderosa Pine without Mountain Mahogany.

h) Riparian Vegetation/Alnus sinuata, Populus tremuloides, Salix-Streamside vegetation.

Herbaceous Vegetation

i) Wyethia - rocky scablands with smooth dwarf sunflower.

j) Lava deserts - rock scablands with some Lomatium, Trifolium macrocephelum, no Wyethia.

k) Moist Meadows - Sedges and rushes.

Water Resources

l) Water

The automatic classification problem is burdened by two major considerations not normally encountered in classification of agricultural vegetation.

Nonhomogeneity

Natural plant communities seldom have the abrupt demarcation lines associated with agricultural vegetation. Since vegetation is often nonhomogeneous, it is difficult to get "pure" samples for use in training an automatic classifier.

Geologic Considerations

The region around Big Summit contains changes in elevation from a maximum of 5000 ft. to a minimum of 45000 ft. The sloping land tends to affect the reflection characteristics of the vegetation. Volcanic activity in the area leads to a wide variety of soil types and textures. In natural vegetation communities the vegetation is strongly affected by the soil type and available moisture.

The Classifier

The features used in the investigation were the data magnitudes provided by the multispectral scanner. This gave a four element vector for each ground resolution element. No normalizing was done to the vectors. It was later noted that some improvements in the data could be achieved by by correcting for gain differences in the sensors on the satellite. Because of the large amount of data, these corrections were not made.

A prototype vector was constructed for each of the classes indicated in the section titled BIG SUMMIT PRAIRIE. Each element of the prototype vector was the mean of the corresponding training set for that class.

Classification of unknown feature vectors was performed based on the euclidian distance between the unknown vector and each of the prototype vectors. Classification was determined by the smalles distance. A threshold distance was included to allow a "none of these" classification if the distance was larger than expected for a given class.

For a prototype vector of class P

$$F_P = \begin{matrix} f_{p1} \\ f_{p2} \\ f_{p3} \\ f_{p4} \end{matrix} \tag{1}$$

An unclassified vector

$$F_X = \begin{matrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{matrix} \qquad (2)$$

$$D_p = (f_{p1}-f_1)^2 + (f_{p2}-f_2)^2 + (f_{p3}-f_3)^2 + (f_{p4}-f_4)^2 \qquad (3)$$

$$D = \text{Min } D_P \qquad (4)$$

T_p = Threshold for class P

if $D \leq T_p$ assign F_X to class P (5)

if $D > T_p$ assign F_X to "none of these"

An alternative classifier involving normalization by the standard deviation of the class was also considered. For this the calculation for D_p became:

$$D_p = \frac{(f_{p1}-f_1)^2}{\sigma_{p1}^2} + \frac{(f_{p2}-f_2)^2}{\sigma_{p2}^2} + \frac{(f_{p3}-f_3)^2}{\sigma_{p3}^2} + \frac{(f_{p4}-f_4)^2}{\sigma_{p4}^2} \qquad (6)$$

σ_{pi}^2 = Varieance of the ith component of the training set for class P

Care must be exercised in using statistical parameters in classificatic schemes for natural vegetation. Natural plant communities, as contrasted to agricultural plant communities are seldom homogeneous. The variance of the class may really be a measure of the non homogeneity rather than a valid feature for the class. Classifiers based on normal distributions cannot be expected to perform well in such situations.

In this work the variance factor in equation (6) was arbitrarily assigned the value of 1 making equation (6) and equation (3) identical.

It may also reasonably be argued that the prototype vector for the distance metric should not be the mean vector for the class because of the biasing effects of secondary plant vegetation. If it can be reasonably determined that the desired species dominates the training set, the statistical mode of the region offers the best estimate of the "pure" vegetation. Our data sets indicated that the median, mean, and mode of the data were approximately equal.

Experimental Procedure

Using photographic reconstruction of the red band of the ERTS data, the approximate location of Big Summit Prairie was determined in the digital data. A gray tone computer output of the region was then constructed using over-strike characters on a line printer.

A team of vegetation specialists visited the 100 square mile region to determine appropriate training sets for the vegetation of interest. These sets were marked directly on the digital "picture" for subsequent work. An approximate overall vegetation map was prepared for selected parts of the region.

Using the specified training sets, an elementary statistical analysis was performed to yield the mean, standard deviation, and a histogram.

Classification was performed on the entire prairie. Discrepancies noted were used to modify test site location and variables in the classification algorithm.

Results

Classification results were printed in "map" format using a standard computer line printer. Each classification was given a unique symbol. Color was used to further delineate the complex plant communities as shown on the printout.

Vegetation experts assisting in the project made several additional trips to the region to verify the classification results. Because of the very large land area involved, it was impossible to quantitatively describe the accuracy of the classification. In the opinion of the vegetation experts the results showed very good agreement with the actual ground conditions.

Of the twelve original classes, ten were distinguishable via computer processing of the data. Artemisia rigida and Artemisia Arbuscula were indistinguishable. Likewise, it was not possible to delineate Artemisia Cana from Artemisia Tridentata.

Conclusion

It is apparent that we are entering an era in which greater emphasis must be placed on the management of our natural resources. This requires information. We will never be able to evaluate our stewardship of natural resources unless we have a continuum of information concerning their status. The aquisition of this information from our wild land regions is especially difficult. Repetitive satellite coverage offers the possibility of cost effective techniques for natural resource information.

Appendix C-2

AN ERTS DIGITAL DATA ANALYSIS OF THE NORTHEASTERN OREGON - SOUTHEASTERN WASHINGTON TUSSOCK MOTH INFESTATION

James H. Herzog
Electrical & Computer Engineering
Oregon State University
Corvallis, Oregon 97331

The Satellite

Since its launch in July, 1972, the NASA ERTS 1 satellite has provided data for a wide variety of remote sensing applications. The satellite is capable of providing the researcher with the intensity level of reflected solar radiation in each of four spectral bands in the green, red, and two infra-red regions. The ground resolution element for the data is 1.125 acres. The data is made available to researchers in the form of digital magnetic tapes or in the form of reconstituted photographs. In this experiment magnetic tapes were used because of their higher resolution of greater fidelity.

The Experiment

The study area was located near the Grand Ronde River in North-east Oregon. It is severely infected by Tussock Moths and of economic importance to private companies and government agencies. Personnel from Oregon State University, the Oregon State Department of Forestry and Boise Cascade selected twenty-six test sites to provide multi-variate statistics for use in the PIXSYS automatic classifier algorithm. The test sites included several stocking densities and four degrees of moth damage.

Results

The PIXSYS classification system was used to prepare maps of the 200 square mile region delineating regions of no damage, light damage, medium damage, and heavy damage among the high density timber of the region. (In this preliminary work other stocking densities were not considered). The results were judged to have a "very high" degree of correlation with the actual damage.

Conclusion

Satellite data sources, despite their resolution limitations, may provide the most cost effective method of natural resource monitoring. Processing costs for this study were less than ten cents per square mile. Satellite data with digital processing has been demonstrated to be a viable alternative to low elevation photography with manual interpretation in monitoring Tussock Moth damage.

ERTS-1 SATELLITE DATA FOR MONITORING SEASONAL VARIATIONS IN MALHEUR LAKE

Introduction

Malheur Lake in Central Oregon is subject to large seasonal fluctuations in contained water. The lake is shallow and exhibits large changes in water acreage. During low water periods the lake is subdivided into several irregular shaped regions separated by areas of exposed lake bottom.

An accurate determination of water acreage throughout the year presents several problems. Coverage of the lake by aerial photography is moderately expensive. It also requires visual interpretation and manual measurement of many irregular shaped water masses. It was also desired to obtain measurement data for several dates throughout the year.

As an alternate source of data the NASA ERTS 1 satellite was considere

The Satellite

The earth Resources Technology Satellite (ERTS 1) was launched into a 500 mile high polar orbit in July, 1972. Its orbital parameters are adjusted so that on an 18 day cycle it provides repeat coverage of every location on the Earth's surface. The orbit is sun synchronous maintaining a near constant angular relationship between the sun, the Earth, and the satellite.

The satellite contains a multispectral scanner which optically sweeps transversely to the satellite motion. The sensors have sensitivity to solar radiation reflected from the earth in the regions of green (0.5μm-0.6μm). red (0.6μm-0.7μm), infrared (0.8μm-0.8μm), infrared (0.8μm-1.1μm). The groundresolution of the sensor system is about 1.5 acres. Due to an overlap of data across the scan line, each resolution element contributes 1.125 acres toward the entire area of a scene. A scene consists of a square region with 100 nautical miles per side.

After satellite acquisition, the data is transmitted to the NASA Goddard receiving station. Following pre-processing it is made available to users in the form of computer compatible digital tape. The data is also processed into "photographic like" images for visual interpretation.

PIXEL

PIXEL (Pictorial Information Extraction and Enhancement Laboratory) of the Department of Electrical and Computer Engineering at Oregon State University has developed a computer oriented data processing system called PIXSYS. This work was accomplished under NASA support. Using PIXSYS the data analyst has available powerful and flexible processing capability for ERTS digital data.

Experimental Procedure

ERTS computer compatible tapes were acquired for the following dates. Dates were selected on the basis of ice free conditions and acceptable weather conditions (no clouds).

Date	NASA Identification
25 July 1972	1-002-18120
23 October 1972	1-092-18102
3 April 1973	1-254-18111
9 May 1973	1-290-18110
2 July 1973	1-344-18102
20 July 1973	1-362-18101
7 August 1973	1-380-18095
13 September 1973	1-417-18150
18 October 1973	1-452-18082

The 0.8μm-1.1μm infrared data was used in the discrimination of water regions from surrounding dry regions. Water absorbs nearly all solar radiation at this wave length resulting in very little reflected radiation reaching the satellite.[1] Land forms provide much greater reflection in this region of the spectrum. This single feature is sufficient to discriminate between water and nonwater regions.

Histograms of reflected energy in the selected infrared band (band 7) were obtained for the region of Malheur Lake. The intensity levels are integers in the range of 0 through 63. Water normally lies in the region 0-5. Land is normally in the region of 10-40. The receeding water levels provided intermediate transition levels of very shallow water and mud which were subjected to close investigation before the threshold between water and nonwater was chosen.

Computer grey-scale graphical reproductions were prepared by assigning each of the lowest intensity data integers a distinctive alphameric character. By observing the computer output and using known lake conditions at selected points, it was possible to accurately define the threshold between water and nonwater areas. Figures 1-9 show the graphical computer representation of the lake for each of the test dates.

It was possible to compute the water acreage by computer enumeration of the total number of resolution cells classified as water. This number was then multiplied by the effective area of each cell to produce the total lake area. Corrections were made to account for water bodies outside of the normal lake boundaries such as rivers and surface water.

1) Wagner, T. W., Polcyn F. C., "Progress of an ERTS 1 Program for Lake Ontario and Its Basin". *Symposium on Significant Results Obtained from ERTS*, Goddard Space Flight Center, March 1973.

Results

The water areas as calculated from the digital data is presented in Table 1.

Date	Total Number of Elements Classified As Water	Water Acreage
25 July 1972	31,509	35,500
23 October 1972	24,074	27,100
3 April 1973	37,012	41,600
9 May 1973	30,789	34,600
2 July 1973	20,849	23,500
20 July 1973	18,919	21,300
7 August 1973	16,529	18,600
13 September	15,157	17,000
18 October 1973	13,941	15,700

Table 1. Water Acreage Determination From ERTS Data.

Appendix C-4

THE ERTS SATELLITE AS A SOURCE OF NATURAL RESOURCE DATA

James H. Herzog and Ray C. Rathja

Introduction

It is ironic that in a world endowed with tremendous technological tools for information processing, that the science of information gathering for natural resource management is still in its infancy. In a world with insufficient food, we have no method of monitoring the wheat or rice crop to predict yields. Techniques for determining the vigor and pest infestation of our forested lands are time consuming, inaccurate, and expensive. Adequate land use planning is difficult because there is a lack of adequate data relating land use, population, ecological communities, and economics.

As a first step in providing a viable source of data relevant to natural resource managment, NASA launched the Earth Resources Technology Satellite (ERTS) in July, 1972. Using a marriage of remote sensing capabilities developed by the military and space technology from the space program, ERTS offers us an initial data source with a scope suitable for planning purposes.

ERTS

ERTS was launched in July, 1972 into a nearly polar, sun synchronous orbit. The constant sun angle corresponding to about 9:30 A.M. local time was selected to provide optimum shadows for delineating surface features. Weighing about 2000 pounds the satellite requires 103 minutes to complete an orbit. Of the fourteen orbits competed per day, three are suitable for gather information. The satellite has repeat coverage of every point on the Earth at 18 day intervals with the same sun angle.

Aboard the satellite are two systems for gathering information about the earth.

Return Beam Vidicon

The return beam vidicon or RBV uses three identical cameras filtered in such a way that each is sensitive to a portion of the solar radiation reflected from the Earth.

Channel 1 - green (0.475-0.575 micrometers)
Channel 2 - red (0.580-0.680 micrometers)
Channel 3 - near infrared (0.690-0.830 micrometers)

An electronic failure in the RBV system resulted in a decision not to use the RBV but instead to use the Multi-Sensor Scanner (MSS) with its better resolution and radiometric accuracy.

Multi-Sensor Scanner

The MSS is a line scanning system. An oscillating mirror is used to direct a narrow ground swath beneath the satellite to a small telescope. At the focus of the telescope are fiber optic bundles which direct the received radiation to an array of 6 groups of 4 detectors. Each of the 4 detectors is sensitive to a different region of reflected solar radiation.

Channel 4 - Green (0.5-0.6 micrometers)
Channel 5 - Red (0.6-0.7 micrometers)
Channel 6 - Infrared (0.7-0.8 micrometers)
Channel 7 - Infrared (0.8-1.1 micrometers)

Each sensor has an instantaneous viewing area (resolution) of a 79 meters square on the ground. The satellite simultaneously images 6 adjacent ground tracks. During the return trip of the mirror, no data is accepted, and the satellite advances 474 meters. (This corresponds exactly to the resolution of 6 of the sensors and no data is lost).

The width of a ground swath is 185 KM. This is considered the horizontal direction and is transverse to the motion of the satellite. The horizontal direction is composed of 3240 samples. Due to overlap of the resolution cells, the effective horizontal sample size if 56 meters. (This means that when measuring distances each sample corresponds to 56 meters).

The data from 390 mirror oscillations (or 6 X 390 = 2340 scan lines) comprises one ERTS scene of approximately 185 KM square. A scene is composed of 2340 scan lines each containing 3240 sample points in each of four spectral bands. A total scene contains about 30 million pieces of data. Each ground resolution point of 79 X 79 meters has four measurements corresponding to the four spectral regions of the sensors.

Signals from each scene are digitized to 128 levels and telemetered to one of three U.S. and one Canadian ground receiving stations. The data is initially processed at the NASA Goddard Space Flight Center in Greenbelt, Maryland.

By using the digital data to modulate the intensity of a light source, it is possible to transform the data into photographic like imager. This imagery may be interpreted using classical photointerpretation techniques. Most interpreters consider the ERTS photographic reproductions to have insufficient resolution for all but gross analysis. It must be remembered that the photographic data has much lower resolution and radiometric accuracy than the digital source data.

Digital tapes are produced by NASA which contain the 30,000,000 pieces of digital data on four computer compatible tapes. Each tape contains the information from a ground track 46 KM wide and 185 KM long.

Data Quality

The quality of the digital data received from the satellite has generally been good. The following statements summarize some of the pertinent features of the data.

Edge Distortion

The ERTS data is obtained from a very high elevation (500 miles) and has a maximum deviation from nadir of $\pm 5.78^{\circ}$. Each piece of data corresponds to a ground point almost directly below the satellite. The maximum edge distortion is 115 meters.

Aspect Ratio

The ground resolution point centers have a separation of 56 meters in the horizontal direction and 79 meters in the vertical direction. The data is commonly displayed using a standard computer line printer. Such printers display 10 characters per inch in the horizontal directiion with 8 lines per inch (in some installations 6 lines per inch are used with the option of using 8 lines per inch) in the vertical direction.

One inch on the computer line printer corresponds to
56 X 10 = 560 meters in horizontal direction
79 X 8 = 632 meters in vertical direction
(8 lines/inch)

Altitude Variations

Since the the satellite orbit is not a perfect circle and the Earth is not a perfect sphere, the nominal 79 meter resolution varies according to the actual vertical height of the satellite. The magnitude of scale changes may be approximated by

$$\Delta X = 9.26 \times 10^{4} \frac{\Delta h}{h}$$

This variation is normally too small to require correction.

Earth Rotation

The Earth rotation beneath the satellite causes the 185 KM X 185 KM scene to correspond to a parallelogram rather than a square on the Earth's surface. It takes approximately 25 seconds to acquire the data for one scene. In this time the earth rotates Eastward about 5 miles.

Frame Rotation

The satellite is not in a north-south orbit, but is inclined at about 9° at the equator. In the U.S.A. this results in a 13° clockwise rotation with respect to true north.

Scan Time Skew

During the sweep time of the mirror, the satellite advances approximately 216 meters. This provides a logitudinal skew to the data.

Banding

Within the array of 24 sensors, each group of six should ideally be well matched for output. Due to aging and calibration inaccuracies differences may appear within the six line scans corresponding to one mirror oscillation. This problem can be especially severe when doing precision work. The NASA calibration of the sensors can balance them to within ± one integer value.

Geometric Corrections

In many situations the geometric errors introduced by the scanner are of negligible importance to the user. It is possible to change the original coordinates (horizontal and vertical point locations) by a linear transformation to remove the rotation and skew distortions and correct for the aspect ratio of the data and the output device. In the case of a line printer

$$\begin{matrix} X_C \\ X_L \end{matrix} = \begin{matrix} 1.03574 & 0.34312 \\ 0.15222 & 0.93351 \end{matrix} \quad \begin{matrix} Y_C \\ Y_L \end{matrix}$$

The Y coordinates are the new line and column numbers. The X coordinates are the original line and column numbers. Since the calculated X position is likely to be a noninteger, the nearest integer to the calculated position is used.

Digital Pictures

ERTS provides us with a source of high quality digital pictures. The data is not photographic but is instead an indication of the average reflected radiation from an acre of the Earth's surface in each of four narrow spectral bands. The data is discrete which means that these reflectance values can be related to a grid arrangement on the surface of the Earth. To each acre of the Earth's surface there are associated four numbers in the range 0 - 127.

The digital form of the data is easily handled by a computer, but to make it useful it must be communicated to a human. This is most conveniently done in pictorial form. A computer line printer or teletype, devices not designed to handle pictorial data, are commonly used as output devices. Pictorial output devices, especially designed for computer graphics, are also available. In some configurations it is possible to transform computer data to color film or color television monitors.

The methods described will deal with line printer and teletype output devices. They have the advantage of being universally available and well suited for remote terminal operation.

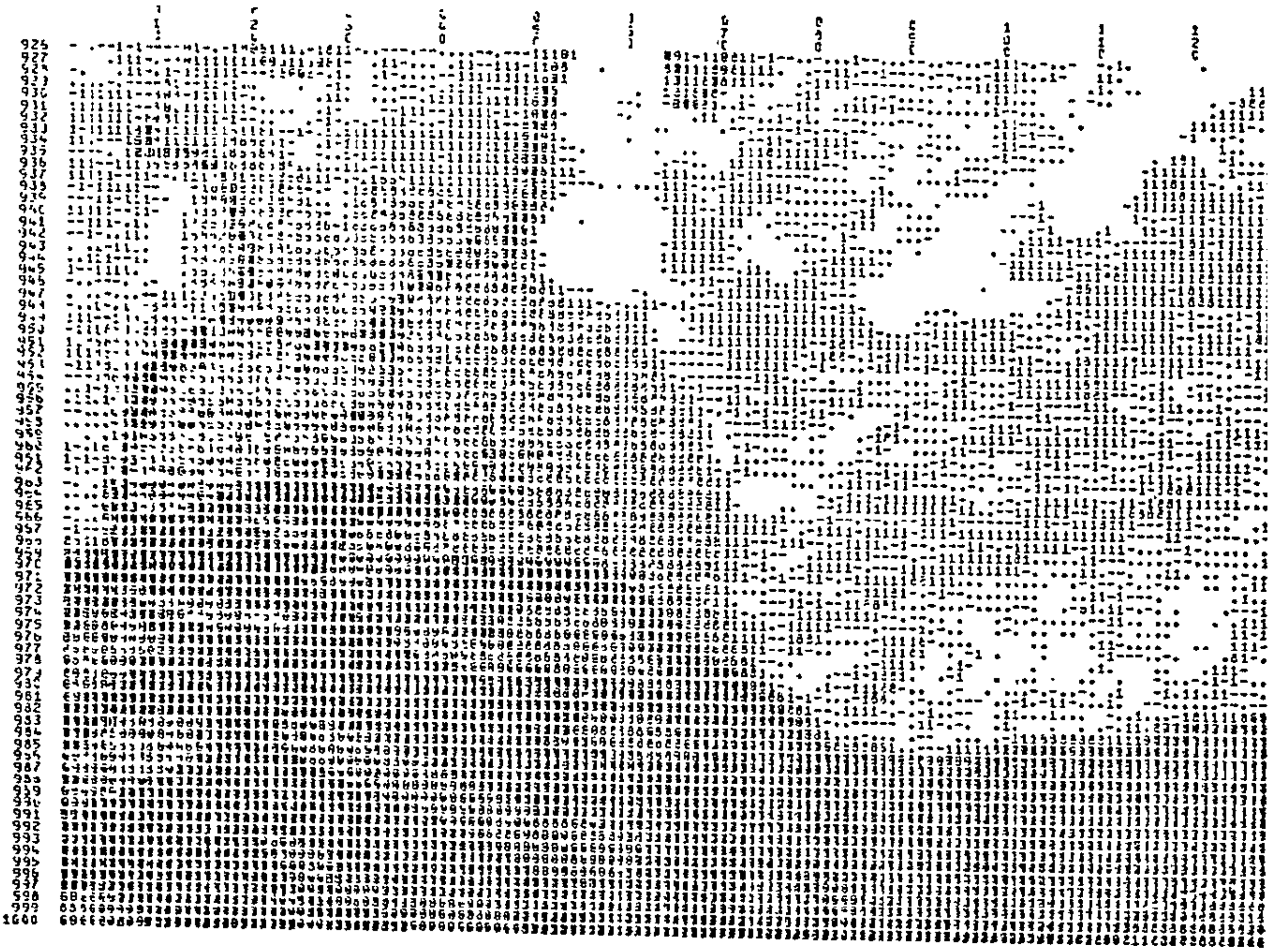
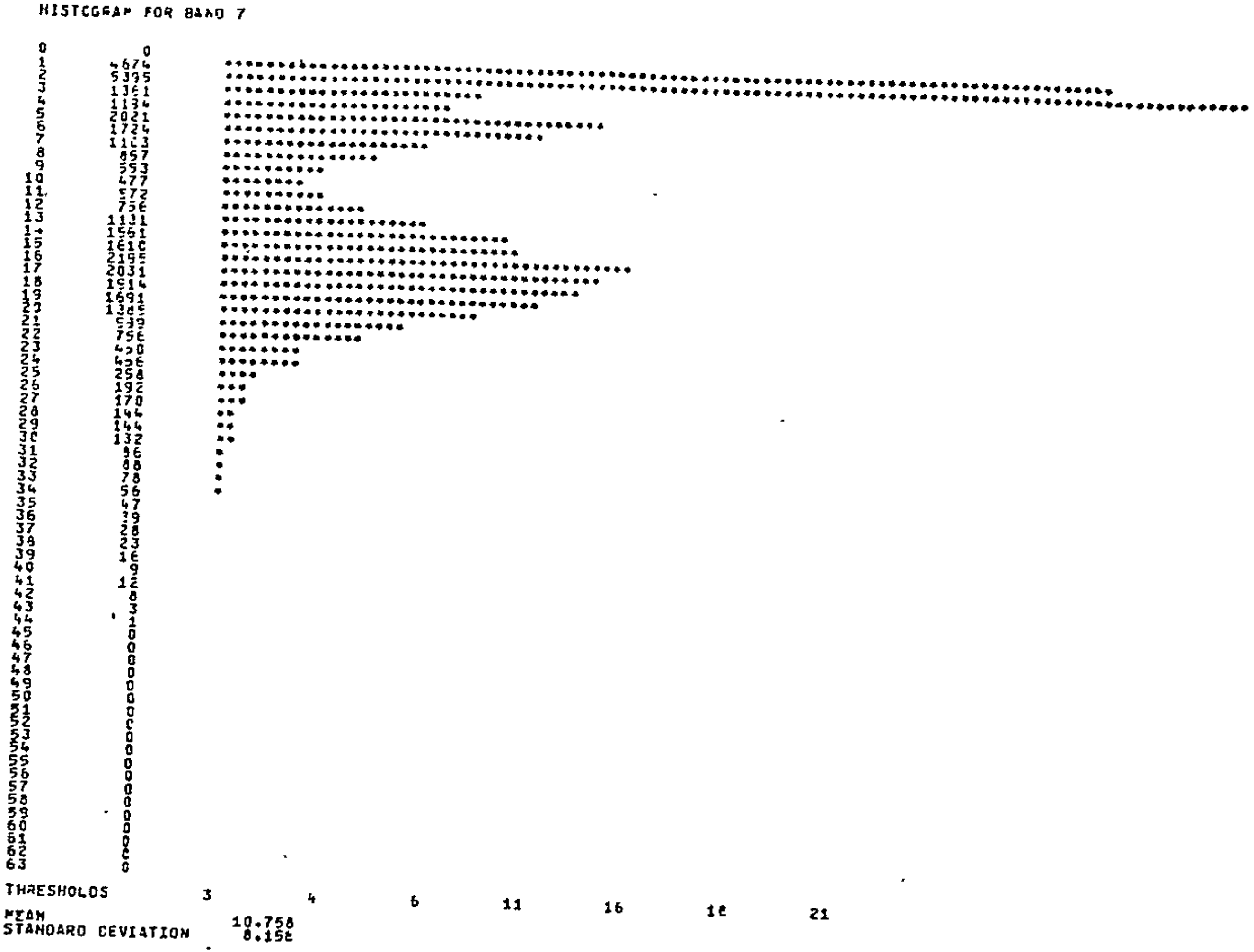


Figure 1

Histogram Equalized Greyscale for Band 7.

A section of the Columbia River approximately 25 miles from the mouth. The thresholds chosen were such that as nearly as possible each symbol appears an equal number of times. The thresholds were 3, 4, 6, 11, 16, 18, 21 as given by Figure 2.



```
HISTOGRAM FOR BAND 7

 0        0
 1     4674
 2     5395
 3     1361
 4     1134
 5     2021
 6     1724
 7     1103
 8      857
 9      553
10      477
11      572
12      756
13     1131
14     1561
15     1610
16     2195
17     2031
18     1914
19     1691
20     1385
21      939
22      756
23      450
24      456
25      258
26      192
27      170
28      144
29      144
30      132
31       96
32       88
33       78
34       56
35       47
36       39
37       28
38       23
39       16
40        9
41       12
42        8
43        3
44        1
45        0
46        0
47        0
48        0
49        0
50        0
51        0
52        0
53        0
54        0
55        0
56        0
57        0
58        0
59        0
60        0
61        0
62        0
63        0
THRESHOLDS          3     4     6     11     16     18     21
MEAN                  10.758
STANDARD DEVIATION     8.156
```

Figure 2

A Histogram of a Small Area for Band 7.

The modes appearing at the lower end of the scale correspond principally to water features. The upper mode is the land. The thresholds given are for histogram equalization.

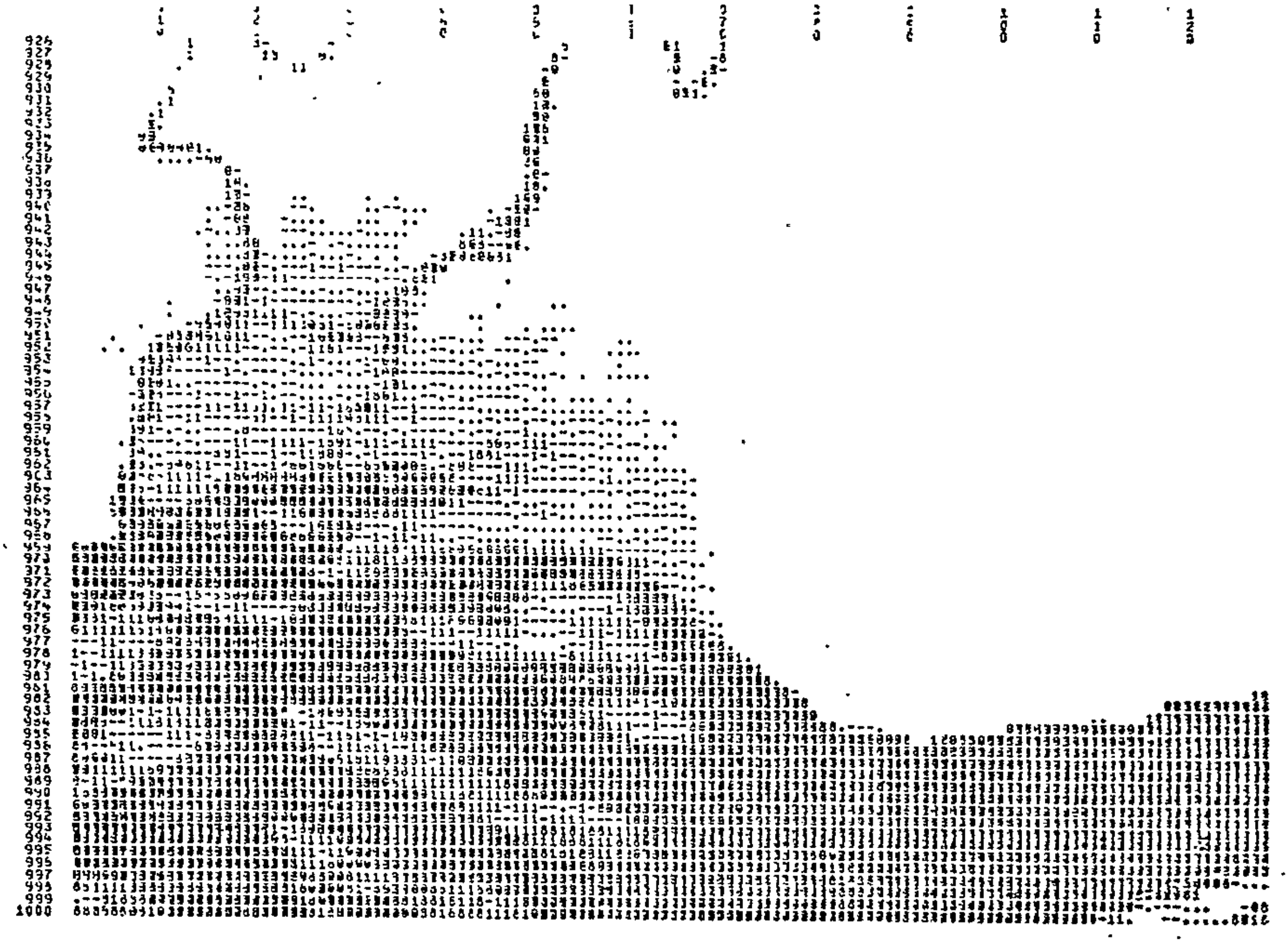


Figure 3

Density Sliced Greyscale for Band 7.

The same area as Figure 1 only the greyscale assignments have been reselected to display only water features. The thresholds chosen were 2, 3, 4, 5, 6, 7, 8.

Greyscale Images

In the simplest form of greyscale image, one band of a portion of an ERTS image is transformed into a pictorial representation by converting the digital magnitude of each ground resolution element into a darkness level. The darkness level is obtained on the output device by using the standard alphameric character set. For very dark levels, overstrikes are used involving several characters.

In many cases, the human interpreter does not need the maximum 127 levels of darkness which may present be present in the data. (Usually the 127 levels are not present anyway). Groups of darkness levels on the data source may be combined and represented by a single line printer darkness representation. Commonly, only 8 darkness levels are used.

For general representation of the digital data, the 8 intensity levels are distributed so that each is used approximately equally in the pictorial reconstruction. This can be done by determining in advance the distribution of intensities in the original data and assigning darkness characters to selected ranges of intensity values. For example, the data magnitudes 0-10 may be assigned the character " " (blank); 11-15 may be assigned "·"; 16-52 assigned "/", etc.

The greyscale image is often used as an intermediate step in more advanced processing. It may, for example, be used to locate test sites for use in the classification program. In other cases it may be used as a basis for human "photo interpretation".

Density Slicing

In some situations the fine structure of digital image can be enhanced by causing "small changes" in the digital data correspond to "large changes" in the pictorial representation. In Figure 3, for example, the fine structure of the water was emphasized by assigning intensities known to not be water the character " " (blank). The available darkness levels were distributed over the intensities known to be water. Small changes in water characterisitics were then emphasized.

Density slicing is commonly done with photographic images. Photography, however, is an irreversible process. Areas which are underexposed or overexposed cannot be enhanced. Since the original digital data is present. This presents no obstacle in digital processing.

Intelligent use of density slicing requires an a priori knowledge of the relationship of the data to the density slicing thresholds. In Figure 3, for example, it was known that in band 7 (infrared) water appears much darker (lower digital magnitude) than land. It is possible to discriminate land forms from water by establishing a single threshold in the band 7 data.

Superpictures

The greyscale and density slicing techniques were described for only one band of the ERTS data. For a human to interrelate the informatio contained on four images is a difficult job. It is possible to create a new digital picture from a linear combination of the four individual pictures. The contribution of each individual image to the composite image may be selected.

As an analogous situation panchromatic film has a uniform sensitivity throughout the visible spectrum. Through the use of filters it is possible to emphasize some spectral contributions and decrease others. The resulting photograph may be easier to interpret.

With digital data there exists an enormous flexibility in selecting the "film - filter" characteristics. All four bands may be equally weighted to provide a "panchromatic" image. The weighting may be unequal to emphasize a particular characterisitic.

Using statistical techniques it is possible to choose a set of "weighting coefficients" so that the composite image contains greater variation than any of the individual digital images. Calculation of the weights is done by performing a principal component analysis for a portion of the ERTS scene.

Classification

Classification is the process in which a set of rules are used by a computer to assign each ground resolution element to one of several classes. As in the case of photointerpretation, classification extends results obtained in known local regions to unknown universal regions.

If a photointerpreter has "known" examples of agricultural crops on a photograph, he can infer that other fields similar to one of his known fields probably have the same crop. Classification requires the use of features. The photointerpreter commonly uses color, texture and shape. Two regions with "similar features" are probably similar.

Computer classification eliminates the repetitous judgement of a human operator. Because of the magnitude of the data, a human operator could not possibly classify the approximately 7.5 million ground resoltion elements of an ERTS scene.

In computer classification the magnitudes of the four pieces of spectral information are used as features. The assumption is implied that two regions on the Earth which are identical will have identical or "very similar" digital representation (set of four numbers). Regions which are different will have different digital representations.

Computer classification normally proceeds as follows:

1) The human indicates the the computer examples of the classes he wishes to classify. This is done by indication line and column locations of such classes. These known examples are called training sets. (Normally a greyscale image is used for location of training sets).

2) The computer abstracts parameters from the data. Normally this includes the mean and standard deviation of each of the four measurements for all elements in each training set. The vector including all of the four mean values is called a prototype vector for that class. Each class will have a different (unique) prototype vector.

3) The human specifies a region for which he wants a classification made.

4) The computer compares each group of four numbers for an "unknown" ground resolution element to all of the prototype vectors. It classifies the ground point according to its largest similarity to one of the prototype vectors. If it is not similar to any of the prototypes, it is classified as "unknown".

5) The results of the computer classification are presented to the human through the line printer. The format is similar to a "greyscale" image except that a distinctive symbol is printed to represent each class.

The concept of similarity is important. No single definition is best. A common measure is the sum of the squares of the differnece between each element of the "unknown" and the prototype vector. If the "unknown" vector and the prototype vector are identical, the similarity measure is 0. The smaller the similarity measure, the greater the similarity.

Computer classification requires extensive interaction of a human interpreter. The"ground truth" requirements are very similar to photo-interpretation. The human must be capable of guiding the computer and introducing value judgements on the results. This type of classification requires the human to indicate known training sets and is called supervised classification.

Unsupervised Classification

In some instances no ground truth or training sets are initially known. It is still possible to perform a classification through what is known as unsupervised (no training sets) classification. (This is sometimes referred to as clustering analysis).

The computer is allowed to examine the specified data set to try to find unique classes. Algorithms to accomplish this are called clustering algorithms since they look for natural clusters of similar vectors.

The classes determined by clustering alogrithms may or may not be suitable. In many cases they are difficult to interpret. Results from classifications using the "natural" classes often allows the human to locate potential training sites and to establish ground truth. Supervised classification may then be used.

Conclusion

Digital data obtained from ERTS offers a valuable source of natural resource information. Techinques necessary to handle this data require the use of computers and highly specialized computer programs.

In computer analysis, the human is elevated to a supervisory role in which he guides the activity of the computer and evaluates its results. This results in a savings of time and money and has the potential of producing superior results.

REFERENCES

ERTS Data Users' Handbook, Document No. 7154249, Goddard Space Flight Center, NASA, Greenbelt, Maryland.

Anuta, Paul E., Geometric Correction of ERTS-1 Digital Multispectral Scanner Data," LARS Information Note 103073, Purdue University.

Herzog, J. H., Rathja, R. C., Yamanuha, L. S., "An Automatic Classifiaction System for ERTS Digital Data", PIXEL Technical Report 111573, Oregon State University.

Appendix C-5

PIXSYS

A USERS MANUAL

Roy C. Rathja
James H. Herzog

ictorial Information Extraction and Enhancement Laboratory
(PIXEL)
Department of Electrical and Computer Engineering
Oregon State University
Corvallis, Oregon

PIXEL Technical Report 080174

INTRODUCTION TO PIXSYS

Since the launching of the Earth Resources Technology Satellite (ERTS-1) in July 1972 there has been, for the first time, a repetitive source of high quality multispectral digital imagery for monitoring the earth's surface. This imagery is relatively inexpensive, easily accessible and provides a viable extension of classical photointerpretation techniques in natural resource applications. However, the data supplied is not in a form that is readily interpretable by those most in need of it. Since the ERTS data became available, it has been the goal of the Pictorial Information Extraction and Enhancement Laboratory (PIXEL) at Oregon State University to develop and implement techniques for the application of this data. It is the purpose of this presentation to provide an overview of the techniques currently implemented in PIXSYS - a group of FORTRAN programs developed to utilize the digital imagery supplied by ERTS.

In the application of digital computers to the processing of remotely sensed imagery, the analysis must produce a product which is readily interpretable by individuals in the various disciplines who can make use of the data. This group of users have widely based interests and place diverse requirements on the data products. This requires that the techniques applied to the data be general enough to have wide applicability. Also, users must be able to easily interact at various stages of the data processing. They alone understand the fundamental problems these techniques are being used to solve. At Oregon State University, we are very fortunate to have a computer system which allows easy access and user interaction.

All programs in PIXSYS are written in FORTRAN and typically require about 10K core locations. Their basic format assumes an on line user and they make use of a question-answer format for control data. Such a format takes full advantage of the improved analysis possible when a human is an integral part of the analysis system at every step. An effort has been made to relieve the user of as much of the burden of learning the computer system as possible. Wherever possible, file manipulation and system control operations are handled by the programs.

The analysis performed by PIXSYS may be broken into two fundamentally different types: single band and multiband. Within the single band analysis current methods include individual band display with greyscale reconstructions of the images and density slicing for enhancement. The multiband analysis techniques include pattern recognition classification and principal component analysis. Cluster analysis, which will automatically classify data without prior knowledge of the classes, is also available.

PREPROCESSING

Prior to making ERTS data available for applications usage, some preprocessing is done. The programs for accomplishing this are not generally available to users but are run by staff personnel. Upon receipt of a set of data tapes, they are reformatted to take full advantage of the instruction set of the CDC 3300. Each band return is placed in 6 bit character form. A data validity check is run and if inconsistencies are found, users are informed.

Due to the large amount of data in a full scene, normally a small area of ERTS data is copied to on-line disk files for analysis. A user therefore should request staff personnel to provide a disk file of data for his area of interest.

SINGLE BAND ANALYSIS

Greyscale Analysis

A greyscale is nothing more than an attempt to produce a photographic type presentation of the digital data provided by the satellite. The goal is a presentation which closely approximates the radiometric and spatial relationships of the data in an economical hard copy form. Figure 1 is a typical greyscale of a small section of an ERTS frame. Each symbol represents the resolution cell of the satellite (about 1 acre). Through the proper selection of symbols and by using overstrike characters, an economical presentation may be generated with 8 levels of intensity (grey levels) displayed. Although most line printers are not ideally suited to the production of grey level images, they do produce a reasonable product which may be used for some elementary analysis or as a basis for a more detailed study.

Since the satellite returns more than 8 reflectance values some basis for assigning the 8 grey levels to the reflectance values must be found. A reasonable decision about an assignment may be made from a histogram of the values for the band to be displayed. Such a histogram is presented in Figure 2. The assignment whichmost nearly produces the same number of each of the eight grey level symbols is known an histogram equalization and produces an image which gives a good general presentation. Figure 1 is such an assignment.

Although histogram equalization produces a good overall image, it does mask some information in local regions of the histogram by grouping several reflectance values into one output grey level. A technique known as density slicing may be used to display the variations in some small region of the histogram. The technique is a reassignment of grey level symbols to a local region. Such an assignment has been made to produce the greyscale of Figure 3 in an attempt to emphasize the variations in water. The component of PIXSYS which produces histograms of ERTS files, gives histogram equalized assignments and produces greyscales is a single FORTRAN program called PIXOUT. It also allows for density slicing techniques of enhancement.

The general procedure to produce a greyscale of an area of ERTS data would, then, be to first use PIXOUT to provide statistics of the file with the data. Then a second run would be made to actually produce the greyscale using grey level assignments to best display the information of interest.

To use the PIXOUT program one should logon to an OS3 teletype terminal. Prior to running PIXOUT, a user should make sure that the logical units (LUNS) used by the program are not already in use. PIXOUT uses LUNS 10, 11 and 20. A simple method to accomplish this is to type RESET. RESET also unequips other units if they are in use. One would then type

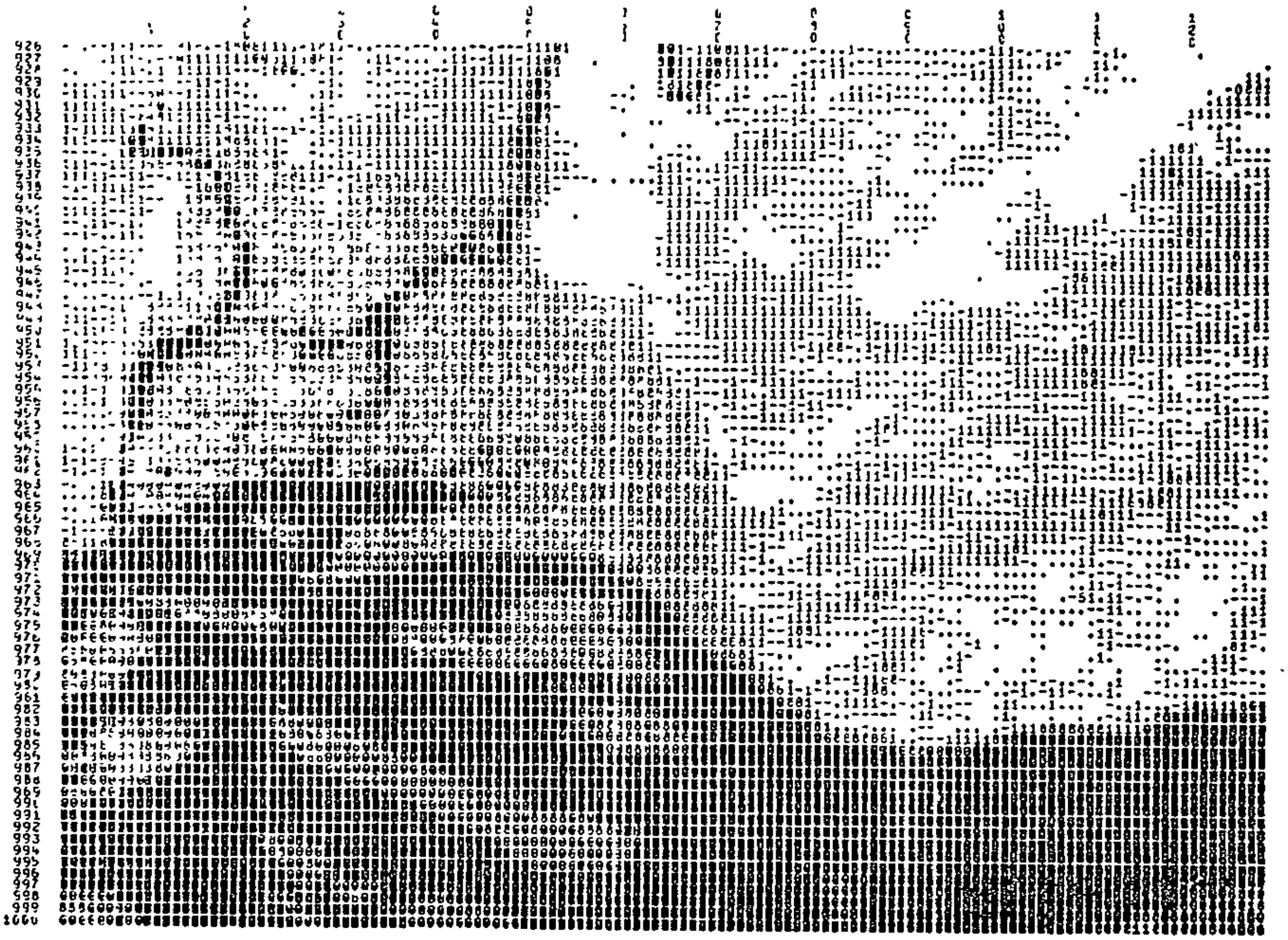
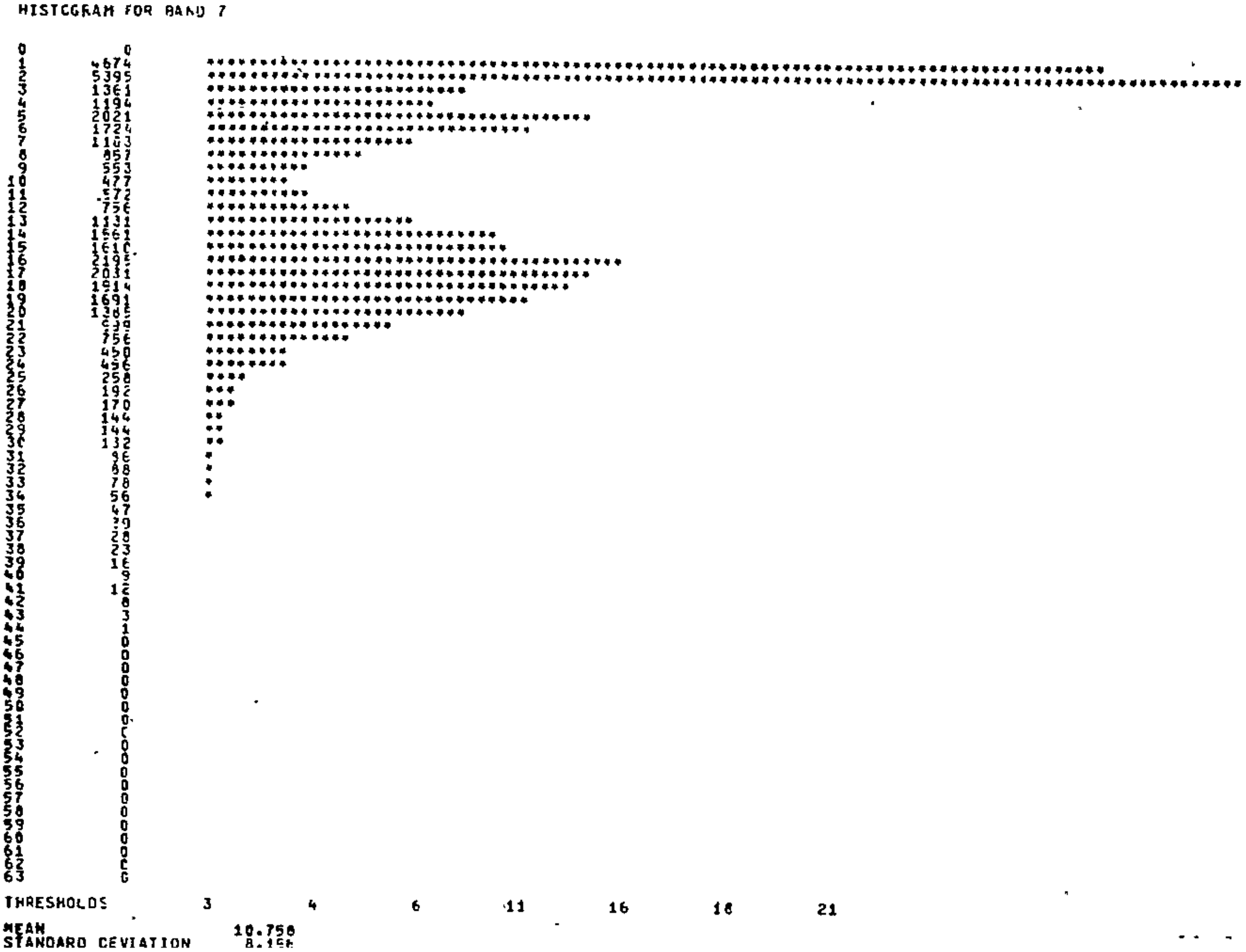


Figure 1



```
HISTOGRAM FOR BAND 7

 0          0
 1       4674
 2       5395
 3       1361
 4       1194
 5       2021
 6       1724
 7       1163
 8        857
 9        553
10        477
11        372
12        756
13       1131
14       1561
15       1610
16       2195
17       2031
18       1914
19       1691
20       1365
21        939
22        756
23        450
24        456
25        258
26        192
27        170
28        144
29        144
30        132
31         96
32         88
33         78
34         56
35         47
36         29
37         28
38         23
39         16
40          9
41         12
42          8
43          3
44          1
45          0
46          0
47          0
48          0
49          0
50          0
51          0
52          0
53          0
54          0
55          0
56          0
57          0
58          0
59          0
60          0
61          0
62          0
63          0
THRESHOLDS          3        4        6       11       16       18       21
MEAN                  10.758
STANDARD DEVIATION     8.196
```

Figure 2

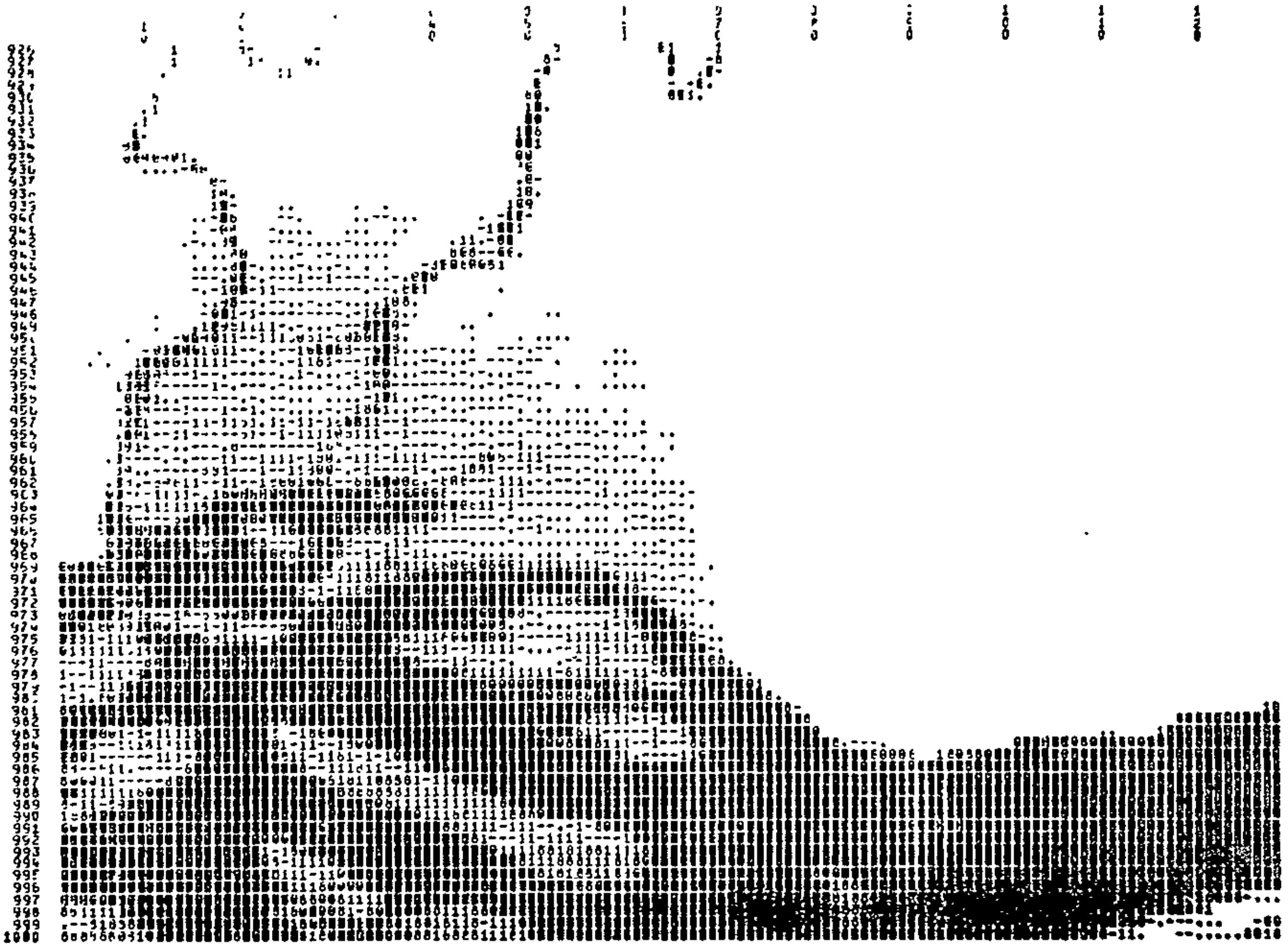


Figure 3

*PIXOUT to load the program into the computer. Responses to questions should be followed by a Carriage Return (CR). The following dialog will then be produced by the program:

PIXOUT VERSION 1.1

If other than version 1.1 an updated documentation should be acquired.

1. DO YOU WANT STATISTICS CALCULATED?
   (Reply YES or NO)

   If your reply is YES, then statistics will be generated. Generally statistics should be generated only once for each file since the process is moderately expensive. If your reply is NO, the next inquiry will be 6.

2. WHAT IS THE INPUT FILE?
   (Reply with file name)

   This is the name of an ERTS data file generated by staff personnel.

3. IS THE FILE NAME CORRECT?
   (Reply YES or NO)

   If your reply is NO, then question 2 will be asked again.

4. COMPUTING

   Normally there will be a time delay before the next output from the program. The length of the delay will depend on the length of the ERTS file and the number of other people using OS3.

5. WHAT FILE NAME WOULD YOU LIKE STATISTICS SAVED UNDER?
   (Reply with file name)

   The name supplied should be one that does not already exist on the users Job number. Should a name which already exists be supplied the program will abnormally terminate. All is not lost at this point though. One may then type SAVE, 10=NAME where NAME is a file name not already in use. Following an abnormal termination, RESET should be typed before any other programs in PIXSYS are used.

6. DO YOU WANT A PICTURE?
   (Reply YES or NO)

   If your reply is NO, the next inquiry will be 18.

7. WHAT IS THE INPUT FILE?
   (Reply with file name)

   This is the name of an ERTS data file.

8. IS THE FILE NAME CORRECT?
   (Reply YES or NO)

   If your reply is NO, question 7 will be repeated.

9. WHAT BAND?
(Enter Band number)

A single digit number from 4 to 7 should be entered.

Band 4	green
Band 5	red
Band 6	infrared
Band 7	infrared

10. CORRECT?
(Reply YES or NO)

If your reply is NO, question 9 will be repeated.

11. WHAT ARE THE THRESHOLDS?
(Enter 7 integer values)

The seven integer values between 0 and 63 to be entered must be in increasing order. Each number can be separated by either a space(s) or a comma. If an error in typing is made, a total of seven numbers must be entered until question 12 is asked. Carriage return has no effect on the input. The darkest greyscale character will be assigned to all data <u>less than</u> the first threshold. The second darkest character will be assigned to all data less than the second threshold, but <u>greater than or equal to</u> the first threshold and so on. The lightest character is assigned to all data values greater than or equal to the seventh threshold.

Normally single character greyscales will be produced. Should the user depress the CTRL and W keys at the same time while entering thresholds, overstrike greyscales will be produced. A message of the following form will then be supplied by the program:

OVERSTRIKE GREYSCALE WILL BE PRODUCED.

Overstrike greyscales, while providing a better appearing greyscale, contain no more information than a single character greyscale. They do, however, cost more to produce and therefore should generally be used to generate finished products.

12. CORRECT?
(Reply YES or NO)

If your reply is NO, question 11 will be repeated.

13. ON THIS FILE
LINES 900 - 1199
POINTS 1 - 128
ENTER START LINE, NUMBER OF LINES,
START POINT AND NUMBER OF POINTS
(Enter 4 integer values)

The four integer values may be any so long as they do not exceed the limits of the area covered by the ERTS data file. If they do an error, message is supplied. The four numbers may be separated by a space(s), comma or carriage return. The line and point numbers supplied by the program give the limits of the data file supplied by your response to 2.

14. COMPUTING

Note the comment under 4.

15. PICTURE IS COMPLETED.
DO YOU WANT ANOTHER PICTURE ON THIS FILE?
(Reply YES or NO)

If your reply is YES, the next inquiry will be 9.

16. WHAT FILE WOULD YOU LIKE IT SAVED UNDER?
(Reply with file name)

See the comment following inquiry 5. A statement of the form SAVE, 11 = NAME should be used if the program abnormally terminates.

17. CORRECT?
(Reply YES or NO)

If your reply is NO, question 16 will be repeated.

18. WOULD YOU LIKE TO START AGAIN?
(Reply YES or NO)

If your reply is YES, question 1 will be asked next. If your reply is NO, the program will terminate.

Following the use of PIXOUT all output will be on files. It is necessary to copy the files to some output device, normally the line printer or teletype. The following set of instructions will copy files to the line printer.

```
#*LPLABEL, 1/ 'YOUR NAME'
#COPY, I='FILE NAME', O = 1, S = 0
```

What follows the / in the first statement will be put out to the line printer to identify it as being your output. The 'FILE NAME' should be the name of a file you have produced.

The following instruction will copy files to the teletype.

```
#COPY, I = 'FILE NAME', S = 0, T = 18
```

The statistics output by PIXOUT are designed to be put out to a line printer. If copied to a teletype, the output will require an excessive amount of time and some parts will be deleted. The greyscale output may be copied to either output device, but should only be copied to the line printer if more than 50 points are specified. After as many copies as are needed of the files are made, they should be removed from the file by typing

```
#DESTROY, 'FILE NAME'
```

MULTIBAND ANALYSIS

Classification Using PIXSYS

Classification is basically the process of assigning unknown data to prespecified classes. Known data sets are used to determine classification rules. For ERTS the entire process may be looked at as the following procedures:

1. Data collection
2. Selection of test sites
3. Descriptive statistics generation
4. Classification of unknown samples

The data collection is performed by ERTS. With PIXSYS, the normal procedure is to produce a greyscale using the PIXOUT program. Based upon this greyscale and known ground truth, samples of the various classes are selected. The statistics generated in step 3 are dependent upon the decision rule used in the classification. The decision rule used by PIXSYS requires only the mean value and standard deviation for each of the four bands for each class. The selection of training sampl and descriptive statistics are produced by the SEL program in PIXSYS.

The PIXSYS classifier uses a modified distance to mean calculation as the basis for its decisions. The calculation uses all four spectral returns from ERTS. The procedure is most easily visualized geometrically and in two dimensions rather than four. Figure 4 is a plot of Band 4 vs. Band 5 for three different classes of data. Each class could represent, for example, water, sand, grasslands, some type of forest or anything of interest that can be discriminated in the ERTS data. The problem becomes: Given an unknown point X, to which class does it belong.

The approach taken by CLASSIFY, the classification program in PIXSYS, is to calcuate the distance between the unknown point X and the mean value for each class

$$d_k^2 = \sum_{i=4}^{7} \frac{(X_i - \mu_i^k)^2}{\sigma_i^k}$$

where X = the unknown sample reflectance values

μ^k = the mean value for class k of the reflectance values

σ^k = the standard deviation for class k of the reflectance values

The index i corresponds to the band. The point X is then classified into whichever class results in the smallest distance, d. There are also selectable guard bands surrounding each class. If the point X is not sufficiently close to any of the known classes as given by the guard bands, then the point is classified as unknown and a special symbol is displayed.

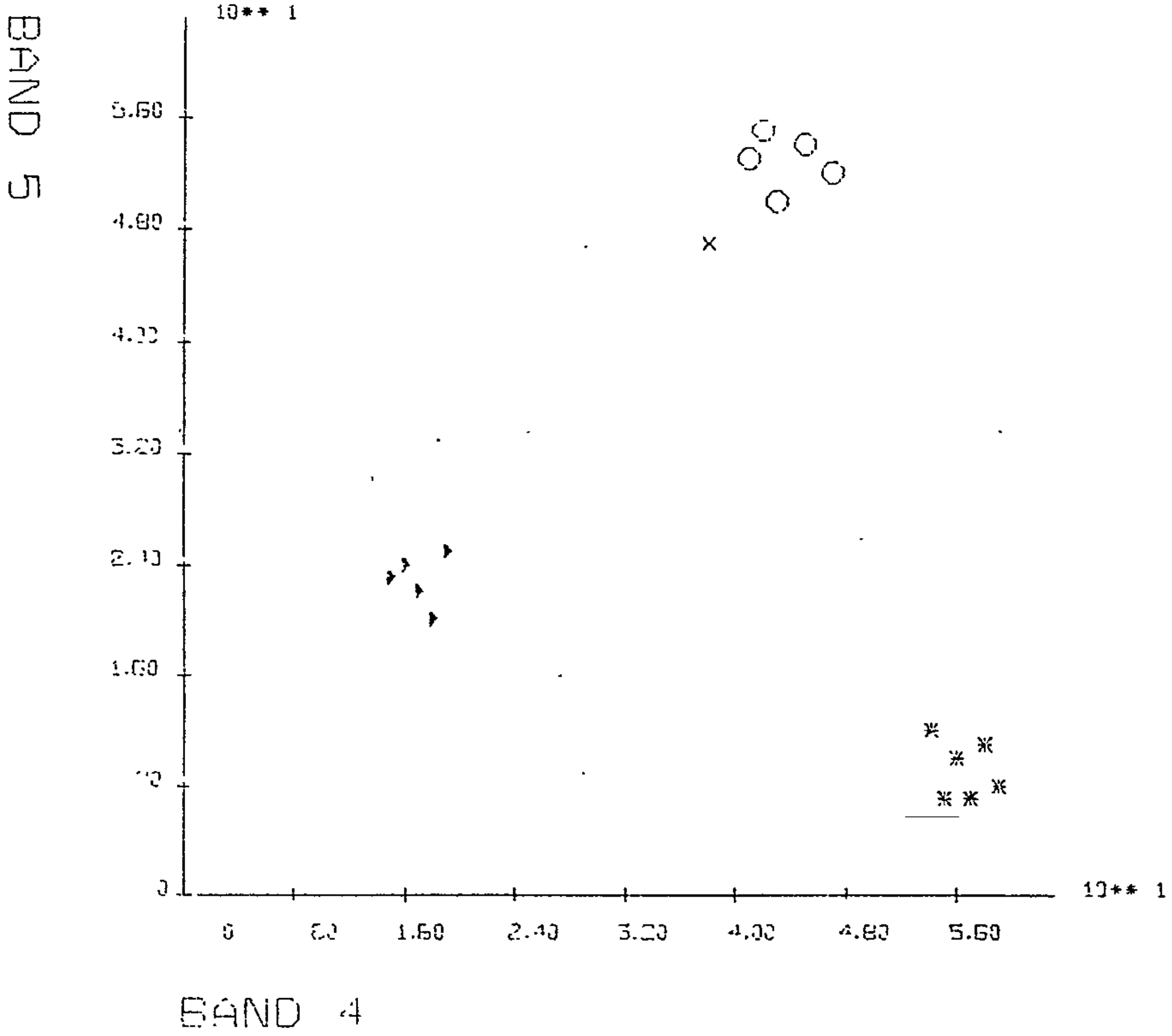

BAND 5
10** 1
5.60
4.80
4.00
3.20
2.40
1.60
.80
0
0
.80
1.60
2.40
3.20
4.00
4.80
5.60
10** 1
BAND 4

Figure 4

The division by standard deviation may be intuitively explained if one realizes that for a given class, the reflectance values may have more vaiation in one band than another. The division has an effect of compensating for this different variation and therefore giving each band an equal weight in the decision. If a user knows, a priori, that some bands are more important than others, he may assign values to the σ^k to reflect this knowledge.

The decision by PIXEL to use this classifier is based on:

1. The classifier is non-parametric. In natural applications, it is very difficult to find classes which have a probability distribution with an analytic form. Further, each class will generally have a different distribution form. While more optimal decision rules may be developed, they are dependent on certain distributions not always found in real data. As an example, the maximum likelihood decision rule commonly used in remote sensing is based on statistically normal distributions.

2. The classifier is computationally simple. While it is true that the digital computer can perform calculations at a high rate, one must keep in mind the large volume of data being processed. For ERTS, remember that there are about 7.5 million points to be classified for a scene of about 100 X 100 nautical miles. Each point to be classified has four numbers describing it. Unless the digital processing of ERTS can be shown to be cost effective, it will not provide an effective tool for natural resource monitoring.

3. The classifier is mathematically simple. To make full use of such an an analysis, individuals from various disciplines must be fully aware of the advantages and disadvantages of the method of analysis. The analysis used by CLASSIFY makes the implication almost intuitive.

An individual who would use the PIXSYS classifier would, then, first gather ground truth for use in the selection of training sites. This is the most important step in the automatic classification process. The final classification results can be no better than the description of the training sites supplied to the classifier. In selecting training sites one should strive for the maximum homogeneity. Such variants as vegetative density, ground slope, moisture content, understory and others make what are essentially the same vegetation types appear different (actually they are different). Automatic classification has, as yet, no ability for subjective or associative decisions. Should a user find that what he thinks is a single class is, in reality, many subclasses, he should assign each subclass as a class. Then in interpreting results of the classification, he may recombine the subclasses to his original class.

Following a careful selection of training sites, one must then relate these sites to the greyscales produced from the ERTS data of the same area. It will be necessary to determine that individual ERTS resolution elements are describing a particular area within the training sites. In order to generate the descriptive statistics for each class needed by the classifier, a user must specify, to the SEL program in PIXSYS, the location of individual ERTS resolution elements within each class. Since there are no legal boundaries marked in the ERTS data, one must relate the data to geographical areas via prominent natural landmarks such as forest boundaries, water bodies, field boundaries, or other natural demarcation. It is often advantageous to select training sites near such natural landmarks to facilitate training sample selection. Remember that each return is an average of the reflected return from an area about 240 ft. square. Thus precaution should be taken when selecting samples on the fringes of a training site.

The normal procedure in using SEL is to first select data points and then manually inspect the data to insure its homogeneity. Points which appear different should not be included when statistics are run if it can be determined that they do not belong to the class in question. Invalid data may be deleted either by rerunning SEL and not specifying the invalid points or by deleting the data from the file generated by SEL using the OS3 on-line EDITOR.

To use the SEL program one should logon to an OS3 teletype terminal. Prior to running SEL, a user should make sure that logical units (LUNS) used by the program are not in use. SEL uses LUNS 10, 11 and 20. A simple method to do this is to type RESET. One would then type *SEL to load the program into the computer. Responses to questions should be followed by a carriage return (CR). The following dialog will be produced by the program:

```
SEL VERSION 1.2
```

If other than version 1.2 an updated documentation should be acquired.

```
1.  DO YOU WANT TO SELECT POINTS?
```

(Reply YES or NO)

If your reply is NO, the next inquiry will be 6.

```
2.  WHAT IS THE INPUT FILE?
```

(Reply with FILE NAME)

This requests the name of an ERTS data file you wish to select points from.

```
3.  IS THE FILE NAME CORRECT?
```

(Reply YES or NO)

If your reply is NO, question 2 will be asked again.

```
4.  ON THIS FILE
    LINES   900 - 1199
    POINTS    1 -  128
    INPUT SAMPLE LOCATIONS
```

(Enter groups of 5 integer values)

Value 1. Enter the start line number
2. Enter the number of lines
3. Enter the start point number
4. Enter the number of points
5. Enter 1 if previous 4 values are correct
0 if previous 4 values are incorrect

Each value may be followed by a space, comma or carriage return. For simplicity, normally separate each entry by a space or comma and each group of 5 entries by a carriage return. As many groups of 5 entries as are necessary may be entered. There are no restrictions on the order of entering sample locations or on the size of sample groups selected as long as all points are on the currently specified data file. To terminate the entry of training sample locations, enter a CTRL W as the first entry of a group of 5 values. The program will respond with:

5. DO YOU WANT TO SELECT POINTS?
(Reply YES or NO)

If your reply is YES, go to 2. This allows the selection of samples from several ERTS data files as belonging to the same class. Any subsequent samples selected will be added to the samples already selected.

6. DO YOU WANT STATISTICS?
(Reply YES or NO)

There are four cases at this point.

Your reply is YES
- a) You did not select points this run - Go to 7.
- b) You selected points this run - statistics for the points you selected will be generated. Question 9 will next be asked.

Your reply is NO
- c) You did not select points this run - Go to 14.
- d) You selected points this run - Go to 11.

7. WHAT IS THE INPUT FILE?
(Reply with file name)

This should be a file that was generated by SEL during a previous run - not an ERTS data file.

8. IS THE FILE NAME CORRECT?
(Reply YES or NO)

If your reply is NO, question 7 will be repeated. If your reply is YES, statistics will be calculated for the samples on the file specified by question 7.

9. ARE YOU USING STANDARD DEVIATION IN THE CLASSIFIER?
(Reply YES or NO)

If your reply is NO, the standard deviations for each band will be set to one when calculating the distances of each of the samples from their class mean.

0. ENTER TRAINING SET ID TO LABEL OUTPUT.
(Reply with 8 characters or less)

11. ENTER FILE NAME TO SAVE SAMPLES UNDER
(Reply with file name)

Not asked unless samples have been selected. A file name not already present on the users Job number should be used. Otherwise the program will abnormally terminate. Should an abnormal termination occur, the files generated by the program be saved as follows

If samples have been selected:

```
#SAVE, 10 = 'FILE NAME'
```

If statistics have been calculated

```
#SAVE, 11 = 'FILE NAME'
```

12. IS THE FILE NAME CORRECT?
(Reply YES or NO)

If your reply is NO, question 11 will be repeated.

13. ENTER FILE NAME TO SAVE SAMPLE STATISTICS UNDER
(Reply with file name)

Not asked unless statistics have been calculated. See the note under question 11.

14. DO YOU WANT TO DO MORE?
(Reply YES or NO)

If your reply is YES, question 1 will next be asked. If your reply is NO, th program will terminate.

Following the use of the SEL program the results may be copied to either the line printer or to a teletype. See the instructions following the description of PIXOUT for an explanation of file copying procedure. Either output may be copied to the line printer or a teletype.

An example of some selected points and the file format produced by SEL is given in Figure 5. A sample of the statistics generated for a class is given in Figure 6. The histogram of the distances should be used to set the thresholds needed by the classifier. The threshold should be selected to include most if not all of the samples. The larger the threshold selected, the more points that will be included in the class during the classification.

Once a user has selected samples, verified them and generated descriptive statistics for each class of interest, he may proceed to the actual classification. Prior to using the classification program, CLASSIFY, it is necessary to generate a file with the descriptive statistics for all the classes to be used. This file may be generated by use of the on-line editor, EDIT, or by punching the data on cards and then copying them to a file. Each line of the description file should contain the description of a single class in the following format

TEST SAMPLES

Band 4	Band 5	Band 6	Band 7	Scan Line	Point
11	9	13	15	1	1
9	6	13	14	1	2
9	6	13	15	1	3
10	7	14	15	1	4
11	8	14	16	1	5
11	8	13	14	2	1
10	8	14	15	2	2
11	9	14	16	2	3
11	10	15	16	2	4
11	9	14	16	2	5

Figure 5. Typical training set selected by use of *SEL.

```
ATISTICS FOR SAMPL      TRAINING SET
STANCES CALCULATED USING ACTUAL STANDARD DEVIATION


NTENSITY BAND 4 BAND 5 BAND 6 BAND 7 DISTANCES


     0         0         0         0         0         57
     1         0         0         0         0         50
     2         0         0         0         0         49
     3         0         0         0         0         43
     4         0         0         0         0         32
     5         0         0         0         0         23
     6         0         0         0         0         15
     7         0         0         0         0          6
     8         0         0         0         0          3
     9         0         0         0         1          6
    10         0         1         0         5          4
    11         0        13         0         3          7
    12         0        17         0        12          2
    13         0        41         0        27          2
    14         0        20         0        44          4
    15         0        66         0        38          0
    16         0        31         0        60          2
    17         0        17         1        51          3
    18         0        23         3        49          1
    19       111        27         7        12          1
    20        21        20         5         4          0
    21        37        19        31         2          1
    22        24        11        23         3          0
    23        51         5        51         0          0
    24         5         0        51         0          0
    25         4         0        32         0          0
    26         0         0        25         0          0
    27         0         0        10         0          0
    28         0         0         2         0          0
    29         0         0         1         0          0
    30         0         0         0         0          0
    31         0         0         0         0          0
    32         0         0         0         0          0
    33         0         0         0         0          0
    34         0         0         0         0          0
    35         0         0         0         0          0
    36         0         0         0         0          0
    37         0         0         0         0          0
    38         0         0         0         0          0
    39         0         0         0         0          0
    40         0         0         0         0          0
    41         0         0         0         0          0
    42         0         0         0         0          0
    43         0         0         0         0          0
    44         0         0         0         0          0
    45         0         0         0         0          0
    46         0         0         0         0          0
    47         0         0         0         0          0
    48         0         0         0         0          0
    49         0         0         0         0          0
    50         0         0         0         0          0
    51         0         0         0         0          0
    52         0         0         0         0          0
    53         0         0         0         0          0
    54         0         0         0         0          0
    55         0         0         0         0          0
    56         0         0         0         0          0
    57         0         0         0         0          0
    58         0         0         0         0          0
    59         0         0         0         0          0
    60         0         0         0         0          0
    61         0         0         0         0          0
    62         0         0         0         0          0
    63         0         0         0         0          0


ANS       20.65   16.17   23.45   15.75       3.99
D DV       1.67    3.07    1.5     2.21       3.82
UMBER OF  SAMPLES  311
```

Figure 6.

Columns	Contents
1-8	Class name
9-12	Number of samples in training set
13-18	Mean for Band 4
19-24	Mean for Band 5
25-30	Mean for Band 6
31-36	Mean for Band 7
37-42	Standard Deviation for Band 4
43-48	Standard Deviation for Band 5
49-54	Standard Deviation for Band 6
55-60	Standard Deviation for Band 7
61-66	Threshold for class
68	Character to represent class

Following the last class entry, an end of file mark should be used. A maximum of 50 classes is allowed.

Similar procedures to these used prior to running other PIXSYS programs shoul be used for CLASSIFY. CLASSIFY uses LUNS 10, 20, and 21. To load the program into the computer type *CLASSIFY. The following dialog will result.

CLASSIFY VERSION 1.1

If other than version 1.1 an updated documentation should be acquired.

1. ENTER FILE NAME TO BE CLASSIFIED
   (Reply with an ERTS data file name)

2. CORRECT?
   (Reply YES or NO)

   If your reply is NO, question 1 will be repeated.

3. ON THIS FILE
   LINES 900-1199
   POINTS 1- 128
   ENTER START LINE, NUMBER OF LINES,
   START POINT AND NUMBER OF POINTS
   (enter 4 integer values)

   The four integer values may be any so long as they do not exceed the limits of the area covered by the ERTS data file. If they do, an error message is supplied. The four numbers may be separated by a space(s), comma or carriage return. The line and point numbers supplied by the program give the limits of the data file supplied by your response to 1.

4. ENTER FILE NAME WITH CLASSES
   (Reply with data file you generated with descriptive statistics)

5. CORRECT?
   (Reply YES or NO)

   If your reply is NO, question 4 will be repeated.

6. COMPUTING

Normally, there will be a time delay before the next output from the program. The length of the delay will depend on the length of the ERTS file and the number of other people using OS3.

7. ENTER FILE NAME TO SAVE RESULTS ON
(Reply with file name)

A file name not already on the users Job number should be used. Otherwise the program will abnormally terminate. Should an abnormal termination occur, the file generated by the program may be saved as follows

```
#SAVE, 10 = 'FILE NAME'
```

8. DO YOU WANT TO CLASSIFY ANOTHER AREA?
(Reply YES or NO)

If your reply is YES, question 1 is next asked. If your reply is NO, the program will terminate.

Following the use of the CLASSIFY program the results may be copied to either a line printer or teletype. See the instructions following the description of the PIXOUT program.

The results of the CLASSIFY program should be inspected for validity. Further sample selection using SEL may be necessary or changes in class descriptions may improve the accuracy.

Appendix C-6

An Automatic Classification System for ERTS Digital Data

J. H. Herzog
Roy C. Rathja
Linda Yamanuha

Department of Electrical and Computer Engineering
Oregon State University
Corvallis, Oregon 97331

I. Introduction

This paper is intended to provide an overview of an automatic classification system developed at Oregon State University for use with data from the NASA ERTS satellite. It provides the basic overall system philosophy and examples of operational parts of the system.

Automatic classification involves the application of three disciplines seldom completely understood by a single individual.

Problem Oriented Specialist - This is the individual that presents the initial classification problem. Often he alone has the experience to judge the eventual success of the results. His continual interaction is necessary to provide selected test sites and ground truth information. Such a specialist might, for example, be a range ecologist interested in a vegetation map of a large region of several types of natural vegetation. He must have examples of the vegetation he wishes to classify and accurate locations of these samples (test sites).

Computer System Analyst - This individual has the skills necessary to assemble the vast quantity of digital data relevant to the problem. He provides an operating system in which the problem oriented specialist can effectively interact with the appropriate digital programs. He works closely with the problem oriented specialist to insure satisfactory results.

Classification Techniques Specialist - This individual assembles his skills in pattern recognition, artificial intelligence, computer hardware, and programming to provide a series of processing techniques which can be integrated by the computer system analyst into the operating system. He must frequently interact with the problem oriented specialist and the computer system analyst.

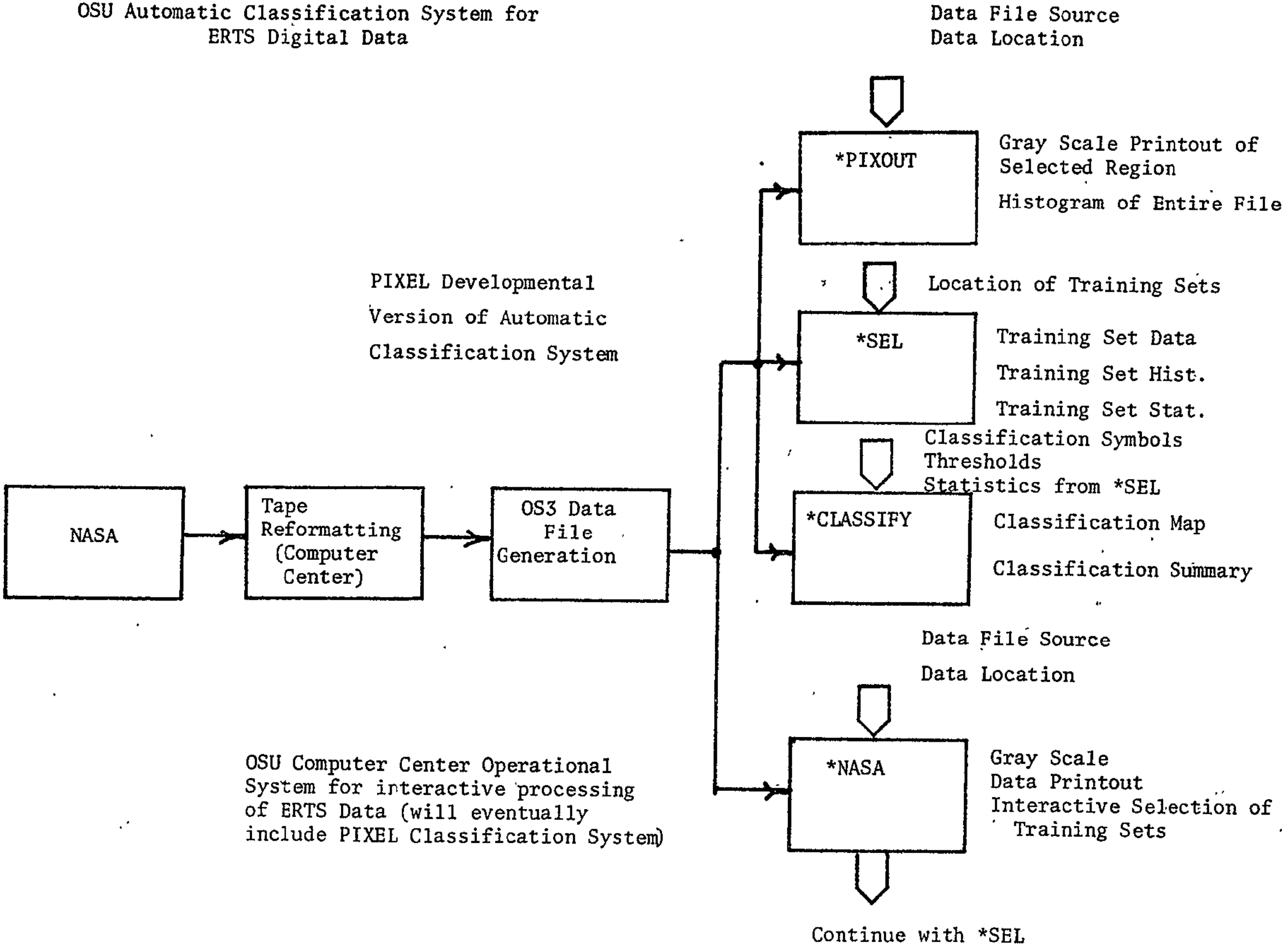
II. Data Processing

Figure 1 shows the overall data flow and data products generated by the OSU Automatic Classification System.

The PIXEL (Pictorial Information Extraction and Enhancement Laboratory) contribution to the system is contained in three operational, interactive programs called *PIXOUT, *SEL, *CLASSIFY. The programs are written in FORTRAN to run on the Oregon State Open Shop Operating System (OS-3) from remote teletype terminals. These programs have been successfully used in several automatic classification problems.

Figure 1

OSU Automatic Classification System for
ERTS Digital Data



A Problem Oriented Specialist desiring to use this system would proceed as follows.

1. Formalize the classification objectives. Obtain ground truth data for selected areas (test sites).
2. Contact the appropriate Computer System Analyst for data acquisition and file management. This specialist would also provide aid in completing the remaining items.
3. Use *PIXOUT to generate gray scale printouts to aid in locating test sites.
4. Specify test sites and their known classification. Determine appropriate line and point numbers from the gray scale print out. Verify ground truth.
5. Use *SEL to inspect test site data (training sets) and calculate statistics and histogram for each class to be automatically classified
6. Create a statistics file to be used by *CLASSIFY.
7. Use *CLASSIFY to produce a classification map.

III. Program Descriptions

*PIXOUT

*PIXOUT is composed of two parts which may be used individually or in tandem. The first part calculates statistics and produces a histogram of an ERTS original data file. The second part produces a gray scale image of a selected area. The latter part uses data produced in the earlier part of the program or data supplied by the user himself.

INPUT The only input necessary is the ERTS original data file and the user's responses. (line numbers, point numbers, file names, etc.)

OUTPUT Output is on two scratch units which PIXOUT later saves under the file names supplied by the user. One of the outputs is a histogram of the ERTS data together with mean values, standard deviations, and threshold values.

The second output is the gray scale image of the selected area from the first ERTS data.

The user must, after completely running the program, use OS-3's COPY routine to get a hard copy of the output on any terminal or the line printer.

Sample Program Run

The following is an example of a PIXOUT program. User responses are underlined.

```
*PIXOUT

PIXOUT  VERSION 1.0
```

PIXOUT USES TWO SCRATCH FILES INCLUDING LUN 20 FOR THE BINARY INPUT. (LUNS 10 AND 11 HOLD ALL STATISTICAL AND PICTORIAL OUTPUT.)

```
DO YOU WANT STATISTICS CALCULATED?
YES

WHAT IS THE INPUT FILE?
*J2SEP2

IS THE FILE NAME CORRECT?
YES

STATISTICS HAVE BEEN CALCULATED.
DO YOU WANT STATISTICS OUTPUT?
YES

WHAT BAND WOULD YOU LIKE STATISTICS ON?
7

WHAT FILE WOULD YOU LIKE STATISTICS SAVED ON?
T1

DO YOU WANT MORE OUTPUT?
NO

DO YOU WANT A PICTURE?
YES

WHAT BAND?
7

WHAT IS THE INITIAL POINT?
7

NUMBER OF POINTS?
50

WHAT IS THE INITIAL LINE?
30

NUMBER OF LINES?
25

PICTURE IS COMPLETED.  WOULD YOU LIKE IT SAVED ON A FILE?
YES

WHAT FILE WOULD YOU LIKE IT SAVED ON?
P1

WOULD YOU LIKE TO START AGAIN?
YES

DO YOU WANT STATISTICS CALCULATED?
NO

DO YOU WANT A PICTURE?
YES
```

```
 1     174     **
 2      47
 3     148     **
 4    1309     *******************
 5    1942     ***************************
 6    1363     ********************
 7    1043     ***************
 8    1194     *****************
 9    1433     **********************
10    2945     ********************************************
11    5132     *****************************************************************************
12    6553     **************************************************************************************************
13    5741     **************************************************************************************
14    3965     ***********************************************************
15    2038     ******************************
16    1442     *********************
17     674     **********
18     391     *****
19     229     ***
20     143     **
21      38     *
22      23     *
23      46
24      34     *
25      31
26      57
27      20
28      33
29       9
30      15
31       6
32       7
33       1
34       4
35       3
36       0
37       1
38       3
39       0
40       2
41       1
42       1
43       1
44       0
45       0
46       1
47       0
48       0
49       0
50       0
51       0
52       0
53       0
54       0
55       0
56       0
57       0
58       0
59       0
60       0
61       0
62       0
63       0

THRESHOLDS            7       11        12        13        14        15        16

MEAN                     11.471

STANDARD DEVIATION        3.709
```

Figure 2 Typical Histogram for one band of MSS data. The thresholds are calculated to allow approximately equal use of each gray scale intensity

Sample Output

```
                                                             EXAMPLE 2
FRAME I.D.      1 41-18265
DATE             2SEP72
STRIP NUMBER        0003
POINTS          385-  512
STARTING SCAN LINE 1001
NUMBER OF SCAN LINES  300

                1         2         3         4         5
                0         0         0         0         0

1001  OXXXOOXX8888888888+--      X8MMM8X8O+  //OOOXXXX//
1002  XOOXO?OX8888X888M888/+-     8MMM8/++O++//-XXX/+-
1003  /O8XOOXXXX8888888O++       OMMM8X//OOO/+-O8/    +/
1004  OX88XXXXXXX?O8888/+       /MMMMX+OXOOXO888+    /O/
1005  X888XXXOXXOXOOX8+/O+     -8MMM8OXOOXOOOOOX/    +-+
1006  X8XO/OOO/OOO/+++ -+/     /XOOXOOO///++//---      -
1007  88O88XXOX8XXOX8XOXXO    ++    -  -XXXOXX/+-+     /
1008  X8/O888XXXXOOX8O        ++    /OO/OOOX8X/O      ++
1009  /OXXXXX8XXXOOO/-        /+//     OO/++-+-       ++
1010  X8XO8888XOXOOO/OX/-     +OO8X   ++    OO//     //+
1011  XOXXXXXXXOXX/OOOO/+     OXOOOX/+         /-     +O
1012  88XX//O/OO//OXX//     -O/OX//OO//+        -     //
1013  X88XOX8X//88XXXX-    /XOXXXXXOXX/++//-       +/OO
1014  XOXXX88X8/+/XXXX/    --OO/OXXX/O//+--  --  -+++/OO
1015  X88XXXXX//+O++/+    -OXOXXXXOOOOXO/++O+/X//+/O/+O
1016  OX8XXOO/OOXO+   + +OXXXX8XX88OOXX88XXO/OOOOXX/OO/
1017  OOXO//+-   +/-//++/XXXX88XOOOXOXXX//OOOxOOXOXO/+
1018  O////OO/OXXXXOO////8X88/+/XXX8X//O/+ OXO/O/+----
1019  XO//XXXX88XXXOX8XOOOOOXXO/+-+/+/OX///O/++    -----
1020  888/ +////XX8XXXOO////OXXO++X///+++++/+XX/++/++
```

Figure 3 Typical gray scale output from *PIXOUT

ORIGINAL PAGE IS
OF POOR QUALITY

```
WHAT IS INPUT FILE?
*NCAT

IS THE FILE NAME CORRECT?
NO

WHAT IS INPUT FILE?
*N7OCT3

WHAT BAND?
7

WHAT ARE THE THRESHOLDS?
7 11 12 13 14 15 16

WHAT IS THE INITIAL POINT?
35

NUMBER OF POINTS?
60

WHAT IS THE INITIAL LINE?
25

NUMBER OF LINES?
25

PICTURE IS COMPLETED.  WOULD YOU LIKE IT SAVED ON A FILE?
YES

WHAT FILE WOULD YOU LIKE IT SAVED ON?
P2

WOULD YOU LIKE TO START AGAIN?
NO
```

*SEL

The purpose of the *SEL program is to select training sets and provide descriptive statistics for them. The user has essentially three options. He may

1. Select training sets.
2. Select training sets and generate descriptive statistics for them.
3. Generate descriptive statistics of training sets previously selected.

INPUT The inputs for parts 1 and 2 above are the ERTS data files and user responses. The input for part 3 is a file previously generated by parts 1 or 2 above.

OUTPUT There can be two outputs realized from this program. The first is a list of the ERTS data values for all four bands and their locations. This output is realized whenever training sets are selected and is used by the second part of the program to generate descriptive statistics. The second output supplies a histogram, mean and standard deviation of the four bands of a given training set. A histogram mean and standard deviation is also calculated for the sample distances to their mean to facilitate setting thresholds for input to the *CLASSIFY program.

Sample Program Runs

The following example shows the selection of two training sets. The first training set is located entirely on a single ERTS data file. The second set is selected from two different data files showing that training sets are not restricted to a single data file. The training set for the first selection is saved under file name SAMPS. The statistics describing the data in SAMPS is saved under file name STATS. The data on any files generated may be analyzed by use of standard OS3 display units and control mode instructions. In general statistics should be output to the line printer since the records are too long for teletype use. The underlined lines are user responses.

```
#*SEL
SELECT VERSION 1.0

DO YOU WANT TO SELECT POINTS?
YES

WHAT IS INPUT FILE?
*P1SEP1

IS FILE NAME CORRECT?
YES

INPUT SAMPLE LOCATIONS                     Enter four values separated by at least
                                                 1 space
     1 1 5 1                                1.   Line number
                 _______________________    2.   Point number
     2 4 5 0                                3.   Number of points
                                            4.   0 data this line incorrect
                                                 1 data this line correct

WHAT?                                      When all sample locations entered depress
2 1 5 1                                          teletype keys CTRL  W at same time

DO YOU WANT TO SELECT POINTS?
NO

DO YOU WANT STATISTICS?
YES

ENTER FILE NAME TO SAVE SAMPLES UNDER
SAMPS

IS FILE NAME CORRECT?
YES

ENTER FILE NAME TO SAVE SAMPLE STATISTICS UNDER
STATS

IS FILE NAME CORRECT?
YES
```

```
DO YOU WANT TO DO MORE?
YES

DO YOU WANT TO SELECT POINTS?
YES

WHAT IS INPUT FILE?
*N7OCT3

IS FILE NAME CORRECT?
YES

INPUT SAMPLE LOCATIONS
10 6 3 1

14 14 9 1

DO YOU WANT TO SELECT POINTS?
YES

WHAT IS INPUT FILE?
*N7OCT4

IS FILE NAME CORRECT?
YES

INPUT SAMPLE LOCATIONS
19 32 12 1

23 12 2 1

DO YOU WANT TO SELECT POINTS?
NO

DO YOU WANT STATISTICS?
YES

ENTER FILE NAME TO SAVE SAMPLES UNDER
SAMPS2

IS FILE NAME CORRECT?
YES

ENTER FILE NAME TO SAVE SAMPLE STATISTICS UNDER
STATS2

IS FILE NAME CORRECT
YES

DO YOU WANT TO DO MORE?
NO

END OF FORTRAN EXECUTION
```

The following example shows the calculation of descriptive statistics from a file, SAMPS, previously generated by *SEL. This feature is used in the event samples are included which are not typical of the training set being developed. It is suggested that training set data values be inspected before statistics are calculated. Single point data values which are very different from all other members of the class may not correctly belong in the training set. In this event it is suggested either a new training set is selected deleting the non-typical elements or the OS3 on line editor, EDIT, be used to delete the incorrect values from the training set already selected.

```
#*SEL
SELECT VERSION 1.0

DO YOU WANT TO SELECT POINTS?
NO

DO YOU WANT STATISTICS?
YES

WHAT IS INPUT FILE?
*SAMPS

IS FILE NAME CORRECT?
NO

WHAT IS INPUT FILE?
SAMPS

IS FILE NAME CORRECT?
YES

ENTER FILE NAME TO SAVE SAMPLE STATISTICS UNDER
STATS3

IS FILE NAME CORRECT?
YES

DO YOU WANT TO DO MORE?
NO

END OF FORTRAN EXECUTION
```

*CLASSIFY

The purpose of the *CLASSIFY program is to provide an automatic classification of ERTS digital data based on descriptive statistics of known samples previously selected by the user. the current version is designed to run only from a standard OS3 teletype device.

INPUT The program will request the names of 2 input files. One should contain the original ERTS data, the other a file containing descriptive statistics of the training sets. The training set file may be generated either by using the on-line OS3 editor, EDIT, or by copying a card deck to a file. One line should be provided for each class in the following format.

TEST SAMPLES

Band 4	Band 5	Band 6	Band 7	Scan Line	Point
11	9	13	15	1	1
9	6	13	14	1	2
9	6	13	15	1	3
10	7	14	15	1	4
11	8	14	16	1	5
11	8	13	14	2	1
10	8	14	15	2	2
11	9	14	16	2	3
11	10	15	16	2	4
11	9	14	16	2	5

Figure 4. Typical training set selected by use of *SEL.

```
BAND     4

                                                  FRAME I.D.       1 40-18210
                                                  DATE              1SEP72
                                                  STRIP NUMBER         0003
                                                  POINTS          129-  256
                                                  STARTING SCAN LINE 1400
                                                  NUMBER OF SCAN LINES  360
  0          0
  1          0
  2          0
  3          0
  4          0
  5          0
  6          0
  7          0
  8          0
  9          2         **
 10          2         **
 11          6         ******
 12          0
 13          0
 14          0
 15          0
 16          0
 17          0
 18          0
 19          0
 20          0
 21          0
 22          0
 23          0
 24          0
 25          0
 26          0
 27          0
 28          0
 29          0
 30          0
 31          0
 32          0
 33          0
 34          0
 35          0
 36          0
 37          0
 38          0
 39          0
 40          0
 41          0
 42          0
 43          0
 44          0
 45          0
 46          0
 47          0
 48          0
 49          0
 50          0
 51          0
 52          0
 53          0
 54          0
 55          0
 56          0
 57          0
 58          0
 59          0
 60          0
 61          0
 62          0
 63          0

MEAN                          10.40

STANDARD DEVIATION              .84

NUMBER OF SAMPLES                10
```

Figure 5 Typical statistics and Histograms of selected training sets.

```
BAND     5

  0              0
  1              0
  2              0
  3              0
  4              0
  5              0
  6              2          **
  7              1          *
  8              3          ***
  9              3          ***
 10              1          *
 11              0
 12              0
 13              0
 14              0
 15              0
 16              0
 17              0
 18              0
 19              0
 20              0
 21              0
 22              0
 23              0
 24              0
 25              0
 26              0
 27              0
 28              0
 29              0
 30              0
 31              0
 32              0
 33              0
 34              0
 35              0
 36              0
 37              0
 38              0
 39              0
 40              0
 41              0
 42              0
 43              0
 44              0
 45              0
 46              0
 47              0
 48              0
 49              0
 50              0
 51              0
 52              0
 53              0
 54              0
 55              0
 56              0
 57              0
 58              0
 59              0
 60              0
 61              0
 62              0
 63              0

MEAN                        8.00
STANDARD DEVIATION          1.33
NUMBER OF SAMPLES             10
```

```
BAND     6

 0          0
 1          0
 2          0
 3          0
 4          0
 5          0
 6          0
 7          0
 8          0
 9          0
10          0
11          0
12          0
13          4          ****
14          5          *****
15          1          *
16          0
17          0
18          0
19          0
20          0
21          0
22          0
23          0
24          0
25          0
26          0
27          0
28          0
29          0
30          0
31          0
32          0
33          0
34          0
35          0
36          0
37          0
38          0
39          0
40          0
41          0
42          0
43          0
44          0
45          0
46          0
47          0
48          0
49          0
50          0
51          0
52          0
53          0
54          0
55          0
56          0
57          0
58          0
59          0
60          0
61          0
62          0
63          0

MEAN                           13.70
STANDARD DEVIATION               .67
NUMBER OF SAMPLES                 10
```

```
 BAND     7

   0          0
   1          0
   2          0
   3          0
   4          0
   5          0
   6          0
   7          0
   8          0
   9          0
  10          0
  11          0
  12          0
  13          0
  14          2          **
  15          4          ****
  16          4          ****
  17          0
  18          0
  19          0
  20          0
  21          0
  22          0
  23          0
  24          0
  25          0
  26          0
  27          0
  28          0
  29          0
  30          0
  31          0
  32          0
  33          0
  34          0
  35          0
  36          0
  37          0
  38          0
  39          0
  40          0
  41          0
  42          0
  43          0
  44          0
  45          0
  46          0
  47          0
  48          0
  49          0
  50          0
  51          0
  52          0
  53          0
  54          0
  55          0
  56          0
  57          0
  58          0
  59          0
  60          0
  61          0
  62          0
  63          0

MEAN                        15.20
STANDARD DEVIATION            .79
NUMBER OF SAMPLES              10
```

```
SAMPLE DISTANCES FROM MEA

 0            1        *
 1            3        ***
 2            3        ***
 3            0
 4            0
 5            0
 6            2        **
 7            1        *
 8            0
 9            0
10            0
11            0
12            0
13            0
14            0
15            0
16            0
17            0
18            0
19            0
20            0
21            0
22            0
23            0
24            0
25            0
26            0
27            0
28            0
29            0
30            0
31            0
32            0
33            0
34            0
35            0
36            0
37            0
38            0
39            0
40            0
41            0
42            0
43            0
44            0
45            0
46            0
47            0
48            0
49            0
50            0
51            0
52            0
53            0
54            0
55            0
56            0
57            0
58            0
59            0
60            0
61            0
62            0
63            0

MEAN                          3.21

STANDARD DEVIATION            2.72
```

Figure 6 A histogram of the "distance to prototype" for each data point within the training set. This indicates the homogeniety of the training set

Characters	Contents
1-8	Class Name
9-12	Number of Samples in the Training Set
13-18	Mean for Band 4
19-24	Mean for Band 5
25-30	Mean for Band 6
31-36	Mean for Band 7
37-42	Standard Deviation for Band 4
43-48	Standard Deviation for Band 5
49-54	Standard Deviation for Band 6
55-60	Standard Deviation for Band 7
61-66	Threshold for Class
68	Character to Represent Class

The Program has the facility to weight each band by the values entered in the standard deviations. Our experience has shown entries of 1.00 in these locations produce the most accurate classification. The numerical entries for means, standard deviations, and threshold should be accurate to 2 places right of the decimal. For example, 12.14, 3.12, etc.

The last line in this file should contain 4 entries which are the correction factors to apply to training sets from one frame which are to be used on a different frame. If the training sets are selected from the same frame that is to be classified, then these values should all be 1.00.

Characters	Contents
1-6	Correction Band 4
7-12	Correction Band 5
13-18	Correction Band 6
19-24	Correction Band 7

Sample file

```
ARRI      124  12.89  12.50  12.79  12.63  1.00  1.00  1.00  1.00   3.00 .
JUNIPER   183  12.74  11.90  12.92  12.68  1.00  1.00  1.00  1.00  30.00 /
PINE       97   9.86   6.99  12.94  14.71  1.00  1.00  1.00  1.00  12.00 P
WATER     156  10.72   5.89   3.00   1.19  1.00  1.00  1.00  1.00   6.00 W
   1.00  1.00   1.00   1.00
```

OUTPUT The program supplies a point by point display of the classification which is saved on the OS3 file system for future analysis. It can be saved under any name which is not currently in use. A user should take special care to insure he does not attempt to use a name already in use, as this results in termination of the program.

The output may be displayed on any of the standard OS3 display devices. Following is the instruction and results of the classification made under the example run described later using a standard teletype.

```
# COPY,I=CLASSED,S=0

FRAME I.D.     1 40-18210
DATE           1SEP72
STRIP NUMBER      0003
```

```
POINTS         129- 256
SCAN LINES       1- 2340
                 1         2         3
                 0         0         0

 1  PPPPP///PPPPPPP///////        //
 2  PPP/PPPPPP///P///////         /
 3  PPPPPP/P///PP/PPPP////        P
 4  PPPP////////PP/PP/////        P
 5  P///////PPPPPPPPPPPPP/        /
 6  ////////PP/////////////
 7  PP////////////////////
 8  ////////  //  //////
 9  P///PPPPPPPP///////
10  ///PPPPP///PPPPPPPP//

NUMBER OF SAMPLES FOR EACH CLASSIFICATION

     .  ARRI      SAMPLES           0
     /  JUNIPER   SAMPLES         131
     P  PINE      SAMPLES          85
     W  WATER     SAMPLES           0
     UNCLASSIFIED SAMPLES          84
            TOTAL SAMPLES         300
```

If the classification is unsuitable for display on a teletype unit it may be displayed on the line printer.

Sample Program Run

The following example was run with intentional user mistakes to indicate correction procedures. The underlined entries are those supplied by the user.

```
*CLASSIFY
CLASSIFY VERSION 1.0

ENTER FILE NAME TO BE CLASSIFIED
*P1SEP1

CORRECT:
YES

ENTER FILE NAME WITH CLASSES
*TEST

CORRECT?
NO

ENTER FILE NAME WITH CLASSES
TEST

CORRECT?
YES

ENTER STARTING LINE
<>1
```

```
CORRECT?
YES

ENTER NUMBER OF LINES
<>10

CORRECT?
YES

ENTER STARTING POINT
<>1

CORRECT?
YES

ENTER NUMBER OF POINTS
<>30

CORRECT?
YES

ENTER NUMBER OF CLASSES
<>5

CORRECT?
MO

WHAT?
CORRECT?
NO

ENTER NUMBER OF CLASSES
<>4

CORRECT?
YES

ENTER FILE NAME TO SAVE RESULTS ON
*CLASSED

CORRECT?
NO

ENTER FILE NAME TO SAVE RESULTS ON
CLASSED

CORRECT?
YES

DO YOU WANT TO CLASSIFY ANOTHER AREA?
NO
```

If an error is made prior to the question "Enter file name to save results on" which results in termination of the program, the user must insure LUN 10, 20,21 used by the program are unequipped, then call *CLASSIFY to start again. Should an error be made after the above question (for example the name to save the classification under is already in use) one may type

```
SAVE,10= name to save file under
```

since LUN 10 contains the classification then UNEQUIP, 10,20,11 prior to making another run.

VIII. REFERENCES

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