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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

Interagency Report
NASA-140
January 1969

Mr. Robert Porter
Acting Program Chief,
Earth Resources Survey
Code SAR - NASA Headquarters
Washington, D.C. 20546

Dear Bob:

Transmitted herewith are two copies of:

INTERAGENCY REPORT NASA-140

THE UTILITY OF RADAR AND OTHER REMOTE SENSORS IN THEMATIC LAND USE MAPPING FROM SPACECRAFT:

ANNUAL REPORT*

by

David S. Simonett**

The U.S. Geological Survey has released this report in open files. Copies are available for consultation in the Geological Survey Libraries, 1033 GSA Building, Washington, D.C. 20242; Building 25, Federal Center, Denver, Colorado 80225; 345 Middlefield Road, Menlo Park, California 94025; and 601 E. Cedar Avenue, Flagstaff, Arizona 86001.

Sincerely yours,

William A. Fischer
Research Coordinator
EROS Program

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*Work performed under NASA Contract No. R-09-020-024, Task No. 160-75-01-32-10

**Department of Geography, University of Kansas, Lawrence, Kansas

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

INTERAGENCY REPORT NASA-140

THE UTILITY OF RADAR AND OTHER REMOTE SENSORS IN THEMATIC LAND USE MAPPING FROM SPACECRAFT: ANNUAL REPORT*

by

David S. Simonett**

*Prepared by the U.S. Geological Survey (USGS) for the National Aeronautics and Space Administration (NASA) under NASA Contract No. R-09-020-024 A/1, Task No. 160-75-01-32-10. Work performed by the University of Kansas for the USGS Geographic Applications Program under USGS Contract No. 14-08-0001-10848.

**Department of Geography, University of Kansas, Lawrence, Kansas

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ANNUAL REPORT

U.S.G.S. Contract No. 14-08-0001-10848

The Utility of Radar and Other Remote Sensors in Thematic Land Use Mapping from Spacecraft

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May 1, 1968
(Covering the period March 1, 1967 - April 30, 1968)

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* This report is collated from materials provided by the following graduate students employed at various times during the course of the contract: David E. Schwarz, Major Roland D. Mower, Florence M. Peterson, Fred C. Caspall, and David E. Berger. Mr. Joe Sabol, William G. Brooner, and Dr. Rex Peterson who were employed on other projects also provided information. Messrs. Peterson and Schwarz shared the responsibility with D. S. Simonett for the collation of this report.

INTRODUCTION

This is the first annual report on U.S.G.S. Contract 14-08-0001-10848 and covers the period March 1, 1967 through April 30, 1968. This represents the first phase of a study documenting the potentials and problems of thematic land use mapping from remote sensor imagery, especially radar imagery, obtained from aircraft and spacecraft.

Since three papers partially supported by the U.S. Contract were issued during the year and four others are in press, the annual report does not attempt to cover the areas given in detail in these papers. Rather, the treatment adopted has been first, to outline the general objectives of the study including new objectives to be added during the second year of the study; second, to list the published and in-press documents generated on the project; third, to summarize the investigations at field study sites and work with the IDECS system; fourth, to give some preliminary observations on questions such as resolution and complementary and supplementary roles of multiple sensors in thematic mapping which will be explored further in the coming year; and, finally, to give succinct accounts of several portions of the work which are not yet far enough along to be in publishable form but for which some interesting results are at hand.

1. GENERAL OBJECTIVES OF STUDY

Before considering the general objectives of this study, it is appropriate first to discuss briefly the meaning intended by thematic land use mapping. As used here thematic land use mapping has an obvious or primary use involving the preparation of such clear cut land use maps as those showing plowed versus uncultivated land, cleared versus uncleared, urban versus rural, transportation nets, and so on. However, it is infeasible to study land use out of the context of the physical environment and we also examine certain secondary land use related maps which aid in the interpretation of land use, hence are supportive in a balanced program of land use mapping. Such secondary land use related maps would include slope maps, maps of major structural linears (of importance because of their relation to mineral ore emplacement) distribution of sink holes in limestone areas, coastal landform types such as plains and terraces, (which may be of ultimate significance in land use) and so on. In addition to considering these static elements of the landscape in the form of land forms, it is also to be understood that the dynamic element of change in man's use of the land and the adequate detection of change constitutes part of this concept of thematic land use mapping.

The five principal objectives of this study as outlined in the original proposal are given below:

1. To evaluate for a number of different climatic environments in the U.S.A. and Puerto Rico, the various ways in which spacecraft and aircraft-borne radar imagery, color and false color photography, and high resolution television, complement and supplement one another for the potential production of thematic land use maps.
2. To evaluate the capability of multi-frequency, poly-polarization radars as devices for obtaining on-demand data for the construction of thematic land use maps. This objective is based on the consideration that an on-demand capability requires all-weather abilities coupled with high resolution. Only synthetic-aperture radar can satisfy this need from spacecraft if data are needed within very narrow time constraints.
3. To evaluate various color combining and image enhancement techniques as means of handling multiple images. This portion of the study is based primarily on the use of the IDECS (Image Discrimination Enhancement Combination and Sampling) system at the University of Kansas.
4. To evaluate the potential of spacecraft high resolution sensors as research tools in land use studies, as separate from data gathering.

5. To develop general recommendations on the ways of using these various space-borne imaging devices for preparing thematic maps in different climatic environments.

New Objectives to be Added During the Second Year of the Study

During the first phase of this contract, while engaged in detailed research studies at Garden City, Kansas; Lawrence, Kansas; Horsefly Mountain, Oregon; and Puerto Rican sites, it became obvious that a number of practical matters also needed attention. In particular, [a thorough analysis needs to be made of the current uses of thematic maps of the various scales which may be made from spacecraft data. At the same time, a systems analysis should be made of the problems and potentials of developing thematic maps from spacecraft data. Consequently, among the principal new objectives of the second year of the study will be to 1) Determine the types of existing and new thematic maps capable of being constructed with spacecraft data, 2) Determine the uses of the present equivalents of such maps, and 3) Prepare estimates of the operational and institutional utility. A significant portion of this study will be a systems analysis of the problems and potentials of obtaining a variety of thematic maps from spacecraft. Careful attention will be given to evaluating the utility of various forms of change-detection and updating between censuses, and also to evaluate the utility of space-derived data in terms of its uniformity or lack of uniformity as a data-base.

2. STUDIES PUBLISHED AND SUBMITTED FOR PUBLICATION BY MARCH 31, 1968

Three papers have been published which were partially supported by the U.S.G.S. Contract. They are:

1. Simonett, D. S., J. R. Eaglemann, A. D. Erhart, D. C. Rhodes, and D. E. Schwarz (1967) "The Potential of Radar as a Remote Sensor in Agriculture: A Study of K-Band Imagery in Western Kansas", CRES Report 61-21, 13 pp.

2. Moore, R. K. and D. S. Simonett (1967) "Radar Remote Sensing in Biology", Bio-Science, Vol. 17, no. 6, pp. 384-390.

3. Moore, Richard K. and David S. Simonett (1967) "Potential Research and Earth Resource Studies with Orbiting Radars: Results of Recent Studies", AIAA Paper, Reprint No. 67-767, American Institute of Aeronautics and Astronautics Fourth Annual Meeting and Technical Display, Anaheim, California, October 23-27, 1967, pp. 1-22.

Five other papers fully or partly supported by this contract are in press:

4. Simonett, D. S. "Potential of Radar Remote Sensors as Tools in Reconnaissance Geomorphic, Vegetation and Soil Mapping", Ninth International Congress, International Soil Science Society, Adelaide, Australia, August 1968, (in press).

5. Simonett, D. S. "The Potential of Radar as a Remote Sensor in Agriculture: Results of Some Preliminary Studies", in "Multispectral Sensing of Agricultural Resources", J. Ralph Shay and Marvin Holter (Eds.), N.A.S.-N.R.C. Publication, (in press)

6. Schwarz, D. E. and F. Caspall "The Use of Radar in the Discrimination and Identification of Agricultural Land Use", (in press), Fifth Symposium on Remote Sensing of Environment, University of Michigan.

7. Simonett, D. S. "Land Evaluation Studies with Remote Sensors in the Infrared and Radar Regions", An invited paper to be read at the International Colloquium on Land Evaluation, a joint CSIRO (Australia) -- UNESCO sponsored colloquium, Canberra, Australia, August 1968. MacMillan Press.

8. Walters, R. L. "Radar Bibliography for Geoscientists," CRES Report 61-30, 36 pp.

One additional paper which will be partially supported by the U.S.G.S. Contract is in preparation:

9. Haralick, R., F. Caspall, R. K. Moore, and D. S. Simonett, "A Conditional Probability and Statistical Study of Crop Discrimination Using Radar Images," Paper presented at IEEE International Convention, March 18-21, 1968, New York. To be published in 1968 IEEE Convention Record.

Two related studies which were produced on other contracts and received no funding from the U.S.G.S. Contract should be mentioned here for the contents of these papers bear on the theme of the U.S.G.S. Contract:

1. Morain, S. A. and D. S. Simonett (1967) "K-Band Radar in Vegetation Mapping," Photogrammetric Engineering, vol. 33, no. 7, pp. 730-740.
2. McCoy, R. M. (1967) "An Evaluation of Radar Imagery as a Tool for Drainage Basin Analysis," CRES Technical Report 61-31, pp. 1-102.

A good deal of the material in Mr. McCoy's thesis has direct relevance to mapping of landforms with radar imagery and it is drawn upon in part in the preparation of this annual report.

3. INVESTIGATIONS AT FIELD TEST SITES

The field test sites where studies have been carried out during the past year include Garden City, Kansas; Horsefly Mountain, Oregon; Lawrence, Kansas; and Puerto Rico.

Garden City, Kansas: All the radar imagery obtained with the AN/APQ-97 multiple polarization K-band radar have now been analyzed and are incorporated in a revision of Simonett, et. al. (1967) being prepared for publication, and Schwarz and Caspall (1968), and in a manuscript prepared by Haralick, Caspall, Moore and Simonett intended for submission for REMOTE SENSING OF ENVIRONMENT: An Interdisciplinary Journal. One additional report which will conclude the analysis of the imaging radar data will be completed during the summer of 1968. At that time, scatterometry data obtained over Garden City and color photography obtained at the same time will be looked at systematically for their separate information content. One set of scatterometry and color photography data was obtained before this project was initiated, and a second set has been obtained during the time of the contract. Several additional flights with both sets of data are planned for the summer of 1968.

Horsefly Mountain, Oregon: Dr. Rex M. Peterson and David Berger carried out field work at the Horsefly Mountain site in conjunction with a NASA overflight which obtained color photography, scatterometry, and other sensor data. The scatterometry data has just arrived (mid-March) and will be worked on in April and May, along with the color photography. A report is being prepared on this material to be read by Dr. Peterson at the Ecological Society of America Meetings in June at Madison, Wisconsin.

Lawrence, Kansas: The Lawrence and vicinity test site was flown twice during the contract year. The color and other photography has now arrived and in addition to studies to be begun by Mrs. Florence Peterson, some unfunded, no-cost-to-contract studies will be made with this data by the State Geological Survey of Kansas in the areas adjacent to the built-up area of Lawrence. For both of these areas a variety of radar imagery is available and it is intended that a careful cross comparison of the information be carried out. This will be additional to the preliminary account given by Mrs. Peterson in one of the attached supplementary reports.

Puerto Rico: In the summer of 1967 David Schwarz and Major Roland D. Mower carried out three weeks of field work in Puerto Rico concerned with land form, cultural, and land use types observed on synthetic aperture radar imagery. Major Mower incurred no salary cost on the project, just the field expenses for his share of the field work. The imagery was obtained in February 1964. The first phase of the Puerto Rico analysis, dealing with the use of radar imagery for integrated landform analysis is given in the attached appendix.

4. STATUS OF THE IDECS SYSTEM

The IDECS System (Image Discrimination, Enhancement, Combination, and Sampling) developed at the Center for Research in Engineering Science at the University of Kansas has been undergoing extensive improvements since May 1967, and it will not be fully operational in its new, improved mode until May 1968. The modifications have been funded by two Department of Defense and one NASA contract. The changes nearing completion include the following:

1. Addition of three new scanning channels so that up to six images may be scanned at a time.
2. Replacement of all the previous cathode ray tubes so that improved resolution is obtained.
3. Development of an effective control panel so that geographers and geologists may make and quantitatively repeat measurements.
4. Development of an adaptive learning system.
5. Development of set-theoretic logic circuitry to find natural clusters which the data on up to 6 images tend to generate.
6. Improved ability todevelop probability and spectral density functions from images. Additional possibilities under consideration include a texture-detection element.

It is planned that the IDECS system will be thoroughly investigated for Horsefly Mountain in the first instance and then will later be used on the Garden City and Lawrence data.

5. QUESTIONS ON THEMATIC MAPPING: SOME PRELIMINARY OBSERVATIONS

The Question of Resolution in Thematic Mapping

In spacecraft and aircraft imaging systems, the resolution needed to produce thematic land use maps involves consideration of the spatial dimensions of the object to be sensed, its spectral qualities, and the level of information desired on the final thematic map. For example, if it is desired, unambiguously to map all the fields of one acre or more in size in a given area, and to obtain acreage estimates in error by no more than 30% for the very smallest (one acre) fields and 5% for 10-acre fields, the poorest resolution we may reasonably use is 50 feet. This however implies that the spectral separation between crops in adjacent fields is such that delineation of each field is feasible. This may not be true with color photography, let alone radar. At certain times of the year the difference in color between adjacent crops, particularly at the height of the active growing season, is sufficiently small that a three color photograph has only very slight differences in shades of green. Consequently the feasibility of detecting and mapping the smallest fields is substantially reduced. In mapping small fields, therefore, the question of timing to insure the maximum spectral separation in gray scale or color response is important. Timing, however, is different for each plant community, crop, or activity of man, and a systematic analysis of the patterns of these events is necessary. We will examine this in the contract year beginning May 1.

The question also arises as to whether it may be possible to detect the presence of fields of one acre or smaller in size when using a resolution of poorer than 50 feet. Theoretically this is feasible if multiple imagery is obtained throughout the course of a growing season and if adjacent fields depart quite widely in their crop spectral response at selected times of the year. For example, corn is juxtaposed to sorghum, winter wheat, and sugar beets at the Garden City test site in western Kansas, hence it may be feasible to infer the presence of these crops by time-sequential sensing. However, inferences on the presence of different crops would be difficult to quantify in terms of their percentage contribution and realistically the best solution to detect the small fields may turn out to be improved spatial resolution. We will study this problem in the coming year.

It follows also from this consideration that the mapping of excessively small fields 0.1 - 0.3 acres, such as in the Orient, will constitute a serious problem for identification and mapping. It may in truth prove quite infeasible to prepare detailed thematic land use maps of such areas, for they are characterized not only by excessively small fields but also by multiculture and interculture which will make the spectral separation of fields and crops exceedingly difficult.

From these considerations it follows that there will not be a <u>single uniform level</u> of information obtained from a given single resolution. The natural variances provided by man's different sizes and styles of cultivation, road construction, housing and so on will in effect have a clipping or filter function exerted on them by the resolution used.

Thus, in identifying various classes of objects there are cut-off spatial resolutions for each class of objects. These cut-off resolutions work both ways. For example, with a resolution of 50 feet it is not feasible to delimit individual species within a forest except under quite rare circumstances. Such a resolution becomes more useful for delimiting the broad distribution of plant communities and plant structures. Actually the same type of information is also available at 100-foot or 200-foot resolution. It follows that if a small scale map needs to be constructed of a broad area showing the distribution of gross features, it may be most efficient to use the poorest resolution which will do the job. An example in the other direction is given in the Aero Service Corporation report (1960) on small scale aerial photography. Certain building assemblages in industrial establishments can be identified on photographs at scales of 1:318,000 and 1:400,000. Increasing the scale in steps to 1:75,000, with accompanying improvements in resolution, in a number of instances gave no additional information which would improve the identification although it made it somewhat easier to obtain. It is obvious therefore that within the urban environment a given resolution will act as a spatial filter and will be able to segregate classes of structures effectively. This is a topic which requires further investigation by geographers interested in various urban aggregates.

As the resolution degrades, the kind of information available varies. The tabulation given on the following pages presents the information available from sensors with resolutions in the range of 10 feet to 400 feet and represents a compilation and modification of material obtained from publications by Jennings, et al. (1963), Frey (1967), Aero Service Corporation (1960), and by unpublished studies at the Center for Research in Engineering Science at the University of Kansas. Urban and forestry uses appear to be lost first, followed in turn by identification of field patterns, natural vegetation, geomorphic, and then major geologic features.

Studies on the identification of cultural targets in aerial photography have clearly shown that it is not feasible to have a single resolution value with which certain targets will be detected, for the time of day the photography is obtained, the nature of the surrounding objects, and the contrast ratio between the object being detected and surrounding material play a major role in identification. In addition the training and intellectual qualities of interpreters are important. The results of tests on the identification of objects by numerous observers have shown that there is a discrimination transfer function (*strictly*, an information transfer function) comparable to that of the modulation transfer function in photography. Thus there is no single cut-off resolution which can be recommended with the assurance that the objects being sought will be positively identified by all photo interpreters or pattern-recognition devices, unless one chooses to make unrealistic requests for very good resolution.

We have not yet had an opportunity to systematically evaluate this discrimination transfer function, but will attempt to do so in the following year. It is common knowledge that detection and identification are notably easier with a high contrast ratio between the object being sought and its background than with a low contrast ratio. Furthermore there are distinct differences between observers. It is these two facts which serve to give the discrimination transfer function its form.

The question of what is meant by identification also needs careful evaluation in the context of thematic mapping. To discriminate between a road and a railroad is one thing. To determine the nature of the road surface is another. There are some types of roads where inference may lead to a correct identification of the surface with a very high degree of accuracy whereas for other roads and environments inference cannot be used.

The significance of this discussion is of course that any recommended resolutions for the production of thematic maps from spacecraft must contain both compromise and some respectable error. It remains to quantify the magnitude of the errors that one will obtain in different environments. For example, to delineate major arterial road systems in a well developed country such as the United States a resolution of 50 feet may be adequate for all primary, secondary, and even tertiary roads. However, in underdeveloped areas where roads may represent little more than tracks, 20 feet or even 10 feet resolution may be needed for firm identification.

The resolutions listed in the following pages are compiled from various sources but still contain a substantial measure of personal judgement. The resolutions are listed with the coarsest first and at each level are given the objects for which that resolution appears to be critical with commonly encountered object-context-contrast ratios. The table is based on photographic resolution and does not apply to radar for which a separate evaluation is necessary. It is stressed that these evaluations are preliminary only and have not been subjected to critical evaluation.

Preliminary Estimates of Photographic Resolution for Thematic Mapping

1. At resolutions of 400 feet the following may be interpreted with sufficient accuracy to produce acceptable thematic maps of scales of 1:750,000 and smaller: timberline, waterline, snowline, desert line, grassland-brushland interface, brushland-timberline interface, grassland-timberland interface. Bare soil versus vegetated area, and individual fields, 80 acres or more in size, dams and large ponds at least 100 acres in size, all third and higher order streams and some second order streams as would be delineated on 1:24,000 topographic maps. Broad land use categories at the agricultural region level, major landforms, and major geologic structures including faults, large folds, and major lithologic units (it is important to note that at this resolution a number of significant, quite substantial geologic structures are not seen. For example, major hogbacks along the front range of the Rockies are not detectable on gross resolution radar imagery and comparable situations are found with Gemini photography in the same resolution range). Considerable ambiguity still prevails over the ability to detect all large urban aggregates, and many small urban aggregates may not be detected.

2. At a resolution of 200 feet one can interpret the following with sufficient accuracy to prepare thematic maps at a scale of 1:500,000. All those items in the preceding list, plus occasional major arterial roads and almost all large airfields. Straight to linear field patterns can be detected but it may not be feasible to discriminate between fields bordered by roads and those that are not. All the items in the preceding section (400 foot) may be resolved with greater assurance by decreasing the resolution to 200 feet. However, it is worth emphasizing that there is no vast new

array of additional possibilities available at this resolution.

3. At a resolution of 100 feet we can interpret all the preceeding and the following items with sufficient accuracy to construct thematic maps at a scale of 1:250,000: Cultural objects, including small villages, rural land uses, categories within urban areas such as newer and older residential areas, shopping centers, light versus heavy industrial establishments, major marshalling yards, iron and steel plants, substantial power plants, etc. It will be noticed that all of these items are either aggregates, (e.g. phenomena such as suburbia) or constitute very large individual industrial units in which the spatial distribution within the unit conveys the information. Agricultural fields between 5 and 10 acres may be distinguished depending on the contrast ratio and the nature of the surface can be inferred. However, smaller roads may not be detectable and the nature of the surface frequently cannot be determined even at this scale. All major geologic structures are shown, lineaments are well expressed at this resolution other than very short lineaments of less than 1/3 of a mile in length.

4. With resolutions of 50 feet identification of the following objects suitable for construction of thematic maps at a scale of 1:100,000 becomes feasible:

All those in the preceding categories plus bridges across major rivers (the nature of the construction material cannot be determined), moderate size business establishments, multiple dwellings, dock facilities, etc., and agricultural fields of about one acre in size up to three acres in size depending on the contrast ratio, estimates of some forms of vegetation density, soil mapping at the association level, topographic mapping at the scale of 1:250,000, internal structure of small rural settlements, detection of large farm buildings (this is feasible in some environments only), estimates of population density from spacing and size of towns and the distribution of farmsteads. The figure of 50 feet seems to be rather a crucial one in the detection of the cultural objects within major urban centers and represents a break between very useful resolutions, which tend to be finer than this, and gross resolutions, which tend to have more academic rather than practical applications. Small private airfields are detectable, dams are detectable, roads can be detected if improved or paved, railroads can usually be discriminated on the basis of shape but not in terms of resolving the material of the road-bed or the lines themselves.

5. At resolutions of 25 feet:

All the preceding may be detected together with objects sufficient for the construction of thematic maps of a detailed type within urban environments suitable for publication at scales of 1:50,000 and 1:100,000. All roads and types of roads, small business establishments, individual houses, bridges (including estimates of type of construction material). At this time it does not seem reasonable to consider finer resolutions than 25 feet from spacecraft photography.

It also follows that the resolution of orbiting sensors probably should not be less than about 400 feet if even exceedingly gross thematic land use mapping is to be carried out, for with such a resolution the minimum detectable size of low-contrast objects tends to be 5 times this, i.e. 2,000 feet across with photographic, radar or IR systems. There are few works of man for which this is an acceptable resolution. It is, of course, true that the detectability of linear features of the landscape is much better than square elements. Consequently, even poor resolution systems may be able to detect linear transportation lines on the earth. It remains, however, for a systematic study to be made with Gemini and other photography on the errors introduced with different resolutions in detecting transportation and other linear features. We will undertake such a study. The information available on photographs and radar images useful for constructing many types of thematic maps, frequently exceeds that normally placed on maps at comparable scales, and comparable information may only be found on conventional maps at about 6 times the scale of the original imagery, depending on the subject matter. To verify certain geologic features seen on radar imagery at a scale of 1:160,000 it may be necessary to consult geologic maps at scales at 1:24,000.

Complementary and Supplementary Roles for Imaging Radar and Photography in Space

A thorough analysis of various ways in which radar and photography may usefully supplement and complement one another in the preparation of thematic land use maps remains for the second and third years of the project. At this time a few general observations are given to set the stage for the studies directly concerned with this topic.

Among the various ways in which remote sensors may support and complement one another are the following:

1. High spatial-resolution sensors with a narrow swath width may be embedded within the areas covered by a gross resolution, wide-swath sensor image.
2. A wide band width sensor may be used with a narrow band width system.
3. Of two systems with comparable resolutions one may show distinct texture effects which convey information which the other will lack.
4. Images obtained with all-weather high resolution systems such as synthetic aperture radar will fill in the gaps caused by cloud and excessive haze in photographic and IR sensor systems. Conversely the photographic systems will serve as a calibration of the radar for those areas where the photography is lacking. Only short distance inferences are thus required, even if the radar is not sensitive to exactly the same materials as in the photographic region.
5. At orbital altitudes panoramic cameras with a 74 degree field of view will overlap most of the side-scan radar images obtained at the same time, a situation which does not occur at aircraft altitudes, where separate passes are usual.
6. The energy matter interactions are dissimilar in the visible, IR, and microwave regions. Hence information, which may be significantly orthogonal is possibly obtained in each area, to aid identification.

Preliminary Observations on Thematic Mapping from Spacecraft

Most thematic maps with scales between 1:100,000 and 1:2,000,000, are laboriously pieced together with data which vary markedly in quality, quantity, and date of collection. It is rarely possible to obtain a single synoptic view with existing methods of data collection, except in single countries at the time of their national censuses. However, for many parts of the world, national censuses are infrequent and are of only modest accuracy. For most underdeveloped nations, thematic maps which are useful for planning and for various levels of policy decisions are inadequate at best.

Multi-sensor space systems may well constitute the best source of contemporaneous data acquisition for construction of some types of existing thematic maps and for the construction of new types of maps. This study will test various ways in which radar imagery may supplement and complement other remote sensors which will be affected by clouds and haze. The bounds on extrapolation between various remote sensors in regard to radar will be established. The degree to which sampling both with photography and radar can establish the basic distributions will also be studied.

Regional coverage within the U.S. is not uniform either in scope, depth or recentness. For example, several areas of the U.S. have little map coverage of any type other than small scales for which data have been grossly generalized. Jackson and Greer counties, Oklahoma, have surface and subsurface geology maps but the largest scale topographic coverage is 1:250,000 and shows less hydrologic detail than McCoy (1967) indicates may be mapped from modest resolution radar imagery. A much greater information gap in the country is in vegetation mapping. Most of these maps are very large scale and the intensive studies on which most are based are few and widely scattered, particularly west of the 100th meridian, with substantial voids between.

The need for updating and greater coverage of the U.S. in thematic mapping is indicated by the increasing use of maps in planning by government and private enterprise for conservation, rapid transit, marketing, agricultural regulation and forecasting, defense and recreation. As our society increases in complexity so does our demand for spatial knowledge that is factually and concisely presented cartographically. Not only are the demands increasing for domestic detail but this is true also on the world scale. Nearly half the world is mapped with antiquated data, with little range in thematic coverage.

Many people turn to thematic land use maps for information on such items as the distribution of major crops, agricultural regions, time of planting and so on. They include such groups as agricultural experiment stations; universities and colleges; federal government agencies; producer and commodity groups concerned with programming, with insurance relief and famine operations; international organizations; agri-business including suppliers, processors, and transport agencies; credit and insurance firms; commodity market managers; range managers; and irrigation managers. It is well known that wild life and recreation organizations make extensive use of thematic maps. These include tourist bureaus, regional park and recreation planners, urban consulting firms, real estate developers, resource managers and transportation consultants, transportation engineers, shippers, map makers, engineers, hydrologists, regional planners, fish and game managers, transport and maintenance crews, university personnel, industrial laboratories, government laboratories, civil defense agencies, the red cross, industries concerned with rehabilitation, utility and transportation agencies, public health services, and insurance organizations. This partial listing is given simply to indicate the wide diffusion of interest and desire in obtaining adequate thematic maps throughout highly developed nations. The construction of topographic maps and some thematic maps has long been recognized as a major government task and has in the strictest sense never been cost-accounted, it being assumed that the benefits to society outweigh the costs.

It is instructive to see how many thematic maps at a scale of 1:7,500,000 given in the National Atlas of the United States of America might possibly prove feasible to map from spacecraft. In our judgement the number would not exceed 40 out of a total of some 230 U.S. maps, and this is generously biased in favor of space mapping.

However, this takes no account of either the many maps the National Atlas chose not to make, or of the new maps feasible only because of the availability of space data, or of the many types of maps which may be made from space data at larger scales than the National Atlas series.

In the following table is listed a number of maps for which space data would certainly provide auxillary and supportive materials. With further analysis we hope to divide these and others into the following categories:

a) thematic maps which may readily be made from space data,
b) thematic maps which may, with difficulty and variable spatial errors, be made from space data,
c) thematic maps for which space-photography will provide auxillary and supportive materials only.

I. Base
  A. Outline of first-order relief features
  B. Outline of second-order relief features

II. Physical
  A. Geology
    1. Bed rock geology, fault lines, etc.
    2. Glacial coverage--present
  B. Geomorphology
    1. Landforms - first, second, and third order
    2. Physiographic divisions
    3. Drainage patterns
  C. Oceanography
    1. General systems of surface ocean currents
    2. Nearshore circulation patterns
    3. Tracking and delineation of limits of floating ice
  D. Soils
    1. Generalized soil types
    2. Soil moisture--on a general scale
  E. Climate
    1. Cloud cover--percent on monthly or annual basis as well as additional surrogates such as sunshine, solar radiation(?) and evaporation(?).
    2. Snow cover--on a regional scale
    3. Length of growing season
  F. Water
    1. Distribution of lakes and rivers
    2. Delineation of drainage basins
    3. Delineation of floods
    4. River effluence--sediments and pollution. Especially visible at river-lake interface.
  G. Vegetation--by coverage and perhaps life forms

III. Economic

- A. Economic Regions
- B. Agriculture
    - 1. Agricultural regions
    - 2. Farm type--ranching, dry-farming, intensive, etc.
    - 3. Agricultural economy
    - 4. Types of agricultural land use
    - 5. Agricultural crops
    - 6. Agricultural animals--animals vs. crop land uses, natural wildlife from surrounding indicators.
    - 7. Crop maturity stages--from repeated flights over several month periods.
    - 8. Rural settlements
- C. Transportation--major railroads, roads, airports, ports, etc.
- D. Manufacturing
- E. Energy Resources and Mining
    - 1. Power plants, dams, refineries
    - 2. Mining and Quarrying
- F. Forestry
    - 1. Forest types and density
    - 2. Type of lumbering practice--block cutting, strip cutting, etc.

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THE POTENTIAL FOR DERIVING LANDFORM REGIONS FROM RADAR IMAGERY: A PUERTO RICAN EXAMPLE

David E. Schwarz
and
Roland D. Mower

NOTE: This study was supported exclusively under U.S.G.S. Contract No. 14-08-0001-10848.

NASA R-09-020-024 A/1
Task No 160-75-01-32-10

The Potential for Deriving Landform Regions from Radar Imagery: A Puerto Rican Example

David E. Schwarz and Roland D. Mower

Introduction

This report is an evaluation of classified radar imagery obtained during a February, 1964, flight over the island of Puerto Rico. Though allusions will be made to such thematic potentials as agricultural land use mapping or detailed landform study, the major purpose is to compare a landform regionalization scheme derived from the radar imagery with the systematic descriptive classification of Puerto Rican landforms as developed by Young (1953).

To date much analysis of remotely sensed imagery, regardless of the particular system, has been directed at studying single, particular phenomena such as natural vegetation, agriculture, geology, transportation, or the like. Those characteristics of remotely sensed data which are normally deemed least desirable for just such studies--the generally small scale and relatively poor resolution--become to a degree desirable for more broad scale analysis. Geographers especially should be cognizant of such potential. Nunnally (1965) was exploring just such an advantage of radar imagery in his "integrated landscape analysis," as also does this report.

Advantages and Limitations of the Site and Radar Imagery

Radar imagery seems to lend itself well to landform regionalization and with much less effort than such standard techniques as Young's (1953) and Hammond's (1964). Side-looking radar imagery, though of rather modest resolution when compared with a framing camera, has several characteristics advantageous for such small-scale mapping. The loss of minute detail imposed by resolution restrictions, in fact, resolves the surface to its major components free of minor or redundant detail. The very scale of the imagery which will be achieved from space is most proper for a small-scale type of mapping. Continuous image swath-widths may be on the order of 40 miles or more--properly large to show broad areal similarities and differences. The side-looking radar illumination mode emphasizes relatively minor terrain features and yet provides the imagery in a quasi-planimetric display. Geomorphic features are thus made more apparent than on other systems, but still are provided in a form for ready mapping. The active nature of radar, the fact that it provides its own known amount of emitted energy, is advantageous for two major reasons; first, the returned energy (or image density) becomes truly quantifiable; and second, because of its independence from solar illumination, "shadows" may be created in any one or several directions most desirable for best delineation of local geomorphic features. McCoy (1967) exploited these features in his study concerning determination of drainage basin parameters and slope measurement from radar imagery.

Certain limitations of the study must be mentioned. Obviously, since the imagery used remains classified, the use of it to illustrate points made in the paper is not possible. Comparisons will be descriptive. It may be said that the imagery is of poor quality and limited coverage. Though the intent was to image the entire island, in fact, something less than fifty percent was imaged, and the imagery of even marginal quality is but half that, due apparently to system malfunctions.

These restrictions further compound the limitations. Since the imagery was obtained in east-west strips across the island and since the system was alternately operational and non-operational, broad areas cannot be mosaicked together. And though, as above stated, radar will potentially image in very broad strips, this particular imagery swath width was less than five miles across, making the integration of large areas impossible. Because of the range in quality, even within single strips, and because strips of imagery were narrow and disconnected, it was difficult to make even simple comparisons with Young's regions. Location was especially difficult in the mountainous interior where urban and transportation patterns are poorly developed and landforms are uniform and monotonous. Coastal locations were readily identified.

Accepting these limitations, Puerto Rico nonetheless offers distinct advantages for such a study. The existence of Young's rather detailed systematic study is paramount, for it allows a direct comparison to be made with landform regions derived from radar. Puerto Rico in itself is an extremely compact area with a great diversity of landforms, is a readily accessible tropical site and has a culture different from any United States location.

Radar Landform Regions and Young's Classification Compared

Young derived his Puerto Rican landform classification from 1:30,000 topographic maps, measuring elements of local relief, percentage of steep land, and percentage of flat land for each unit area of one minute latitude and longitude. "Flat lands" were described as having slopes less than 3 percent, and "steep land" had slopes 60 percent and over, these being the critical factors for best sugar cane land (very flat) and slopes which should never be cultivated (very steep). From these he derived the following classification and mapped the island. Such a landform classification is rather meticulously derived and mapped.

Major Landform Classification by Young

	Percent of Island Surface
LOWLANDS	27%
Flat lowlands	11%
Rolling lowlands with some flat land	11%
Rolling lowlands	4%
Rough lowlands with some flat land	1%
HILL LANDS	37%
Rolling hill land with some flat land	4%
Rolling hill lands	22%
Rough hill lands	4%
Rugged hill lands with some flat land	1%
Rugged hill lands	6%

MOUNTAIN LANDS	36%
Rolling mountain lands	6%
Rough mountain lands	15%
Rugged mountain lands	15%

Though the radar landform categorization is purely qualitative as used in this report, it should be noted that radar imagery lends itself well to quantitative landform analysis. McCoy (1967) described several methods of quantitative landform measurements from radar, and suggests methods of quantitative landform measurements from radar, and suggests also that radar imagery is suited to automatic measurement techniques. Not only did he conclude that most basic drainage basin parameters can be measured from radar imagery, but he found that fairly accurate slope measurements can be made using only monoscopic radar if more than one flight direction of a given area is made.

The image pattern is readily amenable to electronic measurements both of areal variations in density and texture. A crude form of the same kind of information may be obtained simple by making densitometry traces across the imagery, as Nunnally did. Such measurements would be necessary if one were classifying over a broad area, but are not necessary for point by point comparisons of radar to Young's classification. For this initial study, and considering the limitations of the imagery, a descriptive comparison will suffice.

The delineation of any boundary is inexact. Certainly it is not to be expected that Young's boundaries and those derived from radar will be exactly correspondent. That they do not correspond does not suggest that either is an incorrect classification, but only that different landscape and system characteristics were used in the evolution of landform regions. Where Young measured given unit areas and assigned them totally as a given classification, we are looking for more definite boundaries based on image density, pattern and texture. Figure one shows mile-long profiles given as examples of Young's landform types. His landform region map is

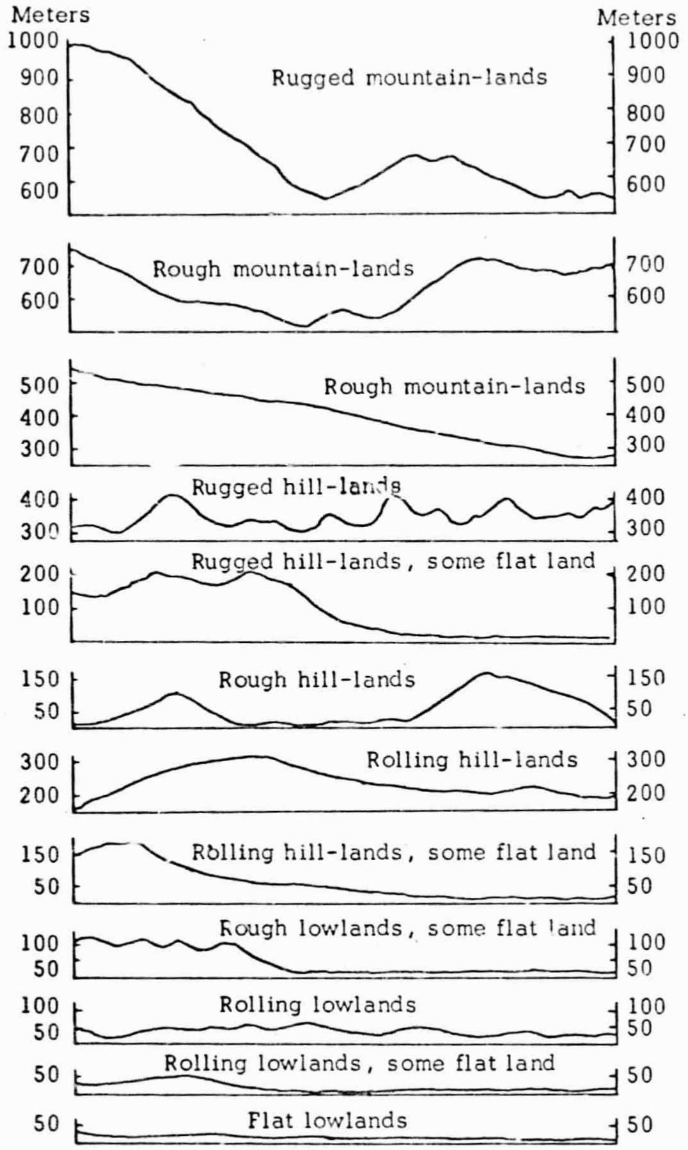


Figure 1. Mile-long profiles which illustrate each of Young's Puerto Rican landform classes. (After Young).

provided in Figure 2 and on it are located the three radar runs analyzed in this report.

The intial three lowland categories show almost exact correspondence on the two systems. The very flat category is especially evident on radar for it is almost universally planted in sugar cane except in undrained marshy areas. This also corroborates Young's assumption that extremely flat lands, as so categorized, were those most desirable for sugar cane cropping. Small undulations in the lowland are evident and easily enough defined on the radar to place them in either of the rolling lowland categories, depending on the relative proportions of flat to rolling land.

Young's final lowland category, "rough lowlands, some flat land" is not readily apparent on the imagery as a type apart, nor does it truly appear so in his example profile (it accounts for but one percent of the island surface, which in itself questions its legitimacy as a separate category). It seems more a combination of "flat lowland" and the "rugged hill lands" categories, and as such is more easily segregated into these component parts using the imagery. Young's necessity for averaging unit areas may have forced him to include this as a separate landform type; it is not so displayed on the radar, but rather is shown as two distinct types.

Of the comparisons made, only in the area in the extreme southeast corner of the island around Maunabo was there disagreement over lowland classification. Young calls this "rolling hill lands, some flat land," while it appears for the most part, almost flat sugar cane land on the radar. The restraints of Young's classification again forced him to average some of the peripheral rugged lands with the alluvial lowlands. As before the radar appears superior in truly identifying the landform type.

Hill land and mountain categories are the most difficult to reconcile on the two systems, but even here a close correlation can be made. The shape and size of radar shadow masses come most prominently into play, as do the shadow edges--sharp ridge features having abrupt tonal changes and rolling topography having gradual changes. The size and arrangement of the shadow masses indicate generally the degree of dissection or the

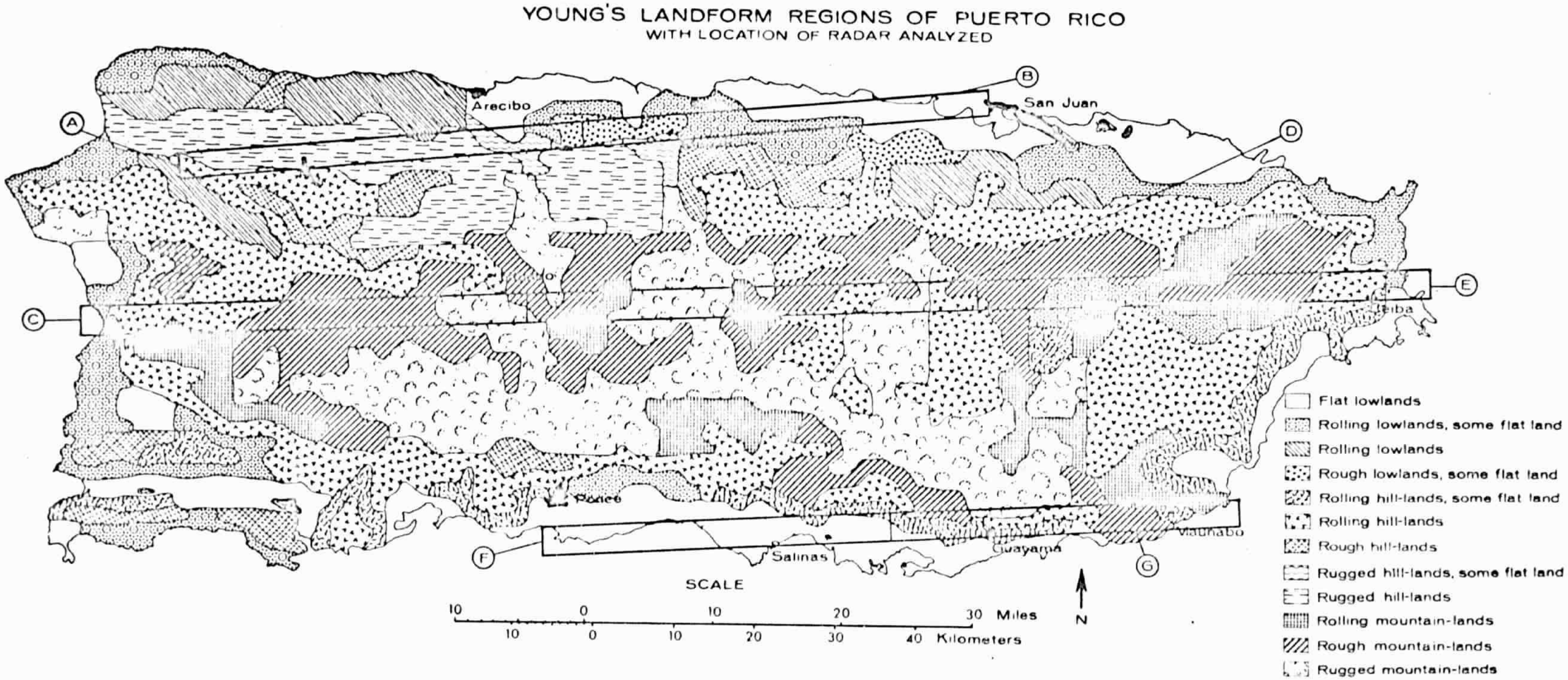


Figure 2. Young's Puerto Rican landform regions. The three bands outlined are the areas of radar coverage studied in this report. They were selected because they illustrate diverse landform types and are images of fair to good quality. See Figure 3 for details of the study areas (After Young).

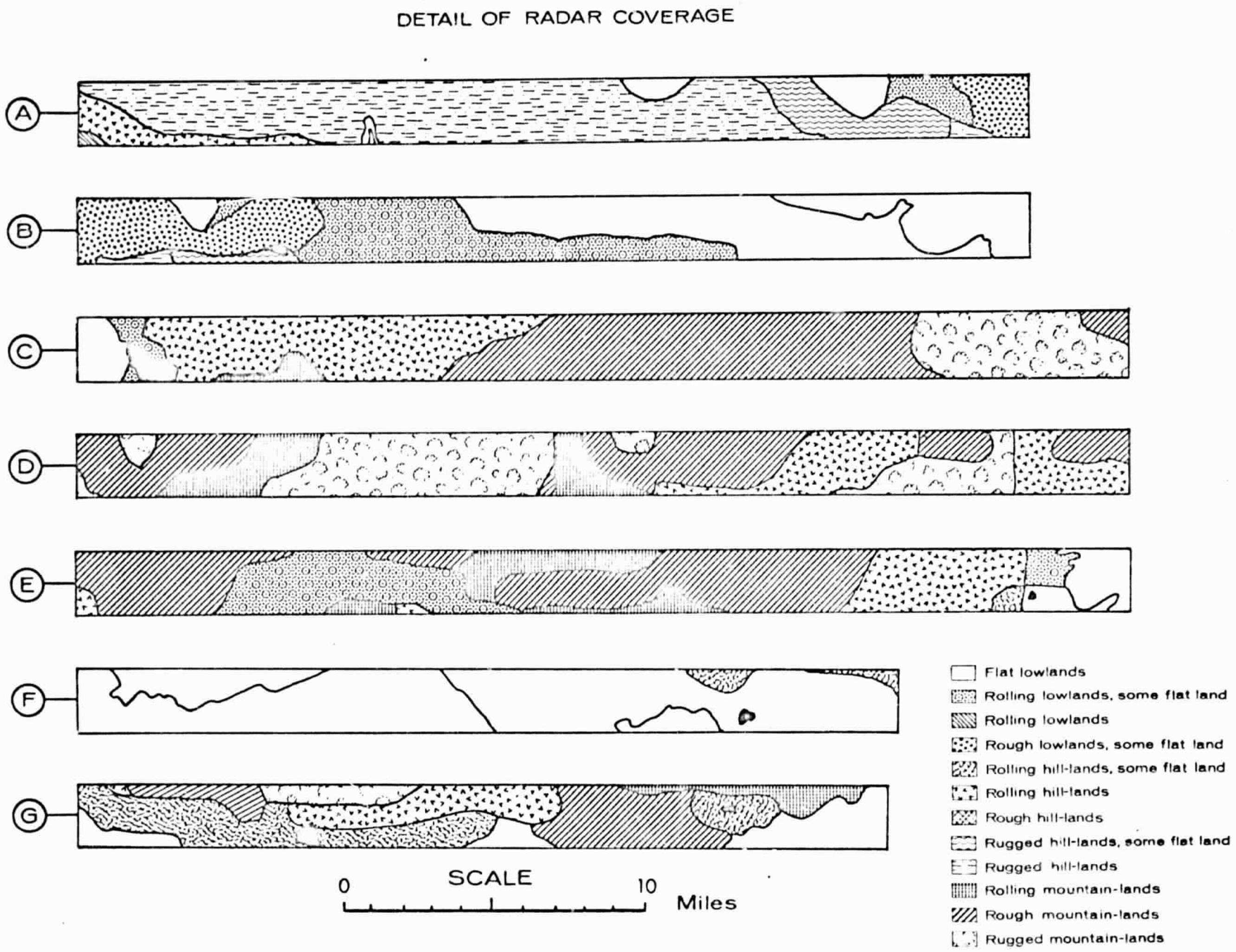


Figure 3. Details of Puerto Rican landform regions outlined in Figure 2. (After Young).

local relief, usually enough to make broad distinctions between hill lands and mountains.

Young's two most rugged mountain categories are inseparable from inspection of radar. Quantification of the return pattern might suggest a division of two types, but "rough mountains" and "rolling mountains" appear similar enough on the imagery that it is doubtful they could be completely distinguished even then. The two as a combined category can be well differentiated from other landform regions on the radar. Only one example of the third mountainous category can be sited, that north of Maunabo in the southeast corner of the island. Ready identification of this area as rolling uplands can be made, but it is not clear whether they are hill lands or mountains.

Hill lands are divided into five categories in Young's classification, though they could readily be reduced to four by eliminating "rough hill lands with some flat land." This category comprises but one percent of the island surface and is actually but a combination of alluvial lowlands of rivers flowing through rugged hill lands. These are distinct entities on both the radar imagery and Young's example profile, and are probably best thought of as two distinct categories rather than a single type.

Young's "rugged hill lands" is a very distinct type and as such have a very characteristic return pattern. This rugged limestone region is well described by Young as "conical hills, often connected with one another, and basins shaped like inverted cones between the hills or belts of hills."

None of Young's "rough hill lands" was encountered in the three radar strips, but it appears that distinguishing such an area from one of "rolling hill lands" would be difficult, and that they best be thought of as a single type. To distinguish the remaining category, "rolling hill land with some flat land," from "rolling mountain lands" has already been described as difficult. Measuring slope angle and slope length might make such a division possible but this cannot be accomplished from a single imaging.

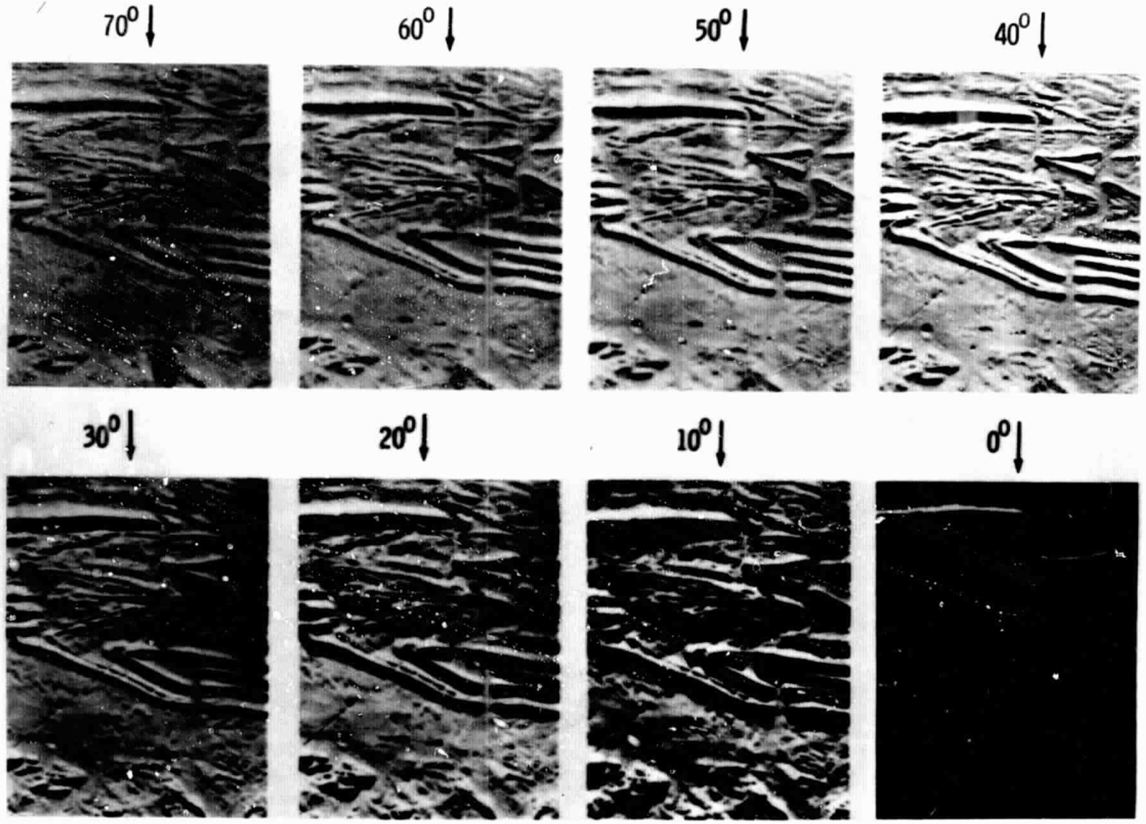
Conclusion

No single sensor can provide all the data desired for the study of landforms or any other terrestrial phenomenon. Multispectral sensing has long been indicated as more desirable. The radar imagery analyzed here has shown real advantages for regionalization of landforms. Cursory comparisons of Gemini photographs with the radar seem to indicate that, for this particular type of study, radar is probably the best single sensor. The complementary use of the two would, of course, be superior to the use of either singly.

Pierson, Scheps and Simonett (1965) detail the relevant advantages of radar, but for our purposes these can be rather broadly reduced to the following. Radar generalizes over very large areas and tends to suppress redundant detail, thus abstracting the gross earth-surface geometry from the melange of cultural and vegetative detail. Radar provides its own measured power thereby acting independently from solar illumination. It thus becomes more inherently quantifiable than photography or other passive sensors, and also illuminates any desired surface independent of weather or the angle of the sun's rays. Certain areas which are perpetually cloud covered or those poleward-facing slopes which are never illuminated by the sun may be imaged by radar. Radar imagery can thus provide not only views similar to most of those in Figure 3, but can provide views from any additional look direction. Figure 4 illustrates the kind of broad-scale picture of geomorphic features which radar provides much more dramatically than photography.

Direct comparison of the radar imagery and aerial photography of Puerto Rico is not really practical. Not only is the radar classified, but photography of comparable scale or resolution is not available. The conventional, large scale aerial photography of Puerto Rico, of course, shows great detail, but delineation of broad landform patterns is far less facile than from the radar.

Figure 5 does well illustrate the comparable information contained in a radar and photographic image. Certainly, the information contained is different. The gross landform texture is far better extracted from the radar, but other detailed geomorphic, cultural and vegetative information is provided by the photograph.



PHOTOGRAPHS OF PLASTIC MODEL UNDER DIFFERENT ANGLES OF ILLUMINATION. ARROW INDICATES DIRECTION OF LIGHT.

U. S. GEOLOGICAL SURVEY PREPARED IN COOPERATION WITH NASA NASA SA66-15799
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FIGURE 4. Different levels of information are available with differing angles of illumination. Radar has an added capability of illuminating from any direction, independent of solar illumination.

FIGURE 5. This radar image of the Tuskahoma syncline, Ouachita Mountains, Oklahoma, clearly shows the gross landform pattern better than it appears on conventional photography.

FIGURE 6. This direct comparison of photography and radar of drumlin topography, Oswego County, N. Y. clearly shows that each contains valuable though differing information, though the gross texture of the landforms is more apparent on the radar image.

Infra-red imagery would probably add only limited regional landform information to that gleaned from radar or convetional photography from space. It would be helpful if thermal characteristics of the surface or sub-surface were needed--if volcanic activity or ground water information were desired--but for the generalized portrayal of the landform surface, its value would be tertiary to radar and conventional photography.

Edwin Hammond (1964), a proponent of landform regionalizations such as those discussed in this study, sees the day when such regions may be derived using rapid, electronic-scanning techniques, and suggests that we "...become accustomed to thinking about land form as a geometry that can be resolved into spatial characteristics." Imagery from space, both radar and photography, lend themselves to such analysis and should be used in concert, but radar seems superior for providing a simple display of gross, textural image regions which lend themselves to both ready pictorialization and rapid quantitative reduction landform regions.

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AN URBAN LAND USE STUDY OF LAWRENCE, KANSAS USING K-BAND RADAR

Florence Peterson

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AN URBAN LAND USE STUDY OF LAWRENCE, KANSAS

Little has been done to analyze urban land use from radar, but the possibilities for generalized, rapid, low-cost mapping by this all-weather sensor are beginning to be realized. Up-to-date maps of land use and transportation in urban areas are required for planning at the local, state, and federal levels. "From a temporal standpoint, six to twenty-four months are often required for the collection of a data set which is frequently out of date before it becomes available. The federal government spends, conservatively, over 24 million dollars a year for the collection of urban land use information and the contributions of state and local agencies would more than double this figure."[1]

This paper reports on the rapid preparation, by one person, of maps showing land use and transportation in Lawrence, Kansas. Both polarizations of K-band AN/APQ-97 radar were examined. Because the scale of the original imagery was too small for easy mapping, enlargements of 2X, 4.8X and 19X were examined. The 2X enlargements, which retained the greatest clarity while providing a mapable scale, was selected as the optimum enlargement. The 2X enlargements of the HH polarization were examined only with a reading glass. Reference was made to the HV polarization on the original positive transparency for cross checking.

The observations, upon which the maps in this paper are based, were made from visual analysis of the radar. These observations included intensity of the radar return, graytone, texture, size, shape, location relative to other objects, together with other clues which may be used by an interpreter familiar with normal patterns of urban geography in the United States (Parenthetically, we might add that it is infeasible to eliminate training and experience for interpretation; see also pp. 10-11).

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[1] Thomas, Edwin N., and Duane F. Marble, "The Use of Remote Sensors in Urban Informations Systems," Urban and Transportation Information Systems, Department of Geography, Northwestern University, Technical Report No. 1, April, 1966.

In essence a geographer who pieces together clues to deduce that a cluster of buildings is a complex of apartments rather than a factory is engaging in the same procedure as a geologist who uses his clues to decide that a partially buried geologic structure is an anticline.

After the land use and transportation maps were prepared from radar, they were compared with large scale panchromatic photography, false color photography, and field checks.

To avoid the possibility of introducing information from sources other than radar, and the general experience of the interpreter, the radar maps were prepared before field checking and comparison with aerial photography. Where wrong identifications were made on radar they are so noted in the text and on Figure 1d. For example, area D (Haskell Institute) although known to the author to be a school for Indians, was listed as a factory because of its location on railroad tracks, relative location to the city and nature of the radar return. For this and other objects, the identification listed was the most probable based on information from radar and a knowledge of geographic relationships.

In this investigation six of the 33 land use areas in Lawrence were mis-interpreted from analysis of radar. Inasmuch as this was the author's first attempt at such a study, it is felt that the results for similar areas would substantially improve with practice and an application of U.S. Air Force techniques for analysis and interpretation of small scale aerial photography (see Aero Service Corporation, 1961).

Transportation features were located first to help determine the location of commercial and industrial areas. Rail lines are easily detected on radar imagery by their high intensity returns and by their smoothly curving patterns. Railroads are differentiated from highways both in intensity of return and the fact that rail lines usually are constructed on land of more moderate relief. Two railroads merge east of Lawrence and two others join in the small marshalling yard east of the central business district (CBD).

The Kansas Turnpike, immediately to the north of Lawrence, is identified by its very low return and great breadth and several overpasses which produce high intensity returns (Figures 1a and 1b). Two - lane

Figure 1a. Positive print of the K-band imagery of Lawrence, Kansas from which urban land use interpretations were made.

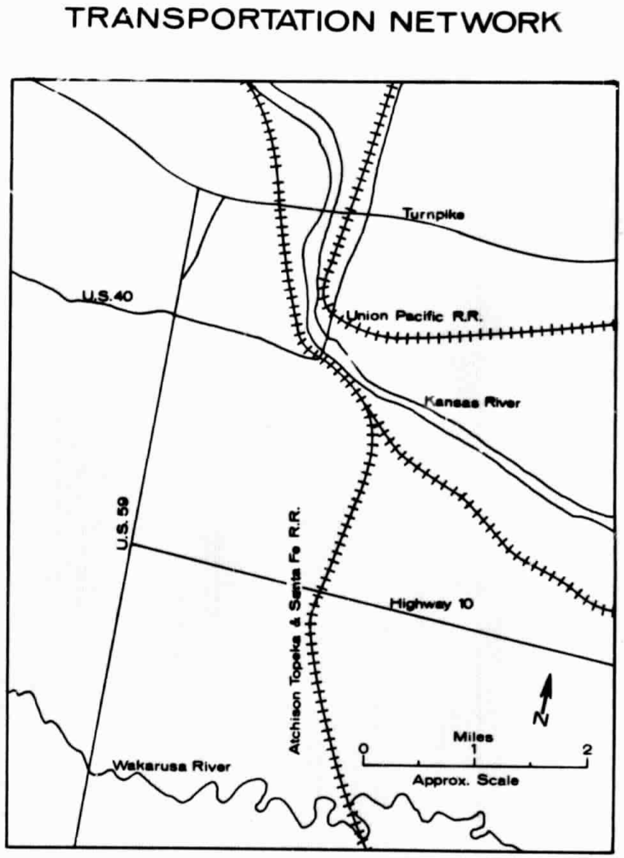


Figure 1b. Transportation network of Lawrence, Kansas and vicinity. Note that most major transportation arteries are well-defined on the radar image and that their location aids in the identification of urban land use regions.

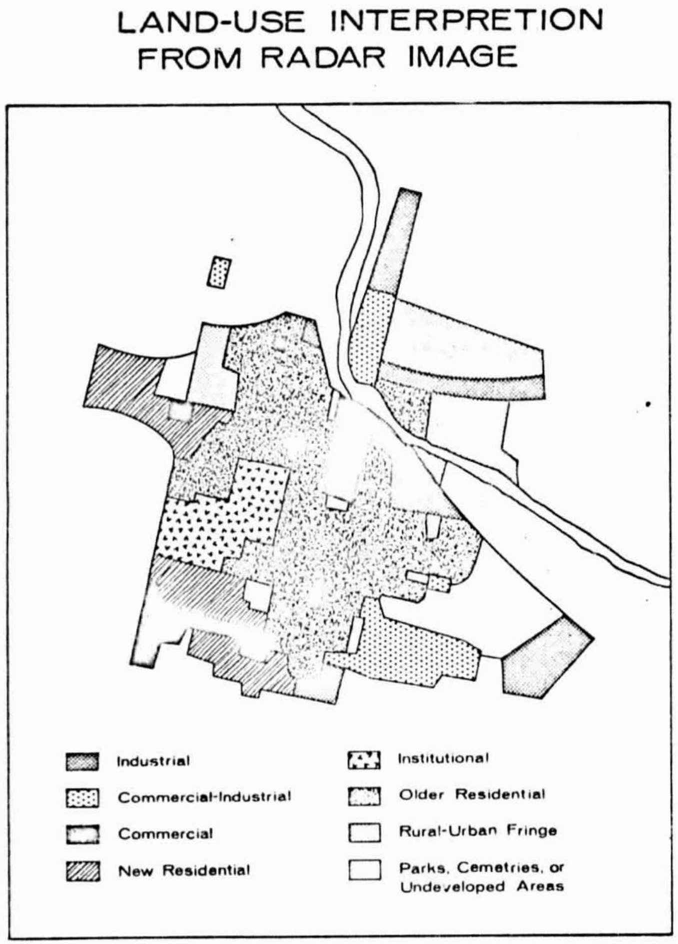
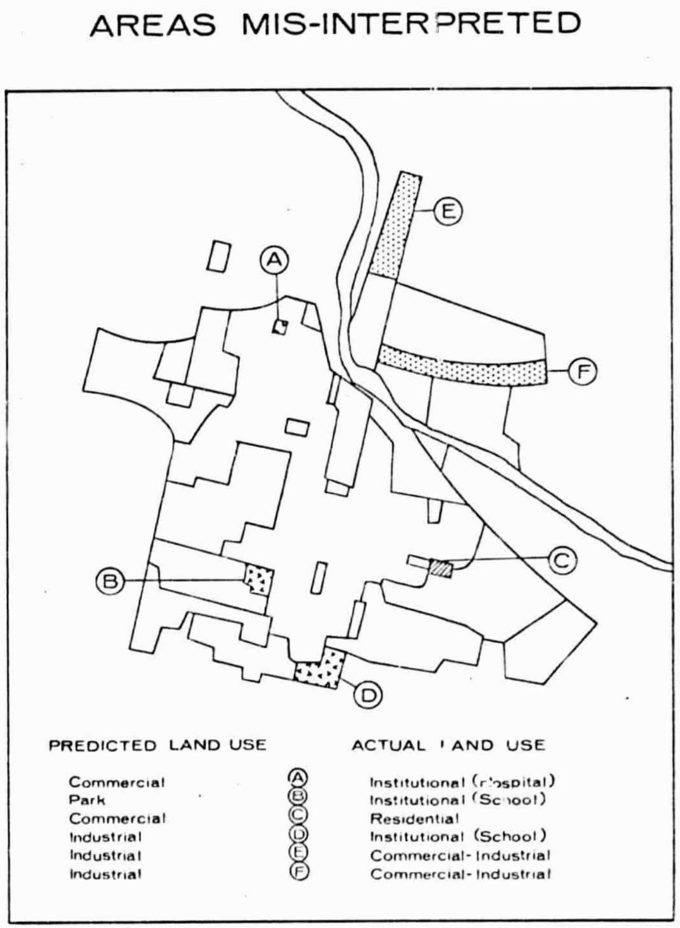


Figure 1c. Urban land use as determined from the radar image. 33 areas have been separated on the basis of tone, texture, proximity to transport facilities and other relative location aspects. Six areas are mis-interpreted (see Figure 1d).



PREDICTED LAND USE		ACTUAL LAND USE
Commercial	Ⓐ	Institutional (Hospital)
Park	Ⓑ	Institutional (School)
Commercial	Ⓒ	Residential
Industrial	Ⓓ	Institutional (School)
Industrial	Ⓔ	Commercial- Industrial
Industrial	Ⓕ	Commercial- Industrial

Figure 1d. These six land use regions had been improperly interpreted from radar (see Figure 1c). They tend to be small areas or areas where the commercial from industrial distinction is not quite clear.

macadam highways are not as readily apparent as railroads or the turnpike, but all except one can be traced from points outside Lawrence through the city. State Highway 10 is visible in the urban limits but is obscured for a short distance just south of the southeastern-most industrial area. A ridge in this section parallel to the line of flight evidently produced a shadow obscuring the highway. Convergence of transportation facilities (primarily highways) in the CBD is evident.

The largest area of high intensity is the CBD in the north-central portion of the urban area. The regular geometry of the rows of buildings and an absence of trees which cause diffuse scatter ensures that much of the energy is reflected directly back to the receiver.

The residential area adjacent to the CBD can be separated from the CBD by the change to lower intensity return and textural difference. The border of the CBD is not abrupt, so the borderline on the map passes through the arbitrary transitional zone from commercial to residential. This older residential area can also be separated from newer residential areas by the different street patterns, and by its relatively coarse textured, medium intensity return from a surface dominated by tree tops.

Most of residential North Lawrence (north side of Kansas River) has radar returns which do not coincide in texture, intensity, or pattern with other residential types. Because gardens and occasional small fields create a different image character, the return is characterized by an intensity intermediate between new and older residential sections and by scattered, coarse-textured areas.

Areas of heaviest industry give the highest intensity returns and are either aligned adjacent to the railroad or in close proximity to it; some rail spurs lead to factories. Lighter industries, not dependent on rail facilities, are difficult to distinguish from commercial areas and are not differentiated on the map drawn from radar.

Parks, undeveloped tracts, cemeteries, and certain institutional land use cannot be visually separated because all give fairly low return. Parks with few or no trees, cemeteries with no buildings or trees, and institutional land produce lower and smoother radar returns. Undeveloped areas and parks with trees are more difficult to separate but have a coarser texture and slightly lighter tone than treeless areas. Parks, institutional lands, and cemeteries are generally more regular in shape than undeveloped lands.

Several small areas, which were tentatively identified as commercial, were proven by field checks to have other uses. One is a hospital and parts of other areas are apartment buildings. However, practice and application of interpretation and analysis techniques used by the U. S. Air Force for small scale aerial photography should enable the interpreter to reduce such errors.

Thirty-three areas have been separated in Lawrence on the basis of tone, texture, proximity to transport facilities, and arrangement relative to the CBD and to residential districts. The following maps (Figures 1c and 1d) offer comparisons between land use interpretations from the radar and actual land use determined from low altitude aerial photography and field checks. Revised classification was necessary for six of the 33 areas which had been incorrectly identified from radar (Fig. 1a). Each of the areas misinterpreted is considered individually below with respect to reasons for original classification.

Area A (hospital-institutional) was incorrectly identified on the radar image as commercial due to the high intensity of return and its position within the residential area.

Area B (Lawrence High School-institutional) was listed as parks, cemeteries, or undeveloped on the basis of large area of low return and small area of high intensity return. The area could have also been classified as commercial since a shopping center could have a large parking area giving a similar low intensity return..

Area C (residential) was called commercial since it is on the fringe of the residential area and has a bright return. It should be classified as residential, as indicated on the adjusted land use map, since it is a mobile home court. The alignment of the trailers, in the direction of the flight path and approximately twenty-five feet apart, may explain the high return on the like polarization and relatively low cross-polarized return. Trailers parallel to the flight path apparently produce high intensity returns similar to those produced by commercial or industrial structures.

Area D (Haskell Institute-institutional) was considered to be industrial because of its position on the periphery of the urban area, high intensity return, and its alignment with rail facilities.

Area E (commercial and industrial) was originally classed as industrial due to remoteness from urban center, high intensity return, and alignment with rail and highway transport. The large rectangular bright area is a salvage yard. Service stations, lumber yards, and a plumbing retail and warehouse facility account for the other high intensity patterns in the area.

Area F (commercial and industrial) was felt to be generally industrial since it so closely parallels rail lines. However, the old commercial district of north Lawrence is spread throughout the western end of the area.

Although approximately 81 per cent of the urban area of Lawrence was correctly identified according to its land use, it may not follow that this level of accuracy could be maintained for all urban areas of similar size. Inference drawn from the interpreters knowledge of urban geography greatly facilitated analysis and identification of urban land use patterns. Many more studies are required involving varied urban orientation internally and externally and with wide ranges in size before the degree of consistency in analysis can be established.

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THE RELATIONSHIP BETWEEN POPULATION AND RADAR-DERIVED AREA OF URBAN PLACES

Joseph Sabol

NNN 34

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THE RELATIONSHIP BETWEEN POPULATION AND RADAR-DERIVED AREA OF URBAN PLACES

Joseph Sabol

This report is on the correlation of population of an urban place and its area on radar imagery. Although there is an obvious relationship between the areal extent of urban population centers and their populations, the relationship is not constant. Differing cultures and environments lead to differences in settlement patterns and the nature of cities. Direct population-urban area comparisons are not expected between Bantu villages in Africa and industrial cities of Europe or North America. Nor is it expected that direct correspondence will be found between the irrigated oases of Utah, the farm centers of the midwestern United States, and the humid eastern United States. Building styles, size of lots, economic activities, and the various cultural or sub-cultural differences decry the existence of one simple relationship. But some set of relationships must exist.* This is only a first attempt at applying imaging radar to the problem of determining such relationships.

Determining the populations of cities and towns will be important in its own right, but an extension may be made further relating urban populations with total population of given sub-cultural or environmentally similar regions. Geographers, demographers and many others are interested in determining world population, its distribution and dynamics.

Though the areas sampled in this study are far from representative of the range of world cultural or environmental regions, they do represent a good sample of U. S. urban areas for which unclassified radar imagery is available. If this initial study indicates feasibility for computation

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*Several investigators have determined that a relationship between urban area and population does exist, and illustrate that this ratio varies for different countries. See especially Stig Nordbeck, The Law of Altometric Growth, Michigan Inter-University Community of Mathematical Geographers, Discussion Paper Number 7, 1965.

of urban population densities from the radar, an expanded sample will be generated and the more complex variables will be considered in detail. It is of course understood that the errors associated with such a measurement will prove unacceptable in the U.S. However in other environments even random errors of 10 to 20% in population estimates distributed over a large enough group of towns could produce acceptable state or country-wide population estimates.

This study is based on the hypothesis that a relationship exists between the area of an urban place, as measured from radar imagery, and the population of that place. Furthermore, the configuration of streets apparent on maps and radar imagery suggests that the two main streets passing through or adjacent to the CBD and at right angles to each other approximate the dimensions of urban places. Thus, these elements--the radar area and the lengths of the two major intersecting streets--were measured to determine if they correlate with urban area or population.

Clark (1951), Clauson (1947), Newling (1966), and others have derived equations relating population and area to population density, which seems to indicate the potential of such a study if, in fact, the radar image area approximates the actual urban area. Nordbeck (1965) applied the law of allometric growth to the relationship between urban area and population. This law states that during growth a specific ratio is maintained between an organ and its parent organism; in this instance area and population represent organ and organism respectively. This work should also be applicable as a stated relationship between urban area and population density.

Data Acquisition

Radar imagery of 19 urban places ranging in population from 125 to 85,000 were selected for measurement. The urban places selected were located in several states and taken from several flights (Appendix 1). Places which were selected had imagery which was visibly free from distortions other than range distortion (normal in SLAR imagery), and ground truth, i.e., population, area, and street lengths for the year 1965. The two parameters measured for each urban area were (1) area, and (2) lengths of the two major streets passing through or adjacent to the C.B.D. at right angles to each other.

Measurements were performed for each place by a total of 21 persons, ten of whom had no prior experience in evaluating radar imagery. The remaining persons had moderate to considerable experience. The only instructions given to the evaluators are those listed in appendix 2 which also describes the equipment used in interpretation. An analysis of variance applied to the data will determine the significance of experience possessed by an evaluator.

Supplementary data obtained from the imagery for use in applying correction factors are as follows: distances from points along the flight track (in a direction normal to the flight path) to the near and far edges of each urban place; the angle of deviation between a line normal to the flight track and a main street which most closely paralleled this line. The need for correction factors arose because of the distortion present in SLAR imagery in the range direction. Other data needed for the correction factors were obtained from the flight log for each of the flights; these data included the aircraft ground speed and altitude.

A number of subsidiary assumptions about the urban places under consideration were made and are related to the way in which the corrections were applied. Each place was assumed to lie on a plane parallel to the horizontal plane of the aircraft's flight path. Differences of elevation within each urban area's boundaries were ignored. The altitude of the aircraft over each place was assumed to be that specified by the flight log for the particular segment of imagery in which the urban place was located. No allowance was made for variations in elevation of terrain in the segments of imagery used.

A form letter requesting data for purposes of establishing ground truth for the year 1965 was sent to all urban places within the swath covered by the system for each of four flights (Appendix 3A). All populations listed in appendix A, with one exception, are those supplied by responses to the form letter. Areas listed are those supplied by the responses or measured on maps included in the responses. All street lengths used were measured on maps. The streets measured were those observed to be most often measured on the imagery by a number of evaluators. The scale conversion factors are included in appendix 3B.

Data Correction

A computer program was written to perform the corrections needed to convert dimensions obtained on the SLAR imagery, with its distortions, to distortion-free ground dimensions (Thomann, 1968, Egbert 1968, Appendix 4A and 4B). Since the imagery virtually never contained urban places whose sides and streets were parallel or perpendicular to the flight track, corrections first involved finding projections for these dimensions using the angle of deviation of one of the main streets from a line normal to the flight track. The dimensions were next corrected for distortion in the range direction. These computations were performed for the data generated by each evaluator for each place. Since distortion in the azimuth direction is absent, no corrections were needed. Several of the computations involved classified information taken from the flight log. These computations are on file with the CRES security office.

Interpretation

Urban places are typically displayed within a range of relatively high intensity on radar imagery and are generally distinguishable from surrounding areas. Reference to Figure 1 discloses that the town of Gardner is clearly visible. As is typical with urban places, the C.B.D. is seen to be a bright nucleus, in this case located in the right-central portion of the town. The intensity of return tends to decrease from the C.B.D. to the edges of the built up area. This phenomenon is more apparent in the photography of imagery of Baldwin shown in Figure 2. Areas of different intensities can also be seen within the built up areas of both these places. Peterson (another section of this report) has shown that major functional regions within urban places can be differentiated on radar imagery of Lawrence, Kansas.

A particular, characteristic pattern is associated with radar imagery of urban places; this is due to the grid-like arrangement of streets and buildings which imparts a coarse texture to the imagery. Streets are smooth and also possess a low dielectric constant. Consequently, they appear in a grid pattern of low intensity. Large buildings are displayed with moderate to

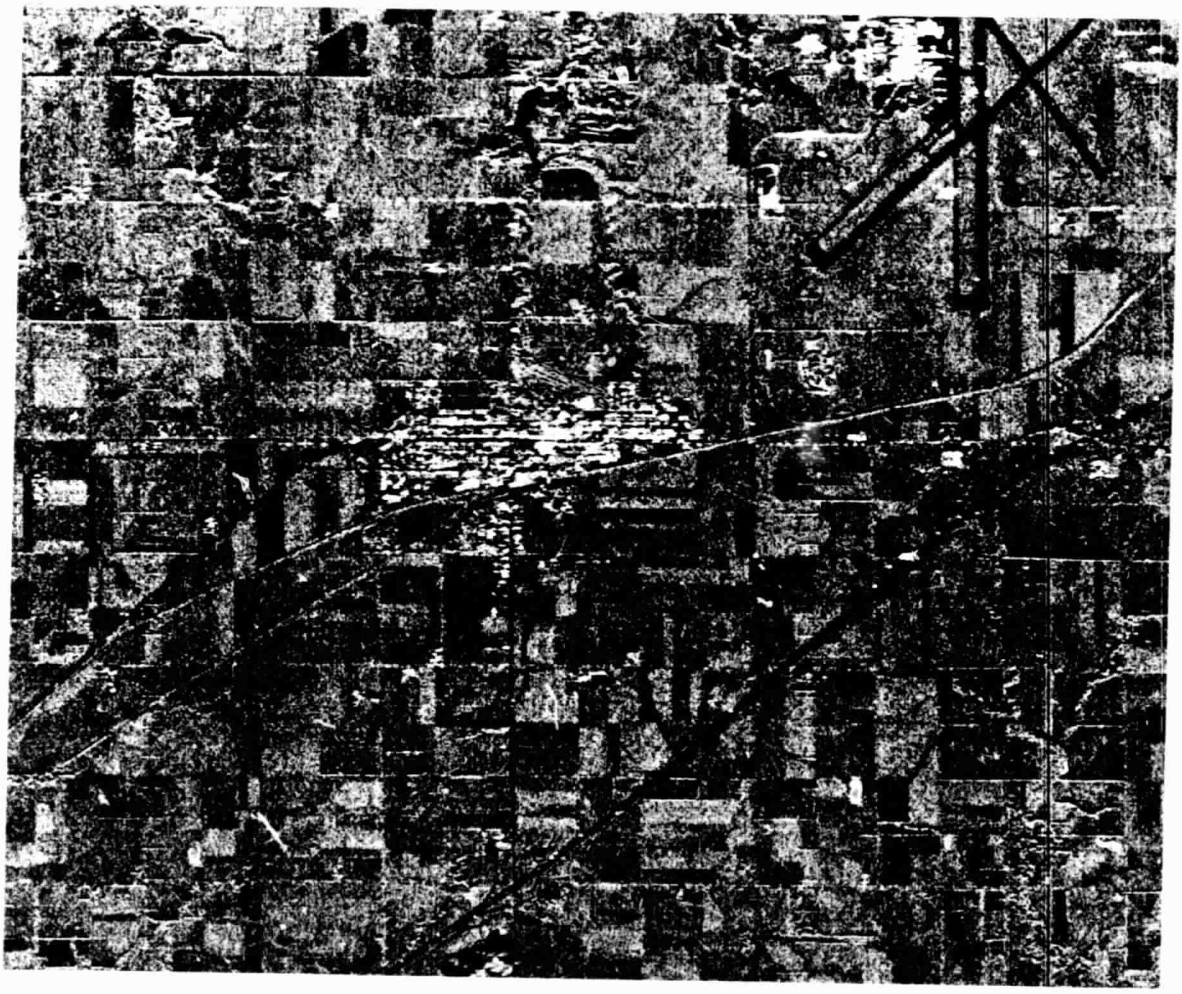


FIGURE 1. A 2x photographic enlargement of K-band imagery of Gardner, Kansas and vicinity taken in the summer of 1965.

FIGURE 2. A 2x enlargement of K-band imagery of Baldwin, Kansas and surrounding area.

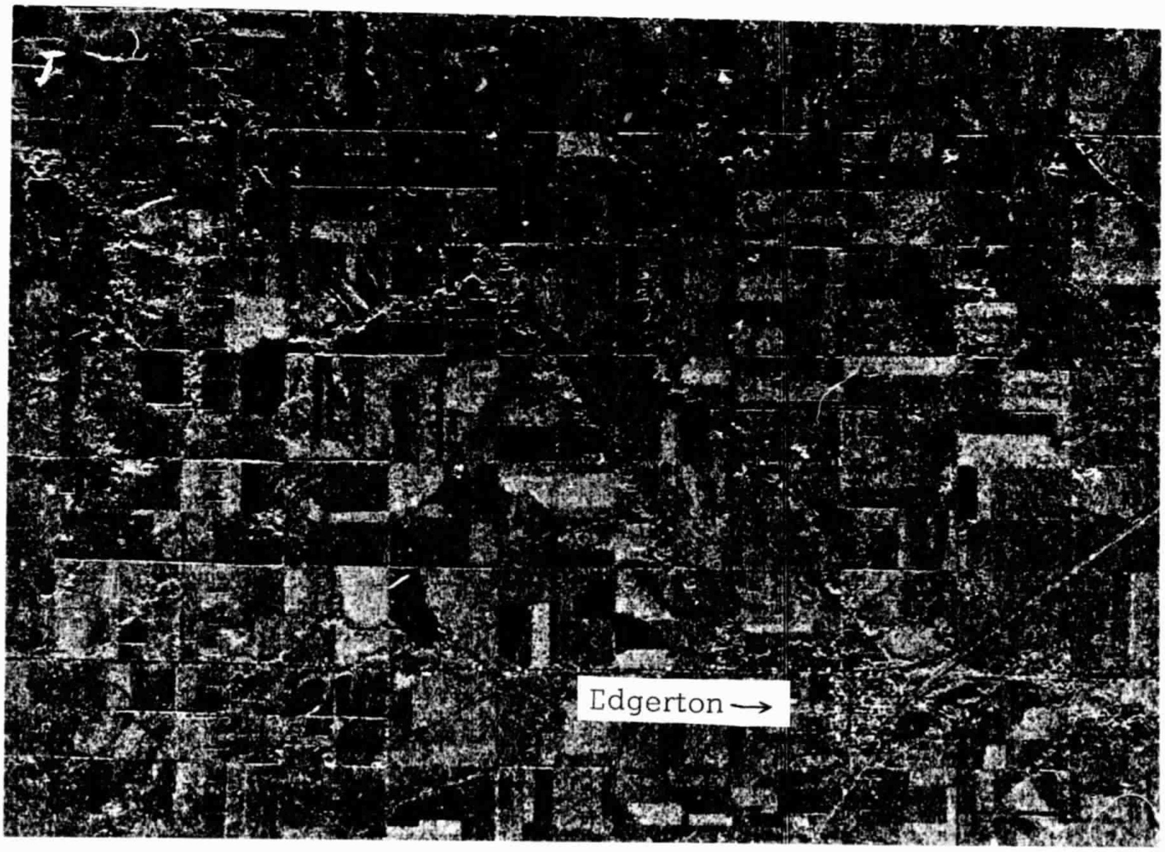


FIGURE 3. A 2x enlargement of K-band radar imagery Edgerton, Kansas and surrounding area.

high intensity as fluffy looking rectangles or squares arranged in strings parallel to streets. These strings are usually interrupted by streets running at right angles to them. Building returns often coalesce to form continuous strings (Figure 1).

Irregularities in the perimeter of urban places force the evaluator of radar imagery to make some rather arbitrary decisions when attempting to establish the boundaries separating built-up portions and surrounding areas. Generally the break between the two is quite visible, but in the case of a highly irregular boundary and low intensity return the distinction is not so obvious. The difficulty arises, in part, from the presence of trees, which obscure the street pattern within the built up area or from a poor return. Note the relatively poor contrast which makes it difficult to fix the lower boundary of the town in Figure 3.

Another problem arises from shadows created by mountains intervening between the antenna and the target which block out part of the target of interest. Satellite-borne radar imagery would not suffer in this respect because of the vertical scanning angle and possible overlap. On occasion, use of a different polarization, HV for example, permits use of imagery with shadows present in the HH mode.

Two adjacent urban places which result in a contiguous built up area create still another problem. The city of Newport Beach, California, was chosen for this study partly because it presents just such an instance of a contiguous area between it and Costa Mesa. The political boundary between the two was consistently misplaced by the evaluators. This is the only case where instructions other than those in the appendix were given. The evaluators were instructed to fix the political boundary after having been shown its approximate location. A diagonal orientation of the street grid of a portion of Costa Mesa adjacent to a major artery and differing from the general orientation of the street grid, induced evaluators to identify, erroneously, the major artery as the political boundary separating the two cities. In addition, a distinct change in contrast at the southern edge of Newport Beach caused some confusion in fixing this portion of the boundary. The change of contrast occurred between two adjacent residential areas.

One other factor must be mentioned as it pertains to interpretation. The city of Quincy was chosen, in part, because of its extreme proximity to the flight track edge of the film where images are compressed. Consequently, the perimeter of the built up area closest to the flight tract was somewhat indistinct. Normally, imagery chosen for evaluation fell in the outer two-thirds of the film strip in order to avoid such pronounced distortions.

Accuracy

Clearly, factors of interpretation bear heavily on the problem of accuracy. The actual process of measurement of the dimensions of urban places will certainly influence the outcome of results obtained. Errors introduced in measurement will be magnified by the scale factors used to convert film to ground distance. In addition, errors may arise in reading the angle of deviation, and then calculating the projections of streets and urban place sides not parallel to the range dimension may magnify these errors.

Hand measurement will undoubtedly be accompanied by errors which limit accuracy. Accuracy can be improved, however, by using a magnifying grid large enough to accomodate the largest place to be measured, thus eliminating the need to use two different measuring devices to obtain the data set. The use of automatic equipment such as a reconstitutor in conjunction with the IDECS would probably speed up the measuring process considerably with a suitable degree of accuracy.

Statistical Operations to be Performed

The following statistical analyses need to be performed to test the validity of the hypotheses advanced.

Phase 1

1. Regression analysis using population, the mean area, and the two street lengths for each of the urban places as variables. The mean areas are those obtained from the data generated by the 21 evaluators. In addition, the squares of the mean areas and the two street lengths, the product of the two street lengths, and the sum of the two street lengths as variables.

in the regression equation may be found to be significant in establishing the relationship being sought.

2. A two-way analysis of variance from which the influence of experience--non-experience could be deduced. This analysis would also provide information concerning the effect of the population range among the urban places selected.

3. Correlation among urban places between ground truth data and radar derived data.

4. Correlation among the evaluators' data.

Phase 2

Assumption: city shape is circular.

A circle on the ground necessarily would be imaged as a ellipse with a SLAR system. Hence area measured on the film is equal to the area of an ellipse and

$$\text{area} = \pi ab$$

where a and b are its semiaxes and would correspond to the two street lengths measured.

Correction of an ellipse to a circle involves the same procedure as corrections used in phase 1 for street lengths and theoretically

$$a' = b'$$

where a' and b' are radii of the corrected circle. But since circularity is assumed the radius of the circle may be calculated as follows

$$r = \sqrt{a'\,b'}$$

thus taking into account instances where $a' \neq b'$.

With the radar area transformed to a corrected circle on the ground, Clark's equation may be utilized for some comparisons with his findings.

He states that population density varies with distance from the center of the city according to the relationship

$$Y = A \ell^{-bx} \tag{1}$$

where x is the distance from the center of the city in miles, y is population density in thousands per square mile, b is a coefficient measuring decline of density; and A is a measure of crowding at the center.

Clark further states that with these assumptions, the total population within a specific distance, d, from the center of the city may be described as a volume of revolution described by the density curve rotated about the central vertical axis. Consequently

$$Pd = \int_{0}^{d} D_{o} \ell^{-bx} (2\pi x)\, dx, \tag{2}$$

which when evaluated yields

$$Pd = 2\pi D_{ob}^{-2} \quad [1 - \ell^{-bd} (1 + bd)] \tag{3}$$

where Pd is the total population within the radius d, D_o is the central density, b is the density gradient, and ℓ is the base of the natural logarithms.

Equation (3) or a modified form of it may thus be used also for comparison. Muth (1961) has developed a number of density parameters which may be used in equation (3). The converse is also true: density parameters may be calculated from the radar data.

Regression analysis would seem to be appropriate for establishing statistical significance as was done in Phase 1.

Phase 3

The third phase would necessitate measurement of the built up areas of the 19 urban places originally used. This could be accomplished by using air photos. Calculation of correlation coefficients between the air photo values and corrected radar values would establish validity of the radar measurements.

Phase 4

The fourth phase would be contingent upon measurement of a statistically significant number of urban places on the imagery. Again, regression analysis would be applied. In addition, the use of residuals could be used to determine if any groupings of urban places result because of size or population. Some type of numerical cluster analysis might be applicable at this point.

Phase 5

Newling, in particular, has done some interesting work using Muth's density parameters. It would be interesting to see if imagery is available for the urban places he worked with and to obtain some comparisons with radar derived data.

APPENDIX 1

DATA SHEET

TOWN	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1. Gardner, Kansas	1,800	.65	1.10	1.59	5.70	6.95		1	0	
2. Baldwin, Kansas	1,508	1.19	.67	.73	2.85	4.30		1	1	
3. Attica, Kansas	782	.29	.76	.46	6.40	8.10		1	15	
4. Garden City, Kansas	13,975	4.27	2.56	2.43	6.15	6.85		1	0	
5. Lawrence, Kansas	27,028	16.42	2.39	2.00	2.75	6.25		0	71	
6. Bonner Springs, Kansas	3,617	1.07	.15	.28	6.40	7.55		1	23	
7. Rothville, Missouri	138	.27	.80	----	4.55	5.05		1	45	
8. Quincy, Illinois	44,935	11.63	3.83	3.34	1.15	2.25		1	27	
9. Palestine, Ohio	232	.14	.57	.42	7.60	7.80		1	21	
10. Springfield, Ohio	85,000	16.73	4.25	4.52	4.30	9.30		0	77	
11. Mechanicsburg, Ohio	1,926	1.00	1.00	1.00	5.60	6.10		1	2	
12. Newport, Oregon	5,700	1.77	1.46	.96	.95	1.20		0	70	
13. Port Orford, Oregon	1,164	.12	.73	.31	8.60	9.20		0	90	
14. Eagle Point, Oregon	910	.30	1.00	.54	1.85	2.90		1	2	
15. Grants Pass, Oregon	12,700	5.22	3.27	1.40	1.30	3.15		1	21	
16. Newport Beach, California	38,352	18.19	3.40	1.18	1.75	8.25		1	3	
17. Carlsbad, California	12,350	10.50	4.30	1.39	2.90	5.65		0	89	
18. Plaster City, California	125	.47	.05	.20	.65	.80		1	2	
19. Calipatria, California	1,951*	1.50	.27	.40	4.55	5.55		0	62	

*February 1966 data - California Population 1966, Dept. of Finance, Rev. and Mgmt. Agency, Sacramento 1966

APPENDIX 1 CONTINUED

Identification of Columns

1. Population
2. Area derived from map.
3. Street length in North-South direction on map.
4. Street length in East-West direction on map.
5. Distance from flight track to near edge of town.
6. Distance from flight track to far edge of town.
7. Altitude of aircraft in 1000's of feet. (classified)
8. Identification of street direction relative to flight track:
    1 signifies North-South street is closest to being normal to flight track,
    0 signifies North-South street is closest to being parallel to flight track.
9. Angle of deviation of main street from a line normal to flight track.
10. Ground speed of aircraft in statute miles per hour. (classified)

APPENDIX 2

MEASUREMENT OF URBAN PLACE AREA ON RADAR IMAGERY

Urban places on radar imagery generally show up as relatively coarse-textured areas with the following characteristics:

1. Smaller places have rectangular or square overall outlines (often with irregularities).
2. Central Business Districts (CBD) are areas of high intensity return.
3. Areas surrounding the CBD have a mottled appearance of lesser intensity.
4. Visible street grid patterns of lower intensity than adjacent areas with buildings appear as bright linear strings parallel to the streets.
5. Fairly distinct breaks in contrast between urban and surrounding areas serve to delineate the boundaries between them.
6. Linear extensions of returns brighter than those of the surrounding rural areas denote roads or rail lines.

PROCEDURE: SMALL TOWNS USING VIEWER

1. Establish left and bottom-most boundaries of the urban place by means of eye and viewer using characteristics described above as criteria.

2. Position the viewer over the urban place so that the outside numbered sides of the viewer grid coincide with the left and bottom image boundaries.

3. Count all cells within the viewer grid which are bounded by the urban place perimeter.

4. Estimate to the nearest one-half those cells along the urban place boundary which are not completely filled.

5. Record the total number of cells. Sum the half cells to obtain whole cells and add the quantity obtained to the total number of whole cells counted.

PROCEDURE:- LARGE TOWNS USING GRID

(Use the same procedure as with the viewer)

PROCEDURE: MEASUREMENT OF STREET LENGTH

1. Determine the main street which is generally characterized by a linear interrupted pattern of bright return passing through or adjacent to the CBD.

2. Determine a second main street, which lies at right angles to the first, in the same manner as above.

3. Measure the two street lengths using the viewer or rule as a scale. Record measurements to the nearest one-half millimeter.

EQUIPMENT

The equipment used to perform measurements consisted of a calibrated 6 power optical viewer with a grid, a clear plastic sheet with a grid, and a metric ruler. The optical viewer grid consisted of a 10 x 10 matrix, each cell of which measured one millimeter on a side. The optical viewer was used for places smaller than the overall dimensions of its grid. For larger places the plastic sheet was used, each cell measuring five millimeters on a side.

APPENDIX 3A

Ground truth was obtained by sending a form letter to 508 urban places requesting the following information for the year 1965, the date the imagery was obtained:

1. Population
2. Area to the nearest hundredth of a square mile.
3. Lengths of the two main streets running at right angles to each other and passing through or adjacent to the CBD to the nearest hundredth of a mile.
4. An accurate map.

The response to the form letter was approximately 20%. The responses which provided usable data comprised approximately 12% of the total mailing.

The maps were used to determine area and street lengths when not given or when the streets given did not correspond to those most visible on the imagery.

APPENDIX 3B

MAP CONVERSION FACTORS

MAP DISTANCE

$$\text{Distance in Miles} = \text{Map Distance cm} \times F_d$$

$$F_d = \frac{\text{Map scale in feet}}{5280 \times \text{length map scale cm}}$$

MAP AREA

$$\text{Area in Mi}^2 = \text{Map area cm} \times F_a$$

$$F_a = \frac{1}{(5280)^2} \times \left(\frac{\text{Map Scale feet}}{\text{Length map scale in cm}}\right)^2$$

APPENDIX 4A

DISTANCE COMPUTATION ON RADAR FILM

Prepared by Gary Thomann

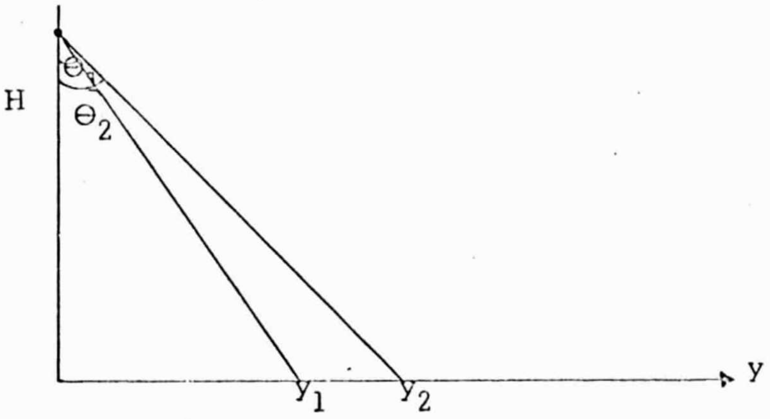


Figure 1. Radar Geometry

The point y_1 is mapped at

$$\beta\sqrt{y_1^2 + H^2}$$

where β is a constant involving the velocity of light and the film recording speed. The point y_2 is mapped at

$$\beta\sqrt{y_2^2 + H^2}$$

By definition, the scale is

$$\lim_{y_2 \to y_1} \quad \beta \left[\frac{\sqrt{y_2^2 + H^2} - \sqrt{y_1^2 + H^2}}{y_2 - y_1} \right]$$

$$= \lim_{\Theta_2 \to \Theta_1} \quad \beta \left[\frac{\dfrac{H}{\operatorname{Cos} \Theta_2} - \dfrac{H}{\operatorname{Cos} \Theta_1}}{H \tan \Theta_2 - H \tan \Theta_1} \right]$$

$$= \lim_{\Theta_2 \to \Theta_1} \quad \beta \left[\frac{\operatorname{Cos} \Theta_1 - \operatorname{Cos} \Theta_2}{\operatorname{Cos} \Theta_2 \ \operatorname{Cos} \Theta_1 \ (\tan \Theta_2 - \tan \Theta_1)} \right]$$

$$= \lim_{\Theta_2 \to \Theta_1} \beta \left[\frac{-2 \text{ Sin } \frac{1}{2} (\Theta_1 + \Theta_2) \cdot \text{Sin } \frac{1}{2} (\Theta_1 - \Theta_2)}{\text{Cos } \Theta_2 \;\; \text{Cos } \Theta_1 \;\; \frac{\text{Sin } (\Theta_2 - \Theta_1)}{\text{Cos } \Theta_2 \;\; \text{Cos } \Theta_1}} \right]$$

by use of identities for cos and tan.

$$= \beta \left[\frac{-2 \text{ Sin } \Theta_1 \cdot \frac{1}{2} (\Theta_1 - \Theta_2)}{\Theta_2 - \Theta_1} \right] = \beta \text{ Sin } \Theta_1$$

In general, for any angle Θ

$$\text{Scale} = S = \beta \text{ Sin } \Theta \qquad (1)$$

The geometry for a particular mapping radar is shown in Figure 2.

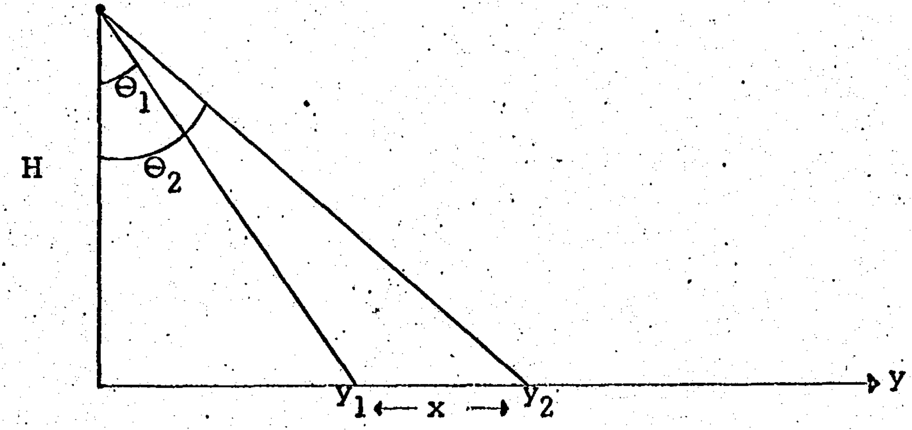


Figure 2. Mapping

The aircraft flies at a height H and maps the strip of ground x lying between the points y_1 and y_2 or between the angles Θ_1 and Θ_2. This strip of ground is mapped onto a film of width a. Assuming a, H, Θ_1, and Θ_2 are known, the first requirement is to calculate β. Since distance on the ground compared to distance on the film is related by the integral of the scale factor, we have

$$a = \int_{y_1}^{y_2} \beta \operatorname{Sin} \Theta \, dy$$

but

$$y = H \tan \Theta \qquad dy = H \sec^2 \Theta \, d\Theta$$

$$a = \int_{\Theta_1}^{\Theta_2} \beta \operatorname{Sin} \Theta \; H \sec^2 \Theta \, d\Theta$$

$$= \int_{\Theta_1}^{\Theta_2} \frac{\beta H \operatorname{Sin} \Theta}{\operatorname{Cos}^2 \Theta} \, d\Theta$$

$$= \beta H \sec \Theta \Big|_{\Theta_1}^{\Theta_2} = \beta H [\sec \Theta_2 - \sec \Theta_1]$$

therefore

$$\beta = \frac{a}{H(\sec \Theta_2 - \sec \Theta_1)} \qquad (2)$$

we can now consider β known. The distance on the ground that an increment on the film represents can now be easily calculated by the integral of the inverse of the scale factor.

Figure 4 shows a point on the film.

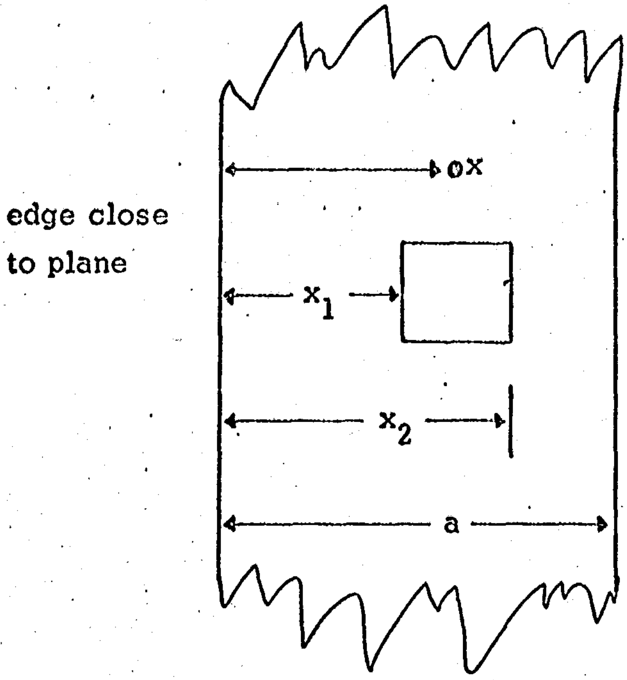


Figure 4. Film

The distance on the ground that this point represents is given by the original equation

$$x = \beta\sqrt{y_1^2 + H^2}$$

or

$$y = \sqrt{\frac{x^2}{\beta^2} - H^2}$$

Thus if it is required to know the ground distance between two points x_1 and x_2, the formula is

$$D = \sqrt{\frac{x_2^2}{\beta^2} - H^2} - \sqrt{\frac{x_1^2}{\beta^2} - H^2} \qquad (3)$$

where x_1 and x_2 are the distances from the points to the edge of the film and β is calculated from (2).

One more case is left to be considered, that of the points being located at other than ground level. This is shown in Figure 5.

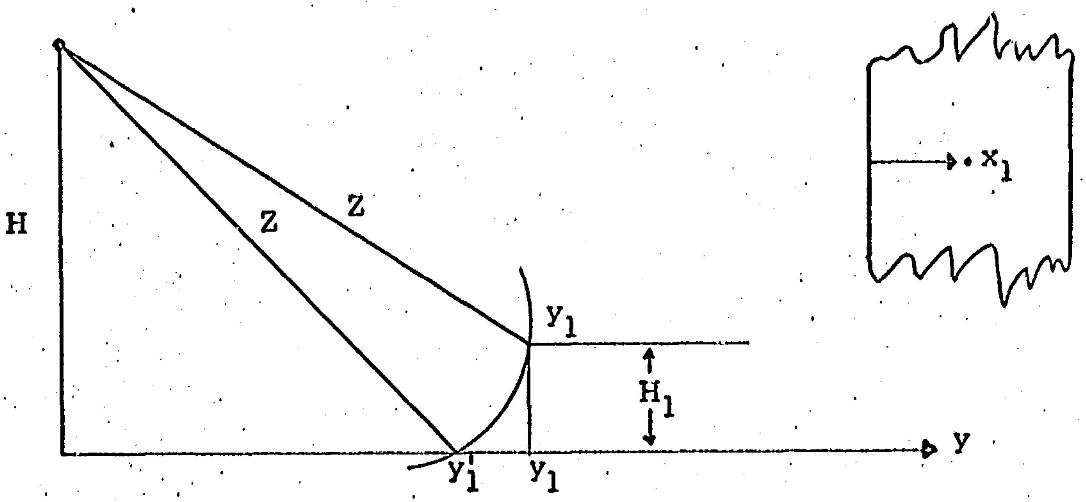


Figure 5. Points Off Ground Level

Consider the point y_1 at a height H_1. Because of its height above the axis it is mapped as if it were actually at a distance y_1', shown in the y axis in Figure 5. Consider the point on the film a distance x_1 from the edge of the film which is the mapping of y_1. If the ground were flat, y_1' would be the correct distance with

$$y_1' = \sqrt{\frac{x_1^2}{\beta^2} - H^2}$$

From the geometry of Figure 5, we get

$$H^2 + y_1'^2 = z^2 = y_1^2 + (H - H_1)^2$$

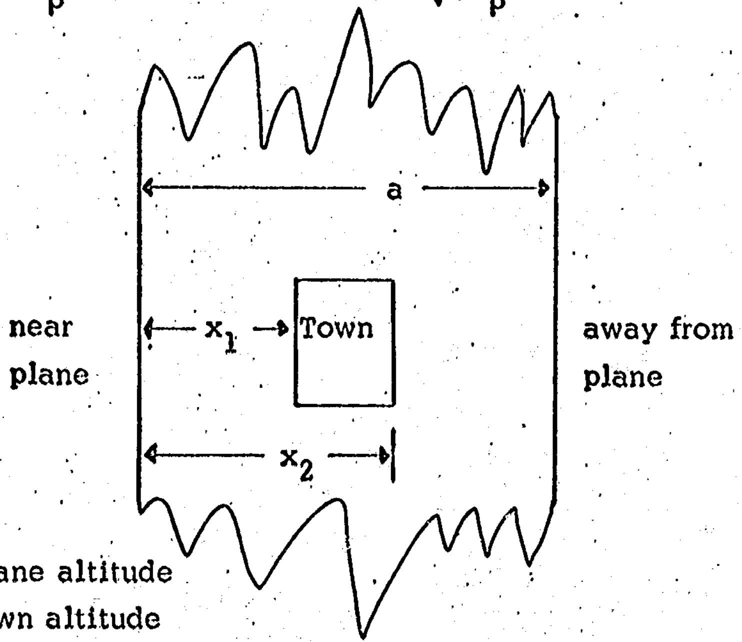
and since

$$y_1'^2 = \frac{x_1'^2}{\beta^2} - H^2$$

$$y_1 = \sqrt{\frac{x_1^2}{\beta^2} - (H - H_1)^2}$$

Thus if the distance between two points x_1 and x_2 on the film are to be calculated, with x_1 and x_2 representing points at a height H_1, the distance formula becomes

$$D = \sqrt{\frac{x_2^2}{\beta^2} - (H - H_1)^2} - \sqrt{\frac{x_1^2}{\beta^2} - (H - H_1)^2}$$



H = plane altitude
H_1 = town altitude
a = width of film

$$\beta = \left[\frac{a}{H\,(\sec \Theta_2 - \sec \Theta_1)} \right]$$

Θ_1 = angle at which mapping starts
Θ_2 = angle at which mapping ends

APPENDIX 4B

Calculation of Ground Street Lengths and Area from Radar Measurements

Prepared by Dwight Egbert

To find the ground street lengths from radar measurements it is necessary to perform two corrections. First the projections of the street lengths parallel to the flight path must be multiplied by a scale factor. This scale factor is a constant just as a scale factor used for lengths measured on a map. Second the projections of the street lengths normal to the flight path must be corrected for scale and inherent radar distortions. These distortions are not constant nor linear. They are corrected for through the use of the following formula[*]:

$$L = \sqrt{\frac{x_2^2}{\beta^2} - H^2} - \sqrt{\frac{x_1^2}{\beta^2} - H^2} \qquad \text{(Eq. 1)}$$

Where: L = Ground length

x_1 = Film distance from film edge near flight line to point 1

x_2 = Film distance from film edge near flight line to point 2

β = A constant involving the velocity of light and film speed

H = Altitude

The procedure used to calculate the ground street lengths is as follows:

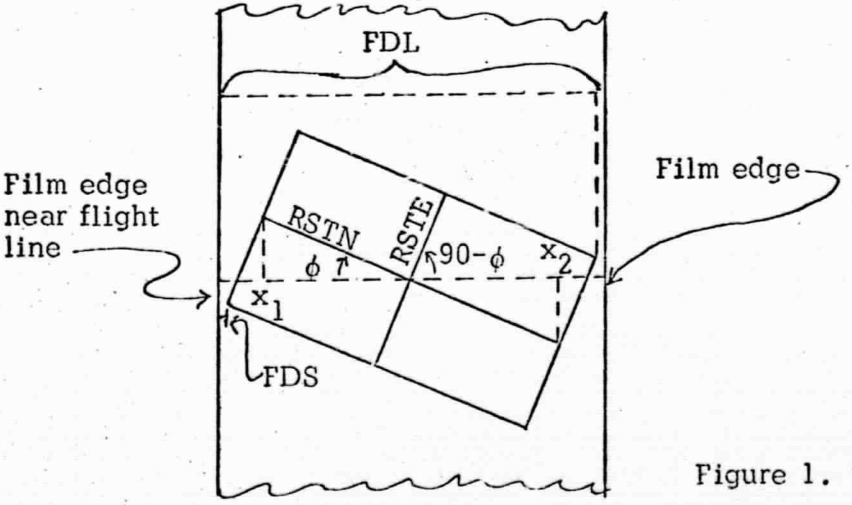


Figure 1.

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[*] Gary Thomann, Distance Computation on Radar Film, Unpublished Paper, CRES, 1968.

(1) Find normal and parallel projections for RSTN

$$E = RSTN \left| \cos(\phi) \right|$$

$$F = RSTN \left| \sin(\phi) \right|$$

(2) Find x_1 and x_2 for eq. 1

$$x_1 = FDS + \frac{RDL - FDS}{2} - \frac{E}{2}$$

$$x_2 = x_1 + E$$

(3) Calculate ground length of RSTN projection normal to flight path.

$$D = \sqrt{\frac{x_2^2}{\beta^2} - H^2} - \sqrt{\frac{x_1^2}{\beta^2} - H^2}$$

(4) Calculate ground length of RSTN projection parallel to flight path.

$G = F \times$ Scale factor

(5) Calculate total ground length of RSTN

$$GRSTN = \sqrt{D^2 + G^2}$$

To find the ground length of RSTE follow the above five steps and substitute RSTE for RSTN and $(90-\phi)$ for ϕ.

To find the ground area from the area measured on the radar, two assumptions are made of this measured area.

(1) The area is rectangular.

(2) The sides of the area are in the same proportion as the two perpendicular main streets.

An area which meets the two assumptions can be found as follows. A rectangle with sides AN and BP where

$$AN = \sqrt{\text{Area} \times \frac{RSTN}{RSTE}} \qquad BP = \sqrt{\text{Area} \times \frac{RSTE}{RSTN}}$$

Note than AN x BP = measured Area, not an area derived from the measured street lengths. The measured street lengths are used only to lend some reality to the proportions of the assumed rectangular shape of the measured area.

After AN and BP are found they must be corrected to ground values. A problem arises in this calculation from the fact that the radar distortion is parabolic. This means that if the rectangular area is oblique with respect to the flight path then all four sides should be corrected separately. This would be necessary for absolute accuracy since the resulting ground area will be a trapezium instead of a rectangle. However, it can be assumed that the resulting ground area will be rectangular. This approximation becomes more accurate as the rectangular area becomes closer to being parallel with the flight path. Finally when the area is parallel the approximation reduces to an exact description. As the sides of the area approach 45° to the flight path the approximation becomes worse and reaches its maximum deviation at 45°. If this approximation is accepted, the amount of computation and input data required for the calculations are considerably reduced. It is merely necessary to correct the two perpendicular bisectors of the rectangle using the same procedure as was used to correct the measured street lengths. The only difference required is to substitute AN for RSTN and BP for RSTE. The resulting corrected ground lengths analogous to GRSTN and GRSTE, call then GA and GB respectively, are then simply multiplied to give the ground area, GAREA.

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OBSERVATIONS ON THE GEOMORPHOLOGY AND LAND USE OF PART OF THE WASATCH RANGE, UTAH

Rex M. Peterson

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OBSERVATIONS ON THE GEOMORPHOLOGY AND LAND USE OF PART OF THE WASATCH RANGE, UTAH

This paper is an analysis of radar imagery of a region near Salt Lake City, Utah. K-band radar of an area 12 miles wide and 30 miles long was examined to document its potential for obtaining information on physiography, surface material, geomorphic history, mineralized areas, drainage, land use, and transportation.

Both HH and HV polarizations of the AN/APQ-97 radar were examined with the naked eye and with a 5 power microscope. 2X prints of the radar imagery were also used in the study.

Thorough study of the radar imagery resulted in a wealth of information, much of which is new and which does not appear in reports or maps of the area. Examples are some ancestral stream patterns with resultant information on the origin of the Wasatch Range, fracture zones and possibly undiscovered mineralized areas.

After a study of the radar, information obtained from the imagery was compared with data on topographic maps, geologic maps, and 1:63,360 scale aerial photo mosaics. It is significant that even though the scale of the radar imagery is only approximately 1:160,000, it was necessary to consult maps of 1:24,000 scale to observe some of the same features. In some cases comparison of first-round radar data with published data gave clues to more features to search for on radar imagery and resulted in new discoveries. Examples are two previously unreported major fracture zones and a joint set that appear to control location of mineral deposits in the Park City area.

The following maps were prepared by tracing information from the radar imagery onto transparent overlays: physiographic maps (2 types), landform classification maps, surface materials, ancestral drainage, present drainage, land use, and transportation.

The study area is a rectangle approximately 12 by 30 miles extending east from Salt Lake City to the east side of Rhodes Valley, Utah (Figure 1). The major portion of the study area is occupied by the Wasatch

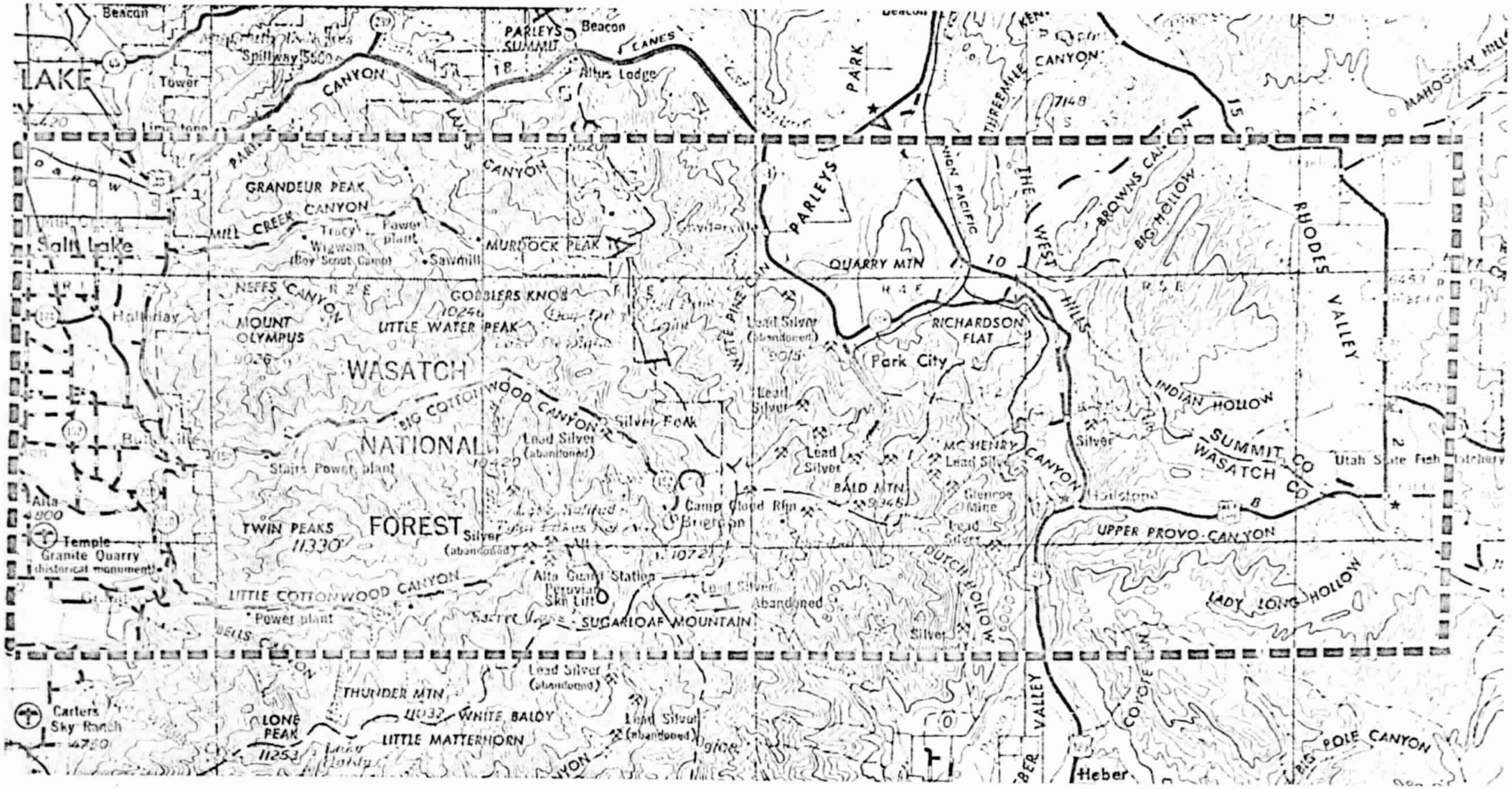

Figure 1. Index map outlining study area in Wasatch Range, Utah.

Mountains whose steep escarpment overlooks Salt Lake City.

The Wasatch Range, the westernmost range of the Middle Rocky Mountains, trends north and south and lies at the east side of the Great Basin. The local relief between the Great Salt Lake Valley and the highest part of the range, which is about two miles from the Wasatch Front, is over 6,800 feet (the highest peaks in this area are Mt. Olympus (0*) at 9,026 feet and Twin Peaks (TP) at 11,330 feet), (Figures 2 and 3A). The drainage divide lies approximately 10 miles east of the front and at a lower elevation than peaks near the front. There is a gentle eastward slope of the Wasatch Range from near the front to the broad back valleys of Parleys Park (PP, Fig. 3B) and Rhodes Valley (RV, Fig. 3e), which are in the Wasatch-Uinta transition area.

Rhodes Valley (also known as Kamas Valley or the Kamas Sag) lies at the extreme western end of the Uinta Range (UR, Fig. 3C) and is a wide, flat-floored valley at an elevation of approximately 6,400 feet. To the west of Rhodes Valley the low, rolling West Hills (WH, Fig. 3C) are covered predominately by sagebrush and scrub oak and are usable primarily for grazing. The only other flat areas in the study area are Parley's Park (PP, Fig. 3B), at an elevation of 6,600 feet, and the narrow flood plains and terraces along the Provo (PR) and the Weber (RW) Rivers and their tributaries (Fig. 3C).

Natural Vegetation

The natural vegetation on the floors of Parleys Park and Rhodes Valley was grass; cottonwood, river birch, willow and box elder trees grew along streams. The lower hills are covered by sagebrush and some juniper, June grass and remnants of the native Indian rice grass. Scrub oak and sagebrush with snowberry and some maple grow between 7,000 and 8,000 feet. At 8,000 to 10,000 feet are coniferous forests of Engleman spruce with some Alpine fir, Douglas fir, and lodgepole pine. The higher parts of the study area are above timber line which ranges from 9,500 to 10,500 feet (Hawkes, 1959, pp. 9-11).

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* Letters and numbers refer to locations of places and features on Figures 2, 3, and 4.

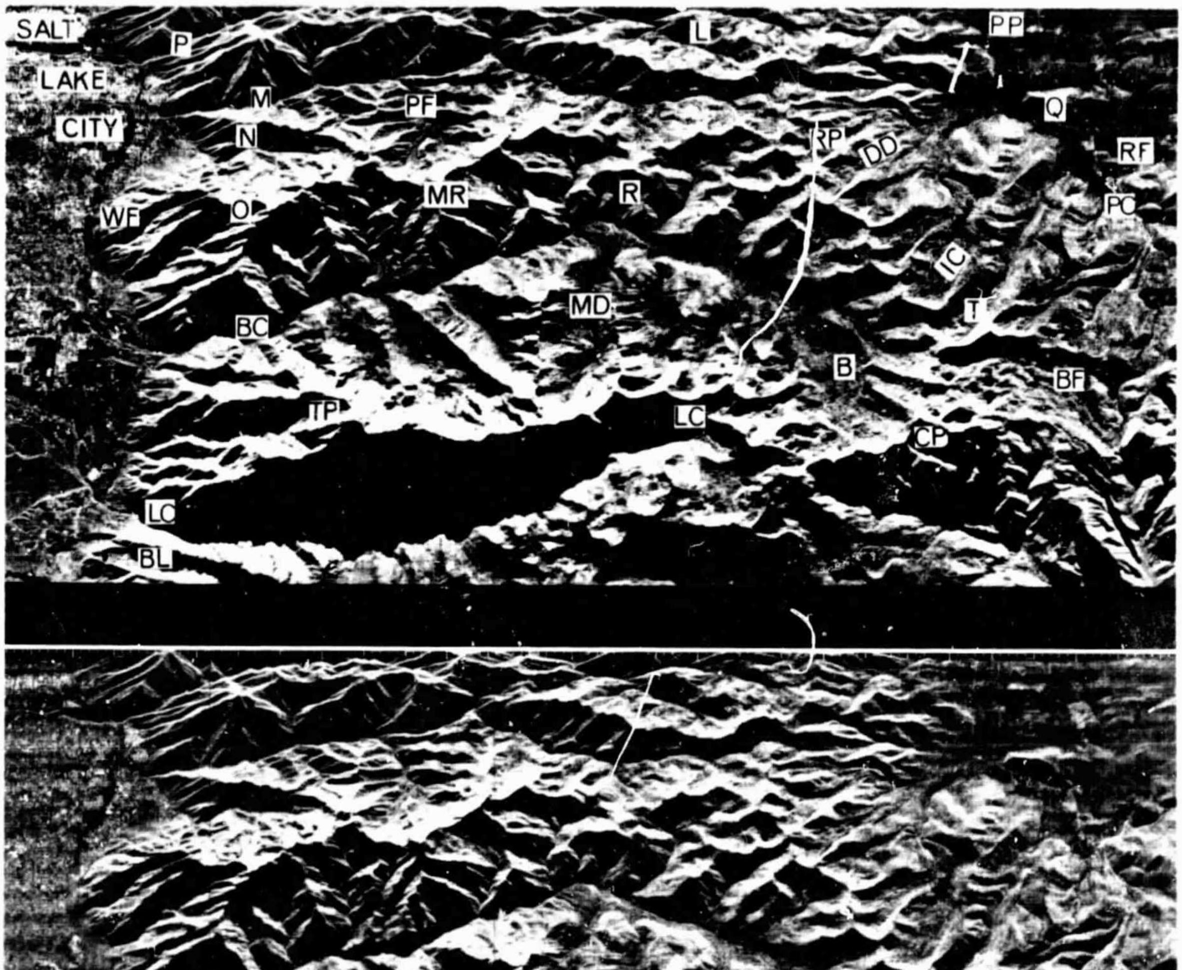


Figure 2. HH (top) and HV (bottom) polarizations of the Wasatch Range from Salt Lake City east to Park City. See Table 1 for explanation of symbols.

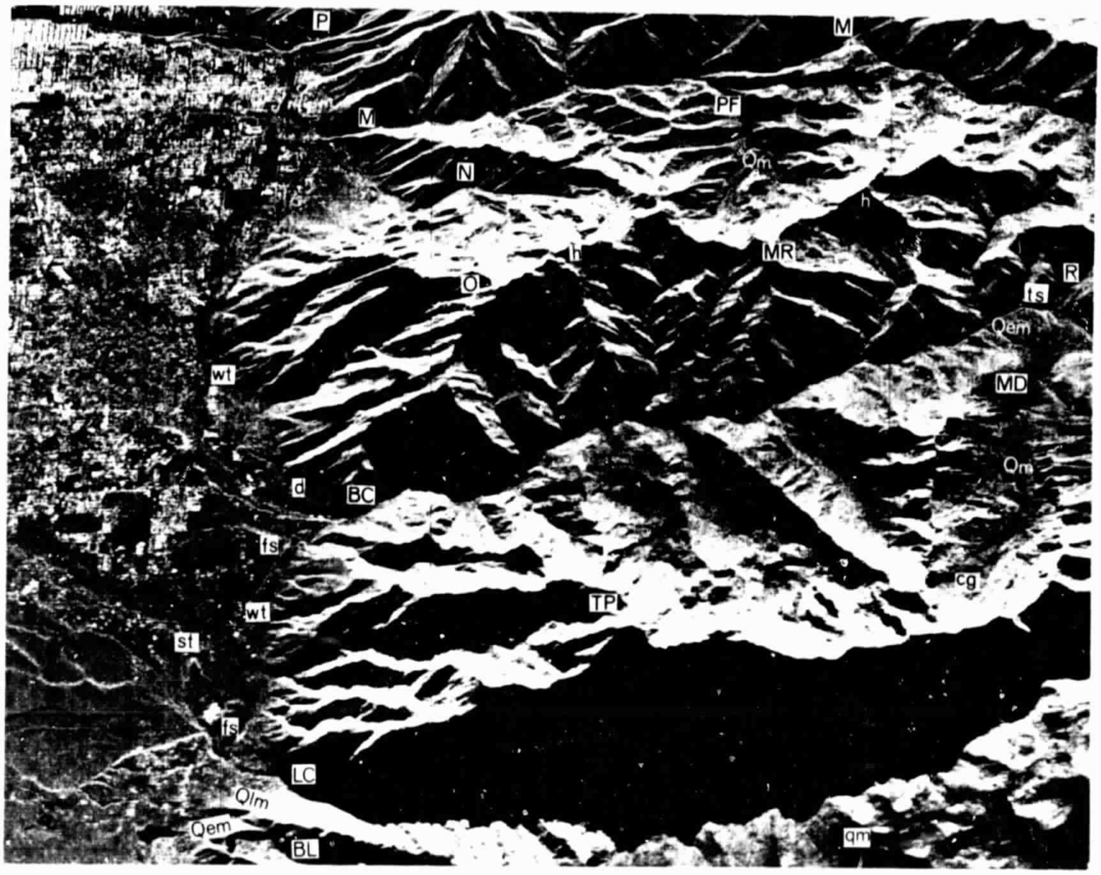


Figure 3A. An enlargement of K-band radar imagery showing western eight miles of the Wasatch Range and part of Salt Lake City. For explanation of symbols see Table 1.

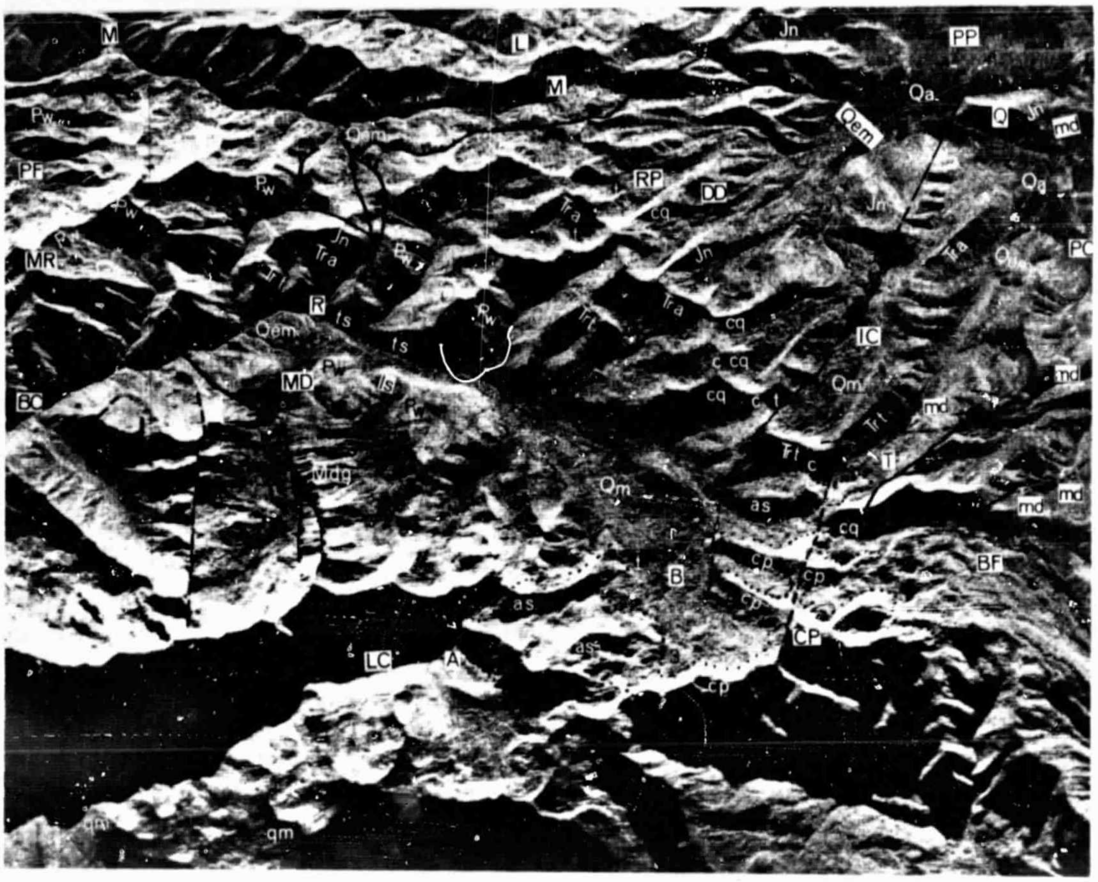


Figure 3B. Enlargement of an 11 mile strip of radar imagery from Mount Raymond east to Park City. Area is approximately the same as in Figure 4. See Table 2 for explanation of symbols.

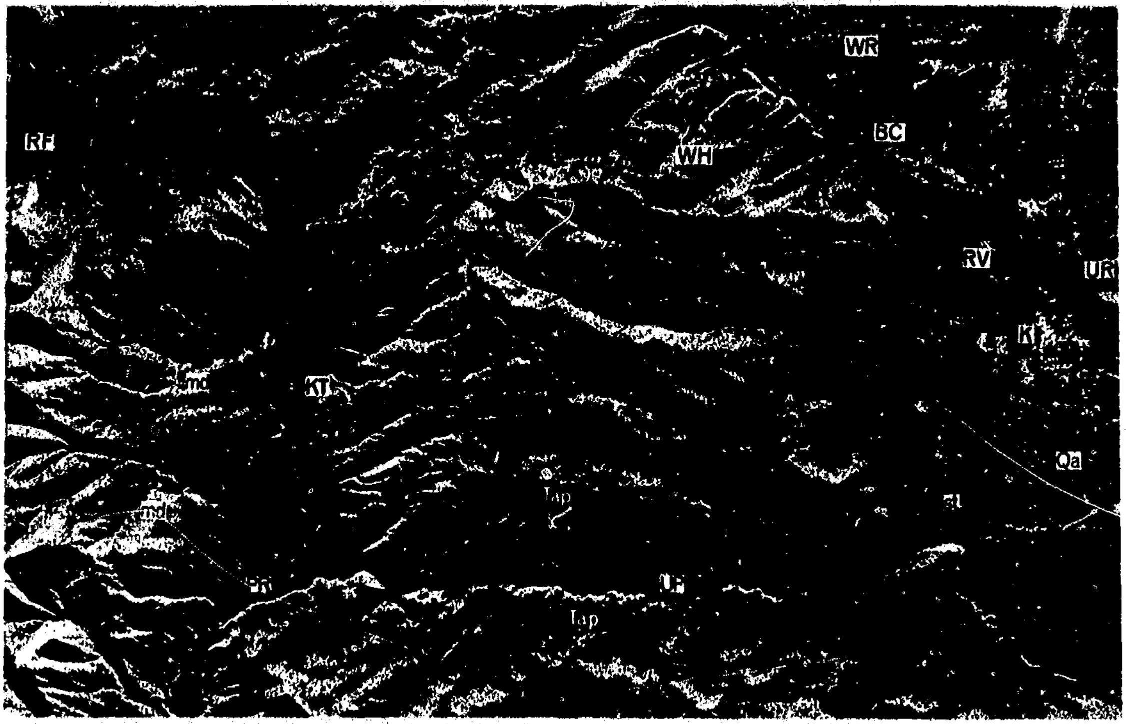


Figure 3C. An enlargement of K-band radar imagery of a 13 mile east-west area showing the Upper Provo Canyon, Rhodes Valley, and the West Hills. See Table 1 for explanation of symbols.

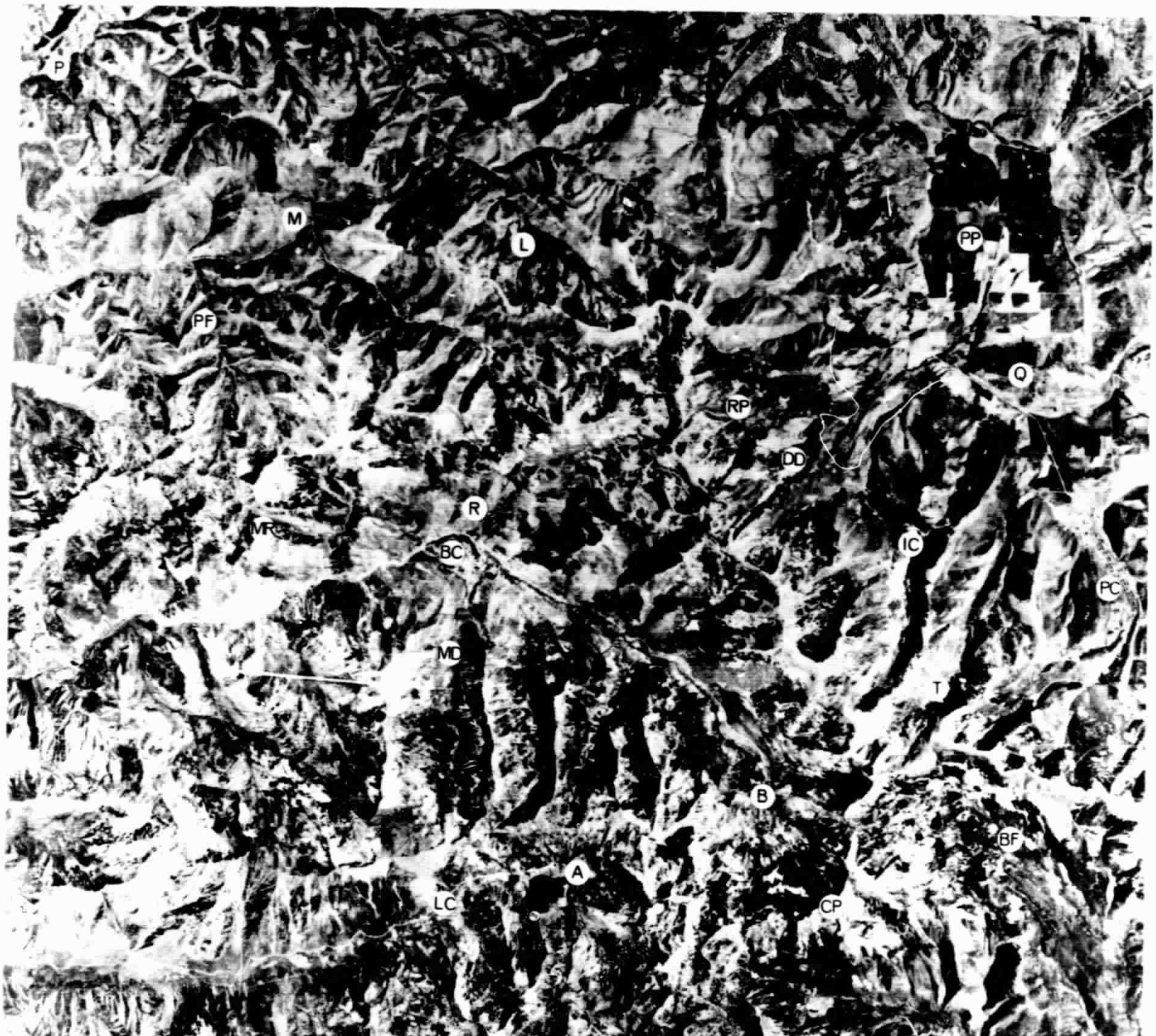


Figure 4. Air photo mosaic of the Wasatch Range drainage divide. Area is approximately same as on Fig. 3B. For explanation of symbols see Table 1.

Table I. Symbols Used in Figures 2, 3, and 4.

A	Alta
B	Brighton
BC	Big Cottonwood Canyon
BF	Bonanza Flat
BL	Bells Canyon
BV	Beaver Creek
CP	Clayton Peak
DD	Dutch Draw
IC	Iron Canyon
K	Kamas
KT	Keetley
L	Lambs Canyon
LC	Little Cottonwood Canyon
M	Mill Creek
MD	Mill D Canyon South Fork
MR	Mt. Raymond
N	Neffs Canyon
O	Mt. Olympus
P	Parleys Canyon
PC	Park City
PF	Porter Fork
PP	Parleys Park
PR	Provo River
Q	Quarry Mountains
R	Reynolds Gulch
RF	Richardson Flat
RP	Red Pine Draw
RV	Rhodes Valley
T	Thaynes Canyon
TP	Twin Peaks
UP	Upper Provo Canyon
UR	Uinta Range
WH	West Hills
WR	Weber River

c	Col
cq	Cirque
d	Delta
fs	Faceted spurs
h	Horn
ls	Landslide
st	Stream terraces
s	Fault scarp
t	Tarn
ts	Truncated spur
wt	Wave cut terrace
as	Alta stock
cp	Clayton Peak stock
pc	Park City stock
qm	Quartz monzonite of Little Cottonwood stock
Qm	Quaternary moraine
Qem	Quaternary end moraine
Qlm	Quaternary lateral moraine
Tap	Tertiary Andesitic pyroclastics
Jn	Jurassic Nugget Sandstone
Ꞧa	Triassic Ankareh Formation
Ꞧa	Triassic Thaynes Formation
Pw	Pennsylvania Weber Quartzite
Mdg	Mississippian Deseret and Gardison Limestone

Drainage

Several westward flowing streams have cut scenic canyons into the Wasatch. Within the study area most of these stream valleys and the higher parts of the range are covered by dense forests and have snow for several months each year. Because of the spectacular alpine scenery, snow cover and proximity to Salt Lake City, three nationally famous ski resorts are located within the study area. These are the Alta (A) at the head of Little Cottonwood Canyon (LC), Brighton (B) at the head of Big Cottonwood Canyon (BC), and the Park City ski area near the mining town of Park City (PC, (Figure 3B).

Drainage of the entire study area is to the Great Salt Lake. Several canyons, cut through the Wasatch Front by westflowing streams, are visible on the imagery. From north to south these are Parleys, Mill Creek, Neffs, Big Cottonwood, Little Cottonwood, and Bells Canyons (Figure 3B). The heads of most of these canyons contain cirques from which Pleistocene valley glaciers advanced down the canyons, in cases as far as the Wasatch Front.

The east side of the region is drained by two rivers that head in the Uinta Mountains. The Weber River has its origin on the north side of the Uintas and flows west across the north side of Rhodes Valley, then in its northward course it receives tributaries which drain most of the central part of the study area. The Provo River heads on the south flank of the Uintas, flows through the south end of Rhodes Valley, through the narrow Upper Provo Canyon (UP, Figure 3C) across Heber Valley and then to Great Salt Lake via Utah Lake and the Jordan River.

Land Use

The land use in this area depends, to a large extent, on elevation, slope of the land, availability of water, and location of mineral deposits. Land use of the study area is shown in Figure 5 which was prepared from radar imagery. Mountainous areas here serve five main uses: water storage, grazing, forestry, mining, and recreation. The function of watershed and storage area for water is especially important for the arid Wasatch Oasis which extends along the west side of the Wasatch Range. Bailey (1941, p 194) states that at least 80 per cent of the usable stream flow in Utah comes from mountain lands over 7,000 feet in altitude and that each acre of irrigated land is dependent upon water from approximately seven acres of watershed land. The Wasatch Oasis, which contains most of Utah's farms, cities, and population, would not exist if there were no watersheds such as those in this study area. Grazing is a second use of the mountain land. Large herds of sheep and some beef cattle are grazed in many parts of the area although the hills between Rhodes Valley and Parleys Park are most heavily grazed. Forestry is a third use of these mountains although this is not as important as it was in earlier times. Mining, a fourth land use, has been conducted near Park City and in Little Cottonwood Canyon since 1868. Over 450 million dollars of gold, silver, copper, lead, and zinc have been mined in the Park City Mining District, although many mines have closed in recent years. A fifth land use in the mountainous areas is recreation. Ski resorts here draw large numbers of people from all parts of the United States each year. In the canyons east of Salt Lake City there are many weekend cottages and summer homes in addition to numerous camps and picnic facilities.

The predominant use of land in the valleys is for agriculture. The majority of the farmers live in nucleated settlements which are readily apparent on the radar imagery. In Rhodes Valley farmsteads not in the villages tend to be on the main north-south road. The imagery shows the relationship between well drained land and the location of the villages and farms; most of the farms are on the better drained sides of Rhodes Valley and Parleys Park. The lower sides of the valleys have weaker return from the wet land covered with marsh vegetation.

Inspection of the radar imagery shows many clusters of cottages, mine buildings and mine dumps. Examination of both HH and HV polarizations reveals more cultural features than either one polarization alone. For example, several mine dumps (md) appear on Figure 3B. Near Keatley (KT) south of Park City, mine dumps and railroads leading to the mines are visible on the imagery (Fig. 3C). South of Parleys Park the waste dumps on Quarry Mountain (Q) can be seen (Fig. 3B).

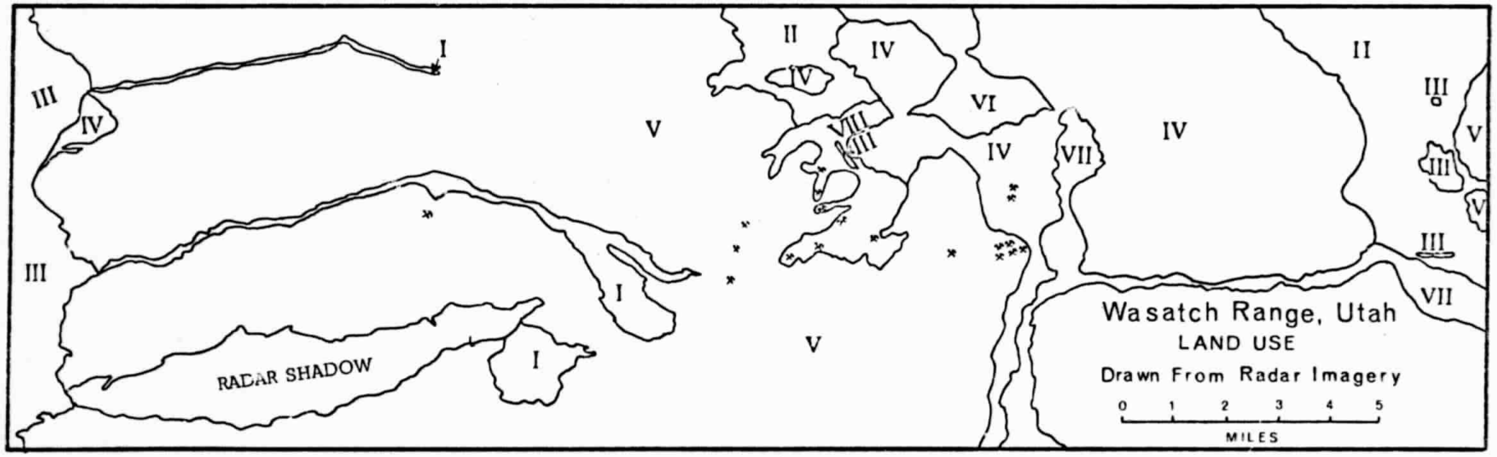


Figure 5. Land use map drawn from K-band radar imagery of the Wasatch Range, Utah. I, Recreation; II, Irrigated Agriculture; III, Urban; IV, Grazing; V, Forestry, recreation and mining; VI, Dry land agriculture; VII, Bottomland pasture and irrigated farming; VIII, Recreation and mining.

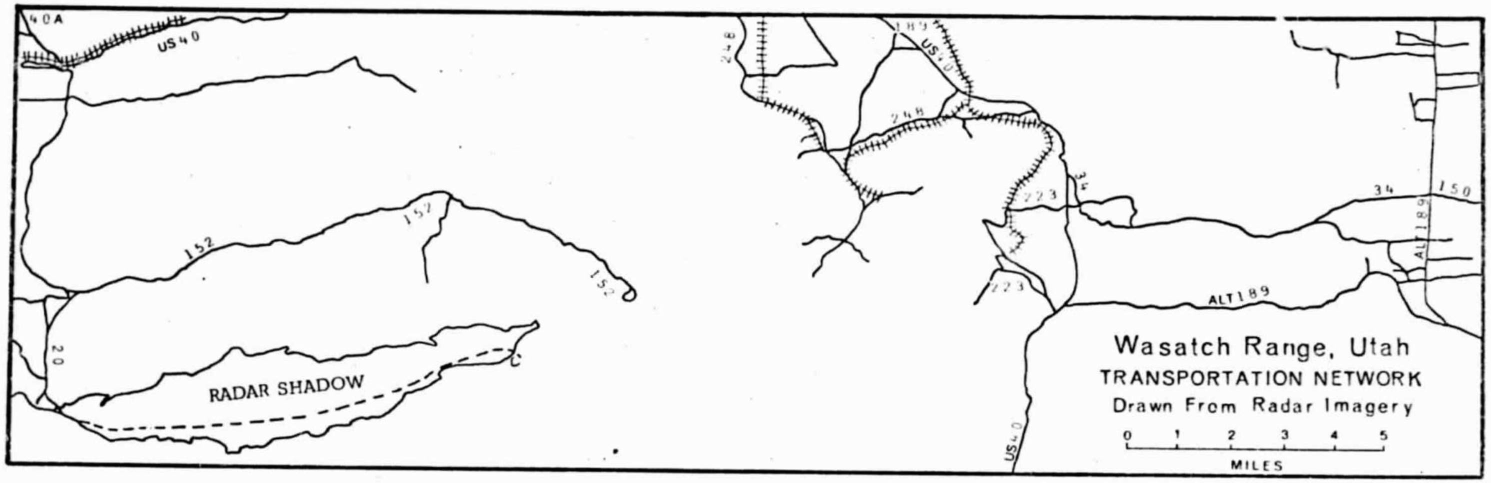


Figure 6. Transportation map of the Wasatch Range, Utah. Drawn from K-band radar.

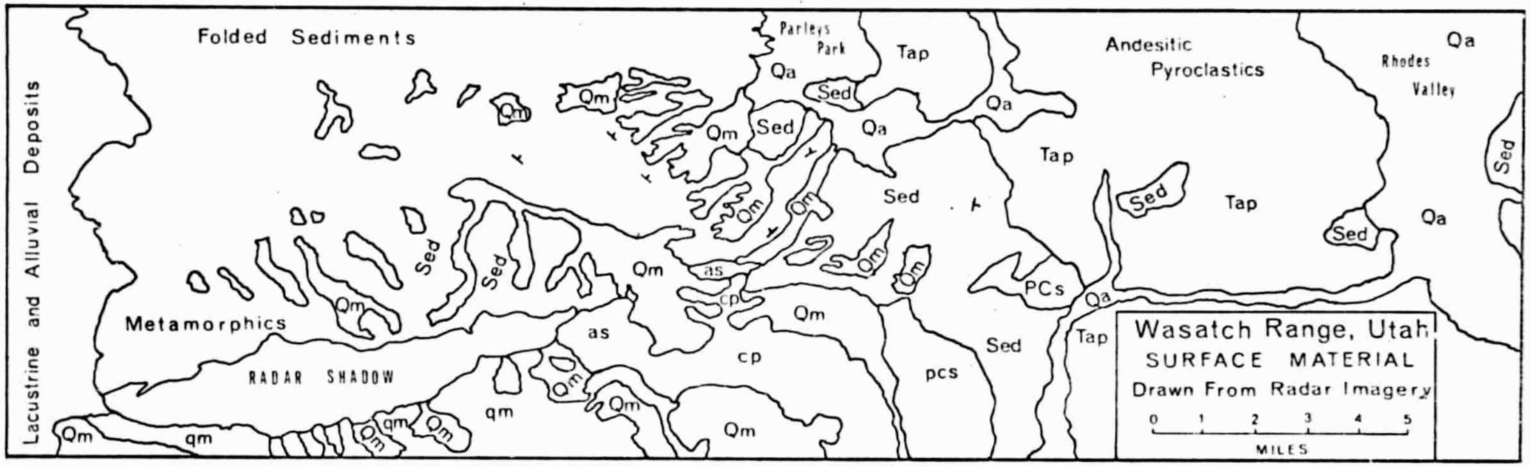


Figure 7. Surface materials of the Wasatch Range, Utah as interpreted from K-band radar.

By comparing both polarizations and combining information from each, it is possible to prepare a transportation map from radar imagery (Fig. 6). Shown are only the hard-surface main roads, not jeep roads which are visible in many places.

Geomorphic history. The geomorphology of the present Wasatch Range is the result of a fairly complex history. As summarized by Granger et al., (1952) and Threet (1959) the following sequence occurred. At the beginning of the Laramide orogeny, in middle and late Cretaceous time, north-south compression formed the east-west folds of the Central Wasatch. Thrust sheets from the west overrode the site of the present Wasatch and clastics eroded from highlands were deposited in adjacent basins. After a quiet period the Cretaceous folds were further compressed in Paleocene or Eocene time; at about the same time the Little Cottonwood, Alta, the Clayton Peak and Park City stocks were intruded.

The Wasatch Range was first elevated by folding, along north-south axes, which began in the late eocene or Oligocene. At this time the major relief features were formed, the courses of the Weber and Provo Rivers were established and lavas and andesitic pyroclastics were extruded.

Regional warping along old trends in late Oligocene or early Miocene was followed by erosion of broad surfaces. One of these broad erosional surfaces, the Weber Valley surface, may be preserved in Big Cottonwood Canyon (Granger et al., 1952, p. 36) where there are elevated, broad valley profiles. The former erosion surface, represented by an extension of the spurs on the sides of Big Cottonwood Canyon has been dissected (see Fig. 3A). This erosion probably began before Pleistocene glaciation, possibly in late pliocene time (Granger et al., 1952, p. 36).

Block faulting and broad warping, which began in late Miocene or Pliocene, was continued in late Pliocene and Pliestocene. Associated with the uplift was dissection of old erosional surfaces, diversion and capture of streams, and erosion of Parleys Park and Rhodes Valley. During the Pleistocene the high parts of the Wasatch were glaciated and Lake Bonneville, the fresh water ancestor of Great Salt Lake, filled part of the Great Basin.

Geomorphic Regions. The area studied can be divided into the following regions: (1) The small portion of the Great Basin where Salt Lake City is situated, (2) The mountainous terrain of the complex Wasatch Range, (3) The valleys of Parleys Park and Rhodes Valley, and (4) The Andesite Hills. The Uinta Range is not discussed in this paper because only the western tip of this range is shown on the imagery.

1. The Salt Lake City Area. Shown on the radar imagery (Figs. 2 and 3A) is part of Salt Lake City and small neighboring cities. Several stream terraces (st) are visible where the distributaries from Big and Little Cottonwood Canyons have deepened their channels. Much of Salt Lake City is built on the floor of Pleistocene Lake Bonneville, which was approximately the size of present day Lake Michigan. Terraces cut by Lake Bonneville are visible along the Wasatch Front (WT, Fig. 3A). A delta (d, Fig. 3A) built into Lake Bonneville at the mouth of Big Cottonwood Canyon can be seen on the imagery as can a lateral moraine (Qlm) at the mouth of Little Cottonwood Canyon and an end moraine (Qem, Fig. 3A) at the mouth of Bells Canyon. Fault scarps which cut across the moraines and delta between Bell and Big Cottonwood Canyons (Fig. 3A) are also visible.

2. The Wasatch Range. This subregion includes the Wasatch Range from the Wasatch Front to Parleys Park and the spur of the Wasatch Range south of Park City and east to the Provo River.

The complex structure consists mostly of sediments folded along east-west axes; these folds are truncated on the west by the Wasatch fault. On the south side of the study area, a series of plutons has intruded a large east-west anticlinal fold which seems to be the continuation of the Uinta fold. Thrust faults and high angle faults occur throughout the area.

The topography of the Wasatch Range is youthful. Most slopes are near the angle of repose. Stream valleys are characterized as having V-shaped profiles in the non-glaciated portions, steep gradients, and valley floors barely wider than the streams in them. Road building in these canyons has always been a problem because of the narrowness of the canyons and the almost vertical cirque walls at the heads of canyons. Hard surfaced roads extend up the canyons on the west side of the range, but, other than jeep roads, no roads (or railroads) cross the area shown on this imagery.

The radar imagery shows that the drainage of the Wasatch Range is well developed. No uplands remain other than the narrow ridge divides. Several stream patterns with a variety of controls can be recognized on the imagery. The drainage pattern of the major west-flowing streams is basically dendritic but some angularity, caused by faults and joints, can be distinguished in stream orientations. The attitude of strata influences some stream orientations; this is especially evident in Thaynes Canyon (T), Iron Canyon (IC), and Dutch Draw (DD) south of Parleys Park (Fig. 3B).

The influence of structure on drainage is evident by the stream pattern around the Alta Stock and Clayton Peak stock (as and cp, Fig. 3B).

The topography of the higher parts of the Wasatch can best be described as alpine. The high Wasatch Range is glaciated to such an extent that one of the most striking features observable on radar imagery, or on geologic maps, is the large proportion of the area covered by glacial moraine. Glacial moraine is conspicuous on radar imagery because of its characteristic graytone and speckled texture. Moraine covers the cirque floors, and in some cases extends for miles down the canyons.

Shown on the imagery (Fig. 3A, 3B) are many alpine features such as U-shaped valleys, end moraines (Qem), lateral moraines (Qlm), ground moraines (Qm), cirques (cq), tarns (t), horns (h), cols (c), and truncated spurs (ts). Several hanging valleys can be seen in Big Cottonwood Canyon (Fig. 3B). A landslide is shown on the imagery in Big Cottonwood Canyon (Fig. 3B).

3. Parleys Park and Rhodes Valley. Parleys Park is an alluvial-filled valley at approximately 6,600 feet elevation. The valley is almost level with a gentle slope to the northeast. Much of the valley, especially the east side is swampy and covered with marsh grass as indicated by dark gray tone on the radar imagery (Fig. 3B). On Quarry Mountain (Q, 3B) at the south side of the valley, waste dumps from large quarries can be seen on the imagery.

Rhodes Valley (Fig. 3C) is a wide alluvial valley with several nucleated farming villages. River terraces (st) are visible along both the Provo River (PR) and the Weber River (WR). The Andesite Hills, locally called the West Hills, lie to the west of Rhodes Valley.

4. The Andesite Hills. The Andesite Hills (part of which are called the West Hills (WH, Fig. 3C)) lie in the eastern part of the study area between Parleys Park and Rhodes Valley and south of Rhodes Valley. The higher hills lie at about 7,800 feet elevation compared with 6,400 feet in Rhodes Valley. Most slopes are moderate, although in the western portion there are many gentle slopes. Local relief is generally moderate; less than 500 feet. The region is characterized as being in a mature stage of an erosion cycle.

The andesitic pyroclastic rock of early Tertiary age (Geologic Map of Northeastern Utah, 1961, compiled by Stokes and Madsen) has a characteristic graytone and texture on radar imagery plus a characteristic erosional pattern (see Tap on Figures 3C). The vegetation cover of grass, sagebrush and scrub oak, characteristic of these hills, seems to be responsible for some of the signal return.

The West Hills (generally the region west of Rhodes Valley and east of Parleys Park, Richardson Flat and Keetly) have a drainage divide near the west side of the region so the streams flowing east are long and have gentle gradients compared with the streams on the west side of the region. The drainage pattern, generally dendritic, is an indication of the homogeneous andesite.

Rock Units

Rocks within the study area range in age from Precambrian to Quaternary. Following is a generalized list of stratigraphic units in the Wasatch Mountains and vicinity.

Igneous Rocks

- Early Tertiary? Andesitic pyroclastic rocks
- Diorite porphyry; Park City stock
- Diorite; Clayton Peak stock
- Granodiorite; Alta stock
- Quartz monzonite; Little Cottonwood stock

Quaternary

- Alluvial deposits
- Glacial deposits

Tertiary

- Fowkes Formation
- Knight Conglomerate
- Crazy Hollow Formation

Cretaceous

- Echo Canyon Conglomerate
- Wanship Formation
- Frontier Sandstone
- Aspen Shale
- Bear River Formation
- Kelvin Conglomerate

Jurassic

- Preuss Sandstone
- Twin Creek Limestone
- Nugget Sandstone

Triassic

- Ankareh Formation
- Thaynes Formation
- Woodside Shale

Permian

- Park City Formation

Pennsylvanian

- Weber Quartzite
- Round Valley Limestone

Mississippian

Doughnut Formation
Humbug Formation
Deseret Limestone
Gardison Limestone
Fitchville Formation

Cambrian

Maxfield Limestone
Ophir Formation
Tintic Quartzite

Precambrian

Mutual Formation
Mineral Fork Tillite
Big Cottonwood Formation

Many of the above rock units can be recognized and traced on radar imagery. Examples are the Weber Quartzite, the Thaynes Formation, Ankareh Formation, the Nugget Sandstone, and various igneous rocks.

An extensive area of volcanics south and west of Rhodes Valley which are mapped as early Tertiary? andesitic pyroclastics (Geologic Map of Utah, compiled by Stokes and Madsen, 1961) are recognizable on radar imagery by characteristic gray tones and textures, plus the group of characteristics one would use to recognize the same type of rocks on aerial photographs.

An especially interesting feature of imaging radar is its ability to delineate glacial moraines. Not only is ground moraine readily apparent, but so also are lateral moraines (in Bonanza Flats (BF, Fig. 3B) for example) and terminal moraines (examples in Thaynes Canyon (TC), Dutch Draw (DD, Fig. 3B) and at the mouth of Bells Canyon (BC, Fig. 3A)). The interface between moraines and alluvium is very apparent (for example in Thaynes Canyon and Dutch Draw). General boundaries of the alluvium which fills river valleys and small basins (as at Parleys Park (Fig. 3B), Rhodes Valley, and the valley of the Provo River (Fig. 3C)) can be readily mapped from radar imagery.

Figure 7, which is a generalized map showing surface materials, was prepared by tracing boundaries of alluvium, moraine, and rock classes from the radar imagery onto a transparent overlay.

Structure

In the west part of the study area the major folds of the Wasatch have east-west axes. The north limb of the large anticlinal fold that appears to be the westward extension of the Uinta Arch can be seen in Mill Creek Canyon and Big Cottonwood Canyon. The south limb of this anticline is now mostly part of the Little Cottonwood stock. Steep northward dips and northeast-striking beds are visible on the imagery north of Big Cottonwood Canyon. Inasmuch as Little Cottonwood Canyon lies at the outer range of the radar scan where the radar beams had a low incident angle, the high north wall of Little Cottonwood Canyon caused a radar shadow in the lower end of the canyon making this portion of the imagery unusable. A few miles up the canyon, however, the imagery shows rock that has erosional characteristics of massive, igneous rock. This agrees with geologic maps which show the Little Cottonwood granitic stock at this location.

In addition to the Little Cottonwood granite stock, already mentioned, the Alta stock, the Clayton Peak stock, and the Park City stock are discernable on the imagery. Since these are mineralized regions which have had considerable economic importance, the ability to recognize such regions on radar is very significant.

Many of the folds in the study area can be observed on radar imagery. Because the attitudes of strata can be ascertained from radar imagery, the orientation of major folds can be determined from imagery. An example is the northeast trending anticline of Park City.

Several faults in the Wasatch Range can be detected by methods similar to those used for fault detection on aerial photographs. In some cases abrupt changes in gray tones and textures characteristic of rock units suggest faulting. When lithologic units are recognized on radar, offsetting, abrupt termination, or abrupt changes in altitudes of rock units can be used as evidence for faulting. Faults with physiographic expression are most easily detected.

The most conspicuous feature on the Wasatch Range is the Wasatch Front fault escarpment. There is relative relief at the front of 6810 feet (4520 feet elevation near Sandy, opposite the mouth of Little Cottonwood

Canyon; 11,330 feet at Twin Peaks north of Little Cottonwood Canyon). In addition to the numerous faceted spurs along the front, the imagery (Fig. 3A) also shows recent fault scarps that cut across terraces and deltas associated with Lake Bonneville.

Along the Wasatch Front in Parleys Canyon and Mill Creek Canyon (PC and MC, Fig. 3A) the imagery shows sediments striking generally northeast and dipping steeply north. In Neffs Canyon (NC, Fig. 3A) changes in strike that are discernable on radar correspond to faults shown on the geologic map by Granger et al. (1952). Attitudes of beds are apparent at many other places on the imagery.

In a geomorphic study of a mountainous region such as the Wasatch Range, structure is a chief element in the development of the geomorphology. It is therefore necessary to know the location and nature of at least the major faults and the dominant joint patterns in order to understand the geomorphology. A few other examples of faults detectable by radar are given below.

In the upper part of Mill Creek's Porter Fork (PF, Fig. 3B) the Lower Strand Mountain branch of the Mount Raymond thrust fault can be discerned by a change in altitude of beds and by lineation along the fault (Fig. 3B). To the east the Mount Raymond thrust can be traced by the position of the Weber Quartzite thrust slices, which lie above the thrust planes, and by lineations along the faults. The Silver Fork normal fault is very apparent where it terminates the Thaynes and Arkereh Formations and the Nugget Sandstone in Reynolds Gulch (R, Fig. 3B) north of Big Cottonwood Canyon. This fault can be traced on the imagery north to the Mount Raymond thrust which was offset by the Silver Fork fault. Ground truth confirming this observation is reported by Granger et al., (1952, p. 24).

In Mill D Canyon (MD, Fig. 3B) a Big Cottonwood tributary, opposite Reynolds Gulch, the imagery shows a zone of north-south faulting that terminates the Paleozoic sediments to the east. The sediments east of Mill D Canyon, which are for the most part of Mississippian Deseret and Gardison Limestones (Mdg) exhibit an east-west joint pattern (as at Mdg, Fig. 3B) that is very pronounced on radar imagery.

Possible faults or fracture zones which do not appear on published geologic maps are suggested by lineations on the radar imagery. South of Parleys Park a lineation, trending generally northeast-southwest, extends from the west side of Quarry Mountain southward up the west side of Iron Canyon and along the west side of the intrusion immediately east of Brighton (Fig. 3B). Dikes, mines, and prospect pits north of this intrusion lie along this zone. Another possible fault or fracture zone, suggested by a lineament on the imagery, lies along the east side of the aforementioned stock. This lineament extends from the west side of Clayton Peak northeastward near the east side of the Alta Stock.

The Park City Mining District

Park City is one of the great base metal mining districts of Utah (Wilson, 1954, p. 182) and has been one of the most important mining districts in the United States. Silver, gold, lead, zinc and copper are the chief minerals mined there. The large mine dumps (md) are visible on radar imagery, especially when HH and HV polarizations are compared.

The mineralized zones at Park City are related to the intrusive stocks of quartz monzonite which caused contact metamorphism in the adjacent sediments, especially in the limestones (Lindgren, 1933, p. 584).

Lode deposits are often between limestone and quartzite, but may be in quartzite. Bedded ores are sulphides that have replaced limestones (the Park City Formation or Thaynes Formation).

An examination of the Park City West Geologic Map (Crittenden, *et al.*, 1966) shows that mines tend to be at contacts between the Woodside shale and Thaynes Formation or between the Weber Quartzite and the calcareous Park City Formation. The mineralizing solutions apparently moved along channels formed by faults and joints. The Park City West geologic map shows a set of parallel faults (shown on geologic maps by both continuous and dashed lines) trending east-northeast and another set trending north-northeast.

A set of lineaments that may be faults or joints, visible on radar but not shown on the geologic map, trends northwest-southeast.

It is very significant that the large mines (shown on radar by the large waste dumps) tend to be located (1) at the contact of a calcareous formation and a relatively impermeable formation and (2) where the lineaments visible on radar intersect a fault (Figure 3B). It might be possible to locate new mineral deposits with a knowledge of the new lineaments shown on this radar imagery.

Ancestral Drainage

A significant feature of radar imagery is its ability to depict former stream courses. The imagery shows distinctly the former courses of the tributaries in Upper Provo Canyon (Figure 3C, 5 and 6). The angles at which these streams join the Provo River form acute angles that point eastward, or up the present course of the Provo. Through almost the entire length of the Upper Provo Canyon the streams apparently flowed east to Rhodes Valley and northward to the Weber River. Rhodes Valley is a grossly oversized valley for Beaver Creek which flows through its central portion. This example of stream piracy has been known since Anderson described it in 1915 and it was chosen by Longwell and Flint in their physical geology text to illustrate stream piracy, but it is so striking on radar imagery that it suggests radar's value as a useful tool for mapping ancestral stream patterns.

The radar imagery shows a well-developed dendritic stream pattern in the headwaters of Mill Creek (Figure 3B). The present stream divide transects the upper part of this stream pattern which results in an abnormal appearing drainage pattern east of the headwaters of Mill Creek. It is postulated that water from Parleys Park may have formerly drained westward through Mill Creek and possibly other westward flowing streams. It should be noted that the streams at the head of Mill Creek Canyon flow at high angles to the strike of the Paleozoic and Mesozoic sediments which have been folded and thrust-faulted. There is also a possibility, suggested by drainage shown on radar imagery, that other westward-flowing streams, such as Big Cottonwood, formerly had tributaries that extended farther eastward (Figures 8 and 9). To illustrate the comparative value of radar

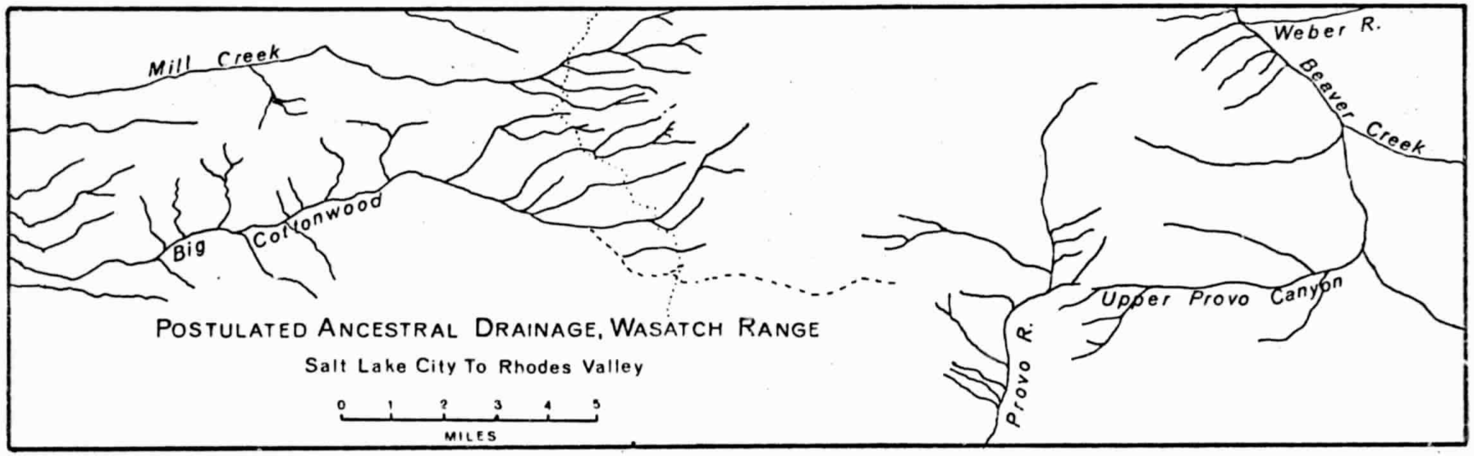


Figure 8. Postulated ancestral drainage of the Wasatch Range, Utah. Drawn from K-band radar imagery.

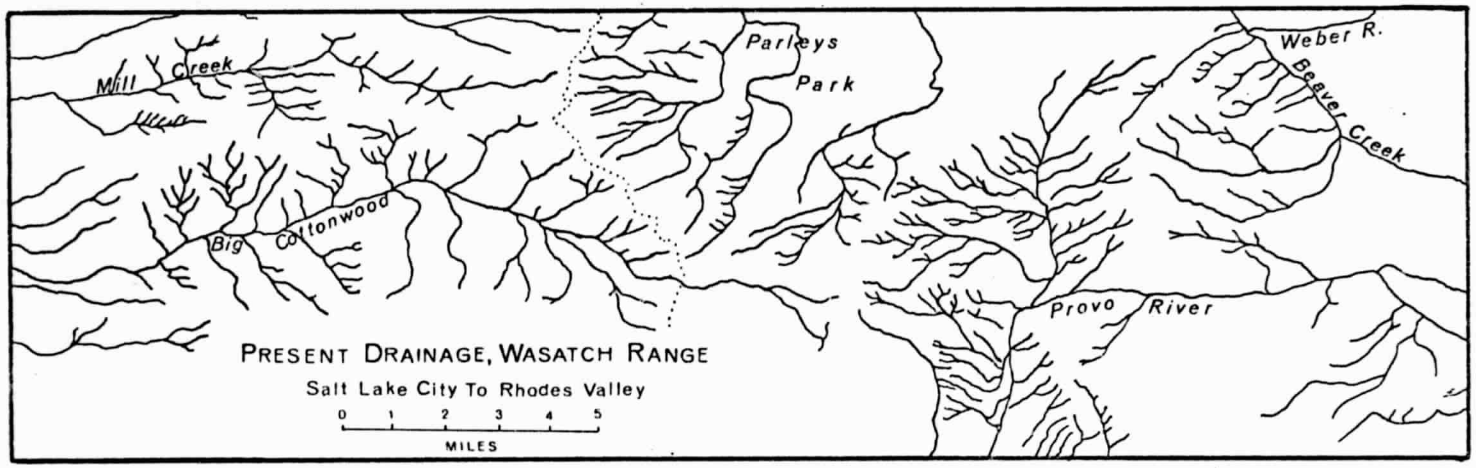


Figure 9. Present drainage of the Wasatch Range, Utah. Drawn from K-band radar imagery.

in detecting old stream courses, upper Mill Creek is shown on an air photo mosaic with a scale larger than the scale of the radar imagery (Figure 4).

There has been much speculation as to why the Weber and Provo Rivers, which drain the eastern Wasatch and the western Uintas, flow across the Wasatch Range. One explanation is Powell's antecedence hypothesis of a river maintaining its course while cutting through a slowly rising mountain range. A later hypothesis was that of superposition, whereby the river courses were superimposed from Tertiary strata which unconformably covered the Laramide structures. However, in the Wasatch Range there are no remnants of the Tertiary cover near the cross drainage of the Weber and Provo Rivers. Hunt, in his 1956 report on the Colorado Plateau, used a combination of Powell's antecedence and Gilbert's superposition in what he called anteposition.

Hinze (1913) and others postulated that consequent streams on the west side of the Wasatch might have cut across the range to capture streams which drained to such lowlands as the Uinta or Bridger Basins. According to this concept rivers, such as the Weber and Provo, that captured sufficient drainage were able to cut gorges through the Wasatch Range.

Eardley believes that the Weber and Provo Rivers were established by Oligocene time and that they maintained their courses as the Wasatch Range was elevated first by folding, then by faulting. He believes that the Wasatch Range has been tilted by uplift of the range along the Wasatch Front. An absolute upward movement on the east side of the Wasatch Fault would have tilted the Wasatch some 3° or 4° along a hingeline. Eardley believes an axis of tilt lies at the head of the Provo Canyon; that below this axis the Provo has cut a gorge and above the axis the Heber Valley is filled with alluvium.

Threet (1959) questions the location of the hinge and its existence, because (1) Eardley's axis of tilt coincides with the intersection of the present profile of the Provo River and the hard Oquirrh Quartzite and (2) it is not known that Heber Valley is deeply alluviated.

The postulated reversal of drainage in upper Mill Creek Canyon supports Eardley's hypothesis regarding uplift and tilting of the

Wasatch Range and the location of the hingeline. It is postulated that Mill Creek was a consequent westward flowing stream; that at that time Parleys Park was still filled by the Tertiary conglomerates and andesites which today cover hills adjacent to Parleys Park. Uplift of the Wasatch Range caused tilting along an axis which is located at or near the present drainage divide between Mill Creek and east-flowing streams. This locality is 20 miles north-northwest of Eardley's Provo Canyon locality and the same distance east from the Wasatch Front.

When the area east of the hinge was lowered by tilting, drainage in the headwaters of ancestral Mill Creek was reversed. That the ancestral stream pattern has been altered by glaciation indicates that the tilting was prePleistocene. Since the tilting, according to this hypothesis, the level of Parleys Park has been lowered by erosion of Tertiary conglomerates and andesites which formerly must have filled the lowland.

Landform Classification

Radar imagery appears to have value as a tool in studying genetic landscape evolution and for quantitative geomorphic classification. Although much research reamains to be done in this area findings to date are encouraging.

As part of a study on integrated landscapes in Puerto Rico, David Schwarz and Major Roland Mower compared landforms discernable on radar imagery with the quantitative landform classification of the island by Young (1953). Young's classification was based on three parameters represented by three digits. The digits show local relief, percentage of steep land, and percentage of flat land. With this criteria for classification, shown in Table 2, Young devised the classification of major landforms shown in Table 3. In many respects Young's classification resembles that of Hammond (1964).

Young's landform classification was developed specifically for Puerto Rico and was based on topographic maps. In their study of Puerto Rico with classified radar imagery, Schwarz and Mower superposed Young's landform regions on the radar imagery. They found that they could identify Young's landform regions on the radar imagery and in some cases were

TABLE 2

Criteria for Young's Classification of Landforms

First Digit: local relief in meters
- 1: 0 - 112
- 2: 112 - 242
- 3: 242 - 770

Second Digit: percent of steep slope*
- 1: 1 - 5
- 2: 5 - 25
- 3: 25 - 100

Third Digit: percent of flat land+
- 1: 100 - 60
- 2: 60 - 3
- 3: 3 - 0

* Steepland - slopes greater than 59%

\+ Flatland - slopes less than 3%

TABLE 3

Major Landform Classification by Young

LOWLANDS

(111) Flat lowlands
(112) Rolling lowlands with some flat land
(113) Rolling lowlands
(122) Rough lowlands with some flat land

HILL LANDS

(212) Rolling hill land with some flat land
(213) Rolling hill lands
(223) Rough hill lands
(232) Rugged hill lands with some flat land
(233) Rugged hill lands.

MOUNTAIN LANDS

(313) Rolling mountain lands
(323) Rough mountain lands
(333) Rugged mountain lands

able to add detail to them. For example, in an area described by Young as rugged hill land (classified 233) with one corner of the region described as rolling hills (213), Schwarz and Mower distinguished two different types of topography, rather than one, on the larger part of the region.

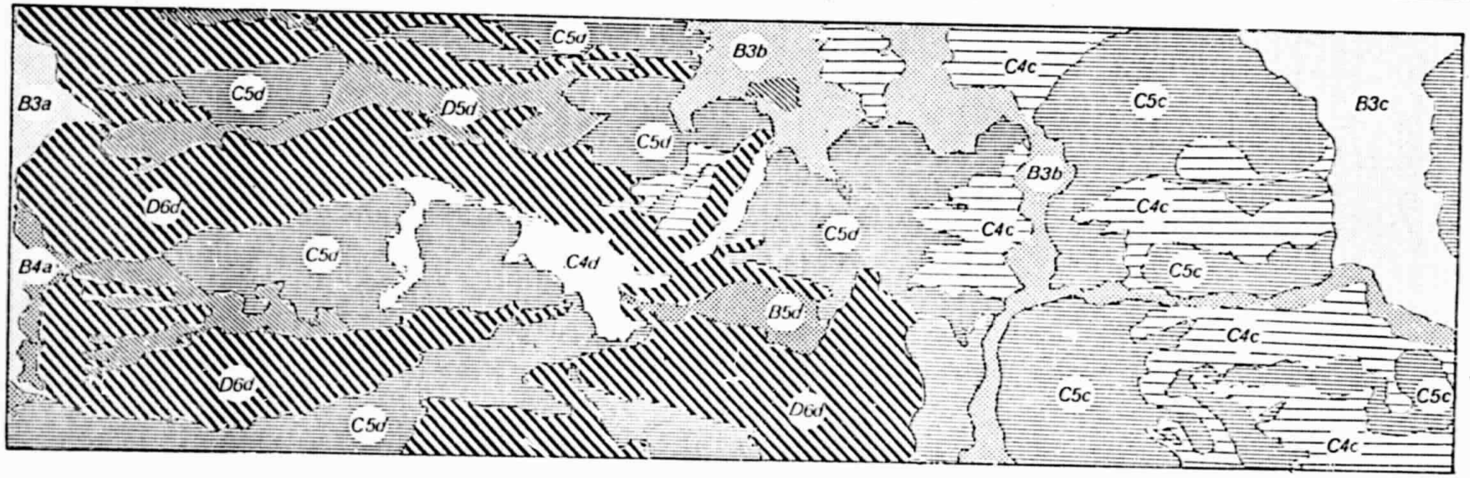
They also found that Young's classification, which was based on topographic maps, was generalized and in many places missed much detail shown on radar. For example, in Schwarz and Mower's regions C-2, C-3, and C-4, the imagery shows many lowland areas between the rugged hills and the rolling hills which were not included in Young's classification. Other examples can be seen in this part of Puerto Rico where the geomorphic classification based on topographic maps generalized much more than a classification based on radar imagery.

Schwarz and Mower concluded that radar imagery could be used to refine and add detail to Young's classification and that radar imagery is adequate for some aspects of regional generalization. Discrimination between landform regions such as flat lowlands and low hills could be accomplished with relative ease. They did experience difficulty in differentiating between various degrees of slopes in mountainous areas.

Included in this paper (Fig. 10) is a landform map of part of the Wasatch Range using Hammond's 1964 classification, for which criteria are given in Table 4. Hammonds classification is included here in Table IV. Although some difficulty was experienced in adapting Hammonds' broad classification to the small study region, with modifications the classification was found to be workable.

Hammond based his classification on the three parameters of slope, local relief, and profile type. The symbols B3b, according to Hammond's classification, describe an area which is 50-80% gently sloping (B); has 300-500 feet of local relief (3); and 50-75% of the gentle slope is in lowland (b). Hammond, who considered areas of about six square miles as the smallest units to be classified, stated that since his map is small scale and is based upon a simple classification, it is a highly abstract version of reality.

Because the Wasatch Range map is drawn to a much larger scale than Hammond's maps, some modifications in the classifications were made.



Wasatch Range, Utah -- Landform Classification*

From AN/APQ-97 Radar

B3a - Gently sloping lowland with 0-100 foot relief
B3b - Gently sloping lowland with 300-500 foot relief
B3c - Gently sloping upland with 300-500 foot relief
B4a - Gently sloping lowland with 500-1000 foot relief
B5d - Gently sloping upland with 1000-3000 foot relief
C4c - Gentle to medium sloping upland with 500-1000 foot relief
C4d - Medium to steep sloping upland with 500-1000 foot relief
C5c - Gentle to medium sloping upland with 1000-3000 foot relief
C5d - Medium to steep sloping upland with 1000-3000 foot relief
D5d - Steeply sloping upland with 1000-3000 foot relief
D6d - Steeply sloping upland with 3000-5000 foot relief

*Based on a modification of Hammond's classification.

WGB/CRES/68

Figure 10. Landform classification map. Derived from K-band radar imagery except for elevations.

TABLE 4

Criteria for Hammond's Classification of Landforms

First Letter: percent of area gently sloping*

A	> 80
B	50 - 80
C	20 - 50
D	< 20

Second letter: local relief in feet

1: 0 - 100

2: 100 - 300

3: 300 - 500

4: 500 - 1000

5: 1000 - 3000

6: 3000 - 5000

Third letter: profile type - percent of gentle slope in lowland or on upland

a	> 75 (in lowland)
b	50 - 75 (in lowland)
c	50 - 75 (on upland)
d	< 75 (on upland)

* Gentle slope - 8% or less slope

TABLE 5

Major Landform Classification by Hammond

PLAINS	
A1	Flat plains
A2	Smooth plains
B1	Irregular plains, slight relief
B2	Irregular plains
TABLE LANDS	
B3c,d	Tablelands, moderate relief
B4c,d	Tablelands, considerable relief
B5c,d	Tablelands, high relief
B6c,d	Tablelands, very high relief
OPEN HILL AND MOUNTAINS	
C2	Open low hills
C3	Open hills
C4	Open high hills
C5	Open low mountains
C6	Open high mountains
HILLS AND MOUNTAINS	
D3	Hills
D4	High hills
D5	Low mountains
D6	High mountains

The local relief and profile type classes remain the same, but the slope classes were changed. Hammond selected the value of eight per cent inclination as the upper limit of "gentle" slope, but for the Wasatch Range, where little of the area is gently sloping, slope was modified to refer to relative slope rather than to any absolute slope gradient. Therefore, in this context, C slopes are steeper than B slopes and not as steep as D slopes; areas characterized as B generally have gentle slopes and D values have extremely steep slopes.

Physiographic Maps from Radar

Radar imagery portrays terrain features in such a way that the imagery is a generalized, shaded, relief map. Not only is there no symbolization problem, as on topographic and physiographic maps, but there are continuous graytone values on the radar imagery to convey a fairly detailed representation of terrain over large areas. With the addition of some place names a print of radar imagery portrays general physiography.

The two physiographic maps in this paper (Figures 11 and 12) portray the same area in the Wasatch Range. Figure 11 was drawn by William Brooner who used a quill pen and India ink to sketch topography on tracing paper laid over the radar imagery.

Figure 12, was drawn by Mrs. William Brooner from a 2X enlargement of radar imagery. Various graytones were achieved by using a brush and different dilutions of India ink. Some features, such as ridge crests, were drawn with pen and ink. Although this illustration incorporates details from the radar imagery, it is more of an artist's concept than Figure 11.

It is necessary to emphasize that both of these physiographic diagrams are first attempts by persons with only limited cartographic experience to show that the technique of tracing generalized terrain maps from radar is feasible and may have potential. It may be that generalized terrain maps could be produced quicker and for less cost from radar, or a combination of radar and space-borne photography, than from large scale aerial photographs and topographic maps.

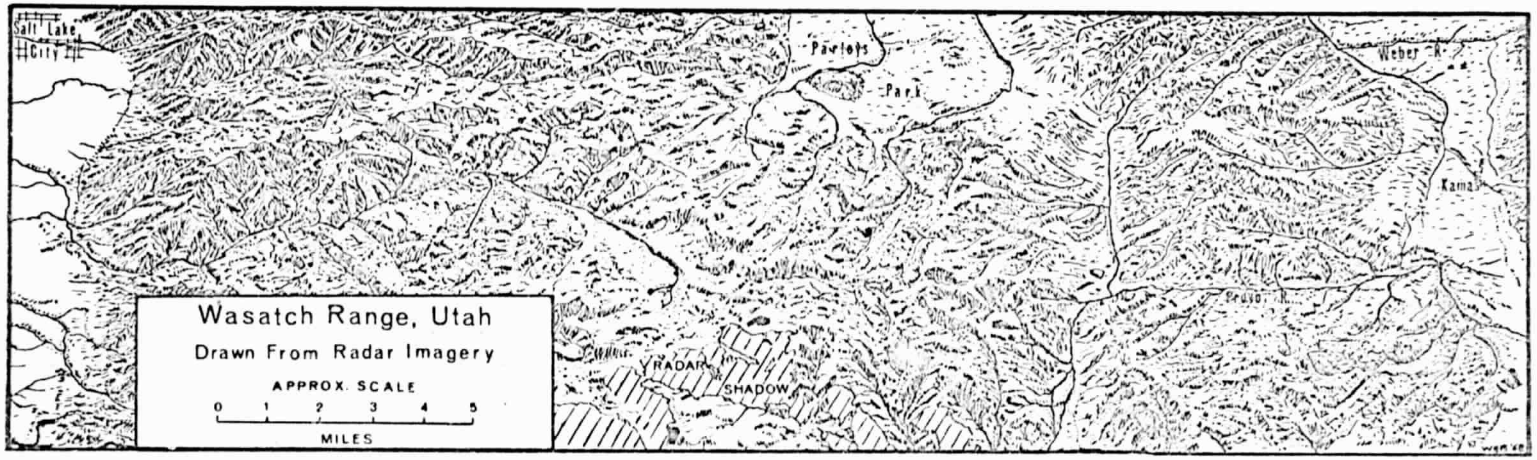


Figure 11. Physiographic Map of the Wasatch Range, Utah.

Figure 12. Physiographic Map of the Wasatch Range, Utah.

Summary

The observations in this report are preliminary. Much work remains to be done in the way of regional description and analysis which will be followed by field checks.

However, this report indicates that radar imagery has utility for regional geomorphic analysis and description and for land use studies. The lack of ground clutter on radar allows one to see geomorphic features that are often obscured on aerial photographs.

The topography of the Wasatch Range is well displayed on radar imagery. Especially striking are glacial features, some fault scraps, and stream patterns. Radar shows unmapped lineaments, possibly representing faults, that control development of certain landforms and apparently deposition of mineral deposits. A postulated ancestral stream pattern with reversal of drainage in the headwaters seems to yield fundamental data on the origin of cross cutting rivers and tilting in the Wasatch Range.

The 8 thematic maps prepared from radar imagery used in this study are: land use, transportation, surface materials, landform classification, present drainage, ancestral drainage, and 2 physiographic maps. In the next phase of research other maps, such as vegetation maps, will be prepared, regional descriptions will be expanded, and field checks will be performed.

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