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ABSTRACT

This teaching guide offers educators glimpses into the value of remote sensing, the process of observing and analyzing the earth from a distance. Remote sensing provides information in forms to see spatial patterns over large areas in a more realistic way than thematic maps and allows a macro-scale look at global problems. The six instructional units in part 1 and the background essay in part 2 lead students through an understanding of the basics of remote sensing and engage them in using images to interpret aspects of the physical and cultural geography of selected U.S. areas. Students are engaged in the changing environmental impact of Death Valley (California), the Ridge and Valley Region of Pennsylvania, the coal mines of Wyoming, and the urban landscape of Boston (Massachusetts). Part I contains classroom activities for student decision-making and analysis. Titled "Learning about the American Landscape Through Remote Sensing," part 1 includes: (1) "Basin and Range Province: Interpreting a Satellite Image of Death Valley" (Paul R. Baumann); (2) "The Appalachian Ridge and Valley: A Landsat Image of Central Pennsylvania" (Percy H Dougherty); (3) "Human-Environmental Interaction at the Black Butte Coal Mine, Wyoming: An Interpretation from Satellite Imagery" (Julie Elbert); (4) "Snake River Plain, Idaho: The Physical and Cultural Landscape Through Landsat Imagery" (Nancy B. Hultquist); (5) "The Urban Landscape of Boston from a High-Altitude Color-Infrared Aerial Photograph" (Aulis Lind); and (6) "Studying the Regional Geography of the American Plains Using Landsat Thematic Mapper Imagery" (M. Duane Nellis; Steven L. Stover). Part 2, "How Does Remote Sensing Work?" contains the essay "Remote Sensing: An Introduction" (Paul R. Baumann). Maps, charts, and tables accompany the text. (EH)

Title No. 8

. PATHWAYS IN GEOGRAPHY
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.e National Council for
Geographic Education

Up Close From Afar:
Using Remote Sensing to Teach the American Landscape

Edited by Paul R. Baumann

Sponsored by the Remote Sensing Task Force

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A PATHWAYS IN GEOGRAPHY Publication

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Using Remote Sensing to Teach the American Landscape

The National Council for Geographic Education

Edited by Paul R. Baumann

Sponsored by the Remote Sensing Task Force

THE PATHWAYS IN GEOGRAPHY series has been created by the Special Publications Advisory Board of the National Council for Geographic Education to support the teaching and learning of themes, concepts, and skills in geography at all levels of instruction.

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FOREWORD

Of the many scientific advances of our generation, perhaps none are more spectacular than human ventures in space. The images and photographs recorded from various forms of satellites and aircraft have revealed the wonderful beauty, yet fragility, of the Earth. This National Council for Geographic Education publication offers teachers glimpses into the value of remote sensing — the process of observing and analyzing the Earth from a distance. Remote sensing provides us with information in forms that help us to see spatial patterns over large areas in a more realistic way than the abstract patterns encoded in thematic maps; this capacity has renewed geographers' interest in macro-scale and global problems. It offers an important and unique window into physical processes in action and into the interactions and interdependence of humans and their environment. It thus helps us to expand basic knowledge about the Earth and to deal with applied problems in resource management.

The six instructional units in Part I and the background essay in Part II lead students through an understanding of the basics of remote sensing and engage them in using images to interpret aspects of the physical and cultural geography of selected areas in the United States. Students will be able to discern the human imprint on the environment and the natural processes of environmental change in places as diverse as Death Valley and the Ridge and Valley region of Pennsylvania, the coal mines of Wyoming and the urban landscape of Boston. In learning to interpret images, they will develop skills in pattern recognition; in using the remotely sensed information to answer questions about places they will be required to relate it to other sources of data such as statistics and maps.

Remote sensing photography and imagery offer a wide range of landscape detail depending on the camera or sensor system used in their acquisition. In the same way that magnifying glasses of varying power enhance our vision to different degrees, remote sensing systems can provide a more general or greater detailed view of the landscape depending on the camera lens used or the capabilities of the sensor system. Landsat, managed by EOSAT as part of the space efforts of the United States, and SPOT, the French version of Landsat, are two primary land resource monitoring satellites offering coverage of most of the world. Other government efforts, such as through the High Altitude Photography Program, offer aerial photographic coverage of the United States. The Snake River Plain scene in this volume, for example, is a Landsat multispectral image made up of thousands of tiny grid cells of the land surface, each representing an area of approximately 80 meters (1.1 acres). In contrast, the image of the American Plains is a Landsat thematic mapper scene made up of thousands of grid cells approximately 30 meters in size (one-fourth acre). Remote sensors also use photography acquired from aircraft, like the scene of the Boston urban area, which offers even greater detail.

The images and photographs in this publication also present students with a view that cannot be seen with the human eye. Remote sensing offers geographers the opportunity to extend our ability to sense earth energy by measuring reflected and thermal infrared radiation. By using this capability, geographers can more fully understand health of vegetation, characteristics of rock exposures, and distribution of urban pollution, for example.

Remote sensing provides a new and exciting tool to geographers and geographic educators. We hope the array of learning activities included in this publication will be only the beginning of your inquiry into geographical remote sensing.

M. Duane Nellis
President, NCGE

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This volume was developed under the auspices of NCGE's Task Force on Remote Sensing. The editor, who chairs the Task Force, appreciates the support of its members:

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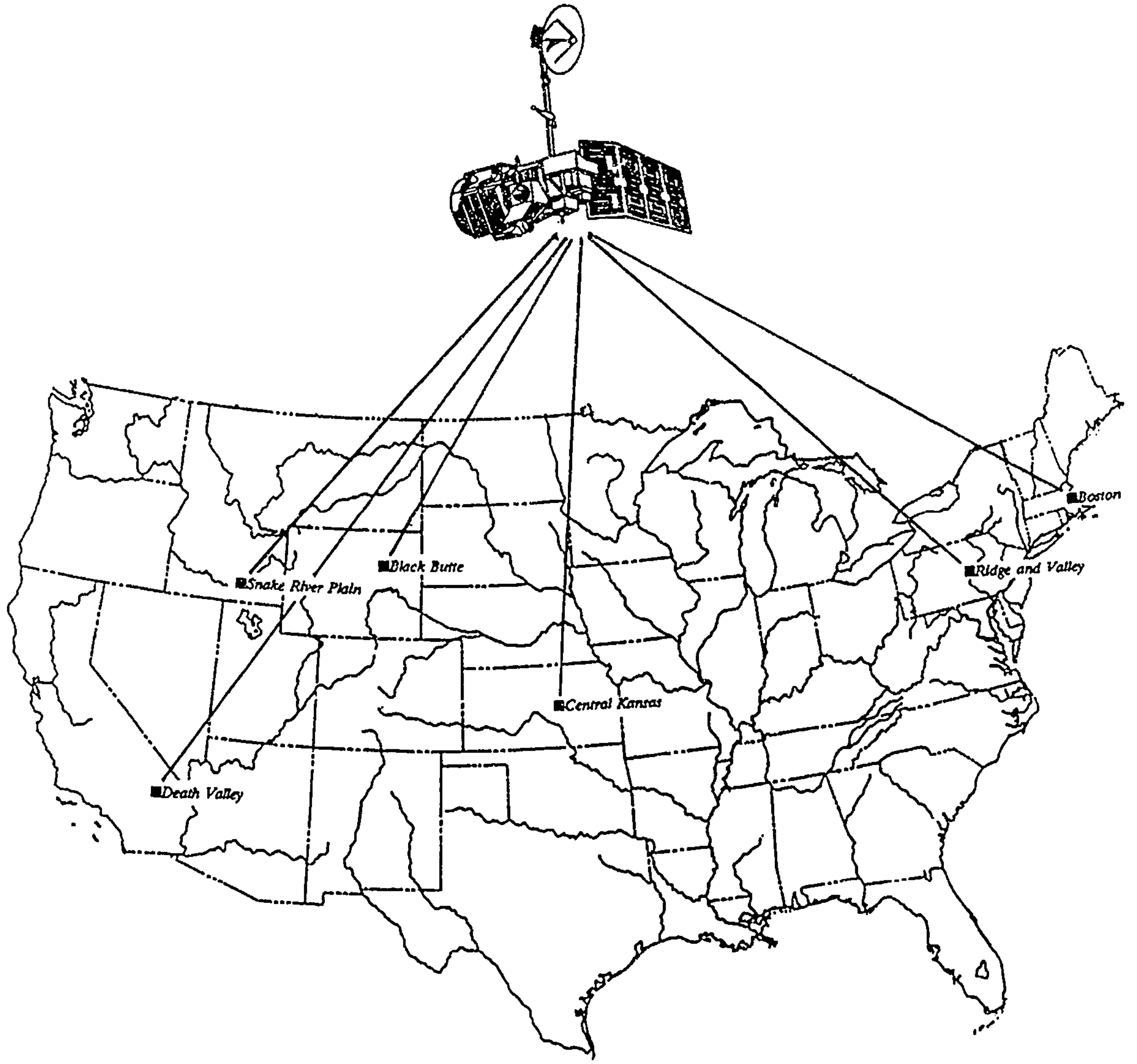
CONTENTS

Part I:
Learning About the American Landscape Through Remote Sensing



BASIN AND RANGE PROVINCE: INTERPRETING A SATELLITE IMAGE OF DEATH VALLEY

Paul R. Baumann

Introduction: This instructional unit introduces students, through a remotely sensed satellite image, to the physical geography of the Basin and Range Province, a region which covers approximately one-tenth of the United States but is home for less than two percent of the country's population. More specifically, the unit concentrates on a portion of Death Valley, showing physical landscapes common throughout the Province. Students are given the opportunity to view and interpret geographic interrelationships and patterns from a satellite image of a landscape representing a region unfamiliar to most Americans.

Grade Level: 9-12 grade and introductory college.

Time Required: Two or three fifty-minute class periods.

Specialized Geographic Vocabulary:

alluvial fan	fault block mountain
alluvial plain	mountain-and-bolson
bajada	playa
basin and range	reg
erg	wash

Objectives:

Knowledge:

a) To identify physical regions within a basin and range desert landscape by using a satellite image.

b) To gain an understanding of some of the ecological relationships within a desert environment.

Skills:

a) To identify and measure physical and cultural features on the earth's surface using a satellite image.

b) To relate information found on a satellite image to information available on a map.

c) To delineate physical regions through the use of a satellite image and an understanding of geographic interrelationships.

Materials:

a) False-color satellite image of Death Valley taken on December 20, 1982, using the Thematic Mapper on Landsat 4. (Required)

b) United States Geological Survey (USGS) 15 minute topographic map entitled "Furnace Creek Quadrangle." Provides a good synoptic view of the southern portion of the image. Published 1952. Scale is 1:62,500. For sale by the U.S. Geological Survey, Reston, VA 22092. (Strongly recommended)

c) Four USGS 7 1/2 minute topographic maps entitled: "West of Furnace Creek," "Furnace Creek," "Devils Speedway," and "Devils Golf Course." These maps cover the same geographic area as the 15 minute topographic map but with more detail. Together they make a nice wall map for class discussion but do not work well for individual student work. Published 1988. Scale is 1:24,000. For sale by the U.S. Geological Survey, Reston, VA 22092 (Recommended)

d) USGS topographic map entitled "Death Valley National Monument and Vicinity, California; Nevada." This map provides a good synoptic view of Death Valley and can be a good wall map. However, it does not contain the detail of either 7 1/2 or 15 minute maps. Good map legend. Published in 1972 and revised 1977. Scale is 1:250,000. For sale by the U.S. Geological Survey, Reston, VA 22092. (Strongly recommended)

e) Set of 20 color slides with description entitled "Geology of Death Valley" prepared by the Death Valley Natural History Association. For sale at the Death Valley Visitor's Center, Furnace Creek Ranch, Death Valley Monument, California. $7.95. (Suggested)

f) A 40 minute color video entitled "Death Valley: Life Against The Land." Prepared by Holiday Inc. as part of its National Park and Monument Series. For sale at the Death Valley Visitor's Center, Furnace Creek Ranch Death Valley Monument, California. $29.95. (Suggested)

The Learning Activity:

Background Information: The Basin and Range Province, covering about 300,000 square miles, extends from Nevada and western Utah down through southeastern California and across southern Arizona and New Mexico to western Texas (Figure 1). Its physical landscape consists mainly of desert basins and mountain ranges. The basins vary in elevation from more than 200 feet below sea level (e.g., Salton Sea), to above 4,000 feet (e.g., Great Salt Lake). Many of them possess no means for exterior drainage and are marked with dry lake beds. Such enclosed basins are referred to as bolsons and form part of the landscape called *mountain-and-bolson* topography. The more than two hundred mountain ranges found throughout the Province are generally oriented in a north-south arrangement with parallel ridges. These ranges are typically 50 to 75 miles long and 10 to 25 miles wide. These rugged mountains usually have a local relief of 3,000 to 5,000 feet above the basins with most summits being less than 10,000 feet in elevation. They are usually upthrust fault blocks and the bolsons are down-dropped blocks; thus, they are named *fault block mountains*.

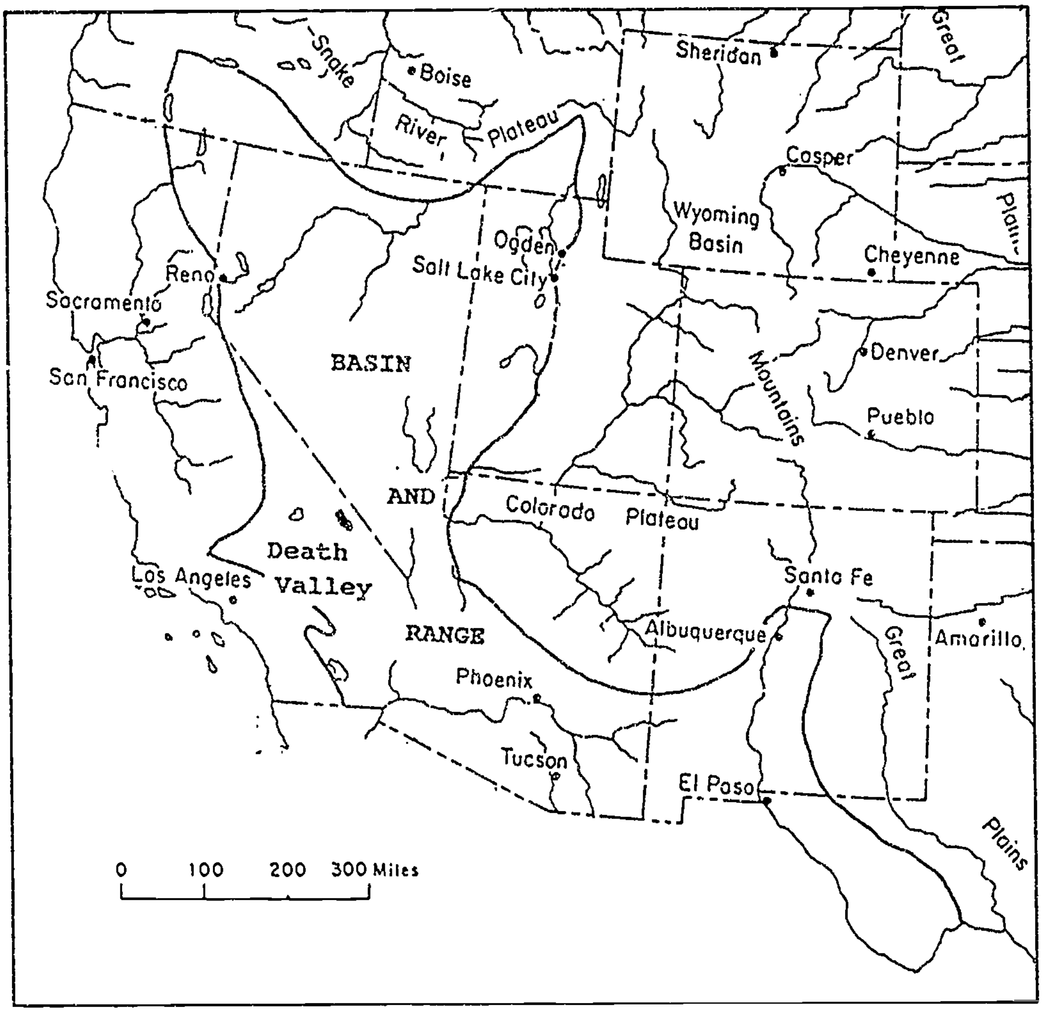


Figure 1: Outline Map of Basin and Range Province

Death Valley represents one of the *basin and range* environments within the Province. It is a deep trough, about 130 miles long and from 6 to 14 miles wide. Its lowest point, 282 feet below sea level, is the lowest elevation found in the western hemisphere. Its parallel mountains range from 4,000 to 11,000 feet above sea level and are characteristically rugged, disjointed, rocky, steep-sided and deep canyoned (Figure 2). The canyons and gullies which drain the mountains contain intermittent streams that are usually dry, and receive water mainly after rains or winter snow melt in the higher mountains. As these streams reach the base of the mountains, they can no longer carry the heavy load of sand, gravel, and boulders washed down from the highlands. The abrupt change in their gradient sharply decreases their carrying capacity, resulting in deposition. The deposition generally forms in fan shaped patterns (called *alluvial fans*), with the apex or stem of the fan occurring at the point where the stream valley leaves the mountains. The fan possesses a gentle slope from its apex to its outer edges. Its upper portion generally contains large amounts of boulders and gravel, whereas the lower portion consists of more sandy materials. When several stream valleys occur along a mountain front, more than one alluvial fan develops. As the fans increase in size, they coalesce creating a piedmont *alluvial plain*, sometimes called a mountain apron or a *bajada* (from the Spanish word for "gentle slope"). At the edge of these plains are the very flat bolson floors, frequently referred to as *playas*. The intermittent streams which form in the mountains and cross the fans create intermittent, shallow lakes in the playas. Water in these lakes evaporates, leaving behind alkali flats or salt pans. Thus, Death Valley, like many areas within the Basin and Range Province, has three major physical regions: the mountains, the alluvial plains, and the playas.

In general, the Landsat Thematic Mapper image associated with this instructional unit clearly defines these regions. The Panamint Range dominates the southwest corner of the image and a portion of the Funeral Mountains shown in the northeast corner. These mountains can be identified by their rugged texture and mixed copper-to-gold color appearance. The bright colors relate to the south and east facing slopes receiving the morning sun. Landsat crosses the area around 10 o'clock in the morning. The very dark areas represent the north and west facing slopes in shadows. These mountains are fault-block mountains, which are common to the region. Northwest-southeast oriented fault lines can be detected along the lower sections of the Funeral Mountains, separating them from the upper portions of the alluvial fans. The alluvial fans are found at the base of the mountains and appear smooth in texture with streak-like patterns. The lines cutting across the fans are intermittent stream valleys called *washes*. Such valleys are also referred to as wadis (Arabic) and arroyos (Spanish). Their dark gray-brown color makes it easy to separate them from the mountains and playas. A sharp line of demarcation exists in most areas between the outer edge of the fans and the bolson floors. The white and gun-silver colored areas correspond mainly to the playa environments. Little texture is shown in the very white colored areas where surface reflectance is so strong that the satellite's sensors find it difficult to distinguish between features. These areas are the alkali flats. The gun-silver colored areas correspond mainly to salt water marshes found around the edges of the flats. The marshes contain low, sparse vegetation suited for soils with heavy amounts of salts. Areas with heavy vegetation coverage show up as red on this image. Since the image's basic picture element covers a land area of 30x30 meters, the combination of sparse vegetation and other surface conditions within this size area produce reflectance values which generate the gun-silver color. The bolson's hour glass pattern is common to this type of environment. The stem of the hour glass, defined by flaring fans, forms a narrow gap through which water flows rapidly, and thereby, less is lost to evaporation. This concentration of flowing water permits greater vegetation growth, clearly indicated by the red color.

Death Valley's desert climatic conditions have been well publicized, and with such descriptive place names as Funeral Mountains, Furnace Creek Wash, and the Devil's Golf Course, one can picture the bleak conditions within the Valley. The term "Death Valley" also conveys a desolate and barren landscape. The annual range of temperature throughout the region is high, with summers being very hot and winters cool (Table 1). The same pattern occurs with the diurnal temperature range; very hot days and cool nights. The temperature figures in Table 1 reflect average monthly conditions and do not convey daily temperature extremes. However, to record an average monthly temperature of above 100^{0} F., a place must maintain very high daytime temperatures. Few weather stations in the world have average monthly temperatures as high as Death Valley. Summer days frequently reach 125^{0} F. at the official weather station, which some argue is not located in the hottest spot in the Valley. The second highest temperature

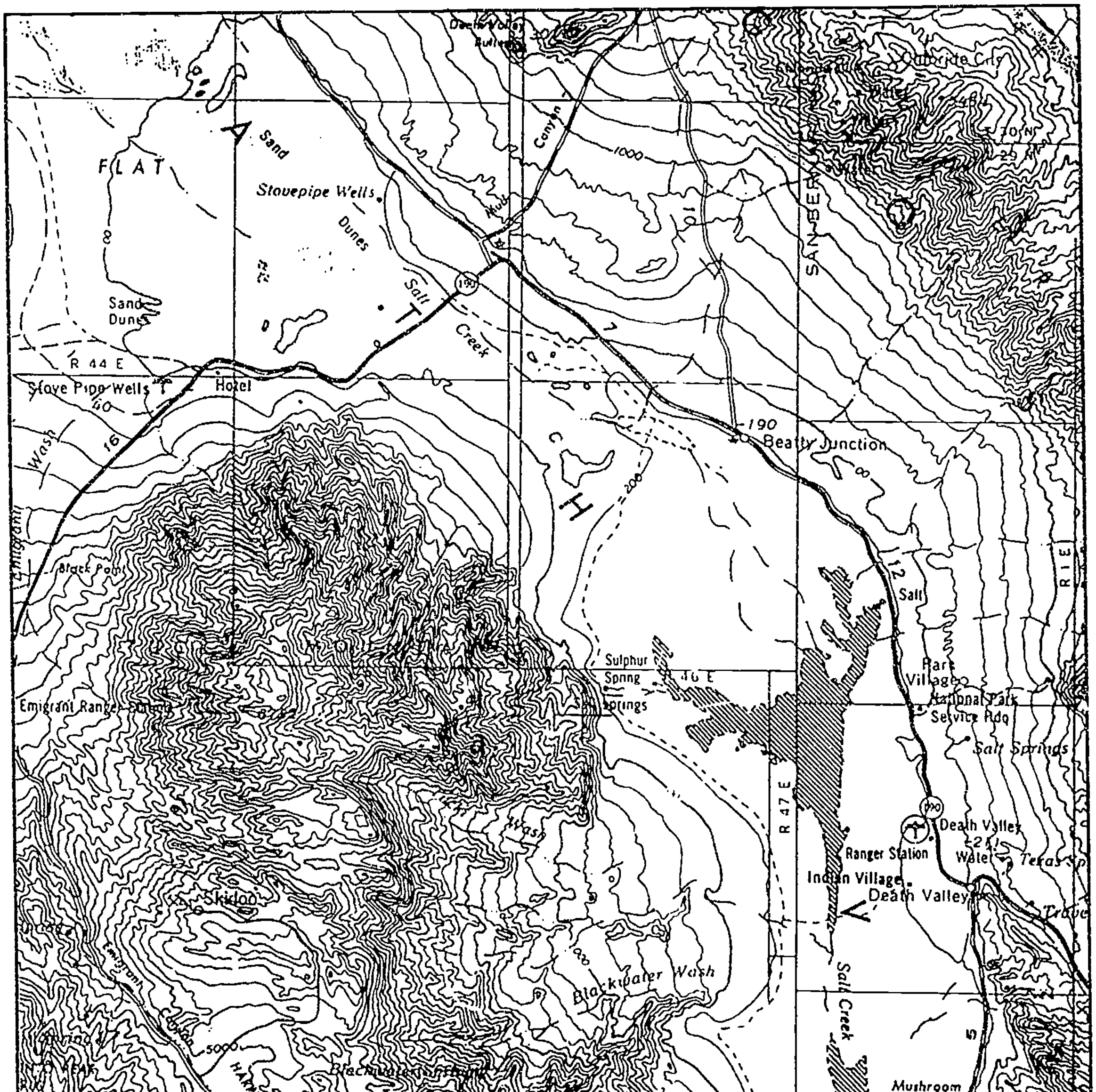


Figure 2: Topographic Map of Death Valley (Scale 1 : 250,000)

ever officially recorded in the world was 134° F. and it occurred on July 10, 1913 at Furnace Creek Ranch when a strong wind carrying hot air from the Nevada desert came across the mountains and was superheated by compression as it dropped over a mile and a half into the Valley. The variation in elevation and temperature creates strong, dry surface winds throughout the bolson environment. These winds are especially strong through the stem section of the hour glass pattern previously identified. These winds carry sandy materials away from certain areas creating rocky surfaces with highly polished patches, known as *regs*. After these sand-carrying winds move through the stem they spread out over the open sections of the bolson where their intensity decreases and they deposit the sand, forming dunes. Such sand surfaces are called *ergs*. Directly north and west of the stem exists a large dune field which appears on the image as a white pitted area.

The average annual rainfall since 1912, when the first records were kept, is only 1.78 inches, well below the humid conditions of New York City, representative of many areas in eastern United States, and even well below semiarid Los Angeles. No rain was recorded in either 1929 or 1953 and the most rain ever reported in a year was 4.6 inches in 1941. The main precipitation pattern is similar to the winter-wet, summer-dry Mediterranean style climate associated with southern California, but the Valley receives considerably less precipitation than the West Coast, due to its low elevation and being on the rain shadow side of the Sierra Nevada Range. Compare Death Valley's and Los Angeles's precipitation patterns in Table 1. The Landsat image was taken on December 20 and a few of the mountain peaks in the west-central and southwest portions of the image appear to have snow, which would correspond to the winter precipitation concentration. A small concentration of rain occurs in the summer, related to cloudbursts which last for only a few moments. The rain falls quickly, making it hard for the water to penetrate the dry baked land and thereby causes flash floods. Relative humidity averages less than 20 percent, and on hot summer days the humidity can drop to 3 percent. The low humidity permits the satellite's sensors to obtain very clear pictures of the land surface and makes possible the recording of several cloud free images per year.

Table 1: Comparative Climatic Data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Death Valley													
Temp (°F)	52.0	58.2	67.3	77.0	85.1	93.9	101.6	99.1	90.9	77.0	61.5	53.1	76.40
Prec (in.)	.21	.24	.17	.16	.07	.01	.12	.14	.11	.10	.18	.27	1.78
New York City													
Temp (°F)	33.6	33.6	40.8	51.2	62.1	71.5	76.8	75.4	68.8	58.6	47.7	36.4	54.70
Prec (in.)	3.31	3.09	4.23	3.57	3.58	3.38	3.71	5.08	3.92	3.37	3.57	3.39	44.22
Los Angeles													
Temp (°F)	54.4	55.2	57.0	59.4	62.0	64.8	69.1	69.1	68.5	64.9	61.1	56.9	61.90
Prec (in.)	2.66	2.88	1.79	1.05	.13	.05	.01	.02	.17	.39	1.09	2.39	12.63

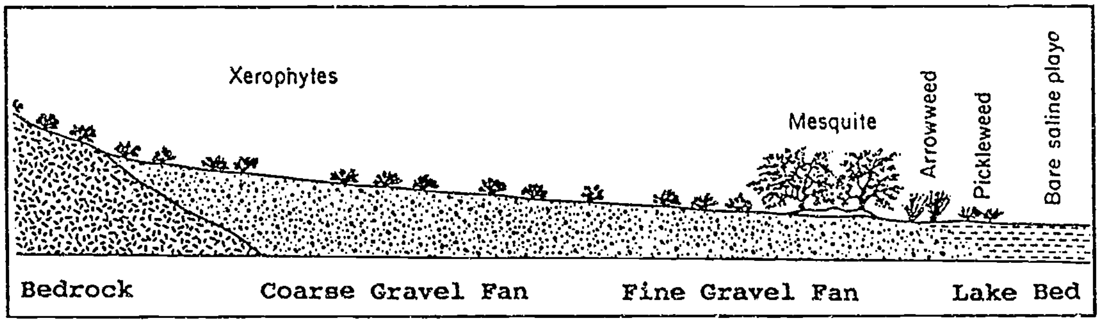


Figure 3: Vegetation Transect Across Alluvial Fan (Modified from Hunt)

With such a dry, hot climate the vegetation is very sparse and found mainly on the alluvial fans. The mountain slopes are too rocky and steep to maintain any soil for vegetation and the playas contain too much salt. Even many of the fans lack the ability to support any vegetation in this severe environment. Figure 3 shows a vegetation transect across a 10 mile alluvial fan. The lower sections of fans generally possess arrowweeds, salt grasses and pickleweed plants that have a higher salt tolerance than vegetation found at the higher levels on fans. Near springs and along certain washes where fresh groundwater is more prevalent, a higher density of vegetation can be found, and larger vegetation, such as the honey mesquite bushes which grow from 15 to 25 feet high, can exist. The lack of vegetation cover allows the satellite image to be used for detecting geological features and minerals.

Wildlife includes bobcats, coyotes, foxes, rats, rabbits, reptiles, and squirrels, which live principally within the vegetated desert. Mountain sheep are found in the higher elevations, and wild donkeys, introduced by miners, are found throughout the bolson. Spatial distribution of the mesquite bush depends heavily upon certain animals. The bush produces a bean pod which breaks open when it drops to the ground, exposing the peas. A heavy wax around the peas makes it difficult for them to germinate. In the Great Plains, the buffalo, and later the cow, would consume the pods, their stomach acids removing the wax from the peas. Some peas would make it through an animal's digestive system and be returned to the soil in the animal's excrement. Under these conditions the pea was able to germinate, and the distribution of the mesquite bush was related to the location and movement of the buffalo and cow. Although these animals are not found in Death Valley, the coyote and wild donkey perform the same function.

Humans have occupied and moved through the Death Valley region for thousands of years. The arrival of people from eastern United States and Europe over the past 150 years represents the most recent period of human development in the Valley. Many of these people were more concerned with the exploitation of mineral resources than permanent settlement, which has resulted in areas being settled and then abandoned, and environments being disturbed and modified. Although some gold mining occurred through the area, the most significant mining was for borax salts developed on the playas. Twenty-mule teams were used to transport the borax, and even today one can purchase, in local grocery stores, the product named 20 Mule Team Borax, used as a detergent booster, natural deodorizer, and stain remover. Some ranching and farming have also occurred in the Valley. The Furnace Creek Ranch originally started as a working ranch using irrigated water to produce hay for its animals; later it developed a large orchard of date palm trees and concentrated predominantly on farming; now it is mainly a resort with its inn and ranch. Today, winter tourism is the principal source of income for the Valley. Few people visit Death Valley during the extreme heat of summer.

Executing Activity: First, introduce the class to the Basin and Range Province, stressing its large geographic dimensions, general physical landscape, and sparse population. Second, present the Death Valley image and discuss remotely sensed data with special emphasis on Landsat, the electromagnetic spectrum, and false color images. Third, describe the three types of physical regions shown on the image, pointing out their interrelationships and how they are representative of the Basin and Range landscape. Fourth, review the image within the context of the five geographic themes, namely location, place, relationships within places, movement, and regions. Finally, have the class work through the questions listed below as means of getting students directly involved in studying the image and map(s). These questions could be used to evaluate a student's comprehension of the materials.

1. With the assistance of the topographic maps, identify and locate the following features on the satellite image: Panamint Range, Funeral Range, Black Mountains, Devil's Golf Course, and Furnace Creek Ranch.

   The Panamint Range covers most of the southwest corner of the image. The Funeral Range and the Black Mountains are located north and east of the valley, respectively. The Devil's Golf Course occupies the valley bottom in the southeast corner of the image. The large red block pattern is Furnace Creek Ranch. All vegetation on this false color image appears red.

2. Using the colors and textures shown on the image, plus other available information, delineate the three different types of physical regions, namely the mountains, piedmont alluvial fans, and playas.

   As previously described under the "Background Information" section, the three types of physical regions are well defined on the satellite image. This question will allow the student the opportunity to deal with the geographic concept of regionalization and to study the image in detail.

3. Of the three physical regions, which one is best suited for human settlement, and why?

   The slope conditions associated with the mountains are too steep for any significant human settlement and the alkali surface conditions of the playas are not able to support any desirable vegetation for human use. The gentle slopes of alluvial fans and their workable surface materials make them the best environment to support any large development of human settlement. Although this situation is not well demonstrated in Death Valley, many other basin and range environments throughout the Province have large settlements on fans. The Mormon settlers are well known for their construction of dams and canals to direct water across the alluvial fans in the Great Salt Lake area, as well as their many colony communities related to "Deseret."

4. Where on alluvial fans should human settlements not be located?

   Settlements should not be placed in the bottoms of the washes, due to flash flood problems. Also, settlements should not be on the upper portions of the fans where much of the surface water percolates rapidly into the ground, nor on the lower portions where alkali accumulates.

5. Note the location of the long, narrow red line extending from the apex of the Furnace Creek alluvial fan to the Furnace Creek ranch. What function does this feature perform?

   Springs exist in the mountains above the Furnace Creek fan which produce about 2,000 gallons of water per minute. This continuous flow of water to the fan creates a unique condition in comparison to water availability on the other fans. At the top of the Furnace Creek fan a ditch has been constructed to carry some of the water to the Furnace Creek ranch, which is identified by the large, angular red patch on the fan. This long, narrow red line represents the ditch providing water to the ranch. This ditch was first established in 1874 by Death Valley's first homesteaders, Andy Laswell and Cal Mowrey, the latter apparently a Mormon who knew how to employ the various irrigation techniques developed by the Mormons. This question introduces students to the human intervention within the physical landscape.

6. Does the red color show the actual function of this line, or does it imply the function through spatial association? Explain.

   The red color on the image represents vegetation. False-color images generally show vegetation in different levels of red. Many images of humid areas are predominantly red. Thus, the red does not represent directly the water associated with the ditch, but the vegetation along the ditch.

7. The edges between the alluvial fans and playas are very well defined, especially on the west side of the Valley. The fans are shown in a dark gray to muddy brown color, whereas the playas are represented in a white to silver blue color. Based on this image, the large red area of the Furnace Creek Ranch appears to be located on the outer edge of the fan, but the accompanying map (Figure 4) shows the Ranch near the middle of the fan. Has the ranch moved over the years, or does the image not show the full areal extent of the fan?

   The aircraft runway associated with the ranch has been moved, but the ranch has remained in its original location. The upper portion of the fan is shown in the dark gray color associated with other fans, but the lower portion is presented in white with long narrow, red lines. In the mountains above the fan exist large springs that together provide a continuous flow of water. This water flows down to the fan where a substantial amount of it goes underground and reappears mid-way down the fan (edge of the gray area). Since the lower portion of the fan has a low slope condition, evaporation removes the slow-moving water, creating an alkali or salt surface similar in character and color to the playas. The long, red features represent mesquite bushes along the wash areas of the fan where the water moves slightly faster than on the interfluves between the washes, and therefore, alkali is not likely to develop.

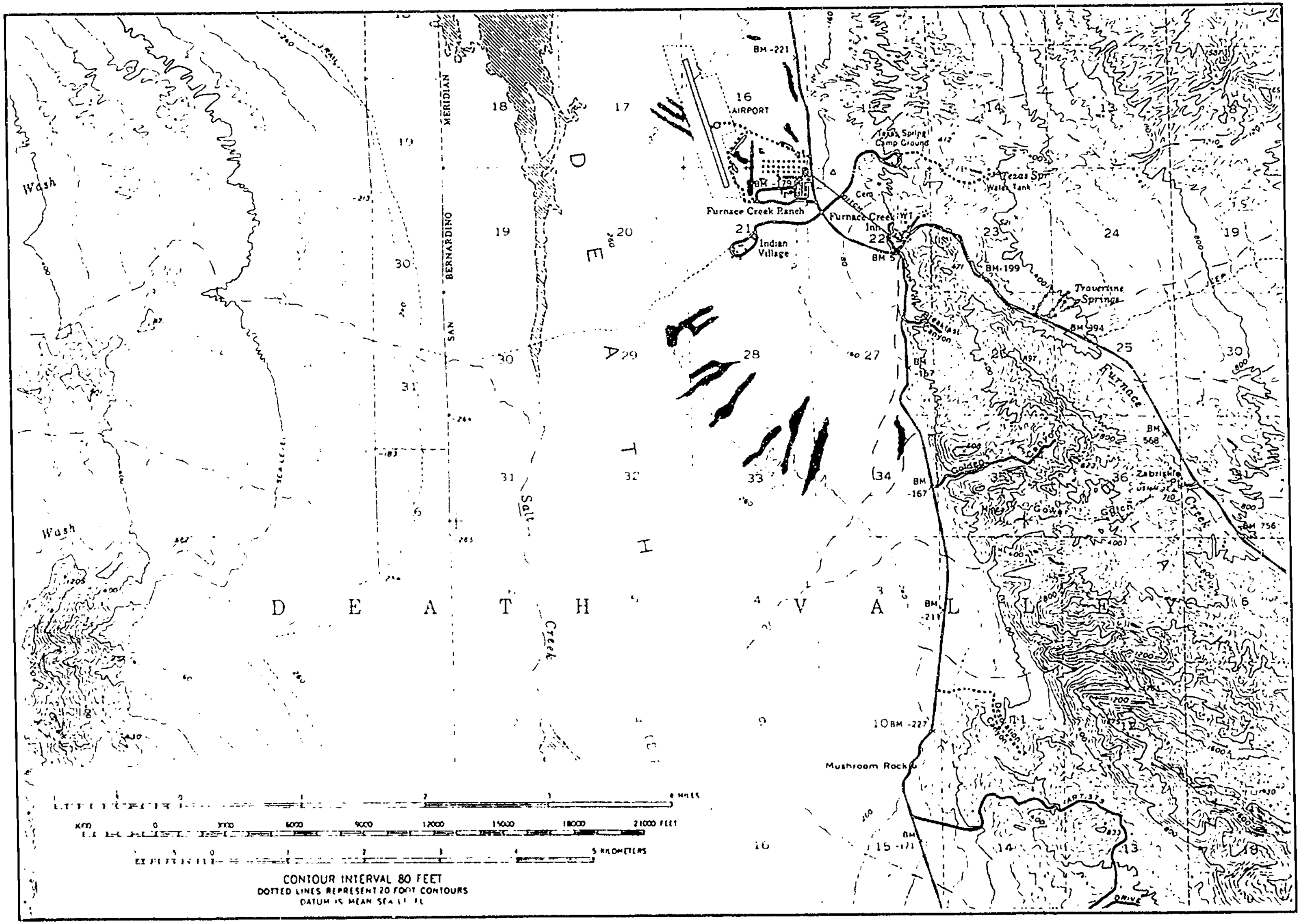


Figure 4: Death Valley

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8. Using the long, narrow red line located on the Furnace Creek fan and the contour map provided with the exercise, calculate the scale of the satellite image and measure the distance from the apex of the fan to its outer edge.

   With a ruler measure the length of the red line on the image (5/16 inch), and the same feature on the map (5/8 inch). Divide the image measurement into the map measurement (2.0) and multiply the result times the map scale denominator (2.0 x 78,125), which should give a fractional scale denominator of 156,250. The fractional scale (RF) of the map is 1:78,125, which means that one inch on the map equals 78,125 inches on the earth. The image RF means that one inch on the image equals 156,250 inches on the earth. The distance across the alluvial fan as shown in the image is 15/16 inches, which, based on the image scale, is 146,484 inches on the ground. Divide 63,360 (number of inches in a mile) into 146,484, which produces a distance of 2.31 miles. With this information, one should be able to measure distances across the image. (Expressed verbally, the image scale is one inch to 2.47 miles.)

9. Knowing the image scale, draw a small box on white paper with each side of the box being equal to one mile. Cut out the box and superimpose the paper on the image. The window shows a one square mile area (or 640 acres) on the image. Approximately how many acres cover the upper portion of the Furnace Creek fan?

   If the image scale is 1:156,250 and the number of inches in one mile is 63,360, one only needs to divide 156,250 into 63,360 to obtain the portion (.4055 or 13/32) of an inch equal to one mile on the image. A portion of the USGS 15 minute Furnace Creek topographic map shows land surveyed into sections under the Township and Range survey system. A section is a mile square area and is shown on the map as a square area outlined in red. One might also use these sections to identify the amount of acreage in an area. A section covers 640 acres.

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Charles B. Hunt. *Natural Regions of the United States and Canada*. San Francisco: W.H. Freeman and Company, 1974. Chapter 16.

Robert Webb, John Steiger, and Evelyn Newman. "The Response of Vegetation to Disturbance in Death Valley National Monument, California." Washington, DC: *USGS Geological Survey Bulletin 1793*. U.S. Geological Survey, 1988.

Richard E. Lingenfelter. *Death Valley & The Amargosa: A Land of Illusion*. Berkeley: University of California Press, 1986.

THE APPALACHIAN RIDGE AND VALLEY: A LANDSAT IMAGE OF CENTRAL PENNSYLVANIA

Percy H. Dougherty

Introduction: The Ridge and Valley region of the Appalachians, also known as the Folded Appalachians, has a long and glorious history in geography. It is the site of William Morris Davis's classical study of the now infamous geographical cycle (youth, maturity, and old age stages of landforms) and the theory of peneplanation. It is also a region in which one can readily observe the influence of physical geography on the development of transportation, land use, and settlement patterns. For the geographer interested in the interaction of the physical and cultural environment, this is an excellent classroom. The accompanying instructional unit introduces students to an interpretation of this complex and unusual geomorphological landscape extending from Newfoundland to Alabama. The following exercise investigates only a small portion of the Appalachian Province, a representative section of central Pennsylvania which was published as a Landsat scene in the November-December, 1990 issue of the *Journal of Geography*. Although most of the scene is in the Ridge and Valley, mention will be made of the Appalachian Plateau, Blue Ridge Mountains, the Triassic Lowland, and the Piedmont which collectively compose Appalachia. Concepts learned from this scene can be utilized throughout the Appalachians as well as similar folded landscapes worldwide. Some materials must be purchased, but most are available at no cost.

Grade Level: 9-12 grade and introductory college.

Time Required: Two or three fifty-minute class periods.

Specialized Geographic Vocabulary:

Allegheny Front	orogeny
antecedent stream	peneplain
anticlinal valley	superposed stream
anticline	synclinal mountain
centripetal drainage (or interior)	syncline
dendritic drainage	trellis drainage
differential erosion	water gap
epeirogeny	wind gap
karst topography	zig-zag ridge
meanders	

Objectives:

Knowledge:

a) To identify relationships between geologic patterns and landforms.

b) To gain an understanding of the influence of the landforms of Ridge and Valley Province of the Appalachians on the transportation, present land use, and settlement patterns of the region.

Skills:

a) To use remotely sensed imagery and geologic maps to identify landform types and drainage patterns characteristic of the Appalachians.

b) To delineate landform regions through the use of a satellite image and correlate these with information found on maps.

Materials:

a) False-color satellite image of the "Folded Appalachians" on NASA/NCGE Poster which also appeared as an insert in the *Journal of Geography*, Vol. 89, No. 6, November-December, 1990. (Required)

b) "Official Highway Map of Pennsylvania," available free from Pennsylvania Topographic and Geologic Survey, Box 2357, Harrisburg, PA 17105. (Required)

c) *The Atlas of Pennsylvania*, Philadelphia, PA: Temple University Press, 1989. (Highly recommended)

d) "Geologic Map of Pennsylvania," free map available from the Pennsylvania Topographic and Geologic Survey, Box 2357, Harrisburg, PA 17105. (Copy in *The Atlas of Pennsylvania)* (Required)

e) "Carbonate Rocks of Pennsylvania," free map available from the Pennsylvania Topographic and Geographic Survey, Box 2357, Harrisburg, PA 17105. (Copy in *The Atlas of Pennsylvania)* (Required)

f) USGS Raised Relief Topographic Map entitled "Harrisburg," NK 18-10-1, $17.95. Scale 1:250,000. For sale by the U.S. Geological Survey, Reston, VA 22092. (Recommended)

g)"Relief Model #7 — Folded Mountains," Hubbard Scientific, Box 104, Northbrook, IL 60065. (Recommended)

h) Set of 20 slides with teacher's guide entitled "Mountain Building" for sale by Ward's, Box 92912, Rochester, NY 14692-9012. $25.75. (Optional)

i) Set of 39 slides entitled "Folds and Unconformities" for sale by Ward's, Box 92912, Rochester, NY 14692-9012 $63.95. (Optional)

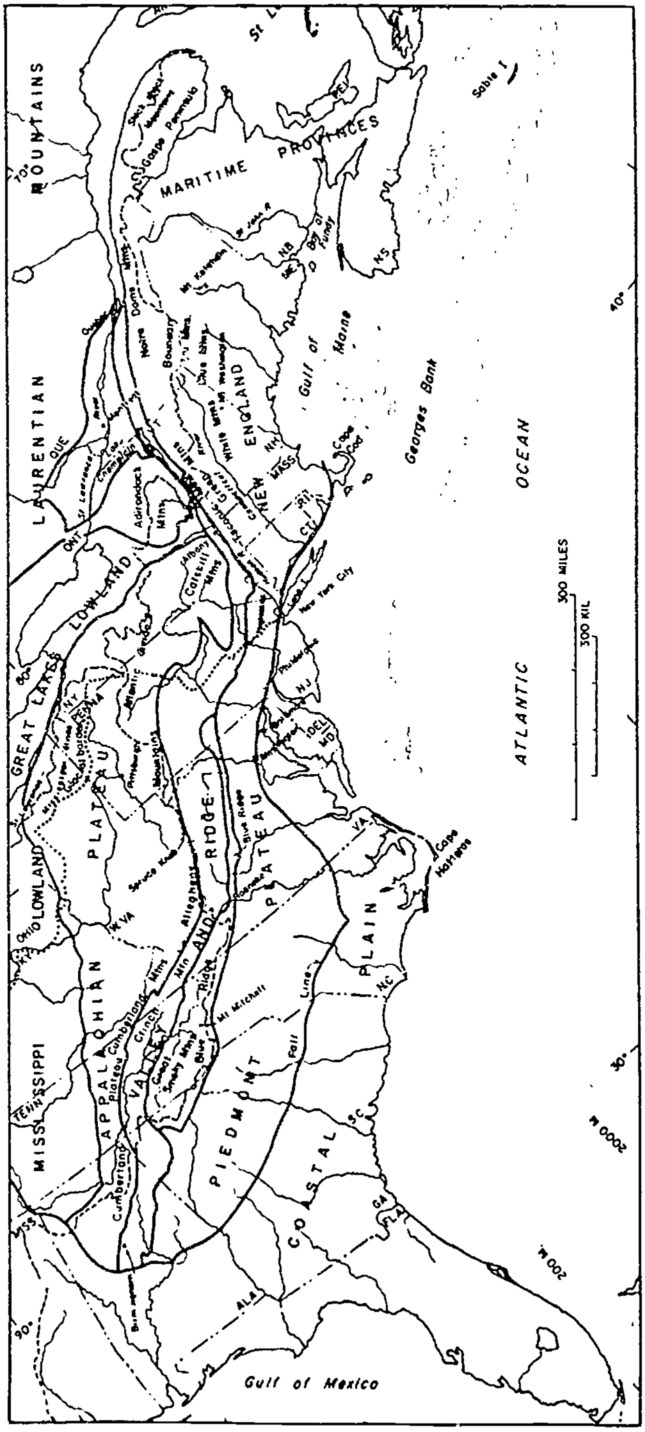

Figure 1: General Map of Appalachian Mountains Showing Principal Features

The Learning Activity:

Background Information: The Appalachian Ridge and Valley is part of the larger structural unit called the Appalachian Province which stretches nearly 3000 km (2000 miles) from Newfoundland in the north to Alabama in the south. The landforms trend in a northeast to southwest direction with the study area forming a "hinge" where the grain of the land changes from north-northeast to east-northeast. Here the greatest width of the Appalachians is reached. A complex conglomeration of mountains, valleys, and plateaus exists in the Appalachian Province as shown in Figure 1 (Rogers, 1970).

Several landform regions comprise the Appalachian Province. From the southeast to the northwest one encounters the Piedmont, roots of much older landforms which have been eroded away. Next are the Triassic Lowlands, a down-faulted area which filled in with sediments from neighboring highlands and then was intruded by igneous rock. Then come the Blue Ridge Mountains, a region of very old Cambrian and Pre-Cambrian igneous and metamorphic rock. Separating the Blue Ridge from the Ridge and Valley is the Great Valley of the Appalachians, a wide, flat to rolling landscape developed on limestone and shale. (Further south the Great Valley is known as the Shenandoah Valley.) Next is the Ridge and Valley, an area composed entirely of sedimentary rock. This area encompasses most of the study area, forming the numerous long, narrow ridges that run parallel to each other on the image. Last is the Appalachian Plateau, composed of sediments similar to those in the Ridge and Valley but not exhibiting the deformation of the latter.

It is interesting that the highest elevations in Pennsylvania are not in the folded Ridge and Valley but on the higher Appalachian Plateau. Mount Davis at 980 m (3,213 ft.) is the highest elevation in the state (Gheyer & Bolles, 1979). The dividing line between the Appalachian Plateau and the Ridge and Valley is an impressive topographic rise called the *Allegheny Front*, an escarpment with a relief of over 500 m (1,500 ft.) (Rogers, 1970). The Allegheny Front has had an important impact on westward migration, transportation routes, and present land use patterns.

The spatial arrangement of the aforementioned landforms is the result of a long and tortuous history in which plate tectonic movements caused a compression from the southeast. Five hundred million years ago an inland sea covered most of the study area. Sediments from highlands to the southeast were deposited in the basin resulting in thousands of feet of limestone and other sedimentary rock. The highland areas to the southeast occurred over a subduction zone and thus provided a steady supply of sediment over hundreds of millions of years. Around 250 million years ago the Alleghenian orogeny resulted from the convergence of the African and North American plates. An *orogeny* is a mountain building period, which in this case resulted from the African plate pushing the older North American fringing mountains to the northwest. The sediments that had been deposited in the inland sea were now uplifted and compressed. The compression resulted in the folding that is so characteristic of the ridge and valley section (*Atlas of Pennsylvania,* 1989). The Appalachian Plateau, composed of the same sediments, was uplifted but not folded. Such a procedure in which materials are uplifted with little deformation is called an *epeirogeny.*

The original landscape has since been eroded away. Some early researchers such as William Morris Davis thought the area was reduced to a relatively flat erosional surface called a *peneplain*. Subsequently this surface was raised to form a higher surface which again underwent erosion. What we see today is the residual landscape resulting from variations in the area's geology. The geology of the area is complex and controversial. Much of the problem occurs because the area is blanketed by vegetation and a thick layer of weathered material, especially in the lowlands, which masks the geology. The lack of oil and coal in much of the ridge and valley has also resulted in little incentive to investigate its geologic structure and history.

Looking at the geologic map of Pennsylvania, one finds that the geographical distribution of the oldest rocks is in the southeast and with rocks becoming progressively younger to the northwest. Exceptions to the rule occur where faulting has thrust older rocks up over younger rocks and where folding has altered the sequence. The rock types are important in interpreting the geographic distribution of landforms in this area. Stronger rocks resist weathering and erosion and therefore form the landforms of greatest relief, as explained by the concept of *differential erosion*. Rocks such as granite, basalt, diabase, gneiss, sandstone and conglomerate are very resistant to weathering and erosion and form residual mountains. Limestone and shale are easily eroded and thus form valleys.

Mountains on the remotely sensed scene take many forms but they show up as orange-rust color on the image. In an initial landscape, before there is any erosion, an upfolded mountain is called an *anticline* and a downfolded valley is called a *syncline*. After millions of years, it is possible for anticlines to be eroded to bare a weaker core of a different rock type. At this time erosion accelerates and a valley forms where the arch of the anticline once existed — this is an *anticlinal valley*. Between two anticlinal valleys is a higher ridge where the harder sandstone or conglomerate still exists. At one time this was the trough of a syncline, but now it is elevated as a *synclinal mountain*. To complicate matters, some of the anticlinal and synclinal structures plunge or dip down into the earth. Where this occurs, one observes a v-shaped landform on the surface. Where adjacent plunging anticlinal and synclinal structures occur, the result is a *zig-zag ridge*.

In general, plunging mountains with their points to the east are anticlinal while those pointing west are synclinal *(Atlas of Pennsylvania,* 1989). Another way to differentiate between an anticlinal and synclinal mountain is to look at the age of adjacent rocks on the geologic map. If the ridge is composed of older rock with younger rock on both sides, it is anticlinal. This is caused by older rocks being bared as erosion progresses. If the ridge is composed of younger rock with older rock on both sides, it is synclinal. The reason for this is that the ridge is capped by younger, more resistant rock, while the same rock layer has been worn away during the formation of anticlinal valleys on either side of the synclinal mountain.

Differences in drainage patterns can also be easily seen on this image. The Ridge and Valley is famous for having its major rivers (Susquehanna, Juniata, Potomac, Delaware, Schuylkill, etc.) cut across the grain of the landscape. Were these rivers here before the mountains formed, and continued to flow in their courses as the landforms evolved? If so, we call such a stream an *antecedent stream*. Most research states this is not the case. Most researchers believe that the study area was reduced to a relatively flat surface over which streams had little resistance. Uplift occurred and the streams started to cut downward into the rock. Places where there was weak rock eroded rapidly while sandstone, conglomerate, granite, etc., resisted erosion and formed mountains. The erosive power of the river was able to wear away the resistant rock in its course, thus resulting in a *water gap*. Such a stream is called a *superposed stream*. Where the river could not continue to erode faster than the uplift, or where stream capture occurred, the river was diverted, leaving behind a notch known as a *wind gap*. Many examples of water gaps and wind gaps exist on the image.

While the rivers cut across the grain of the land through water gaps, the tributaries are relegated to the weaker and more easily eroded valleys between the ridges. The Susquehanna and Juniata rivers exemplify the pattern called *trellis drainage*. On the Allegheny Plateau where there are no parallel ridges and where the rock type is more homogeneous, the drainage into the rivers is random with streams having a pattern looking like deciduous trees without their foliage. This type of drainage with tributaries coming in at a high angle is called *dendritic drainage*. Another type of drainage is characteristic of this area but cannot be seen on the scale of the image. This is *centripetal* or *interior drainage*, which is characteristic of limestone areas where streams sink into caves and sinkholes, such as in the Great Valley and the larger valleys of the Ridge and Valley Section. Areas of limestone where there are sinking streams, large springs, sinkholes, caverns, and subterranean drainage are said to exhibit *karst topography*.

Soils and agricultural production are also closely related to the landforms, with the best soil and most productive agriculture being in the limestone valleys. The light yellow on the remotely sensed scene represents good farmland. The Great Valley and Nittany Valley form some of the most productive farmland in Pennsylvania. Limestone valleys are readily apparent by the yellow color denoting agricultural land, while the shale valleys are represented by the mottled orange-rust color showing the land is marginally farmed with large areas remaining in woodland.

The adjacent hills, which are composed of sandstone and conglomerate, are mantled by a thin, rocky, infertile soil and are not agriculturally productive. Instead they are cloaked in a mantle of forest that during the 1800s made this section a major site of world lumber production. Trees show up as the tan to dark yellow color which so amply illuminates the ridges. After the exploitation of the landscape by the forestry interests, much of the land lay abandoned, for the soils were too poor to be farmed. Many of the land-holdings were taken over by the state for back taxes and became the core of a collection of large state parks and state game lands.

Another color on the image is black which is found on water bodies. Raystown Lake, the Susquehanna and Juniata rivers, and other streams show up as black. Water is an excellent absorber of reflected infrared radiation, therefore one can tell that one of the bands composing this image is in the infrared portion of the spectrum. The trellis drainage pattern of the ridge and valley and the dendritic drainage of the Appalachian Plateau show up nicely. In the southern portion of the Great Valley, the Shenandoah Valley of Virginia, there is an excellent representation of a meandering stream. *Meanders* are loops in a low gradient river where the main channel sweeps back and forth across a floodplain.

Few natural resources are found in the Ridge and Valley. The most notable exception is anthracite coal, found northeast of the study area in the Wyoming Basin and nearby coal fields. Within the study area there is a coal deposit found on Broad Top Mountain which shows up as a heavily forested area south of Raystown Lake. Note the light blue patches are not urban areas but are surface-mined areas. A better example of mined lands is seen on the Appalachian Plateau on the northwest portion of the image — the mottled blue area shows extensive surface mining locations.

This blue color is not to be confused with urban areas which also show up as blue. Note that in the Great Valley there are several urban centers such as Carlisle, Shippensburg, Chambersburg, and Hagerstown. Careful examination shows the urban development radiating out from the towns along major highways. At this scale one can only see the development associated with the highway and not the actual highway. Other urban centers line the rivers in the area with State College and Lewisburg being two of the largest. The blue along the rivers is not water, it is urban land use. The largest city on the scene is Altoona, which is located half way between the top and the bottom of the scene as the large north-south blue area on the edge of the Allegheny Front. Altoona has an interesting past as a rail center, for it was founded by the Pennsylvania Railroad Company as a rail yard and repair facility. Here is the easiest route through the Appalachians and the best location to surmount the imposing Allegheny Front.

The Ridge and Valley has played an important part in the human geography of not only Pennsylvania but the country in general. The original thirteen colonies were hemmed in by the Appalachians, unable to expand westward easily. Three routes existed through the mountains and thus influenced where transportation corridors for canals, railroad, highways, and the present interstate system would develop. The routes through the Appalachians included: 1) the Forbes Road, paralleling present route US 30; 2) down the Great Valley by-passing the Blue Ridge; and

3) a major zig-zag route upstream from Harrisburg, up the Juniata and across the Allegheny Front and down the tributaries of the Ohio (*Atlas of Pennsylvania*, 1989).

At the time of the American Revolution, Philadelphia was the largest city in the country, but it was soon overtaken by New York City which had an easier route to the interior via the Hudson-Mohawk Lowland. Although not as important as the Hudson-Mohawk lowland as an access to the interior of the continent, the route up the Susquehanna and the Juniata and across the Allegheny Front continued to be important. In 1859 the completion of the Pennsylvania Railroad along this route made it an important link in the transcontinental railroad system that opened up the interior. It is still the mainline of the Conrail System. A string of cities was built along the route, including Harrisburg, Altoona, and Johnstown.

Inspection of a highway map will show a high correlation of the topography with highways running through the long, narrow valleys. The water gaps and wind gaps, which serviced early settlers, are still important today as the routes of major highways through the mountains. One can tell where the folded Appalachians are on a road map by the northeast to southwest orientation of the highway system.

Executing Activity: Using the remotely sensed image entitled the Folded Appalachians and the additional maps listed under Materials, complete the following:

Exercise:

1. Take a piece of acetate or tracing paper and using present day land-use and landform patterns on the image, trace the boundaries between the major geomorphic regions and label each.

   On this scene one can start with the Triassic Lowlands of the Piedmont in the southeast and then progress through the Blue Ridge Province, Great Valley, Ridge and Valley and end up on the Appalachian Plateau in the northwest.

2. Compare the official state highway map with the remotely sensed image and analyze how the landforms have influenced the resulting transportation, urban, and cultural features.

   Most of the highways and railroads follow the lowlands and therefore have a northeast to southwest orientation. The major exception to this is where there are rivers, water gaps, and lowland routes through the mountains. Note how the county lines also have the northeast to southwest orientation since many political boundary lines follow ridge tops. Most of the cities and towns will also be located at water gaps and lowland routes through the mountains, with the remainder being primarily in the valleys.

3. Take the geologic map of Pennsylvania and analyze the correlation between rock type and the landforms of the Ridge and Valley.

   The mountains are composed of sandstone, conglomerate and quartzite while the valleys are primarily shale and limestone. This is caused by differential weathering and erosion since *sandstone, conglomerate, and quartzite are harder and more resistant and thus form the mountains. Shale and limestone are weaker and form the lowland areas such as the Great Valley and the valleys in the Ridge and Valley section.*

4. Compare the distribution of limestone and dolomite on the carbonate rocks map with the agricultural regions, shown as light yellow, on the remotely sensed image. Explain this relationship.

   There is a high correlation between carbonate terrain and agricultural production on the scene. The Great Valley is the largest area of cultivation, with other secondary areas being in Nittany Valley and the other valleys of the Ridge and Valley province which are carbonate. Limestone areas are usually good agricultural areas because they are often flat and easily mechanized, plus they have more fertile soils because of the higher lime content.

5. What color is the forested land on this scene and why is it located where it is?

   Dark yellow. The forests are located on the steeper slopes of the sandstone ridges. The land is not only too steep for agriculture and other uses, but it is also less fertile and will not support crops as well.

6. How can one recognize a plunging anticline or a plunging syncline where there are zig-zag ridges?

   In general, the ridges that are pointing eastward are synclinal in nature. Note that on the geologic map these are older ridges with younger materials in the intervening valleys. The anticlinal ridges plunge westward and have younger materials forming the ridge and older materials forming the valleys where coves have been formed from erosion of the softer materials.

7. The largest urban area on this scene is Altoona. Why did it become the largest urban area?

   Altoona is a railroad town located at a fortuitous route through the Ridge and Valley at a location where the railroad can scale the Allegheny Escarpment. This is the location where extra engines were needed to pull the cars over the steep incline known as Horseshoe Curve. It also became a logical location for rail repair facilities and car sorting activities. Altoona was the epitome of the company town during the heyday of the Pennsylvania Railroad.

8. What evidence can you find on this scene to substantiate plate tectonics or continental drift?

   The landforms have been compressed by a force from the southeast which resulted when the African block collided with the North American block. The northeast to southwest ridges show the force of compression of the deep sea sediments.

9. An important Civil War Battle was fought at Gettysburg. Look at a map of the northeastern US and tell why this area figured so prominently in the Civil War.

The Confederate forces were trying to run a flanking operation by marching north through the Great Valley of Pennsylvania from the Shenandoah Valley of Virginia. The intent was to do an end run around the Blue Ridge Mountains, reach Harrisburg, and head down the Susquehanna so that Washington, DC would be cut off from the Union. Unfortunately for General Lee and the confederates, the troops were diverted to Gettysburg, where the Union forces occupied the more strategic heights and were able to win the battle. This is a classic military campaign showing the impact of landforms on the conduct of a battle. Many excellent books are available on the topic.

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Hatcher, R.D. et al. *The Appalachian Ouachita Orogeny in the United States*. Boulder, CO: Geological Society of America, 1986.

Rogers, John. *The Tectonics of the Appalachians*. New York: John Wiley & Sons, 1970.

HUMAN-ENVIRONMENTAL INTERACTION AT THE BLACK BUTTE COAL MINE: AN INTERPRETATION FROM SATELLITE IMAGERY

Julie Elbert

Introduction: This instructional module is designed to make students more aware of remotely sensed imagery as a tool for obtaining geographic information. Its setting is the Black Butte Mine in Wyoming, an area which has been modified by coal mining. The module will examine the geographic theme of human-environmental interaction.

Grade Level: 9-12 and introductory college.

Time Required: 50 minutes for the background material and 50 minutes for each of the three activities (total 200 minutes)

Specialized Geographic Vocabulary:

anthracite	lignite
bituminous coal	reserves
Btu	resource
landscape	spoil ridges

Objectives:

Knowledge:

a) To gain some understanding of the physical processes of coal formation.

b) To relate the type of coal deposits to the form of mining practiced.

c) To understand how coal mining can affect human activities.

d) To understand some of the relationships between reserves, production, and consumption of coal.

Skills:

a) To develop maps from statistical data (i.e., coal production, coal reserves).

b) To use remotely sensed images and topographic maps to interpret mining's influences on other human activities.

c) To develop arguments for and against the activity of mining.

Materials:

a) SPOT image of Black Buttes, Wyoming imaged on 21 February 1986. Lamination of the image is suggested. (Required)

b) United States Geological Survey 15 minute topographic map, "Black Buttes, Wyoming" 1968. N4130-W10837.5 Denver, Colorado 80225. (Lamination of these maps is essential for their preservation.) (Required)

c) NAPP photos (EROS Data Center), 1756-15 7-2-89 and 1757-171 7-2-89. (Highly recommended)

d) Outline maps of the United States for students. (Required)

e) Washable pens for topographic maps, and pens, markers for preparing coal reserve/production maps. (Required)

The Learning Activities:

Background Information: The importance of coal justifies its study. Of the principal energy sources in the United States today, coal use accounts for about 20%. Its importance, relative to other fuels, has decreased since 1900 (Figure 1); however the tremendous coal *reserves* of the United States and the world should ensure it as a continuing source of energy. It may even expand in the next 80 years as a source of energy, as reserves of the other fossil fuels diminish. Coal can also be converted into gas or petroleum where it is economically feasible. Various products are also made from coal: aspirin, plastics, dyes, and various chemicals, to name a few.

The formation of coal is a slow and rather complicated geological process (Figure 2). Peat is the precursor of coal. It is partially decayed plant matter. Sometimes it is used as fuel itself, but it has a very low heating value (*Btu* per lb.). As the peat is buried under the sediments, the heat, and pressure increase. The water is driven off, organic compounds are formed and the carbon content increases. As this process continues, peat becomes *lignite* (a true coal), then *bituminous coal*, and if there is enough time, heat and pressure, it then becomes *anthracite* (which has twice the heating value of lignite). It would be an ideal situation to have thick seams of anthracite; however, most coal is bituminous, and seams may vary considerably in thickness. Coal may also contain impurities like sulfur or sand which present problems.

The first objective in mining coal is to remove the coal by the lowest cost method. The two basic methods used are underground, or shaft, mining, and surface, or strip, mining. In the Appalachian Basin, coal seams have been deformed from horizontal by the extensive tectonic folding which characterizes that physiographic region. Consequently, it is frequently necessary to reach the seams through vertical, sloping, or horizontal shafts, i.e., underground mining. On the other hand, the interior fields (Illinois and Western Interior Basins) have been undisturbed by tectonic processes, and are generally horizontal and near the surface. These seams can be reached by removing the overburden with very large machines, i.e., surface mining. Many of the western fields also have horizontal seams suitable for surface mining.

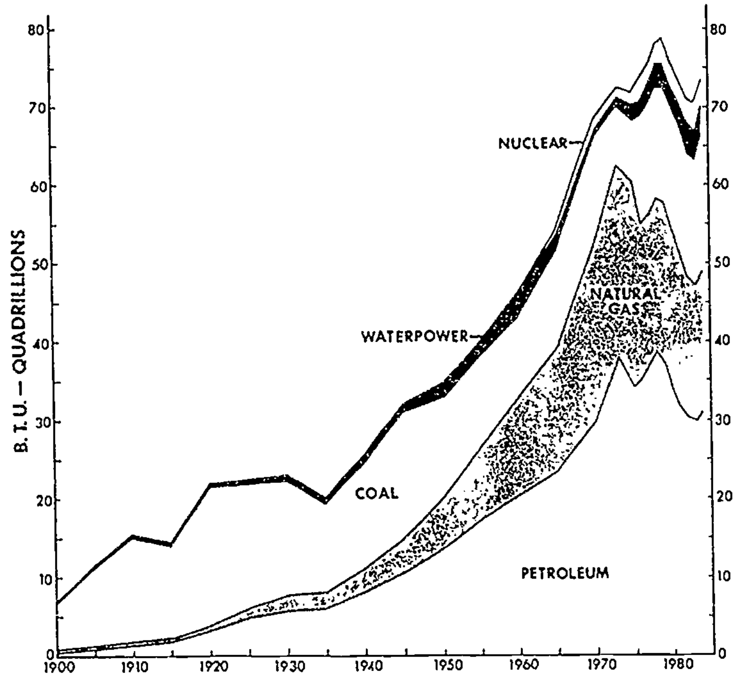

Figure 1

Figure 1: Consumption of Energy in the United States, 1900 to 1984, by Source (Expressed in Btu*) (Cameron, 1986)

*Btu is the amount of energy required to raise the temperature of a pound of water by one degree Farenheit.

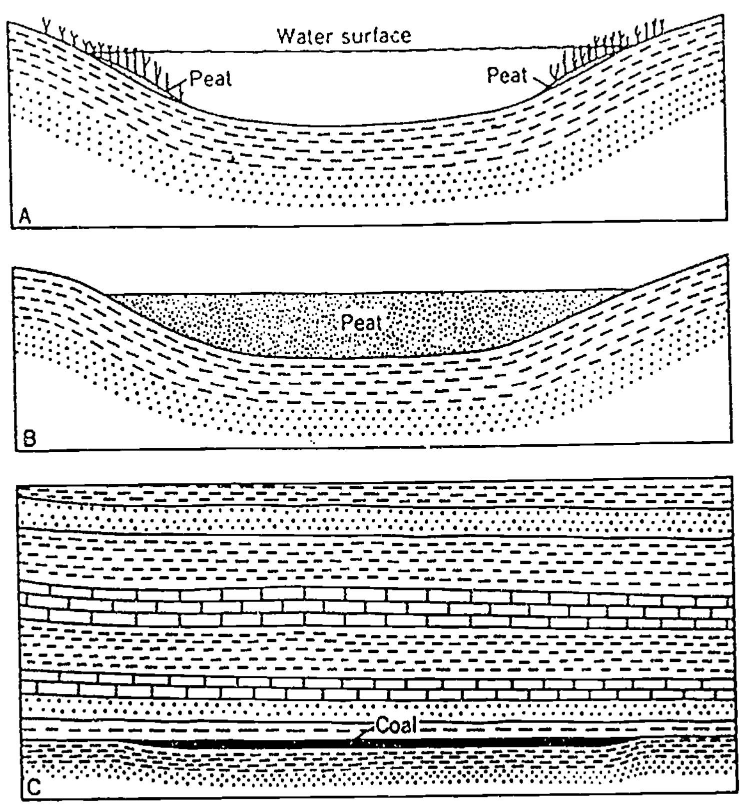

Figure 2

Figure 2: Stages in the Formation of a Coal Deposit (Cameron, 1986)

(A) Vegetation, changing to peat by partial decay, gradually accumulates along the margins of a lake and extends slowly inward. (B) The lake is filled with peat. (C) The layer of peat is buried beneath a great thickness of sediments, only the lower part of which is shown. The layer is compacted and in the time converted to coal by heat and pressure.

In underground mining, a horizontal, inclined or vertical opening is created to reach the coal (Figure 3). This is usually necessary where coal seams are thin, deep, and/or deformed from horizontal. Air shafts are excavated to provide ventilation. Entries or haulways are then excavated, creating a pattern much like a city street network (Figure 4). The coal is then systematically removed, usually by a method called room and pillar. Rooms are hollowed out of the coal with pillars left to support the roof. The coal is loaded and hauled to the main shaft to be brought to the surface. In the past, the sources of power for mining and hauling coal were people and animals. Machines have almost entirely replaced these power sources. Today, machines are usually used which continuously tear the coal loose and load it for transport to the surface.

In surface mining, the overlying materials are removed to expose the coal. This much cheaper method of mining is used where seams are shallow and horizontal, and disturbance of the surface is feasible. Although it sounds simple, it is rather complicated. First, all the trees, buildings, etc. are removed from the area. The topsoil is removed and stockpiled for use later in the reclamation process. The first excavation is called a box cut; this involves digging a big box down to the coal seam (Figure 5), usually done with a dragline. The size of this cut allows room for the loading shovels and large trucks to move in and haul the coal away. The next cut, or pit, is made and the material is put in the box cut. This process of "spoiling" material continues, creating the *spoil ridges*. Surface mining and draglines are both well suited to rather level terrain like the Black Buttes area. To give a perspective on the size of this surface mining, consider Big Muskie, the largest dragline operating in the United States. It cost $24 million, weighs 26.3 million tons, and has a 310-foot boom that travels 40 miles per hour. What can it do? It can dip eight stories below ground level and dump 325 tons of spoil on top of a nine-story building, one tenth of a mile away.

The stripping ratio (the ratio of overburden thickness to coal seam thickness) is generally used as a measure of the economic feasibility of mining a particular coal seam. At Black Butte it is 6 to 1; 6 feet of overburden must be removed for every 1 foot of coal mined.

In the past, after mining was complete, the area was left with the ugly scars of surface mining, or the piles of waste material from the underground mines. Today Public Law 95-87 provides for the reclamation of mined areas. It further provides money for reclaiming abandoned mined areas.

Additional information on the Black Butte Mine: 5.8 million tons are mined annually; the coal is sub-bituminous; 2 walking draglines with 80 cubic yard buckets; 2 electric shovels; 100 minable seams, 2-30 feet in thickness; stripping ratio of 6 to 1; employs 400 people; Union Pacific Railroad hauls coal; fill 90-110 cars in 2 hours; less than 7 inches of precipitation; area is revegetated in sagebrush; most coal is sold to Commonwealth Edison.

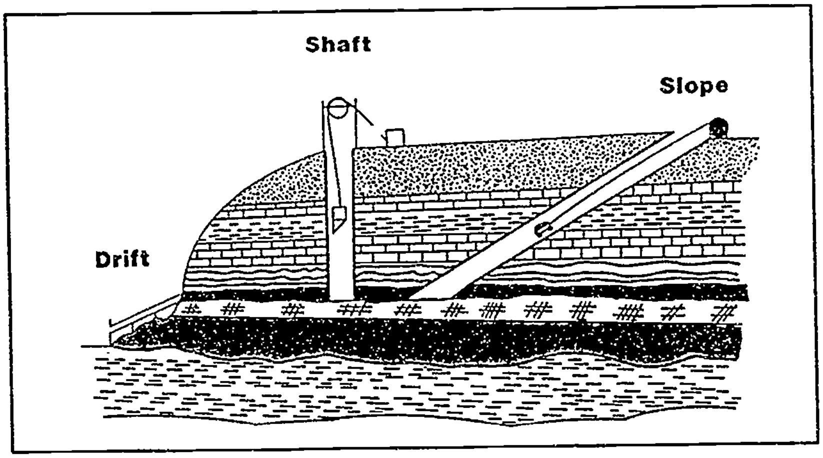

Figure 3: Idealized Types of Underground Mining (Elbert)

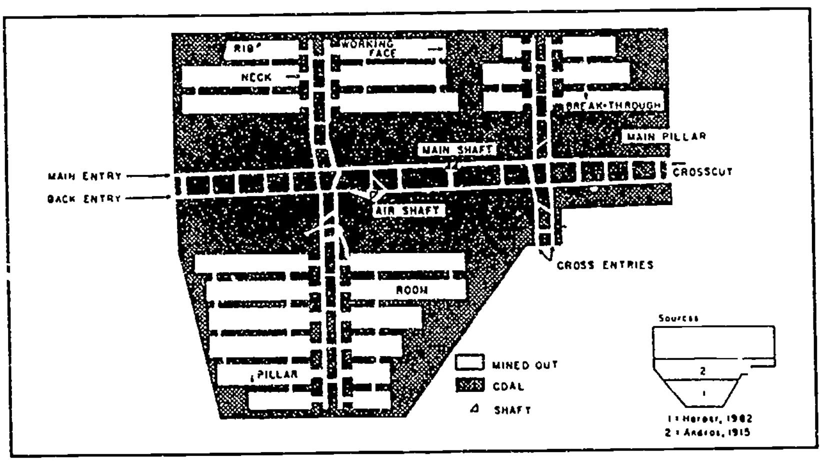

Figure 4: Systematic Rom and Pillar Method (Elbert)

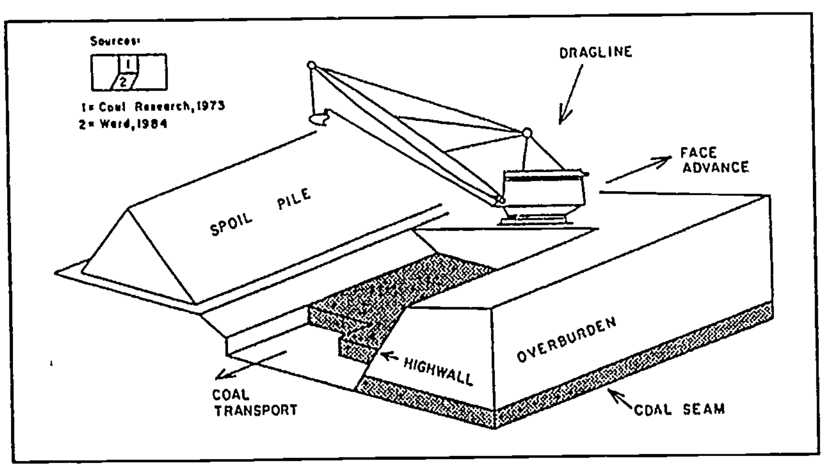

Figure 5: Idealized Surface Mining Techniques (Elbert)

Executing the Activities: First, introduce the background material on the importance of coal, its formation, and coal mining. Second, complete Activity 1, then introduce the specifics of Black Butte Mine. Finally, complete the remaining 2 activities.

Activity 1: Coal production.

1. Discuss the map of coal fields for the United States (Figure 6). Where are the different types of coal located? What states have no coal at all? Which states do you think should produce the most coal? Which states may produce the most energy from coal and why?

   The large coal fields, Appalachians, Interior, and Western, were all at one time sea floors where the coal-forming processes operated. The Appalachians have been uplifted, deforming the coal beds considerably; the Interior Basin beds are largely undisturbed. The different types of coal have greatly different Btu content; therefore, tonnage mined does not necessarily correlate with energy produced.

2. To reinforce the global importance of coal look at the world coal *reserves* and production (Figure 7, Table 1). How do the United States coal production and reserves compare with the rest of the world? Are the leading coal producers the countries with the most reserves? Do various countries' production, expressed as a percentage of the total, match their share of reserves?

   If students compute production percentages for countries shown in Table 1, it is apparent China is "different". Suggest to students that this indicates relative importance of coal among energy sources for those countries.

3. With the United States outline map and the data from Tables 2 and 3, construct proportional symbols to show coal production or reserves by states.

   (Figure 8 is an example.) The data provided allow at least 6 variations: total coal production, underground production, surface production, total reserves, underground reserves and surface reserves. These maps could be done individually or in groups. After the students have completed this task, have them compare their maps.

4. Do the states with the largest reserves produce the most coal? Is surface or underground mining the most common method of mining in Wyoming or Illinois or Pennsylvania? Are the largest coal producing states near major cities?

   It is notable that some very large production areas are far removed from their markets. This is possible because of the suitability of coal for efficient (cheap) rail transport. (Coal makes up about 40% of all rail miles of freight.)

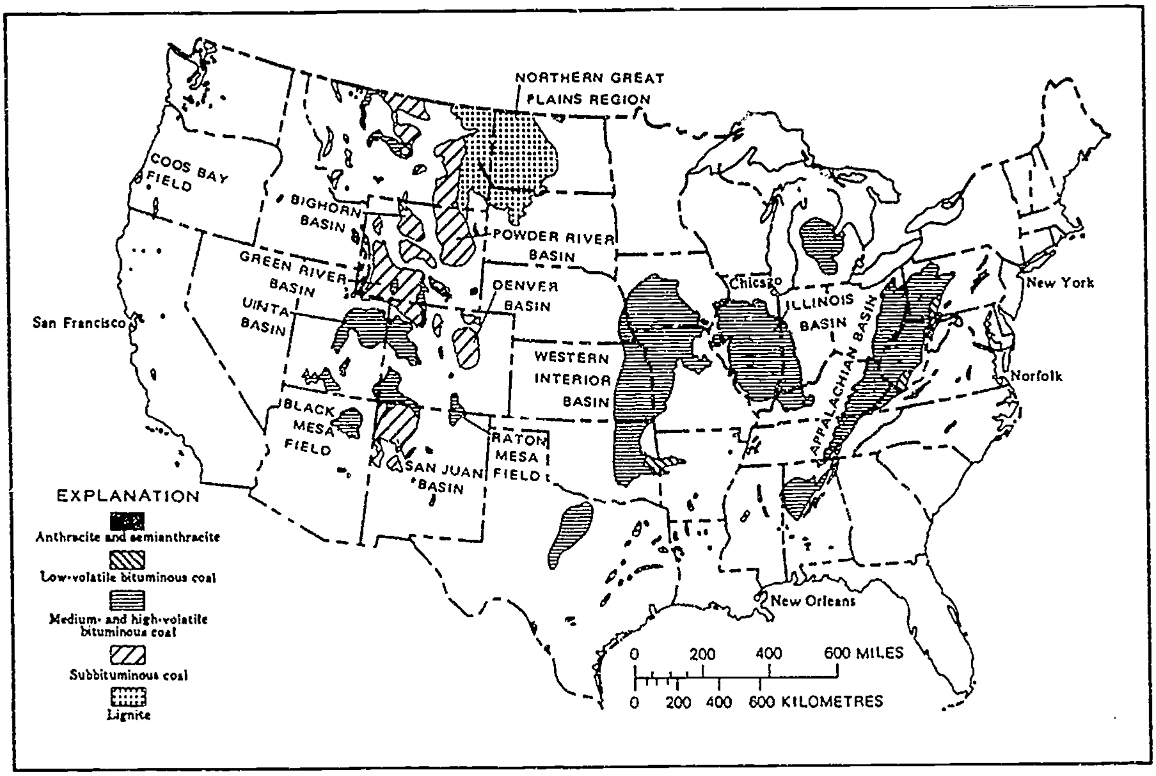

Figure 6: Coal Fields of the Contiguous United States (U.S. Geol. Survey)

Table 1: World Coal Production, 1982.
(Millions of Short Tons)

United States	838
Soviet Union	791
China	734
East Germany	294
Poland	250
West Germany	247
Australia	161
South Africa	154
Czechoslovakia	138
United Kingdom	134
India	118
Yugoslavia	60
Others	463
Total	4382

Source: Energy Information Administration, *Annual Energy Review*, 1984

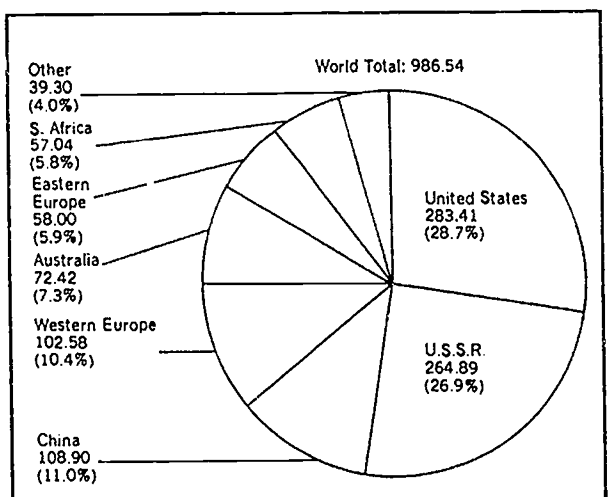

Figure 7: World Coals Reserves

Table 2: Total U.S. Coal Production[1] and Number of Coal Mines by Coal Producing States and Type of Mining, 1987 (Thousands Short Tons)

Coal-Producing State	Type of Mining				Total	
	Underground		Surface		Number of Mines	Production
	Number of Mines	Production	Number of Mines	Production		
Alabama	16	14,342	83	11,198	99	25,540
Alaska	--	--	1	1,492	1	1,492
Arizona	--	--	2	11,379	2	11,379
Arkansas	--	--	8	84	8	84
California	--	--	1	46	1	46
Colorado	13	5,645	9	8,775	22	14,420
Illinois	29	37,521	22	21,634	51	59,155
Indiana	5	2,447	62	31,761	67	34,208
Iowa	1	63	3	405	4	468
Kansas	--	--	5	2,021	5	2,021
Kentucky Total	816	92,882	612	72,310	1,428	165,192
Kentucky, Eastern	791	66,996	532	52,910	1,323	119,906
Kentucky, Western	25	25,885	80	19,400	105	45,285
Louisiana	--	--	1	2,751	1	2,751
Maryland	2	2,400	33	1,563	35	3,962
Missouri	--	--	12	4,292	12	4,292
Montana	--	--	8	34,399	8	34,399
New Mexico	1	620	9	18,512	10	19,131
North Dakota	--	--	11	25,142	11	25,142
Ohio	16	12,617	194	23,171	210	35,788
Oklahoma	1	1	18	2,889	19	2,870
Pennsylvania Total	173	38,450	510	31,974	683	70,423
Anthracite	90	636	110	2,925	200	3,560
Bituminous	83	37,814	400	29,049	483	66,863
Tennessee	60	4,865	33	1,577	93	6,442
Texas	--	--	15	50,529	15	50,529
Utah	21	16,508	--	--	21	16,508
Virginia	343	36,943	134	7,599	477	44,543
Washington	--	--	4	4,449	4	4,449
West Virginia	478	107,463	300	29,213	778	136,676
Wyoming	2	107	27	146,743	29	146,850
East of the Miss. River	1,938	349,931	1,983	231,998	3,921	581,929
West of the Miss. River	39	22,944	134	313,889	173	336,833
Appalachian Total	1,879	284,077	1,819	159,204	3,698	443,281
Interior Total	61	65,918	226	135,745	287	201,662
Western Total	37	22,880	72	250,938	109	273,818
U.S. Total	1,977	372,874	2,117	545,888	4,094	918,762

1. Excludes silt, culm, refuse bank, slurry dam, and dredge production except for Pennsylvania anthracite
Note: Total may not equal sum of components because of independent rounding
Source: Energy Information Administration, Form EIA-7A, "Coal Production Report."

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Table 3: Recoverable Coal Reserves[1] and Average Recovery[2] at U.S. Coal Mines[3] by Coal-Producing Region, State, and Type of Mining, 1987 (Million Short Tons)

Coal-Producing Region and State	Type of Mining				Total	
	Underground		Surface		Recoverable Coal Reserves	Average Recovery Percentage
	Recoverable Coal Reserves	Average Recovery Percentage	Recoverable Coal Reserves	Average Recovery Percentage		
Appalachian Total	w	w	w	w	7,008.8	70.84
Alabama	361.3	54.00	176 3	84 57	537 6	78 97
Kentucky, Eastern	769.9	64 53	345 0	81 90	1,114.9	70.49
Maryland	w	w	w	w	75 2	84 50
Ohio	447 0	55.00	307.7	82 42	754.7	79.42
Pennsylvania	1,051.9	64.16	316 7	77 07	1,3[illegible]8 5	73 94
Tennessee	w	w	w	w	102 7	67.78
Virginia	437.5	62 43	70 0	82 82	507 5	67 60
West Virginia	2,127 6	61 04	420 0	80 13	2,547 6	66 82
Interior Total	w	w	w	w	4,205 5	73 84
Arkansas	--	--	w	w	w	w
Illinois	1,290.4	44 90	140 8	79 24	1,431 2	57 59
Indiana	65 6	52.20	448 8	83 11	514 3	80 13
Iowa	w	w	w	w	35 9	81 25
Kansas	--	--	w	w	w	w
Kentucky, Western	486.6	49 25	137 6	86 55	624 2	73 94
Louisiana	--	--	w	w	w	w
Missouri	--	--	154 6	84 22	154 6	84.22
Oklahoma	--	--	49 1	82 92	49 1	82 92
Texas	--	--	1,214.5	84 67	1,214.5	84 67
Western Total	1,016 2	57 29	12,010 6	89 81	13,026 9	78 97
Alaska	--	--	w	w	w	w
Arizona	--	--	w	w	w	w
California	--	--	w	w	w	w
Colorado	462.3	53 91	206.1	89 25	666 4	68 79
Montana	--	--	1,610 5	91 13	1,610 5	91 13
New Mexico	w	w	w	w	1,557 5	87 22
North Dakota	--	--	1,384.3	90 30	1,384.3	90 30
Utah	489 6	58 67	--	--	489 6	58.67
Washington	--	--	w	w	w	w
Wyoming	w	w	w	w	6,596.1	90 96
U.S. Total	8,171.2	61.58	16,070 0	81 66	24,241 2	71 58

1 Represents the quantity of coal that can be recovered (i e. mined) from existing coal reserves at reporting mines
2. Represents the percentage of coal that can be recovered from coal reserves at reporting mines, averaged for all mines in the reported geographic area
3 Excludes silt, culm, refuse bank, slurry dam, and dredge operation Excludes mines producing less than 10,000 shon tons of coal during the year
w Withheld to avoid disclosure of individual company data
Note: Total may not equal sum of components because of independent rounding.
Source: Energy Information Administration, Form EIA-7A, "Coal Production Report"

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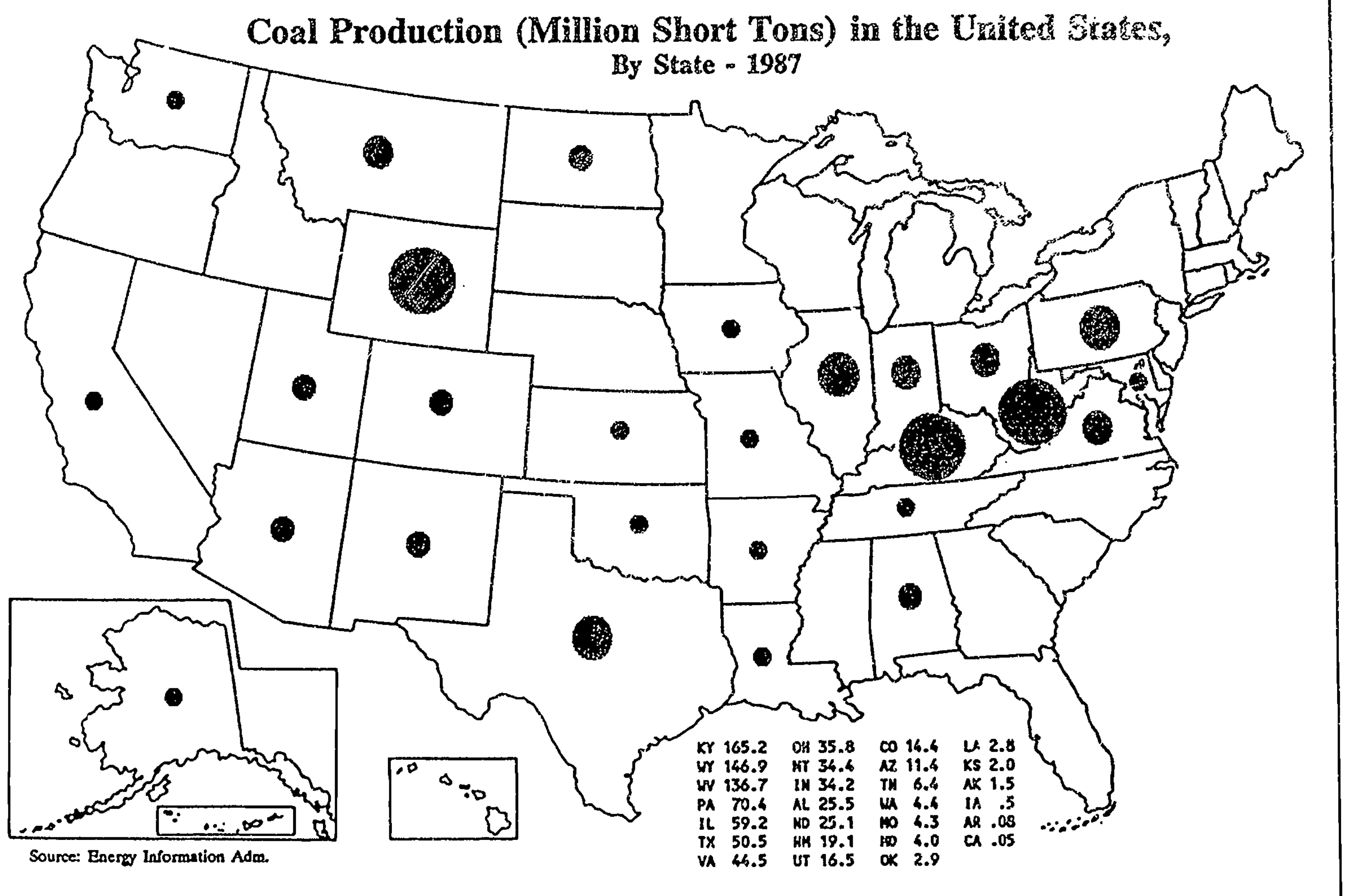

Figure 8: Coal Production, 1987

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Activity 2: Environmental impact of mining.

The students may work in groups for this activity. Distribute the laminated topographic maps and remotely sensed images. First reinforce the difference between the two types of information sources and the difference in scale.

1. Locate the railroad, the coal seams, the draglines, the spoil ridges and the loading facility. Which source did you use to locate these and why? Using the remotely sensed data, update the topographic map. What roads are new? In comparing the map and image, has mining changed the drainage pattern of the area? What areas remain relatively undisturbed? Drill holes are scattered around. What do you think they found? How far is the coal hauled from the pit to the loading facility?

   Note that the fractional scale of 1:24,000 is not correct because the map-image size has been changed, but the bar scales remain accurate.

2. How would the amount of precipitation in this area influence reclamation?

   Conclude this activity by reinforcing the usefulness of using remotely sensed data to update maps and as a way of looking at how human activity can modify the landscape.

Activity 3: Debate — The benefits of mining.

First have the students write down two positive and two negative aspects of mining. Then organize an oral debate on the question.

1. Does the value of coal as a *resource* to eastern markets justify the negative impact of mining on this dry environment at Black Butte?

Alternative Strategies: Materials on world coal reserves and production are included to give the option of adding a global perspective. A follow-up to this activity could be a study of the transportation of coal both in the United States and globally, examining where coal is exported and imported. This would introduce the geographic theme of movement.

Sources:

Black Buttes Quadrangle, USGS, 7.5' Series 1968 N4130-W10837.5 Denver, Colorado 80225.

Cameron, Eugene N. 1986. *At the Crossroads, the Mineral Problems of the United States.* New York: John Wiley.

Elbert, J.A. 1987. "An Analysis of Extreme Danger Problems Associated with Abandoned Coal Mine Lands in Southwestern Indiana." Unpublished dissertation, Indiana State University, Terre Haute, Indiana.

Elbert, Julie and Lee Guernsey. 1988. "An Analysis of Extreme Danger Problems Associated with Subsidence of Abandoned Coal Mine Lands in Southwestern Indiana," *Proceedings of Mine Drainage and Surface Mine Reclamation, Volume II* (Information Circular 9184, Bureau of Mines), Pittsburgh, PA, April 19-21, 1988.

Energy Information Administration, *Coal Production 1987,* DOE/EIA 0118 (87).

Interview - Lee Dongirno, Black Buttes Mine, August 1991.

NAPP Photos, 1756-15 7-2-89, 1757-171 7-2-89

Spotlight, Quarterly Newsletter from SPOT Image Corporation, Volume 3, Number 1, p. 4-5, January, 1989.

SNAKE RIVER PLAIN, IDAHO: THE PHYSICAL AND CULTURAL LANDSCAPE THROUGH LANDSAT IMAGERY

Nancy B. Hultquist

Introduction: This instructional module involves using a remotely sensed false-color Landsat satellite image to introduce students to the physical geography of a fascinating area and to the human use of this environment. The general area contains diverse aspects of 250 million-year-old metamorphosed mountains to the north, part of the Basin and Range Province to the south, and in between a relatively smooth looking, crescent-shaped area full of younger and varied volcanic features. Specifically, this module identifies many of these physiographic features which form the physical landscape and influence the cultural landscape as well.

Grade Level: Grades 9-12 and introductory college.

Time Required: Two or three fifty-minute class periods.

Specialized Geographic Vocabulary:

- aa lava
- alluvial fan
- aquifer
- crater
- eruptive fissures
- fault
- fault-block mountains
- flood basalts
- graben
- hot spot
- igneous rocks
- lava flow
- lava tube
- loess
- pahoehoe lava
- rift zones
- scabland
- shield volcano
- springs
- steptoe (or kipuka)
- vent

Objectives:

Knowledge:

a) To become familiar with the land forms of a distinctive region of the United States.

b) To relate the physical landscape to its use by humans.

Skills:

a) To identify and recognize physical and cultural landscape features shown in the satellite image.

b) To relate the satellite image to information obtainable from topographic maps of the region.

c) To observe and recognize physiographic regions evident on the satellite image and to relate them to the likely interrelationships of humans with their environment.

Materials:

a) False-color satellite image of the Eastern Snake River Plain taken August 27, 1972 using Landsat's Multi-Spectral Scanner (MSS). (Required) Note: North is not straight up; rotate the image 11 degrees to the right.

b) United States Geological Survey (USGS) Western United States topographic maps named Hailey, Idaho Falls, Twin Falls, and Pocatello. Scale 1:250,000. The entire image is contained within these four maps in the quadrant order above: NW, NE, SW, SE. (Required)

c) The official State Highway Map of Idaho is available by calling 1-800-635-7820 and by pressing "2" on a touch tone phone. Other information is available also. (Very useful)

d) Geological maps for the areas involved are available from the Idaho Geological Survey, University of Idaho, Moscow, ID 83843. (Particularly suggested for teachers with a geological background, or for others who would like to see specific rock-types with associated ages)

e) Geologic Map of The Craters of the Moon, King's Bowl, and Wapi Lava Fields, and the Great Rift Volcanic Rift Zone, South-Central Idaho, by Mel Kuntz, Duane E. Champion, Richard H. Lefebvre, and Harry R. Covington. Scale 1:100,000, Map I-1632. Excellent recent research indicating the age of the lava flows throughout the region; unfortunately, it is currently out-of-print. It should be in Government Document Depository holdings in university libraries. It used to be sold through the Craters of the Moon National Monument and through regional USGS offices ($3.60). Perhaps enough requests will encourage reprinting of this valuable resource. It was used to prepare this unit.

f) Greeley, Ronald and John S. King, *Volcanism of the Eastern Snake River Plain, Idaho: A Comparative Planetary Geology Guidebook,* NASA CR-154621. A classic publication which may be available in Government Document Depositories. Obtaining a copy is well worth the effort for background information, detailed field trips of the area, and interesting photographs. This 1977 document was published to accompany a conference which sought to teach scientists interested in planetary exploration the closest landscape in the U.S. related to volcanic landscape features seen on Mars, Mercury, and the Moon.

g) Although Craters of the Moon National Monument is only part of this satellite image, interesting materials are available from the Park Support Organization, Craters of the Moon Natural History Association, Inc., P.O. Box 29, Arco, ID 83213; Phone (208) 527-3257; FAX (208) 527-3073. Their publication list includes pamphlets, books, maps, posters, slide sets (5 slides/set for $2.00 each), postcards, and videos. (Suggested)

h) Blakesley, Jennifer A. and R. Gerald Wright (February, 1988), *A Review of Scientific Research at Craters of the Moon National Monument.* Station Bulletin 50 of the Forest, Wildlife and Range Experiment Station, College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow, ID 83843. (Suggested for those wishing a more complete accounting of Craters of the Moon)

The Learning Activity:

Background Information:

a) General Location: The entire Snake River Plain is evident in the relief map of Idaho (Figure 1). This region occupies about 25 percent of the total land area of the State. The Landsat image covers just the Eastern Snake River Plain which actually is somewhat different geologically from the western part of the plain, which contains more sedimentary units along with the volcanic layers. The Eastern Snake River Plain stretches from Thousand Springs on the west and bends in an arc toward Yellowstone National Park on the eastern edge of Idaho at the Wyoming border. It is flanked to the north by the older mountain complex of Paleozoic and Cretaceous rocks and to the southeast by *fault-block mountains* of approximately the same age (100-400 million years old). The plain (or basin) is a filled depression which may have been related to volcanism at an earlier period. Some scientists attribute this phenomenon to a *hot spot* (now centered in Yellowstone Park) which over thousands of years influenced the area as the westward moving North American Plate passed over the heat source. Today, the plain is marked with evidence of this volcanism and is one of the world's fine examples of *flood basalts.* This is "recent" volcanic activity dated from 2,000 years (the youngest and darkest in image), through 15,000 years (lighter browns/grays in image), to Snake River *pahoehoe lavas* up to 1.5 million years old. Flood basalt features on the plain include *lava flows*, *lava tubes*, *volcanic craters* (primarily *shield* or dome structures), and fissure flows with *rift zones* (Figure 2). Other prominent features are buttes, a few cinder cones, and as well, some remnants of former older rocks which now are sitting above the surface of lava flows and named *steptoes* or *kipukas.* Elevations range from about 3,500 feet east of the Thousand Springs area near Gooding, Idaho on the Eastern Snake River Plain, to Big Southern Butte at 7,517 feet on the northeast part of the plain.

b) Geology and Physical Geography: Besides the flood basalts, there are some noticeable geologic *faults*, which are detected nicely in satellite images, and some *alluvial fans* noted by vegetation growth. The Snake River and particularly reservoirs show up well because water bodies reflect almost none of the longer wavelengths of light energy detected by the satellite sensors for this image.

Figure 1: Relief Map of Idaho with Image Location

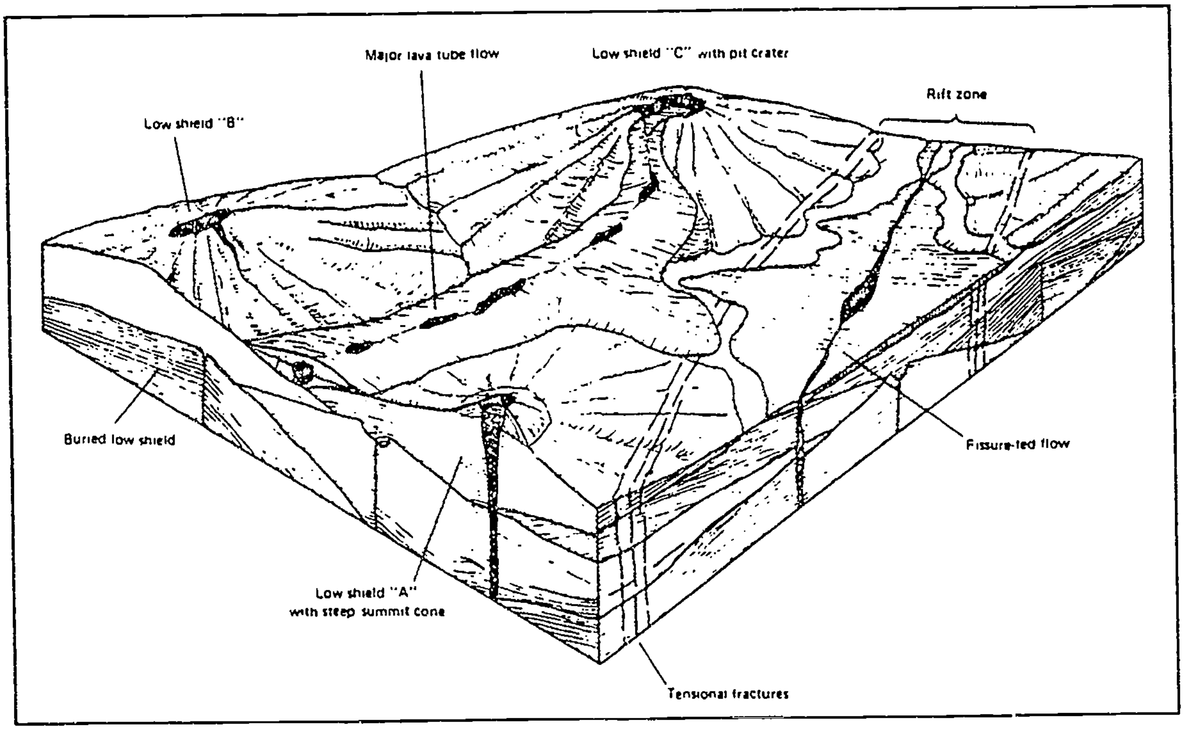

Figure 2: Diagram of Volcanic Features

The image provides a nice regional perspective of the physiography which is one of the major advantages of the early images from space. Certain features are not as easily detected on the ground as from space, particularly faults and the extent of lava flows.

Magma, which has reached the surface through volcanic *vents*, flows across the land as lava and then cools to form *igneous rock*. Various lava flows dominate the image's NE quadrant. In fact, Landsat images have allowed the correction of the extent of the lava flows in the area, as shown on previously published maps, by using the different multi-spectral bands to isolate spectral reflectances of specific lava flow characteristics. Even the USGS topographic maps do not portray the flows as accurately as does the Landsat image. Different albedos or reflectances are apparent even in the printed image, allowing some differentiation among the ages and textures of the flows. Aa (pronounced ah-ah) lava is recognized at the surface by masses of jagged blocks, while the surface of pahoehoe (pronounced pa-hoy-hoy) lava is smoother and billowy. These texture differences make up different spectral reflectances as well.

The darker lava flows, as represented on the satellite image, are younger. Older flows look lighter because they are weathered or covered with a thin film of *loess*, a wind-deposited sediment, mostly silt size, but also including some fine clays and sand. Not all flows were fed by vents; some emanated from *eruptive fissures*, or cracks in the earth. Some of these faults are visible on the image and are discussed in the question and answer section.

Northwest of the Wapi Lava Field (Figure 3) are the large lava flows, depicted as shades of black and gray, which include Craters of the Moon National Monument. Look in the apex of the darkest flow for a gray area with a darker NW-SE trending center. That is the *rift zone* along which many of the Craters of the Moon craters lie. Located on the image directly above the top black-looking flows is the town of Arco, the first all-nuclear powered city in the U.S. It is not evident on the image. What is evident is a circular patch surrounded by vegetation. That represents the Arco Hills, with some rocks over 400 million years old.

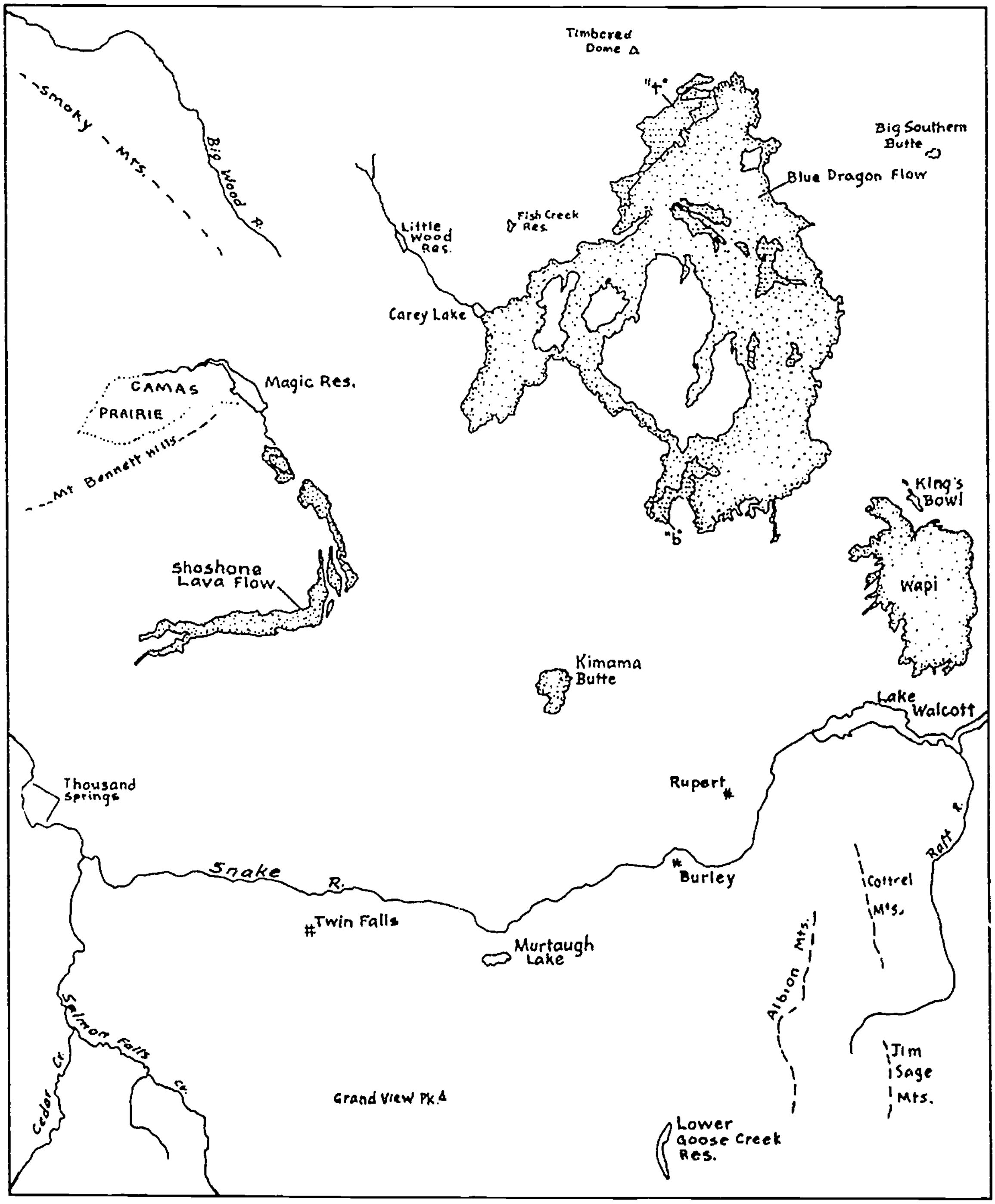

Figure 3: Snake River Plain

A hilly area in the shape of a bear paw is at the bottom center of the image. This area is predominantly Idavada Volcanics from Miocene time, or about 13 million years ago. In the higher elevations are outcroppings of Paleozoic quartzites and Permian limestone which are 250 million years old. Numerous *springs* and creeks issue from this hilly area whose highest point represented on the image is Grand View Peak (7,222'). This is found on the Twin Falls quadrangle. To the east (found on the Pocatello quadrangle) are Lower Goose Creek Reservoir, the Jim Sage Mountains, and Cottrel Mountains, all of which show volcanic rock types from Miocene time mixed with much older Paleozoic outcroppings.

Just southwest of the Wapi Lava Field is Lake Walcott (Figure 3). Do not be misled if the text with the NASA image you are using identifies the river on which Lake Walcott is located as the "Salmon" River. It should be the "Snake" River.

c) Climate and Vegetation: The climate of the Snake River Plain is semi-arid. Comparing rainfall data from Twin Falls (in the image area covered) with two other cities in the United States shows the true dryness of the climate (Table 1). The climate at Twin Falls, Idaho represents a dry midlatitude climate with an annual mean temperature of 49.6^{O}F and a total of only 9.3 inches of precipitation. In comparison, at about the same latitude, but influenced more by its coastal location, Boston, Massachusetts, has a mean annual temperature of 52^{O}F and 41 inches of precipitation. In a mid-continental situation, St. Louis, Missouri, shows a mean annual temperature of 57.4^{O}F and 36.5 inches of precipitation, but with a temperature range nearly 4 degrees greater than Twin Falls whose elevation is 3,746 feet.

With less than 20 inches of precipitation there is little tree growth except near streams. Rainfall is not adequate in the Snake River Plain for agricultural crops without irrigation from the Snake River and reservoirs through a network of canals.

Table 1: Comparative Climatic Data
(Average monthly temperature and precipitation.)

Twin Falls, Idaho (on the Snake River, elevation 3,746 feet)
Temperature Range: 43.3°

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temp (°F)	29.4	34.4	39.3	47.6	57.0	64.5	72.7	70.4	60.5	50.0	38.8	30.8	49.60
Prec (in.)	1.14	.73	.79	.84	1.06	.96	.21	.35	.47	.62	.98	1.14	9.29

Boston, Massachusetts (elevation, sea level)
Temperature Range: 40.2°

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temp (°F)	34.8	33.6	38.1	48.5	58.6	68.0	73.2	71.2	64.6	55.4	45.0	33.4	52.00
Prec (in.)	3.55	3.37	3.80	3.24	3.22	3.56	3.12	3.24	3.22	3.19	3.85	3.63	40.99

St. Louis, Missouri (elevation, 465 feet)
Temperature Range: 47.0°

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temp (°F)	34.0	36.0	44.0	56.0	67.0	77.0	81.0	79.0	72.0	61.0	46.0	35.0	57.40
Prec (in.)	2.20	2.20	3.20	3.60	3.80	3.90	3.30	3.60	3.00	2.80	2.70	2.20	36.50

The red color, representing photosynthesizing vegetation (and hence moisture), seems to be concentrated in a few places, (certainly around the Snake River and other river drainages, in high mountain areas, in areas downslope from the mountains) but for the most part is absent from all other areas to any noticeable degree.

At the top of the image, the area of the Sawtooth National Forest with parts of the Soldier, Smoky, Boulder, and Pioneer mountain ranges have forest vegetation on many of the slopes with an apparent lack of vegetation at the top of a few peaks. Just to the northeast but not on the image is Borah Peak (12,665'), the highest elevation in Idaho and the site of an earthquake in 1983. On the image is Hyndman Peak (12,009').

d) Agriculture and Settlements: The agriculture noted in most of this image is near the Snake River. At times during the height of the growing season, parts of the Snake River upstream from the Thousand Springs area nearly run dry. Some control is maintained and has been regulated through the development of canals, dams, and reservoirs upstream.

Crops grown in the Snake River Plain include grains, such as wheat and barley, alfalfa, potatoes, corn, beans, and sugar beets. Many of the fields are square in shape, but if you use a magnifying glass you can detect some circular fields. This shape results from center-pivot irrigation setups in which water is conveyed underground to the center of a field and forced toward the perimeter through an overhead pipe along which sprinklers are spaced. Supports for the pipe have wheels and are motorized. As the apparatus rotates about its center, water is metered through the sprinklers for the appropriate radius of the extended pipe.

Population centers are few and small, and are not easily distinguishable on the image. The largest city is Twin Falls with a population of 27,591. Twin Falls and Burley can be seen on the image, but locating smaller places on this image is difficult. Highways are difficult to distinguish

Table 2: Population Concentrations within the Study Area, 1970 and 1990

	1970	1990	Change		1970	1990	Change
Acequia	90	106	16	Heyburn	2940	2714	-226
Albion	330	305	-25	Jerome (3600')	6960	6529	-431
Arco (5318')	990	1016	26	Ketchum	3590	2523	-1067
Bellevue (5190')	1630	1275	-355	Kimberly	2710	2367	-343
Buhl (3793,)	3640	3516	-124	Malta	180	171	-9
Burley (4165')	8290	8702	412	Minidoka	80	67	-13
Butte City	80	59	-21	Oakley	780	635	-145
Cary	300	(1988 Pop. Est.)		Paul	860	901	41
Castleford	160	179	19	Picabo	50	(1988 Pop. Est.)	
Corral	15	(1988 Pop. Est.)		Richfield	390	383	-7
Declo	290	279	-11	Rogerson (4895')	65	(1988 Pop. Est.)	
Dietrich (4065')	150	127	-23	Rupert (4158')	5070	5455	385
Fairfield (5065')	300	371	71	Shoshone (3970')	1180	1249	69
Gooding (3576')	2830	2820	-10	Sun Valley (5920')	740	938	198
Hailey	3130	3687	557	Twin Falls (3746')	27540	27591	51
Hansen	1090	848	-242	Wendell	2130	1963	-167

on the image, even though portions of two interstates (I86 and I84) are located in the image area. Only a few cities and towns are noted on Figures 3 and 5, but populations of almost all places in the study area are listed in Table 2. Overall, population is sparse in this area because of its remoteness, high elevations, cold dry climate, and rocky nature.

Most importantly, recognize this area is not one of population growth or high population density. In the past twenty years, since this image was taken, there has been a net loss of 1,374 persons. The major areas of increase are towns close to larger communities along the Snake River and the recreation/retirement centers of Sun Valley and Hailey.

The Snake River Aquifer is considered one of the world's largest capacity *aquifers*. Like others, however, it can be overdrawn, and there has to be careful scrutiny of withdrawals so that the aquifer is not depleted. With heavy agricultural use, the withdrawal of groundwater may exceed the recharge. The groundwater of the area is confined and generally trends to the southwest through the interbedded sediments and gravels among the underlying lavas of the plain. Numerous springs replenish the Snake River at the Thousand Springs area (a north trending stretch of river 2.5 to 3 inches up from the bottom left border) where the Snake River Canyon cuts across the confined aquifer.

You might look at the noticeable occurrence of water (i.e., vegetation evident) issuing from the mountains to the north and appearing to cease at the lava fields. Lava fields are notoriously permeable and capture much of the runoff. Off the image to the north is the area known as the Big Lost River, where there and to the south of Arco the river disappears. There are no obvious tributaries to the Snake River from the north, except the Big Wood River (top western edge of the image), which sends water down through its alluvial fan (apparent on the image) to Magic Reservoir. Water from Magic Reservoir and from Carey Lake via the Little Wood River feeds the Wood River which, along with numerous streams and canals, move water eventually to the Snake River just about where it leaves the image on the west.

The major soils around the Snake River are eolian (wind-blown) in origin. Loess, derived from ancient lakebeds (Old Lake Idaho) to the west, is the parent material of the soils of the agricultural areas. Old Lake Idaho, about the size of present-day Lake Ontario, existed ten million to one million years ago, covering the Western Snake River Plain as far east as present-day Twin Falls. None of these lake sediments can be seen now because they were covered by the lava flows. The soils are very fertile and also highly erodible. A map is provided of the extent of loess in the region (Figure 4). Notice how well this area corresponds with the agricultural (red) fields on the image.

The Landsat image covers most of the Eastern Snake River Plain which extends westward to the Thousand Springs area. Only a part of the Plain, to the east and northeast, is not covered. The urban concentration at Pocatello is just off the image to the east.

There is one very noticeable transportation corridor evident on the image, downstream from Lake Walcott and to the left of the southward trend of the Snake River. Keep looking as the river turns and then forms a "bump." Just below this upturned "bump" in the river is the town of Burley, and trending up and to the right corner of the image is a faint line which is caused by rail and highways. Looking at this on the image while looking at a topographic map will be useful

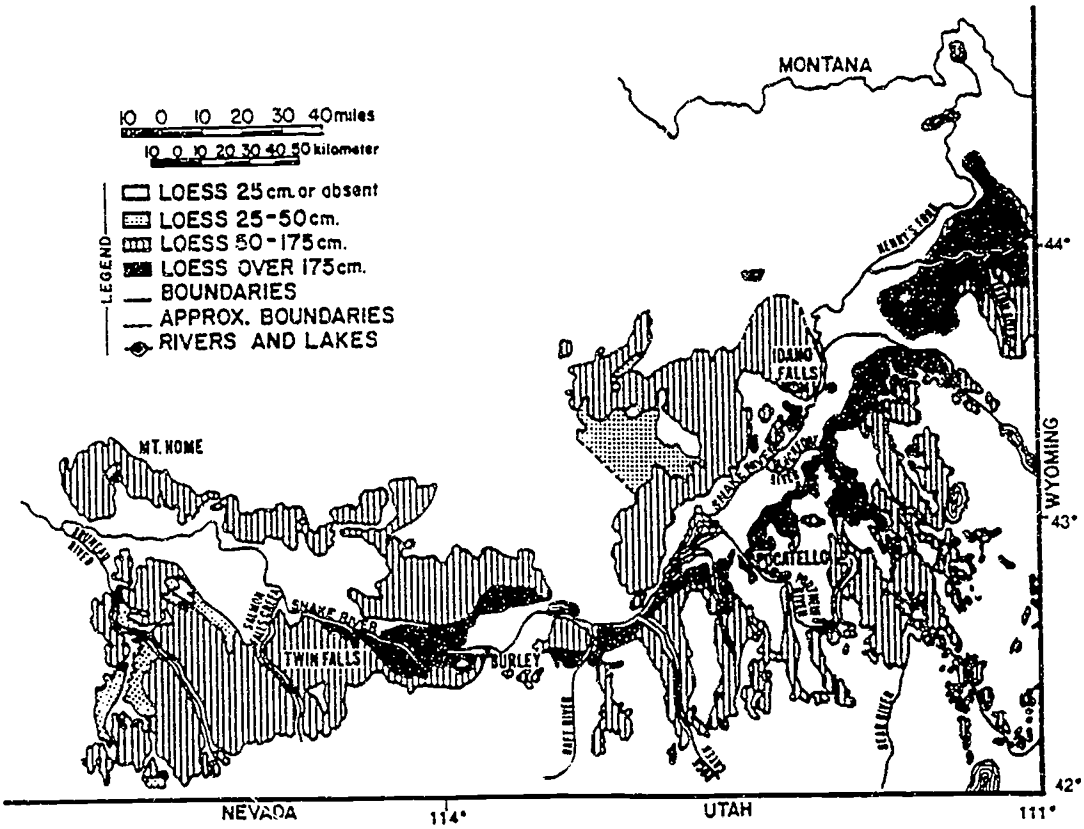

Figure 4: Loess Distribution and Thickness — Snake River Plain

for clarification. Refer also to Figure 3 for town locations. This corridor connects Burley with Rupert.

Humans have been in the region for thousands of years. The Shoshoni Indians (who lived by hunting, fishing, and gathering) preceded the fur trappers, and the fur traders built forts. The Oregon Trail wound its way into the region along the Snake River from the southeast, and a leg came north from California from just below and east of Lower Goose Creek Reservoir. More people arrived in the 1860s looking for mineral resources. Today, while agriculture is still a very important economic activity for the region, tourism is also a quite important activity.

Chambers of Commerce work diligently to attract people into their areas to see geologic oddities. The State of Idaho, not unlike others, provides "1-800" telephone numbers from which individuals can gather information. The official road map of Idaho contains excellent information on many of the places mentioned here, plus historic routes, such as the Oregon Trail. Larger scale maps, descriptions, and brochures are available as well. There are some spectacular canyons, falls (212' Shoshone Falls), and dry cataracts in the Snake River Valley which were caused by the rapid drainage of old Lake Bonneville, but these "*scabland*" features are not as easily detected here (from satellite imagery) as in eastern Washington State because the Snake River carried much of the runoff in its deep canyon. If discussion of this aspect is desired, then using 7.5 minute topographic quadrangles is the best alternative. The monograph by Greeley and King mentioned earlier addresses some of these features through low level aerial photography.

e) Other Obvious Features on the Image and their Description: Apparent in the NW quadrant is a river valley (the Big Wood River) culminating in a large alluvial fan. Just to the east is the Little Wood River. To the west is Magic Reservoir. This reservoir is within the Camas Prairie, a *graben* trending east-west, flanked by a fault on the north, evident as a line trace on the image. A graben is a depression bounded by parallel faults. Other faults (or rift zones) show up as well elsewhere on the image (for example above the Wapi Lava Field through the King's Bowl area). These rift zones are shown on Figure 5, which should be used in conjunction with the image. The Mount Bennett Hills are situated to the south of the Camas Prairie.

Lava flows are quite evident as dark irregularly shaped splotches throughout the Snake River Plain north of the river. Some of the grays and grayish browns are older volcanic flows, most of which have very little or no soil cover.

The boomerang-shaped brown area south of Magic Reservoir is the Shoshone Lava Field, a lava accumulation fed from lava tubes. The oval-shaped brown area with some darker black spots enclosed (N end of boomerang) is centered on a 5,170' high butte where a tourist attraction, Shoshone Ice Caves, is located. The large brownish formation on the middle right side of the image is the Wapi Lava Field which is primarily a low shield type lava flow.

Note: There is a little triangular blue-black spot in the left quadrant of the image, below the Shoshone Lava Field. This is a rip or tear in the film and has no equivalent feature on the earth's surface.

Executing Activity: First, introduce the class to the entire region — its physical setting, the creation of the Snake River plain (by movement over the hot spot now under Yellowstone Park), and the adjacent mountain topography (northwest and southeast). A relief map of Idaho serves this purpose well (Figure 1). It shows the obvious trough-like shape of the plain and the relative "smoothness" in relief. The Snake River Plains make up about 25 per cent of the area of the state. A table of population figures for cities (Table 2) shows no large cities in the area of the image. Most students have never visited such a sparsely populated region. In this 90 by 110 mile area fewer people live than attend the Rose Bowl game. The official State Highway Map shows cultural features, such as the location of historic trails.

Second, present the Landsat image and discuss remotely sensed data, particularly emphasizing the electromagnetic spectrum and how different surfaces reflect differently and are portrayed on the false-color image. Make particular note of the non-reflectivity of water bodies in the infrared wavelengths, hence their "black signature." The exposure required to produce a print such as the image provided (which emphasizes infrared bands) will overexpose water causing it to "bleed" and appear larger than actual. If we had a digital image, the hydrology would be clearer and crisper. Detailed measurements on water features are not possible, whereas measurements on the "reds" are. The reds appear in river valley and mountain areas, representing the presence of vegetation with moisture availability. The red colors represent places where photosynthesis is taking place. If a field has been harvested, or a hay field cut, then it will no

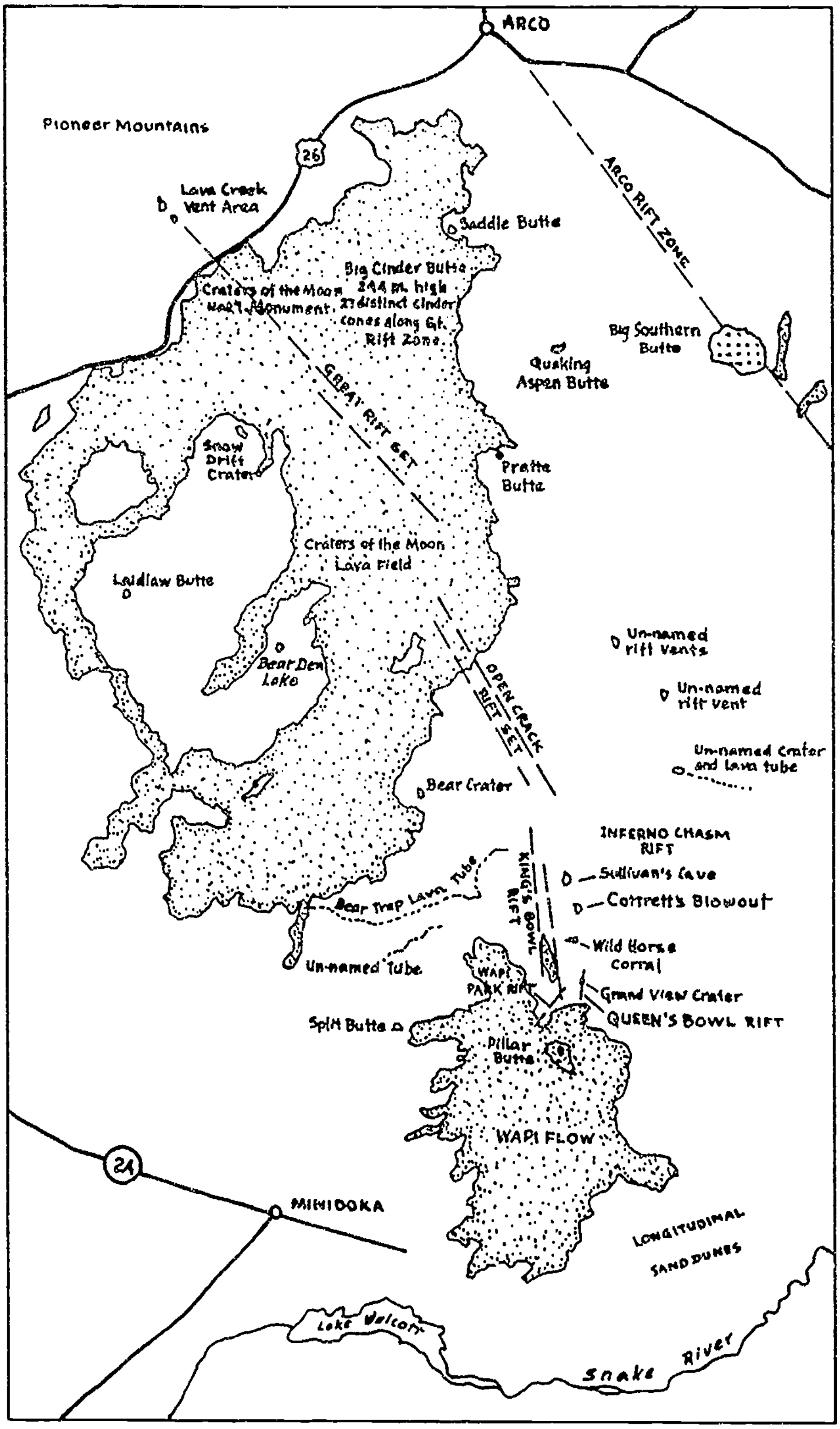

Figure 5: Diagrams of Flows and Rifts

longer appear red. Certain fractures or regional fault patterns show up better in satellite images than on the ground.

Third, point out the different landscapes: the mountains, the lava flows, the agricultural lands, the river, and other water bodies.

Fourth, review the image while considering as many geographic themes as possible, such as location, relative location, interaction with the physical environment, availability of water and movement. Finally, have the class work through the tasks and questions below. Comparing the image to the actual topographic maps should produce an excitement which will promote learning.

Suggested Procedure: Using the four topographic maps of Hailey, Idaho Falls, Twin Falls, and Pocatello, divide the class into four groups. Have each one answer questions related to the part of the image covered by their own map. Then, have them examine their map to develop questions to ask of others. Once each group has completed its questions, have them present their findings to the class. Devise some orderly means of assigning each student to another group and have them answer the questions provided here, and the other questions put forth by the students. Keep the questions provided by the students and organize them according to topographic map. Put all of the topographic quadrangles together (as a mosaic) at the front of the classroom. Project the image along side, using either an opaque projector or a slide projector. A 35mm slide is provided with this module. You can adjust the scale by moving the projector to match the topographic map composite. Try having each student answer one of their own questions but put it in the larger perspective of the whole scene. The scene is tilted about 11 degrees away from North (Figure 1) because of the Landsat flight path. Notice the orientation of the fields and position the topographic maps accordingly.

1. What is the extent of irrigation (distance away from source) along your section of the Snake River; from a lava flow; from a mountain stream; crater; etc.? Can you find sources of water on the topographic maps?

2. With the aid of the topographic maps, identify and locate the following mountain/butte features on the satellite image:

   NW (Hailey):Smoky Mts., Mount Bennett Hills

   NE (Idaho Falls):Big Southern Butte (7,517'), Timbered Dome (8,356')

   SW (Twin Falls):Sawtooth National Forest, Grand View Peak (7,222')

   SE (Pocatello):Cottrel Mts., Jim Sage Mts., Albion Mts.

3. With the aid of the topographic maps, identify and locate the following hydrologic features on the satellite image:

   NW (Hailey):Magic Reservoir

   NE (Idaho Falls):Carey Lake, Fish Creek Reservoir

   SW (Twin Falls):Salmon Falls Creek, Murtaugh Lake

   SE (Pocatello):Lake Walcott, Lower Goose Creek Reservoir

4. With the aid of the topographic maps, identify and locate the following vegetation features on the satellite image:

   NW (Hailey):Wood River Valley, the crescent-shaped area (at 4,795' on top) east of Kinzie Butte.

   NE (Idaho Falls):area around Carey Lake and the Big Lost River

   SW (Twin Falls):area north and south of Snake River (note canals cannot be seen on the image); refer to topographic maps

   SE (Pocatello):Raft River Valley and the canal area north and south of Snake River near Burley, Idaho

5. There are red colors found in the mountains, adjacent to rivers, and next to lava flows. In each case, what do you suppose is represented by the red color on the image? Note the reds have slightly different hues, depending on the location.

   The deeper reds in the mountains to the northwest and southeast probably denote ponderosa pine in lower, dry elevations in the hills with changes to douglas fir, and grand fir, and likely to juniper at higher elevations. At the highest elevation, there is a lack of reds, represented by tundra at the elevations above 10,000 feet, such as Hyndman Peak (12,009'). Areas above 8,000 feet have glacial valleys and some cirques containing glacial lakes, developed during Pleistocene times. Note even the Big Southern Butte has some evidence of vegetation on its top (7,517').

6. Have the student look carefully at and explain the regional setting of the area(s) of vegetation. For example, the unnamed butte east of Kinzie Butte (Hailey quadrangle) appears to be an old crater which now has radial drainage patterns created by canals from the higher elevations. The old crater slopes are vegetated.

7. Where in this image do you expect to find population concentrated? Why?

   Population is likely to be near water sources which provide opportunities for economic activity.

8. Using the topographic maps, find a city. From Table 2 determine its population. Determine the elevation of the city from the topographic map. Can you see the "color" on the image which represents towns? Can you find another town without looking at the map? Find one, and verify your choice by referring to the topographic map.

9. Look for other things on the topographic map and determine if you can identify them on the image. Do they occur in other places on the image?

10. The agricultural areas appear to be within reach of water, as expected. What other important resource is needed for vegetation growth? Why do you think there is sparse vegetative cover on the lava flows?

    The availability of water in addition to fertile soil is necessary for agricultural activity. There is insufficient water in the lava flow areas, except where wells have been sunk into the aquifer. The water from the Big Lost River disappears into the permeable lava flows and underlying gravels and eventually surfaces as springs in the Thousand Springs area of the Snake River.

    Much of the water taken from the Snake River and applied to the irrigated fields also recharges the aquifer. In recent years the Idaho Department of Water Resources has been involved with protecting this resource and regulating the actual water use by all landowners.

    Figure 4 is a map of the areal distribution and thickness of loess deposits in south-central and southeastern Idaho. The image includes the area between Salmon Falls Creek and the Raft River. This gives a good approximation of where agriculture can be expected if soils have developed from the parent material to a depth sufficient for tillage, and provided water is available for irrigation.

    Looking at the field patterns in all the agricultural areas reveals different shapes, sizes, and colors of fields. The whitish fields interspersed are either fallow fields or harvested fields (by August 27th, wheat and barley most likely have been harvested, while potatoes, corn, and beets likely have not). Alfalfa may be doubled cropped and remain red even when cut.

11. This activity may offer an opportunity to do some measurements on the image and on the map. We know the topographic maps are at a scale of 1:250,000, or 1" = 3.95 miles. Either present some distances for the student to determine the scale of the image, or offer the estimate of 1 inch equals about 11.3 miles and calculate the distance from the Magic Reservoir dam to the Lake Walcott dam. Alternatively, present the student with a problem of measuring a distance on the image and determining its corresponding measurement on the topographic map, so that the student has some feel for the difference in scales of the image and the map. What is the image scale if 1 inch equals 11.3 miles?

    1:715,968. Compute by multiplying 11.3 times 63,360, the number of inches in one mile.

12. Notice the lava flows on your topographic map. Can you identify them on the image?

Many of the lava flows are larger than they appear on the topographic maps. To aid discussion, make an overhead transparency from Figure 3 and also from Figure 5 to project with the image.

13. Using the topographic maps, identify and locate the following lava flow features on the satellite image:

NW (Hailey):Shoshone Lava Flow

NE (Idaho Falls):Craters of the Moon/King's Bowl/Wapi Lava Field

SW (Twin Falls):lava flow north of Wilson Lake Reservoir and westward (north of Twin Falls)

SE (Pocatello):Pillar Butte (5,261'); Kimama Butte (5,074')

Look at the lava flows in the base outline map in Figure 3. The age of the Wapi Lava Field is about 2,270 years old, and is made up of pahoehoe lava and some aa lava flows which are tube fed and radiate from a vent complex at Pillar Butte (see Figure 2 for examples of volcanic features).

Another young member of the Wapi Lava Field to the north is in the King's Bowl area. It has a rift running through it trending North. In fact, look up and to the left to view two shadowy parallel lines barely visible on the image. These are documented faults. Check Figure 5 for the location of these fault lines.

The youngest flow in the Craters of the Moon is the Blue Dragon area, about 2,070 years old. It is the farthest north near Arco and encircles the grayish island (a steptoe) west of Big Southern Butte. Compare the image with Figure 3.

The lighter brown/grays at the top and left of the Craters of the Moon flows are much older, occurring 12,100 years ago. These flows are marked "t" for top on Figure 3. The one to the west isn't marked, but is closest to Carey Lake. The flow at the south end of the lava flows is older, having occurred about 15,000 years ago, and is marked "b" for bottom.

14. Do you suppose Kimama Butte (Pocatello quadrangle) is basically lava and therefore emitting the reflectance associated elsewhere on the image with lava? (There are no apparent canals or springs on the butte according to the topographic map, and without sufficient soil cover, it would not be useful as an agricultural area.)

Kimama Butte is Snake River Pahoehoe lava, with 25-75 per cent outcrop exposed, from Pleistocene time (1.5 million years old).

15. The growing vegetation identifiable in this image seems to be concentrated in a few places, particularly around the Snake River, but also in areas downslope from the mountains, and near reservoirs. In other areas of the image it is lacking. Why do you think that is? What governs the landscape throughout much of Snake River plain to the north? From where is the Snake River fed? Does it originate in the mountains to the south? or from the east?

    Vegetation responds to available moisture, which is available at the foot of the hills and mountains, from wells or canals, from reservoirs, or adjacent to the Snake River. Other places are mostly out of the reach of surface rivers. The rivers are disappearing under or through the lava to gravels below and traveling beneath the surface until they emerge as springs on the cliffs of the Snake River. The Snake River originates from the east of the image.

Acknowledgements: The author wishes to thank William B. Hall (retired geomorphologist, University of Idaho) for geologic and imagery interpretation; Margi Jenks, Bill Bonnichsen, Kurt Othberg, Vicky Mitchell, and Roger Stewart of the Idaho Geological Survey, Moscow, ID; Sue Jones and Betty Zuck from the Twin Falls Area Chamber of Commerce. A special thanks to Allan Jokisaari, University of Idaho, and Joel Andress, Central Washington University for cartographic work, and to Gibb Johnson for permission.to use his copyrighted relief map. Thanks to Marty Kaatz (Prof. Emeritus, CWU) and Margi Jenks both for searching their shelves and files for Eastern Snake River Plain information and for help in editing the final manuscript. Thank you, John Hultquist, my resident physical geographer/editor.

THE URBAN LANDSCAPE OF BOSTON FROM A HIGH-ALTITUDE COLOR-INFRARED AERIAL PHOTOGRAPH.

Aulis Lind

Introduction: This instructional unit examines the dynamic urban and environmental geography of Boston, Massachusetts. A high-altitude, aerial photograph, dated July 7, 1970, is used to highlight and study the nature of Boston's urban geography. Students will be able to investigate its natural setting, the magnitude of human landscape modification and characterize the various "cityscapes" resulting from the processes of urbanization. Census data are incorporated to assist in the interpretation of the aerial photograph.

Grade Level: 9-12 and introductory college.

Time Required: Two to four fifty-minute periods.

Specialized Geographic Vocabulary:

census tract	port functions
Central Business District-CBD	recreational land use
commercial land use	residential land use
density	shoreline modification
glacial deposits	tidal flat
housing units	transportation
industrial land use	urban renewal
landfill	wetlands-marsh
neighborhood	

Objectives:

Knowledge:

a) To gain an understanding of urban geographic processes through the use and interpretation of high-altitude aerial photography.

b) To provide some insights into the complexity of urban spaces and urban structure through detailed analysis of urban features in conjunction with historical maps and U.S. Census Bureau data.

c) To develop an appreciation of the massive human modifications of land areas associated with the urbanization process in Boston.

Skills:

a) To develop photo-interpretation skills using high-altitude aerial photography.

b) To transfer information between an aerial photograph and maps with a view toward correlating information.

c) To use and apply census data as an aid to characterizing urban neighborhoods and feature mapping.

d) To apply quantitative techniques for area measurement and the calculation of 'densities'.

e) To develop historical and geographical interpretation skills using diverse sources of data: air photos, maps, and census data.

Materials:

a) July 7, 1970 color-infrared aerial photo at a scale of approximately 1:54,000. (Required)

b) National Geographic Society, 1988. *Historical Atlas of the United States,* pp. 289. (Strongly recommended — required for detailed learning tasks) Pages 240-243 provide excellent historical maps tracing the development of the city.

c) Mapping and interpretation aids: magnifying glass, acetate or overhead transparency stock, transparency markers (fine point) and graph paper -- 10 to 20 squares per inch — for planimeter.

d) United States Geological Survey (USGS) 7.5 minute quadrangle, *Boston South Quadrangle,* 1956 and 1979. Available for loan through most College/University map libraries or through purchase from the U.S. Geological Survey, Reston, VA. 22092. (Strongly recommended)

e) 1775 map entitled "A Plan of the Town and Harbour of Boston" by DeCosta. (Required — reproduced as Figure 1)

f) U.S. Bureau of the Census, 1970 Census, Boston — selected tables. (Reproduced)

The Learning Activity:

Background Information: Boston is sited around one of the several natural harbors found in southern New England. Many of these natural harbors owe their existence to the post-glacial rise of sea-level which culminated some 9,000 years ago. Unconsolidated *glacial deposits* (i.e. sand, silt, clay, and gravels) were submerged, thus producing an irregular shoreline with numerous shallow area exposed at low tide (*tidal flats*). Where the tidal currents are not excessive, *marshes* with tall grasses may be found. These are also known as coastal *wetlands*. The topography is generally low and rolling with elevations up to about 200 feet above sea-level. Colonial settlement in this area can be traced back to the early 1600s. By 1697, the population was about 7,000. By 1717, it was the largest English town in America. Boston developed into a major port during colonial times, and it was the seat of many activities during the American Revolution. Numerous historical sites still remain in Old Boston, including Old North Church, Faneuil Hall, the Granary Burying Ground, and many others. By 1970, the population of Boston proper was close to 641,000. About one-half of the land area shown in the central area of the 1970 aerial photo is *landfill* which provides some notion of the massive *shoreline modification* in the area since colonial times (Figure 1). As new land was created from wetlands and marshes, *port functions* (warehousing, shipbuilding and repair, naval activity) and urbanized area increased dramatically, and *commercial and residential land use* areas developed their own distinctive plans and arrangements. During the nineteenth century, along with large scale immigration, residential *neighborhoods* developed, waned and were sometimes replaced by massive *urban renewal* projects involving the construction of commercial centers. *Industrial land use* developed along with the increase in population, especially close to the port areas. An appreciation of the enormous magnitude of landscape modification can be gained by comparing the 1775 map (Figure 1) with a section of the 7.5 minute USGS quadrangle map reproduced as Figure 2. The aerial photo provides a basis for comparing the changing complexity of urban Boston. The significance of the patterns, tones, colors, and arrangements shown by the aerial photo are not only clues to its past development, but also provide useful information for investigating Boston's cityscape. Census data can be combined with aerial photo and map information to aid in defining neighborhoods. A *census tract* map is keyed to the sample census data tables using the various number codes shown on the tract map (Figure 3). The census tract is a basic unit for compiling census information.

According to the flight information relating to altitude and camera focal length, the scale of the remotely sensed image is approximately 1:54,000. This means that one inch on the map is equal to about 0.85 mile. Because of the radial distortion that ordinarily occurs with photographic lenses, the scale is approximate. The scale generally decreases toward the edges of the photo. The image was recorded on color-infrared film providing a "false color" rendition of the city. Vegetation is rendered as red in this scene, while water features are very dark, and paved surfaces or buildings show up in shades of medium blue to white.

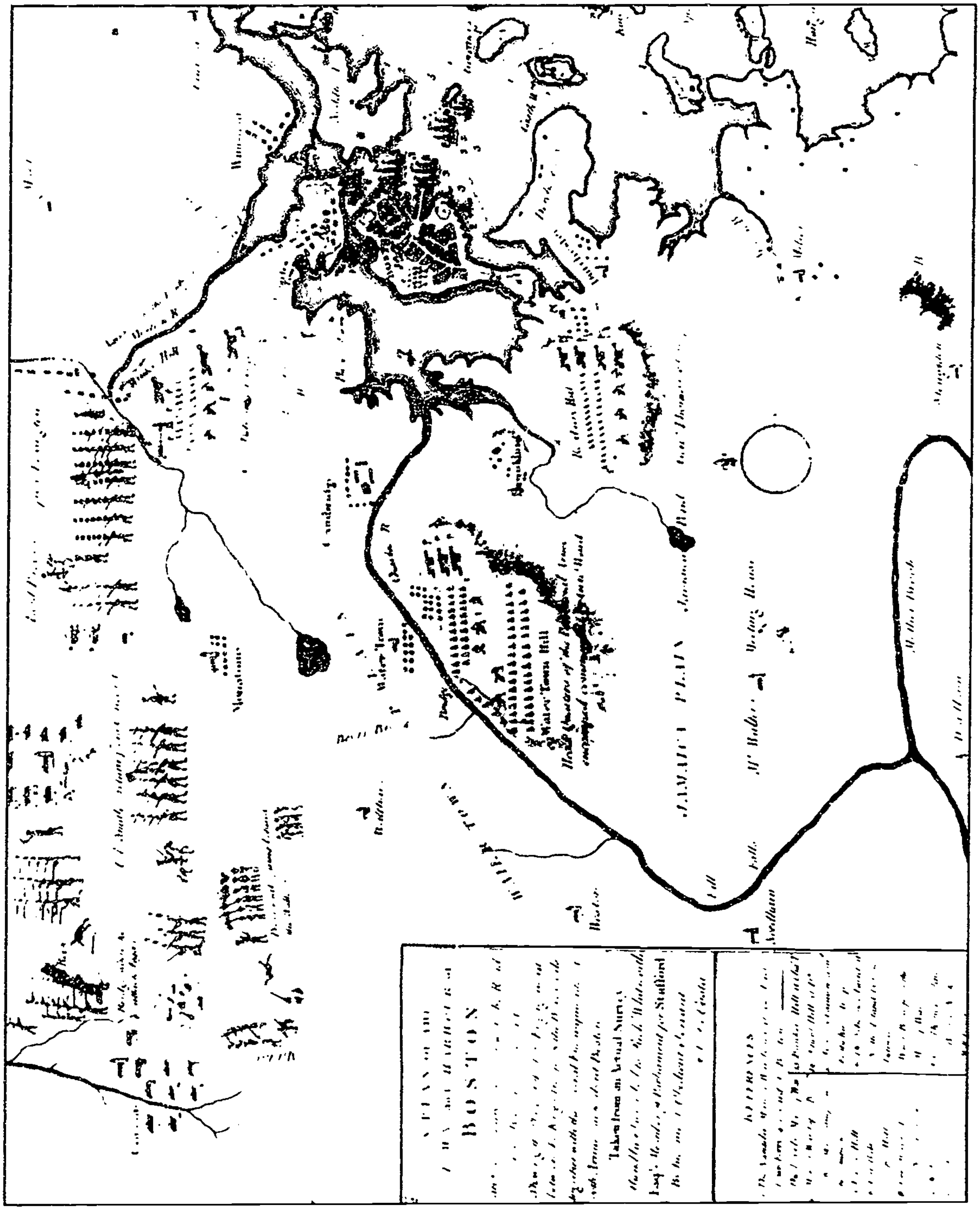

Figure 1: Boston in Colonial Times (DeCosta)

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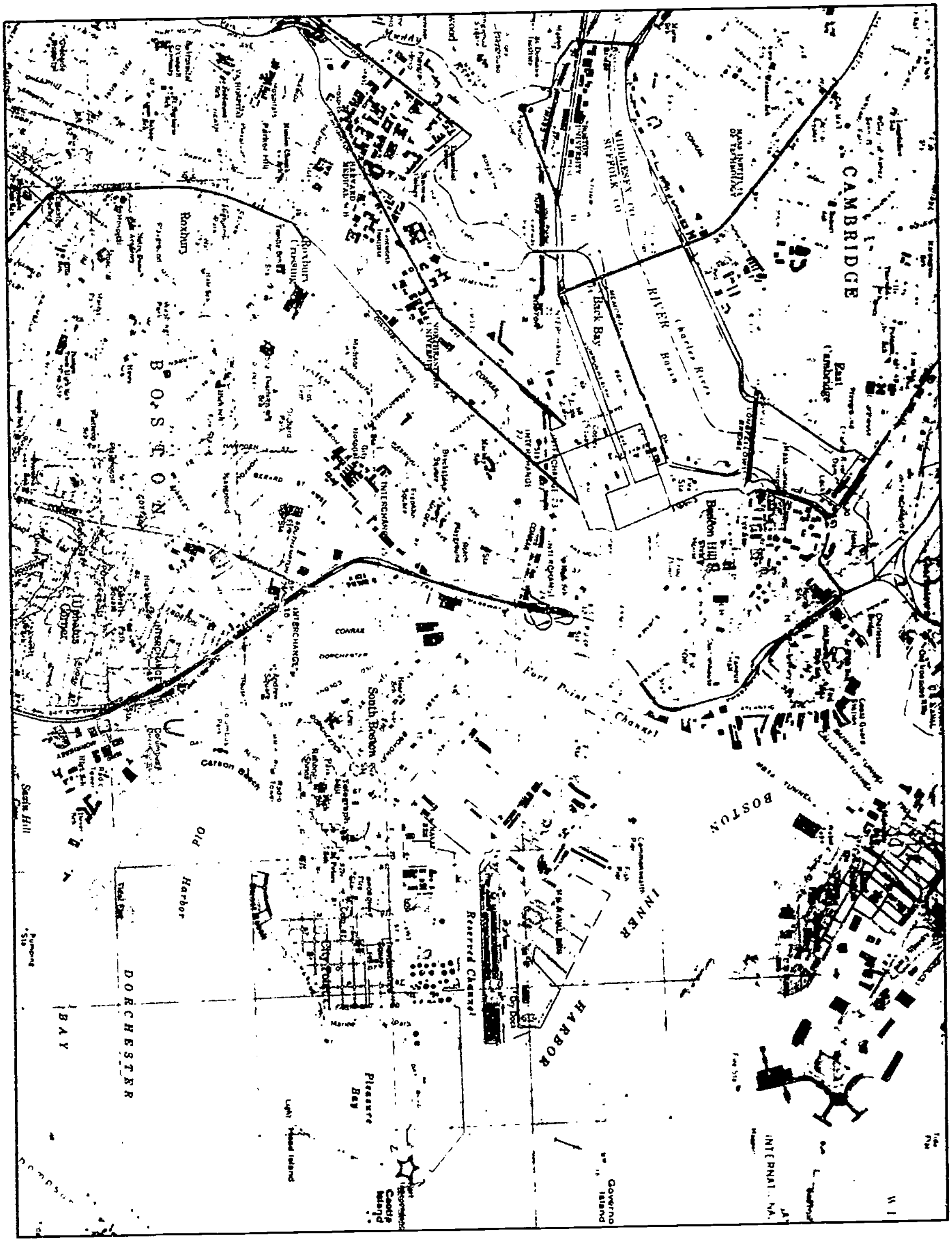

Figure 2: Portion of Boston South Topographic Map, 1979

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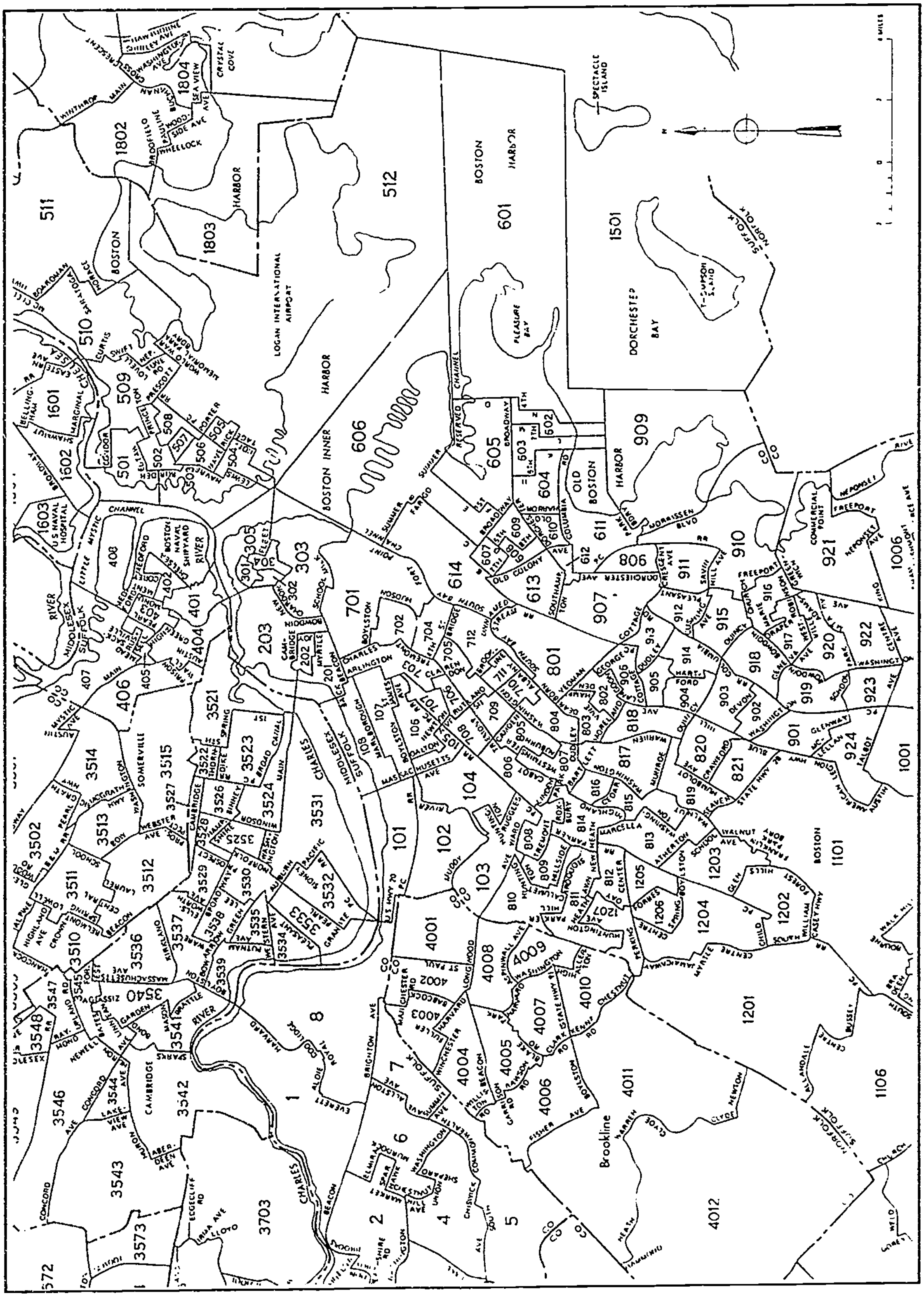

Figure 3: Census Tract Map, Boston, 1970

Executing Activity: At the outset, it is important to provide some principles relating urban geography in general to features found within cities. In particular, the types and geographical arrangements of land use and the basic functions of cities (i.e. commercial, industrial, residential, *transportation*) should be discussed. It is of paramount importance for students to be able to properly translate the false colors in the scene on the image and to identify basic geographic features for orientation. These should be illustrated using both the USGS quadrangle, the historical map, and the aerial photo. The substance of the image can now be addressed in the following ways:

1) Describe the need to fill in wetlands and marshes, resulting in shoreline changes and growth of land area during historic times. Use of the *Historical Atlas of the United States* provides much of the information needed for elaborating on the points below.

2) Describe how the port function of Boston has altered the shoreline. Include the airport in this discussion.

3) Describe how the city is partitioned into different land uses and neighborhoods.

4) Explore the themes of location, place, relationships within places, including human environment relationships, movement, and regions in relation to this image.

5) Use the image, maps, and census data to explore a range of urban and environmental problems. The following questions/problems are examples intended to involve students in identifying important geographic characteristics of cities. They may also serve as a guide to the students' comprehension of the materials. Students may prepare written reports on some specific aspects of the information extracted from the imagery, maps, and census data.

An operational note: A simple overlay technique may be used for student mapping. Use a piece of overhead transparency material or acetate and a fine point marker pen designed to write on film. Have students place the film over the image, carefully marking the corners for proper placement and alignment. This protects the image and provides the student with an opportunity to make various 'thematic' maps. Two or three films can be overlaid to study geographic correlations.

With the aid of the topographic map, or the maps in the *Historical Atlas of the U.S.*, identify the following land and water features and place their names on an individual image overlay or project an overhead transparency of the general shore outline for class participation: Boston Inner Harbor, Charles River Basin, South Bay, Fort Point Channel, Pleasure Bay, Dorchester Bay, Beacon Hill, Back Bay, East Boston, East Cambridge, South Boston, Charlestown.

1. Which bodies of water have been nearly obliterated by landfill operations over the years?

   The main water features from west to east (left to right) are the Charles River Basin, Boston Inner Harbor, and Dorchester Bay. Smaller sections of the inner harbor include Fort Point Channel and Pleasure Bay. The topographic map shows the location of Beacon Hill, and other locations. Examples of water bodies that have been nearly or entirely obliterated are South Bay, Fort Point Channel, and large sections of the Charles River embayment.

2. What three areas of modern Boston were largely underwater during colonial times? Sketch the probable configuration of the old shoreline on the image (use overlay).

   There are actually many areas that could be delineated. Best examples include the Back Bay area (landfill), Logan International Airport (virtually all landfill), and the South Boston area adjacent to Fort Point Channel. Also note the disappearance of Castle and Governor's Islands as islands. Clues to landfill areas on the image include darker tones, straight, angular shorelines and pier structures. Note that the creation of Logan International Airport involved large scale filling.

3. What clues can be found on the image which relate to Boston's colonial heritage? Use the Census tract map to identify these areas (it will be helpful to use a magnifying glass or plastic magnifying sheet).

   Since the oldest areas of Boston are near Beacon Hill (the colonial center of town) and the north end of the city, a pattern of very close, and often irregular street spacing can be detected. These areas lack vegetation (red tones) because of high building density. Such areas coincide with census tracts 202, 301, and 305.

4. How well do the census tracts appear to coincide with distinct patterns of streets and buildings on the image? (Overlay a transparency of the census tract map over a section of photo — they are close to the same scale.)

   The census tract boundaries follow the street patterns except where there is water. Note that few areas of the city have rectangular patterns, but that census tracts clearly define those areas. For example, the Back Bay is mainly defined by areas 107 and 108.

5. What kinds of land use can be identified in South Boston? Identify and map (overlay) them using a color or number code.

   In this case, census tracts may prove to be useful. Note the block patterns of the residential areas in tracts 602, 603, and 604. These represent residential land use. Compare this to the patterns in 605. Circular structures (tanks) and warehouses (large shed-type buildings) indicate p t functions and industrial land use. Note the smoke plume in this area.

   Recreational land use, or park, is revealed by abundance of red tones. Note the historical fort on what was formerly Castle Island (area 601). It also contained a fort in 1775.

6. How is it possible to identify different residential neighborhoods on the image? Characterize three such neighborhoods (census tracts often coincide) using a combination of the census data and information from the image such as street arrangement, street density, and amount of vegetated area (red areas on the image).

   The concept of a "neighborhood" should be discussed. Usually these are urban areas with relatively uniform social and cultural structures, and sometimes they may have similar building types. Ethnic terms are sometimes used to describe neighborhoods. The condition of buildings and social structure may also be used, e.g. slum neighborhood. A contrast would be found among census tracts 305 (North Boston), 108 (Back Bay), and 604 (South Boston). Check the census data in Tables 1 and 2. Tabulate the results of key indicators. Which one of these might be described as an "Italian neighborhood"? Note the population proportions categorized by ethnic origins. Based on the Census of 1970, tract 305 might qualify. A strong Irish component is found in 604, for example. Also note the characteristics of housing units in each area: 108 largely contains apartment houses. 604 typically has three to four family apartment units often carved out of larger, older houses. Note that in area 202, over 95 per cent of the buildings are pre-1939 while in 106 less than half of the buildings are older than 1939. Note too that urban renewal has been taking place with a surge of new buildings in the 1960s. The Back Bay is also "new" land filled in during the nineteenth century. Note how the overall appearance of these census tracts differs on the imagery. One can explore the street pattern and block size as well as the amount of vegetation appearing in each of the tracts.

7. (For advanced study) Compare and evaluate the *density* of buildings and population within a census tract near the city center and one near the southern edge of the image. (Density is a measure of closeness which in geographical terms is equal to the number of objects, people etc. per unit area [Sq. Mi., Sq. Km., acre, etc.].) How does the density relate to the a) historical development of the city, and b) distance from the *Central Business District* or *CBD*? Provide possible explanations.

   *In order to calculate density, area measurements must be available. A qualitative estimate (high, medium, low) may be obtained from the imagery by studying the details of street pattern, building size and distribution, and the amount of vegetation in the area. One would also take into account land use conditions that show up on the image. For a quantitative value of density, the area of each tract can be obtained by outlining the area of interest on either the photo or the topographic map. If the area is rectangular or square, simple plane geometry may be applied. However, this is usually not the case. Thus a simple planimeter * can be used. Since the population for each tract is listed, it will be possible to obtain density values for any number of variables. It would be instructive to construct bar graphs or to enter the data into a computer spread sheet with basic graphic functions. Challenging questions on urban growth and development can be explored with these data and the use of the Historical Atlas of the United States. Transportation issues, now critical in most urban areas, can be addressed since the census tables reveal modes of transportation used, and the aerial imagery shows much of the transportation structure. The density of population and the density of residential units is generally known to decrease with distance from the city center. This reflects the dynamic character of city growth, with the intensification of urban activities in the city center. A simple transect diagram might be constructed to show* *these relationships. Follow a specific line from the CBD area outward and identify density features along that line.*

**Planimeter technique for area estimation: 1) Obtain a copy transparency of a sheet of graph paper with 10-20 squares to the inch. 2) Randomly place the graph transparency on the area of interest. 3) Count the number of squares that fall within the area. 4) Define a rule about squares on the boundary, e.g. count every other one. 5) Note the scale of the map/aerial photo. Since the aerial photo scale works out to 1"=0.85 mi. then one square in. is 0.85 x 0.85 or 0.72 sq. mi. Using ten squares to the inch graph paper, one square unit (one tenth inch) would be equal to .0072 sq. mi. Multiply the number of squares counted by the appropriate factor. Using acres or hectares would alleviate the decimal place problem somewhat.*

Sources:

For an overview of the urbanization process in the Northeastern U.S.,the writings of geographer Jean Gottman are classic. These are:

Megalopolis: The Urbanized Northeastern Seaboard of the U.S., New York: Twentieth Century Fund, 1961.

Megalopolis Revisited: 25 Years Later, College Park, MD: University of Maryland Institute for Urban Studies, 1987.

For historical and descriptive background, a book by Walter M. Whitehall would be useful:

Boston, a Topographical History, Cambridge, MA: Belknap Press of Harvard University Press, 1968.

For information on the workings of the Census, consult:

U.S. Bureau of the Census, *Census Geography - Concepts and Products*, CFF No. 8 (Rev.) (Additional Boston census information can be obtained by calling 617/421-1440), 1991.

Table 1: Social Characteristics of the Population, 1970
Boston Selected Census Tracts

Census Tracts	Tract 0106	Tract 0107	Tract 0108	Tract 0201	Tract 0202	Tract 0203	Tract 0301	Tract 0302	Tract 0303
All persons	1 830	7 266	6 277	5 443	3 940	4 285	3 204	1 911	952
Native of native parentage	1 043	5 647	4 621	3 904	2 466	2 656	1 195	518	594
Native of foreign or mixed parentage.	514	1 019	1 067	1 066	926	1 070	1 045	705	271
Foreign born	273	600	589	473	548	559	964	688	87
Foreign stock	787	1 619	1 656	1 539	1 454	1 629	2 009	1 393	358
United Kingdom	134	156	180	131	124	166	13	--	83
Ireland (Eire)	35	231	117	120	189	176	--	15	24
Sweden	19	9	29	37	21	5	--	--	--
Germany	29	155	62	84	103	84	--	--	--
Poland	11	50	137	78	71	102	5	--	14
Czechoslovakia	--	8	26	30	7	--	--	--	--
Austria	--	35	20	23	57	5	--	--	--
Hungary	11	47	7	19	15	--	--	--	--
U.S.S.R.	135	94	194	167	106	199	--	--	37
Italy	89	101	141	110	188	254	1 839	1 318	104
Canada	119	326	335	286	201	268	18	9	55
Mexico	--	--	--	--	--	--	--	--	--
Cuba	9	14	23	6	7	--	--	--	--

Census Tracts	Tract 0304	Tract 0305	Tract 0512	Tract 0601	Tract 0602	Tract 0603	Tract 0604	Tract 0605	Tract 0606
All persons	3 033	1 916	3 074	4 311	2 664	4 083	6 061	4 750	989
Native of native parentage	936	521	1 659	2 591	1 649	2 502	3 450	3 171	699
Native of foreign or mixed parentage.	1 129	674	956	1 349	790	1 193	1 806	1 277	166
Foreign born	968	721	459	371	225	388	805	302	124
Foreign stock	2 097	1 395	1 415	1 720	1 015	1 581	2 611	1 579	290
United Kingdom	15	--	42	117	39	135	76	133	6
Ireland (Eire)	33	23	45	798	376	394	956	496	40
Sweden	--	--	11	13	14	53	7	8	--
Germany	--	--	--	35	35	8	45	5	--
Poland	6	18	--	7	24	52	68	15	53
Czechoslovakia	--	--	--	4	--	--	--	--	--
Austria	--	7	6	4	--	7	18	25	--
Hungary	--	--	--	--	--	--	--	--	--
U.S.S.R.	21	--	7	19	--	17	21	14	--
Italy	1 924	1 229	987	227	91	267	318	333	63
Canada	30	9	114	184	142	339	388	296	34
Mexico	--	--	--	--	--	--	--	--	--
Cuba	--	--	4	--	--	--	13	--	--

Source: U.S. Census Bureau

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Table 2: Characteristics of Housing Units, 1970
Boston Selected Census Tracts

Census Tracts	Tract 0106	Tract 0107	Tract 0108	Tract 0201	Tract 0202	Tract 0203	Tract 0301	Tract 0302	Tract 0303
All year-round housing	1 277	4 042	3 442	3 404	2 474	2 708	1 274	781	591
UNITS IN STRUCTURE									
1 (includes mobile home or trailer)	15	58	99	318	98	29	22	--	9
2	--	35	17	64	23	29	18	25	5
3 and 4	70	231	138	514	511	188	501	396	63
5 to 49	273	3 520	3 009	2 279	1 621	1 067	716	355	147
50 or more	919	198	179	229	221	1 395	17	5	367
YEAR STRUCTURE BUILT									
1969 TO March 1970	13	5	6	12	--	6	--	7	--
1965 to 1968	754	10	93	5	--	598	--	5	143
1960 to 1964	29	5	60	10	--	740	9	5	5
1950 to 1959	5	20	75	165	6	69	6	--	4
1940 to 1949	--	93	60	106	41	5	39	7	7
1939 or earlier	476	3 909	3 148	3 106	2 427	1 290	1 220	757	432

Census Tracts	Tract 0304	Tract 0305	Tract 0512	Tract 0601	Tract 0602	Tract 0603	Tract 0604	Tract 0605	Tract 0606
All year-round housing	1 317	764	1 128	1 470	954	1 435	2 121	1 768	452
UNITS IN STRUCTURE									
1 (includes mobile home or trailer)	35	7	111	174	68	269	431	229	91
2	22	6	180	260	279	305	463	310	43
3 and 4	547	261	719	740	535	786	988	1 036	262
5 to 49	703	482	106	291	74	75	124	193	56
50 or more	10	--	12	5	--	--	115	--	--
YEAR STRUCTURE BUILT									
1969 TO March 1970	--	--	--	--	--	--	11	--	--
1965 to 1968	--	--	--	105	--	--	36	--	--
1960 to 1964	--	--	12	14	--	4	108	--	--
1950 to 1959	12	4	11	53	21	11	22	10	--
1940 to 1949	13	--	10	123	33	30	33	60	--
1939 or earlier	1 292	772	1 095	1 175	900	1 390	1 911	1 698	452

Source: U.S. Census Bureau

STUDYING THE REGIONAL GEOGRAPHY OF THE AMERICAN PLAINS USING LANDSAT THEMATIC MAPPER IMAGERY

M. Duane Nellis and Stephen L. Stover

Introduction: This instructional unit introduces students, through Landsat satellite views of northeast Kansas, to the regional geography of a portion of the North American Plains. More specifically, through use of the five organizing geographic themes (location, place, human-environment interaction, movement, and region), the unit provides students with an understanding of the cultural and physical landscape of a portion of one of the most productive agricultural areas in the world.

Grade Level: 9-12, introductory college

Time required: Approximately two fifty-minute class periods.

Specialized Geographic Vocabulary:

dendritic drainage pattern	scale
floodplain	section
Interior Lowland	tall grass prairie
local relief	township
Plains	U.S. Public Land Survey (rectangular)
reservoirs	

Objectives:

Knowledge:

a) To become familiar with the geography of the Interior Lowlands by applying the themes of location, place, human-environment interaction, and region.

b) To gain some understanding of the relationship between the cultural landscape and environmental conditions.

Skills:

a) To identify and analyze cultural and physical geography features on the earth's surface using satellite imagery.

b) To relate information found on a satellite image to information on a map.

c) To analyze the differences between satellite data recorded using visible light versus infrared energy.

Materials:

a) False-color and visible satellite images recorded in September 1982, using the Landsat thematic mapper sensor (Required).

b) United States Geological Survey (USGS) 1:250,000 scale topographic map of Kansas City (Recommended).

The Learning Activity:

Background Information: "There is nothing there," or "it's flat as a pancake," are typical phrases used by some when they hear the name Kansas. Certainly parts of Kansas do not possess grand spectacles of nature or sprawling cities, but a close look reveals a fascinating physical and cultural landscape for this portion of the North American Plains. Kansas is divided into two major physiographic provinces: the Great *Plains* (to the west), and the *Interior Lowlands* (to the east). A physiographic province is a region with similar landform features. A closer look reveals an even more complex physical landscape (Figure 1).

The Landsat images (both of the same area and recorded at the same time) are of northeast Kansas, a portion of the Interior Lowlands (Figure 2). The Interior Lowlands drain the greatest rivers of the continent--the Missouri, Mississippi, and Ohio. The images include the Kansas River, a tributary of the Missouri river. The Kansas River extends across the images from east to west (just over half way up the imaged area). The Missouri River cuts across the northeast corner of the imaged area. *Local relief* (the difference in elevation between the highest point and lowest point in a local area) varies from 50 to 300 feet. The greatest amount of local relief in the imaged area is in the Flint Hills of Kansas (left hand edge of the images), an area of cherty limestone that is more resistant to erosion.

The northeast Kansas region is part of the humid continental climatic type. Annual precipitation generally exceeds 30 inches, with peak rainfall months occurring in May and June.

One of the Landsat thematic mapper images of northeast Kansas is displayed in natural color (based on variations of blue, green and red light — much like a photograph you would take with your camera), while the other northeast Kansas Landsat image is a false-color composite using green, red, and near-infrared energy. In the false-color scene you will notice that the vegetation appears as various hues of red. This is because healthy vegetation reflects a high level of infrared which is depicted as red in color on the image (thus the name "false color"). Objects reflecting high levels of red appear as green, and those objects reflecting green appear as blue. Since vegetation has a higher reflective response in the infrared range over the green range of light energy, the infrared sensor picks up this intense response and depicts the vegetation as red. Because false-color composites generally provide a greater range of detail than natural color, the false-color image will be the image referenced in the remainder of this background section.

You will also note that some of the water bodies are black in color on the false-color composite image. This is because relatively pure water, which reflects blue on normal color film, is displayed as black on color infrared composite displays. If water appears light blue on the

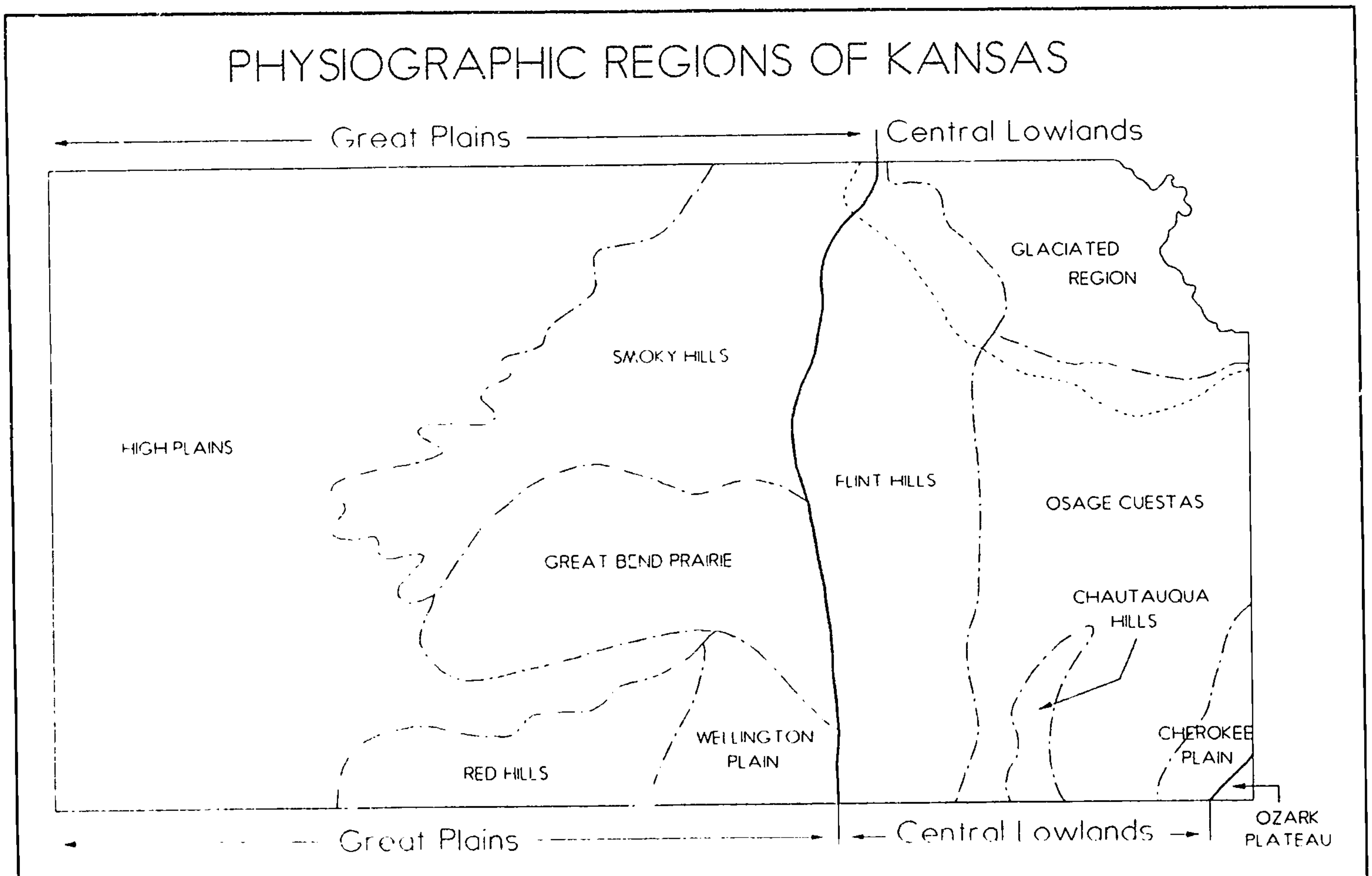

Figure 1: Major Physical Landscape Units of Kansas (Self, 1978)

79 80

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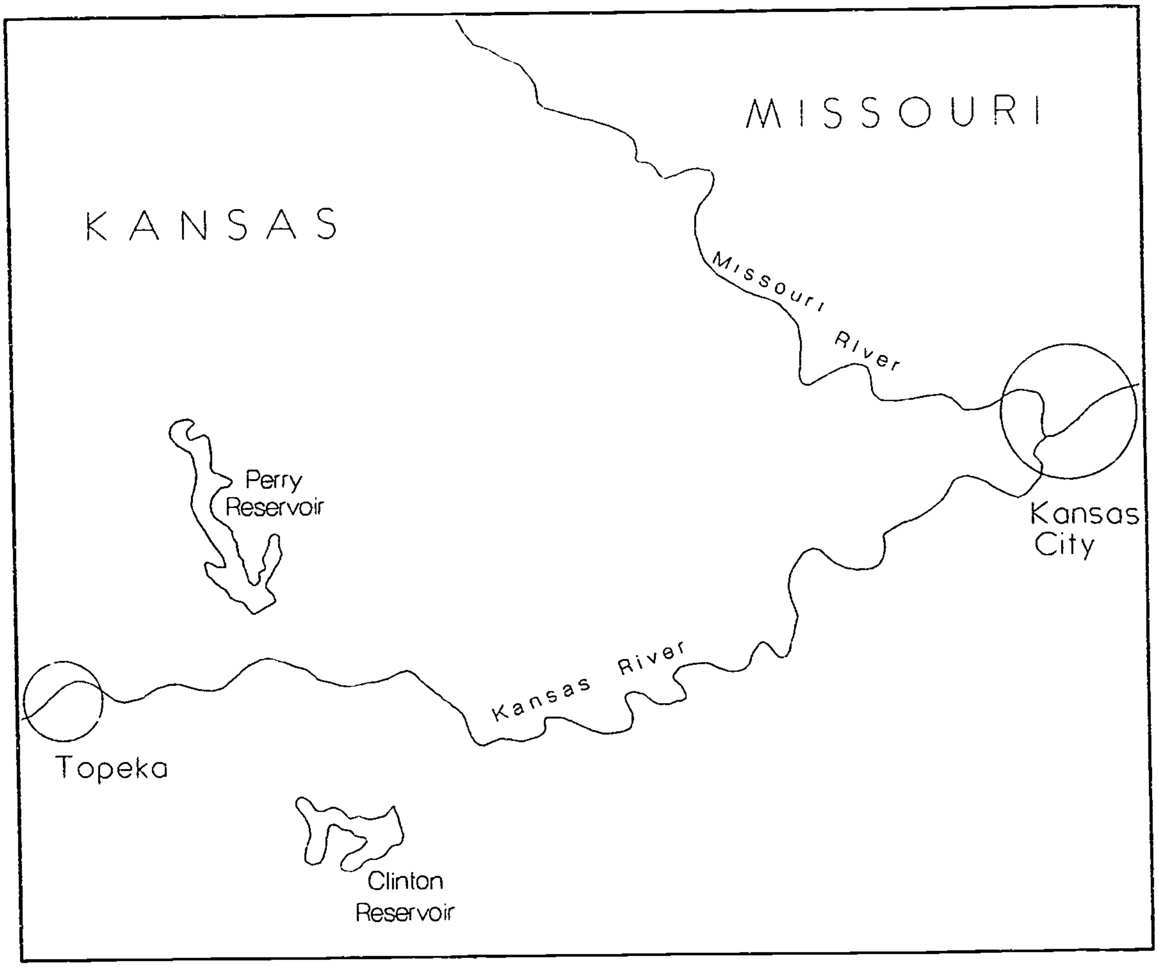

Figure 2: Area Covered by the Landsat Thematic Image

infrared image, it likely has a high level of suspended sediment. In this region there are a few federal earthen dams and *reservoirs* built by the U.S. Army Corps of Engineers to control flooding, as well as to provide recreational opportunities. The surface reflectivity of Perry Reservoir, for example, differs considerably from Clinton Reservoir because of differences in their levels of suspended sediment. Perry Reservoir has a light blue color which suggests a higher level of suspended sediment than in the Clinton Reservoir. This is due to the larger proportion of cultivated land in the Perry Reservoir watershed (the region that drains into this particular lake). That Perry Reservoir is a dozen years older also helps explain the difference in accumulated sediment, but this cannot be substantiated from the image.

Many of the rural land use patterns of the imaged area, as indeed, throughout the middle and western United States generally, bear the influence of the *U.S. Public Land Survey*. Rectangularity is especially apparent in road and field patterns; less in rangeland than in cropland. Roads in plains farm country follow section lines which bound the surveyed square miles. Since these roads often show up on satellite imagery (light blue grid pattern), they provide a means for measuring the *scale* (the relationship between distance on the image and true ground distance) of an image, or for determining distance between points of interest. Each six by six mile area (or 36 sections) represents a *township*. *Sections* (one square mile or 640 acres) and townships were commonly used units of land measurement in the process of land transfer from federal government control to private ownership during the settlement period.

Cultivated land in this region is primarily devoted to wheat, alfalfa, sorghum, corn, and soybeans. The bright red hues along the Kansas River *floodplain* and interspersed throughout the Landsat images are areas of crop growth (probably alfalfa, soybeans, corn, and sorghum, since this is a September image). Some fields appear as light green color and represent bare soil areas. These are fields plowed in preparation for the planting of winter wheat. Winter wheat, the primary wheat grown in the United States for bread, is planted in the late fall, and harvested in late spring.

In places, *riparian* (adjacent to a stream) deciduous *woodland* (e.g. oak, walnut, hickory, and hackberry) show up as dark red bands along the various streams or rivers. They serve as an important habitat area for wildlife and as a buffer from surface erosion related to cultivated fields.

In contrast to cropland, areas of native pasture show less rectangularity and more conformity to the *dendritic* (tree-like) *drainage pattern*. These areas have a less intense red to brown color. Differences in stocking rates for grazing animals (number of animals per unit area), in burning practices, and in soil types all contribute to the variations in color (spectral response) on the false-color composite. The Kansas Flint Hills, a major region of livestock grazing and one of the few remaining expanses of *tallgrass prairie* in North America, occupies approximately the western fourth of the image. These native grasslands, generating less biomass than woodlands and cropland, reflect less strongly (are not as bright red). Some of the pastureland's color variability may be related to the fact that portions of the Flint Hills are burned on an annual basis in an attempt to enhance the quality of the pastureland. Burning of fields usually occurs in late March or early April.

Urban areas are distinguishable by their lighter hues (light blue to white color) and their contextual relationship to transportation facilities. The two largest urban areas in the image are Topeka (just west of the image center) with a population of about 120,000, and Kansas City (east edge of image) with a metro population of 1.6 million. The relationship between transportation and settlement is well shown in the case of Kansas City, at the confluence of the Kansas River with the Missouri River. Interstate highways and airports, other dimensions of transportation, are also evident on the image. Just north of Kansas City, for example, is Kansas City International Airport (triangular shape and light blue color). Interstate 70 is visible in several areas between Kansas City and Topeka (again a light blue color).

Executing Activity: After reviewing the five themes of geography with your students, and providing them with the background to the imaged area of northeast Kansas, have them apply the five themes to the region covered by the Landsat image. Use the U.S.G.S. topographic map as necessary in locating specific features on the image.

1. What is the absolute and relative *location* of the imaged area?

   The absolute location is northeast Kansas; the relative location is the central United States, or using the physiographic province — Interior Lowlands.

2. Describe the image area as a *place*.

   Physically, the imaged area is part of the Interior Lowlands with local relief varying from 50 to 300 feet. Climate is humid continental. Natural vegetation varies from tallgrass prairie to deciduous woodlands. Drainage is in a dendritic pattern, but has been modified by earthen dams constructed by the U.S. Army Corps of Engineers.

   Human characteristics impacting the imaged area include the (rectangular) U.S. Public Land Survey, and rural land use practices (see background section).

3. Describe evidence of human-environmental interaction for the imaged area.

   Earthen dams and reservoirs constructed to control flooding; cropland in lower local relief areas; transportation systems follow river floodplains in several areas.

4. Are there indications of *movement* in the imaged areas?

   Airports, highways, and rivers.

5. How would you characterize the imaged area as a *region*?

   Agriculture is important to the local economy; the terrain is rolling. Native vegetation (grasses) indicates soil and climate resources favorable for grain agriculture. (See background for additional points about the region).

6. Have students prepare a table (see below for example) with a list of different landscape features (e.g., water, cropland, idle land, woodland, urban land, etc.). Have them identify the color of the feature as it appears on the natural versus the infrared image. After the students have prepared the table, have them discuss the reasons for the differences in color and clarity of features on the natural color relative to the infrared image.

Landscape Feature	Color on Natural Color Image	Color on Infrared Image
Cropland	Green	Red
Water	Blue	Black-Light Blue

Sources:

Buchanan, R. and J. McCauley. *Roadside Kansas*. Lawrence: University Press of Kansas, 1987.

Ham, G. and R. Higham (eds). *The Rise of the Wheat State*. Manhattan: Sunflower University Press, 1987.

Self, H. *Environment and Man in Kansas: A Geographical Analysis*. Lawrence: Regents Press of Kansas, 1978.

Part II: How Does Remote Sensing Work?

REMOTE SENSING: AN INTRODUCTION

Paul R. Baumann

What is remote sensing?

The term "remote sensing" possesses several recognized definitions; however, in its broadest meaning, remote sensing is the science and art of obtaining knowledge about phenomena from a distance. This definition could include the use of one's own senses of sight, smell, and/or hearing. At a more technical level, remote sensing deals with the detection and measurement of phenomena with devices sensitive to electromagnetic energy such as light (cameras), heat (thermal scanner), and radio waves (radar images). Nonelectromagnetic energy such as force fields (magnetometers and gravity meters) and sound waves (sonar) has generally been omitted from the definition of remote sensing, but some strong arguments exist for its inclusion. Geographers, like other earth scientists, use remote sensing to view and study the Earth's physical and cultural landscapes from aerial or space platforms; thus, for the purpose of this volume, only the electromagnetic spectrum of remote sensing will be considered.

For a remote sensing system to function, a source of radiant energy (terrestrial energy via solar energy), a propagating medium (atmospheric transmission), and an energy detector (sensor) are needed (Figure 1). The source of energy may be emitted directly from a phenomenon (e.g.,

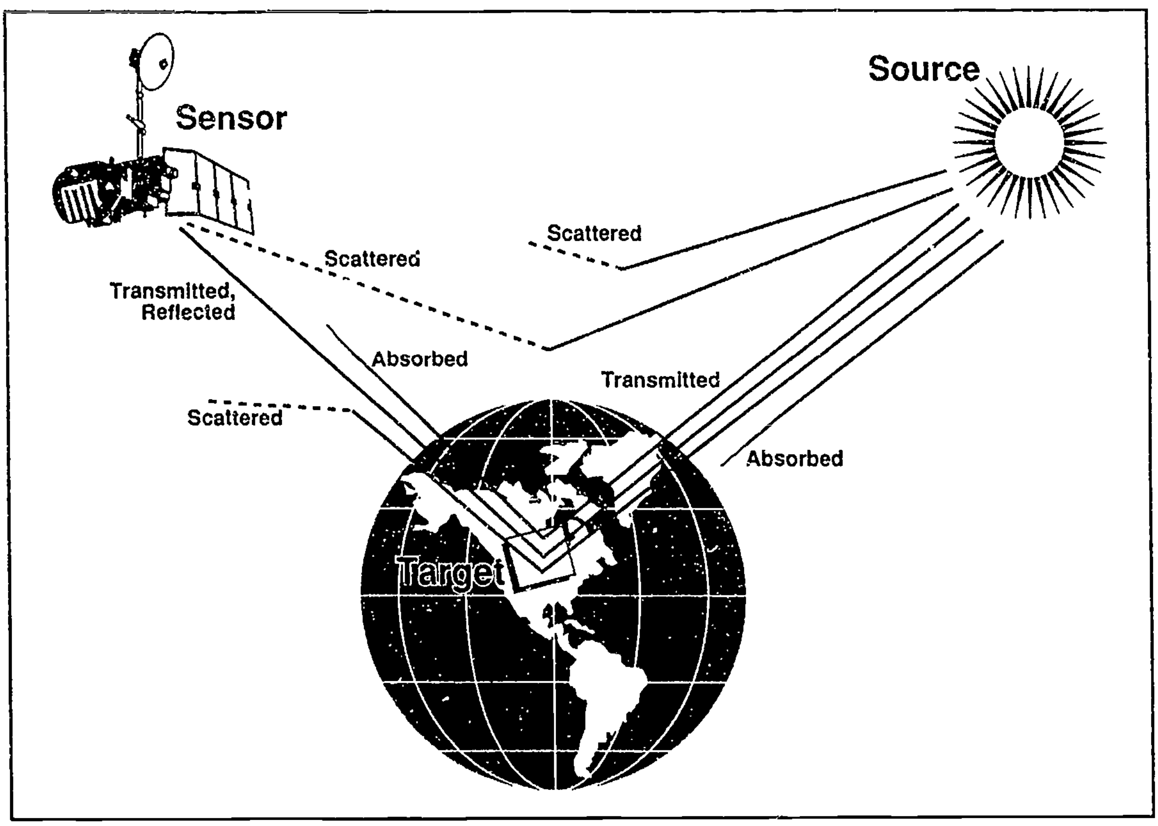

Figure 1: Satellite Remote Sensing

thermal energy from a forest fire) or be reflected/backscattered (e.g., sunlight off buildings). The propagating medium is usually the atmosphere, which is a heterogeneous medium with different effects on electromagnetic energy.

Sensor systems can be grouped in two different ways: active or passive, and photographic or digital. An active sensor both transmits the electromagnetic signal and receives the backscattered/reflected signal (radar). A passive sensor only receives signals and requires a separate source of energy. Most remotely sensed data are obtained by passive sensors such as cameras, thermal scanners, and multispectral scanners. A photographic sensor records electromagnetic radiation on film as an image and is a photo-optical system. A digital sensor employs an electro-optical system to transform electromagnetic radiation into an electrical signal that can be amplified, recorded, and converted to digital values.

Historical Summary

Although the term "remote sensing" was first introduced in the early 1960s, remotely sensed imagery from electromagnetic energy was first obtained in 1839 with Daguerre's invention of light-sensitive copper plates. Certain geography-related applications of photography were quickly realized, with the French starting to use this new technology in the 1840s to develop topographic maps, and the Americans employing it during the Civil War for military reconnaissance. Before the end of the 19th century, color photography, stereo-photography, and multispectral cameras were becoming available. The 19th century also saw the use of various aerial platforms to carry photographic equipment aloft. Early aerial photographs showing the urban patterns of Paris and Boston were taken from balloons; the English, French, and Russians all sent cameras airborne on kites; and the Germans used miniature cameras attached to trained pigeons to obtain pictures of the Bavarian landscape. However, the airplane, being more stable and versatile, quickly became the principal platform for aerial photography.

With the two World Wars and other military actions of the 20th century, remote sensing, mainly in the form of black and white aerial photography, steadily advanced in importance and as a science. In addition to the military, other U.S. Government agencies as well as state and local governments made extensive use of aerial photography for agricultural, forestry, geological, and land use planning purposes. Faster films and better color photography techniques were developed which increased the utility of remote sensing. The expansion of the photographic portion of the electromagnetic spectrum beyond the visible range into the shorter ultraviolet wavelengths and the longer infrared wavelengths provided imagery containing information not detected by the human eye. Color infrared soon followed and became popular through the introduction of new applications for military, forestry, and agricultural uses. By having films and lens filters designed to handle different portions of the spectrum (see Figure 3), multispectral photography developed where several cameras working in unison took aerial photographs of the same area at the same time in various portions of the spectrum.

With the introduction of thermal infrared scanners and all-weather active systems utilizing microwaves generated and beamed at a target through radar, nonphotographic sensors expanded the remote sensing realm into emitted radiation. These developments provided the possibility of obtaining quantitative as well as qualitative information about images. This path has led remote sensing into a highly specialized and digitally based technology.

In 1912, the Germans launched a gyro-stabilized camera mounted on a rocket. Space pictures were obtained in 1946 from V-2 rockets launched at the New Mexico White Sands Proving Ground; however, it was not until 1960 with the introduction of the meteorological satellite, Tiros I, that earth observations from space were made on a systematic basis. Since then, a progression of meteorological satellites such as the Nimbus, ATS, and ESSA have transmitted images of the earth. During the same time period, manned satellites (Mercury, Gemini, and Apollo) were involved in color and multispectral photographic experiments which revealed outstanding physical as well as cultural landscape patterns on the earth's surface. The combination of these technical advancements and photographic accomplishments led to the launching in 1972 of the first Landsat, initially known as ERTS-1 (Earth Resources Technology Satellite). Landsat, devoted to civilian mapping and monitoring of the earth's resources, became the first space platform to provide digital and multispectral images on a systematic basis.

The success of Landsat 1 led to the launching of two almost identical platforms in 1975 and 1978, known as Landsats 2 and 3, respectively. In 1982, Landsat 4 was placed into operation followed by Landsat 5 in 1985. In addition to the multispectral scanner (MSS) used on the first three satellites, Landsats 4 and 5 included the Thematic Mapper (TM) which 1) recorded reflectance data at a 30 x 30 meter ground resolution rather than the 56 x 79 meter MSS resolution, 2) collected data for seven bands including a thermal infrared band within the electromagnetic spectrum versus the four MSS bands, and 3) had specific bands designed to detect certain land cover conditions rather than general bands. These two satellites are still in use.

Today, operational remote sensing satellite systems are maintained by France, Japan, India, and Russia in addition to the United States. The French system is called SPOT (Satellite Pour l'Observation de la Terre) and was launched in 1986. This system can provide: 1) 10 meter resolution coverage in a broad panchromatic band and 20 meter resolution in three multispectral bands, and 2) oblique views up to 27 degrees from nadir, which allows for more frequent coverage of particular geographic areas and enables stereoscopic image pairs. SPOT 2 and 3 are now operational and one more satellite in this series is planned. In 1987, both Japan and India launched remote sensing satellites. The Japanese MOS-1 (Marine Observation Satellite) carries three systems: 1) a 50 meter resolution system with similar bands to the Landsat MSS; 2) a visible and thermal infrared system; and 3) a passive microwave instrument. India's IRS-1 satellite operates in the same wavebands as SPOT and can capture 73 and 36.5 meter resolution images simultaneously. Other experimental platforms have been used and a number of countries are designing their own systems to meet their own economic and environmental concerns.

The Electromagnetic Spectrum

The term "electromagnetic spectrum" has already been used several times in this introduction and some of the authors refer to it in their modules. What is the electromagnetic spectrum? It is a continuum of all electromagnetic waves arranged according to frequency and wavelength. The sun, the earth, and other bodies radiate electromagnetic energy of varying wavelengths. "Light" is

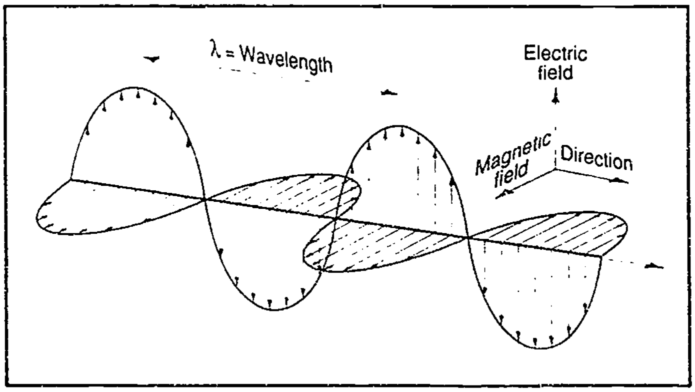

Figure 2: Wavelengths

a particular type of electromagnetic radiation that can be seen and sensed by the human eye. Electromagnetic energy passes through space at the speed of light in the form of sinusoidal waves. The length of a wave is the distance from wavecrest to wavecrest and its frequency is determined by the number of wavecrests passing a given point per second (Figure 2). The micron (μm) is the basic unit for measuring a wavelength with respect to the electromagnetic spectrum and a single μm = 10^{-6}m. The spectrum is divided into sections based on wavelength starting with the short gamma rays and ending with the long radio waves.

Visible light consists of the narrow portion of the spectrum ranging from 0.4 (blue) to 0.7 (red) μm. This is the only portion of the spectrum which the human eye can sense. Since most of the images discussed in this volume are from Landsat sensors, the spectral bands for the Landsat MSS and TM are identified on Table 1.

Table 1: Landsat MSS and TM Bands (μm)

Band	1	2	3	4	5	6	7
MSS	.50-.60	.60-.70	.70-.80	.80-1.10			
TM	.45-.52	.52-60	.63-69	.76-.90	1.55-1.75	2.08-2.35	10.4-12.5

Electromagnetic energy can be sensed only through its interaction with matter. When energy strikes matter, it is reflected, transmitted, absorbed, or scattered by the matter. Matter can also emit energy previously absorbed or generated internally. The nature of matter plays a key role in how it will interact with electromagnetic energy. The face of the earth-matter varies considerably with the different land and water surfaces, and the atmosphere around the earth, another form of matter, contains a variety of gases, water droplets, and dust. The atmosphere is the medium through which electromagnetic energy passes as it journeys from the sun to an earth target and then to a satellite sensor. This medium transmits, absorbs, and scatters energy. Energy which is transmitted through the atmosphere reaches a sensor unaltered; however, energy which is absorbed and warms the atmosphere is altered spectrally when re-emitted. Scattered energy is unpredictable in terms of its direction, and when light is scattered by atmospheric particles and molecules, haze results, and thereby, diminishes image clarity. Visible and infrared wavelengths generally move through the atmosphere with little scattering. Portions of the spectrum where wavelengths encounter little scattering are referred to as "atmospheric windows" and represent the best areas for obtaining remotely sensed images. Not all portions of the spectrum can be utilized for remote sensing (Figure 3).

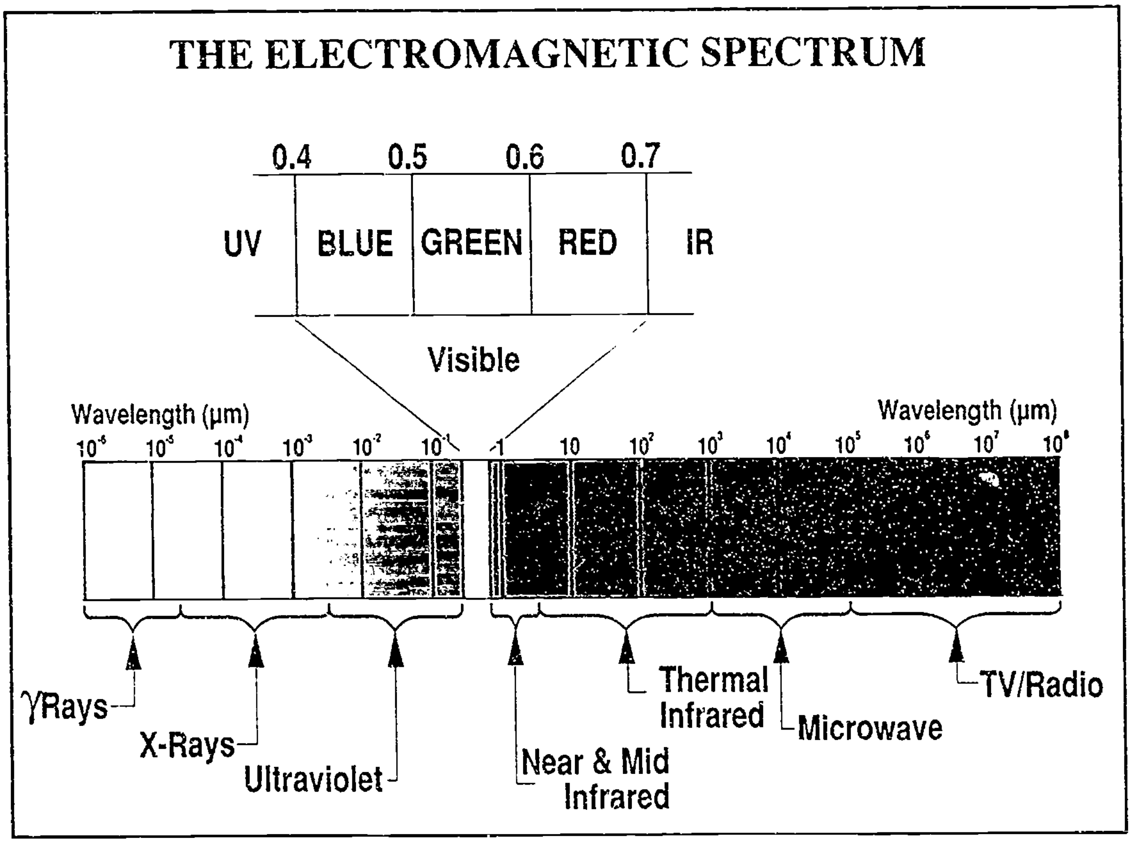

Figure 3: The Electromagnetic Spectrum

Landsat and SPOT

Since 1972, Landsat satellites have orbited the earth continuously, imaging nearly every section of the planet's land mass. More than 3.1 million images have been collected and archived from this system. Another 2.0 million images have been recorded since 1986 from the SPOT satellites. Landsat and SPOT are the two major commercial satellite systems in operation and images from these systems are appearing more and more in textbooks and popular magazines found in school libraries. Students viewing these images should possess some basic knowledge of how these systems work.

Both the Landsat and Spot satellites have repetitive, circular, sun-synchronous, near-polar orbits. A sun-synchronous orbit means that the satellite's orbital plane precesses about the earth at the same angular rate that the earth rotates. This feature enables the spacecraft to cross the equator at the same local time (about 9:30 to 10:00 a.m.) on the sunlit side of the earth (Figure 4). Thus, east facing surfaces will receive the morning sun and west facing surfaces will be in the shadow. Many of the brighter portions of an image might be east facing slopes, particularly in hilly or mountainous areas. A near-polar orbit makes it difficult, and in some cases, impossible to obtain imagery in the polar latitudes during periods of low sun.

The orbit altitude for Landsats 4 and 5 varies from 696 km (432.2 miles) to 741 km (460.1 miles), depending on orbit irregularities and the earth's nonspherical shape. Highest altitudes

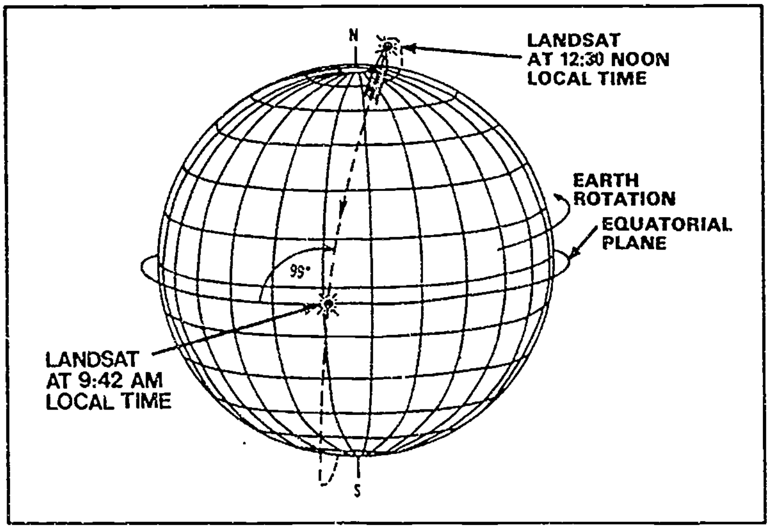

Figure 4: Landsat Spacecraft Orbit

occur over the North and South Poles; minimum altitudes over the equator. The standard altitude is 705.3 km (438 miles). The earlier satellites, Landsat 1-3, had a nominal altitude of 917 km (570 miles). The change in altitude was made to accommodate the higher ground resolution associated with the TM sensor and to increase how often a satellite crosses over a given geographic area. For Landsats 4 and 5, each trip around the earth takes 98.9 minutes, with 14 9/16 orbits completed each day. After each 16 days, the satellites cross over the same area. It took 18 days for Landsats 1-3 to return to a given area. The SPOT satellites have a nominal orbit altitude of 832 km (517.1 miles) and repeat the same ground path every 26 days. This long repeat interval is compensated by the off-nadir capability of the SPOT satellites.

As the earth rotates under the orbiting satellites, the orbit's path moves from east to west around the world. If, as illustrated in Figure 5, the first orbit for a particular day crosses over eastern United States, the next orbit on that same day will be over the Great Plains. This pattern is repeated around the world. Also, as indicated in Figure 5, the area immediately to the west of the first day orbit will be covered by the satellite on the next day and the area to the east will have been viewed the preceding day. At the equator, a 26 km (16 miles) sidelap in coverage exists between adjacent orbits. The amount of sidelap increases at the higher latitudes, to approximately 57 percent at 60^{o} N and S Latitude. The sidelap at higher latitudes permits stereoscopic viewing and a greater potential for monitoring change for certain areas over a one day period. Environmental conditions within a sidelap area can change radically from one day to the next day, which can also make it difficult to use adjacent images for stereoscopic purposes.

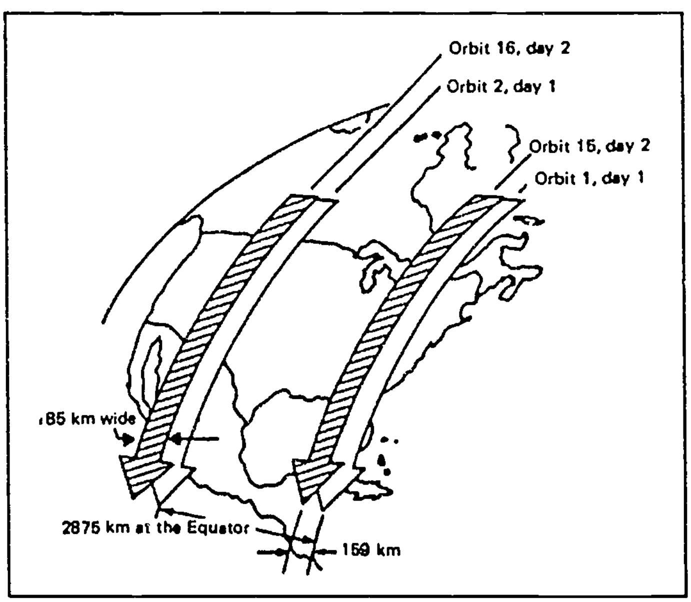

Figure 5: Landsat Ground Coverage Pattern

SPOT has two identical high resolution (HRV) imaging sensors which can be programmed to function at both nadir and off-nadir settings. The off-nadir capability allows the satellites to reach out to areas 27^{0} relative to the vertical path, or 475 km (295 miles) to either side of the ground track. With this capability the sensors can revisit a given area at the equator 7 times during the satellite's normal 26 day flight cycle and 11 times at a latitude of 45^{0}. Another important application offered by the HRV sensors' off-nadir viewing ability is that of recording stereoscopic pairs of images at the same time, rather than a day apart as with the Landsat satellites. The main uses for stereoscopic imagery are in photogrammetry and photo-interpretation.

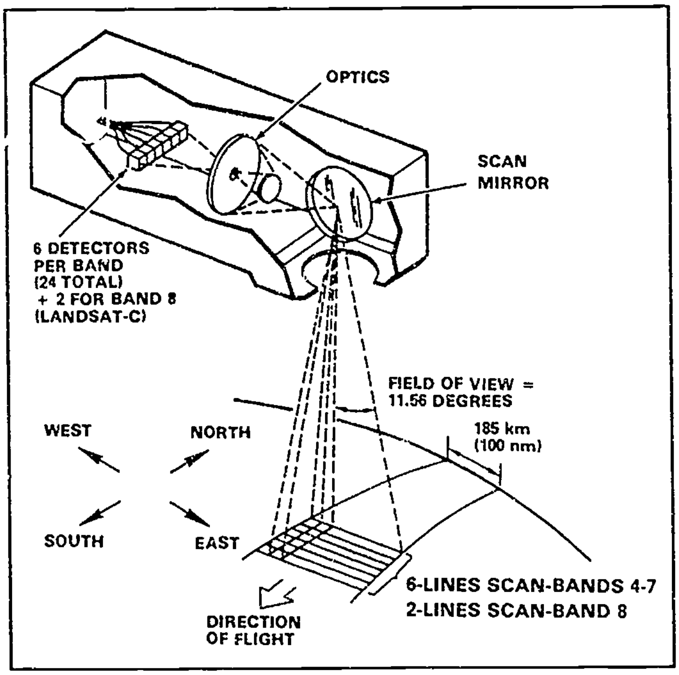

Figure 6: Landsat MSS Scanner Operation

Landsat sensors are line scanning devices that scan the earth's surface in a swath perpendicular to the satellite's flight path. Scanning is accomplished in a west-to-east direction by an oscillating mirror. The mirror detects reflected sunlight from the surface and transfers this sunlight through filters that separate the reflected energy into different spectral bands (Figure 6). A scan line is divided into ground resolution units which vary in size depending upon the sensor being used. The sizes of these ground resolution units for the TM and MSS sensors were previously indicated.

The SPOT HRV instruments employ a "pushbroom" scanning mode which eliminates any moving mechanical parts such as those associated with line scanning devices. Each line of the image is electronically scanned by a linear array of detectors situated in the instrument focal plane, and successive lines of the image are produced as the array of detectors are pushed along due to the satellite moving down its orbit. The SPOT 20m MSS sensor requires an array of 3,000 detectors per spectral band over a 60 km wide path and a recording is taken every 3 milliseconds. The 10m panchromatic sensor takes 6,000 detectors per line which are sampled every 1.5 milliseconds.

Each satellite orbital path is divided into 248 rows and each path/row segment constitutes a full Landsat scene, 170 km (north-south) by 185 km (east-west). Based on the 30 x 30 meter ground resolution associated with the Landsat TM sensor, each image consists of approximately 5667 scan lines with 6166 elements per line or roughly 35 million grid cells. With each grid cell containing information for seven different spectral bands, one Landsat TM scene consists of nearly 245 million pieces of data, and over a million TM scenes have been recorded. This amount of data is staggering and only through the speed of computers are investigators able to handle this volume of remotely sensed information.

A full SPOT scene covers a ground area of 60km by 60km at nadir. The east-west dimensions of a scene will increase at off-nadir up to 80km. Working in conjunction the two HRV instruments can cover a 117km east-west swath at nadir with a 3km overlap. At a 20m resolution, a full scene contains 9 million elements, and with three spectral bands, the scene has 27 million pieces of information. At the 10m resolution, a scene has 36 million elements.

Spectral Data and Images

The above discussed sensors detect different levels of electromagnetic radiation from the earth's surface and transform this radiation into electrical signals which can be converted into digital values. These values represent the amount of radiation recorded over a given ground surface area, an area which relates to the smallest informational level available on an image, known as the picture element or pixel. As previously indicated, the Landsat ground resolution or pixel size is 56 x 79 meters and 30 x 30 meters for the MSS and TM sensors, respectively, and the SPOT pixel size is 20 x 20 meters and 10 x 10 meters for the MSS and panchromatic sensors, respectively. An image consists of millions of pixels arranged in a grid format and for each pixel a separate value exists for each of the spectral bands being used by a sensor. Thus, for a Landsat MSS data set, four values exist for each pixel within the data set, each pixel value representing a radiation reading in one of the four spectral bands. These values can potentially range from 0 to 255, the data range of an 8-bit computer byte. The lower portion of the range frequently indicates low reflectance or emittance and the upper portion high reflectance or emittance.

From these values, different gray tones can be established to form an image which resembles a black and white photograph of the earth's surface. A separate black and white image can be created for each spectral band and an image's gray tone levels can be calibrated to different portions of the data range to stress or detect certain surface features. Since the human eye can only distinguish between 13 to 16 gray levels, the potential data range of 0 to 255 for any one spectral band can be grouped into numerous combinations. Through the aid of a microcomputer with a graphics monitor, images generated from these combinations can be quickly displayed and an analyst can seek out various information. In addition to creating single band images, color composites can be developed by generally using three spectral bands, each band being assigned to one of the basic colors of red, green, and blue. The radiation intensity, which is recorded between 0 and 255 for each pixel in a spectral band, is used to identify the intensity of the selected basic color. This process is repeated for each of the three basic colors but with different spectral bands. For each pixel in an image, three different intensities for red, green, and blue, respectively, are combined to form a new distinctive color, and an image can contain a multitude of colors. Since different spectral bands can be used, a tremendous number of color composite images can be created. The colors in these images frequently do not relate to the colors that people associate with surface features; thus, these images are referred to as "false color" images. All of the satellite scenes in this publication are false color images.

Further Readings

This chapter introduces some of the basic concepts of remote sensing and provides a general overview of the field particularly with respect to satellite image processing. It was not written for the purpose of providing a comprehensive review of the field. A list of further readings are provided below to help meet this purpose. Remote sensing is a rapidly growing discipline; thus, this list is not meant to be exhaustive. Also listed below are sources of free newsletters which frequently contain brief and colorful articles on various applications of remote sensing.

Books and Atlases

Drury, S.A. *A Guide To Remote Sensing: Interpreting Images of the Earth*. Oxford, England: Oxford University Press, 1990.

National Geographic Society. *Atlas of North America: Space Age Portrait of a Continent*. Washington, D.C.: National Geographic Society, 1985.

Rand McNally. *Images of the World*. Chicago: Rand McNally, 1984.

Sabins, Jr., Floyd F. *Remote Sensing: Principles and Interpretation*. San Francisco: Freeman, 1986

Short, Nicholas M. *The Landsat Tutorial Workbook*. NASA Ref. Pub. 1078, 1982.

Short, Nicholas M., Lowman, Paul D., Stanley, C. Freden, and Finch, Jr., William A. *Mission To Earth: Landsat Views The World*. NASA Special Publication 360, 1976.

Williams, Jr., Richard S. and Carter, William D., (ed.). *ERTS-1: A New Window On Our Planet*. U.S. Geological Survey Professional Paper 929, 1976.

Newsletters

Landsat Data Users Notes
EOSAT
4300 Forbes Blvd.
Lanham, MD 20706
Phone: (800) 344-9933

SPOTLIGHT
SPOT Image Corporation
1897 Preston White Drive
Reston, VA 22901
Phone: (703) 620-2200

Monitor
ERDAS, Inc.
2801 Buford Hwy., Suite 300
Atlanta, GA 30329
Phone: (404) 248-9000

SHORT GLOSSARY

active system: A remote sensing system that transmits its own electromagnetic emanations at an object(s) and then records the energy reflected or refracted back at the sensor. (C)

band: A wavelength interval in the electromagnetic spectrum. For example, in Landsat the bands designate specific wavelength intervals at which images are acquired. (A)

detector: A device providing an electrical output that is a useful measure of incident radiation. (C)

digital image processing: Computer manipulation of the digital values for picture elements of an image. (A)

electromagnetic radiation (EMR): Energy propagated through space or through material media in the form of an advancing interaction between electric and magnetic fields. The term radiation, alone, is commonly used for this type of energy, although it actually has a broader meaning. Also called electromagnetic energy. (C)

electromagnetic spectrum: The ordered array of known electromagnetic radiations extending from the shortest cosmic rays, through gamma rays, X-rays, ultraviolet radiation, visible radiation, infrared radiation, and including microwave and all other wavelengths of radio energy. (C)

emissivity: The ratio of the radiation given off by a surface to the radiation given off by a blackbody at the same temperature; a blackbody has an emissivity of 1, other objects between 0 and 1. (B)

emittance: The obsolete term for the radiant flux per unit area emitted by a body, or exitance. (C)

ground path: The vertical projection of the actual flight path of an aerial or space vehicle onto the surface of the earth or other body. (C)

high resolution visible (HRV): The imaging instruments used on the SPOT satellites which function in both nadir and off-nadir viewing positions.

infrared (IR): The infrared portion of the electromagnetic spectrum that includes wavelengths from 0.7 micron to 1 millimeter. (A)

micron: Equivalent to and replaced by micrometer. A micrometer is a unit of length equalled to one-millionth of a meter or one-thousandth of a millimeter (C)

millisecond: A unit of time equal to one-thousandth of a second.

nadir: The point on the ground vertically beneath the center of a remote-sensing system. (A)

off-nadir: The ability to view a surface from an angle other than vertical. This allows imaging instruments to view areas situated off of the regular flight path.

orbit: The path of a satellite around a body under the influence of gravity. (A)

passive system: A sensing system that detects or measures radiation emitted by a target. Compare active system. (C)

picture element: In a digitized image this is the area on the ground represented by each digital value. (A) A data element having both spatial and spectral aspects. The spatial variable defines the apparent size of the resolution cell (i.e., the area on the ground represented by the data values), and the spectral variable defines the intensity of the spectral response for that cell in a particular channel. (B) Commonly abbreviated as pixel.

pixel: A contraction of picture element.

reflectance: The ratio of the radiant energy reflected by a body to that incident upon it. (C)

scan line: The narrow strip on the ground that is swept by the instantaneous field of view of a detector in a scanner system. (A)

scanner: An optical-mechanical imaging system in which a rotating or oscillating mirror sweeps the instantaneous field of view of the detector across the terrain. The two basic types of scanners are airborne and stationary. (A)

sun synchronous: An earth satellite orbit in which the orbit plane is near polar and the altitude such that the satellite passes over all places on earth having the same latitude twice daily at the same local sun time. (A)

thermal infrared: The preferred term for the middle wavelength range of the IR region, extending roughly from 3 microns at the end of the near infrared, to about 15 or 20 microns, where the far infrared begins. In practice the limits represent the envelope of energy emitted by the earth behaving as gray body with a surface temperature around $290^{o}K$. (C)

visible wavelength: The radiation range in which the human eye is sensitive, approximately 0.4-0.7 microns. (B)

Key to Glossary

(A) Sabins, Jr., Floyd F. *Remote Sensing: Principles and Interpretation*. San Francisco: Freeman, 1987.

(B) Swain, P.H. and Davis, S.M. *Remote Sensing: The Quantitative Approach*. London and New York: McGraw Hill, 1978.

(C) Reeves, R.G. (ed.), *Manual of Remote Sensing* (Vol. I & II). Falls Church, VA: American Society of Photogrammetry, 1975.