the original, geometrically correct map space. The DTS can also superimpose two images (e.g., a raster image displayed on the internal monitor and hardcopy image) for change detection analysis. A digital camera can be attached to the built-in camera port of the DTS (the black cylinder located on the top of the instrument head) for capturing the superimposition of a digital map and hardcopy image for use in publications or further analysis.

## 4.4 LAND USE/LAND COVER MAPPING

A knowledge of land use and land cover is important for many planning and management activities and is considered an essential element for modeling and understanding the earth as a system. Land cover maps are presently being developed from local to national to global scales. The use of panchromatic, medium-scale aerial photographs to map land use has been an accepted practice since the 1940s. More recently, small-scale aerial photographs and satellite images have been utilized for land use/land cover mapping.

The term *land cover* relates to the type of feature present on the surface of the earth. Corn fields, lakes, maple trees, and concrete highways are all examples of land cover types. The term *land use* relates to the human activity or economic function associated with a specific piece of land. As an example, a tract of land on the fringe of an urban area may be used for single-family housing. Depending on the level of mapping detail, its *land use* could be described as urban use, residential use, or single-family residential use. The same tract of land would have a *land cover* consisting of roofs, pavement, grass, and trees. For a study of the socioeconomic aspects of land use planning (school requirements, municipal services, tax income, etc.), it would be important to know that the use of this land is for single-family dwellings. For a hydrologic study of rainfall-runoff characteristics, it would be important to know the amount and distribution of roofs, pavement, grass, and trees in this tract. Thus, a knowledge of both land use and land cover can be important for land planning and land management activities.

The USGS devised a land use and land cover classification system for use with remote sensor data in the mid-1970s (Anderson et al., 1976). The basic concepts and structure of this system are still valid today. A number of more recent land use/land cover mapping efforts follow these basic concepts and, although their mapping units may be more detailed or more specialized, and they may use more recent remote sensing systems as data sources, they still follow the basic structure originally set forth by the USGS. In the remainder of this section, we first explain the USGS land use and land cover classification system, then describe some ongoing land use/land cover mapping efforts in the United States and elsewhere.

Ideally, land use and land cover information should be presented on separate maps and not intermixed as in the USGS classification system. From a practical standpoint, however, it is often most efficient to mix the two systems when remote sensing data form the principal data source for such mapping activities. While land cover information can be directly interpreted from appropriate remote sensing images, information about human activity on the land (land use) cannot always be inferred directly from land cover. As an example, extensive recreational activities covering large tracts of land are not particularly amenable to interpretation from aerial photographs or satellite images. For instance, hunting is a common and pervasive recreational use occurring on land that would be classified as some type of forest, range, wetland, or agricultural land during either a ground survey or image interpretation. Thus, additional information sources are needed to supplement the land cover data. Supplemental information is also necessary for determining the use of such lands as parks, game refuges, or water conservation districts that may have land uses coincident with administrative boundaries not usually identifiable on remote sensor images. Recognizing that some information cannot be derived from remote sensing data, the USGS system is based on categories that can be reasonably interpreted from aerial or space imagery.

The USGS land use and land cover classification system was designed according to the following criteria: (1) the minimum level of interpretation accuracy using remotely sensed data should be at least 85 percent, (2) the accuracy of interpretation for the several categories should be about equal, (3) repeatable results should be obtainable from one interpreter to another and from one time of sensing to another, (4) the classification system should be applicable over extensive areas, (5) the categorization should permit land use to be inferred from the land cover types, (6) the classification system should be suitable for use with remote sensor data obtained at different times of the year, (7) categories should be divisible into more detailed subcategories that can be obtained from large-scale imagery or ground surveys, (8) aggregation of categories must be possible, (9) comparison with future land use and land cover data should be possible, and (10) multiple uses of land should be recognized when possible.

It is important to note that these criteria were developed prior to the widespread use of satellite imagery and computer-assisted classification techniques. While most of the 10 criteria have withstood the test of time, experience has shown that the first two criteria regarding overall and per class consistency and accuracy are not always attainable when mapping land use and land cover over large, complex geographic areas. In particular, when using computer-assisted classification methods, it is frequently not possible to map consistently at a single level of the USGS hierarchy. This is typically due to the occasionally ambiguous relationship between land cover and spectral response and the implications of land use on land cover.

The basic USGS land use and land cover classification system for use with remote sensor data is shown in Table 4.3. The system is designed to use four

**TABLE 4.3 USGS Land Use/Land Cover Classification System for Use with Remote Sensor Data**

| Level I | Level II |
|---|---|
| 1 Urban or built-up land | 11 Residential |
| | 12 Commercial and service |
| | 13 Industrial |
| | 14 Transportation, communications, and utilities |
| | 15 Industrial and commercial complexes |
| | 16 Mixed urban or built-up land |
| | 17 Other urban or built-up land |
| 2 Agricultural land | 21 Cropland and pasture |
| | 22 Orchards, groves, vineyards, nurseries, and ornamental horticultural areas |
| | 23 Confined feeding operations |
| | 24 Other agricultural land |
| 3 Rangeland | 31 Herbaceous rangeland |
| | 32 Shrub and brush rangeland |
| | 33 Mixed rangeland |
| 4 Forest land | 41 Deciduous forest land |
| | 42 Evergreen forest land |
| | 43 Mixed forest land |
| 5 Water | 51 Streams and canals |
| | 52 Lakes |
| | 53 Reservoirs |
| | 54 Bays and estuaries |
| 6 Wetland | 61 Forested wetland |
| | 62 Nonforested wetland |
| 7 Barren land | 71 Dry salt flats |
| | 72 Beaches |
| | 73 Sandy areas other than beaches |
| | 74 Bare exposed rock |
| | 75 Strip mines, quarries, and gravel pits |
| | 76 Transitional areas |
| | 77 Mixed barren land |
| 8 Tundra | 81 Shrub and brush tundra |
| | 82 Herbaceous tundra |
| | 83 Bare ground tundra |
| | 84 Wet tundra |
| | 85 Mixed tundra |
| 9 Perennial snow or ice | 91 Perennial snowfields |
| | 92 Glaciers |

"levels" of information, two of which are detailed in Table 4.3. A multilevel system has been devised because different degrees of detail can be obtained from different aerial and space images, depending on the sensor system and image resolution.

The USGS classification system also provides for the inclusion of more detailed land use/land cover categories in Levels III and IV. Levels I and II, with classifications specified by the USGS (Table 4.3), are principally of inter-

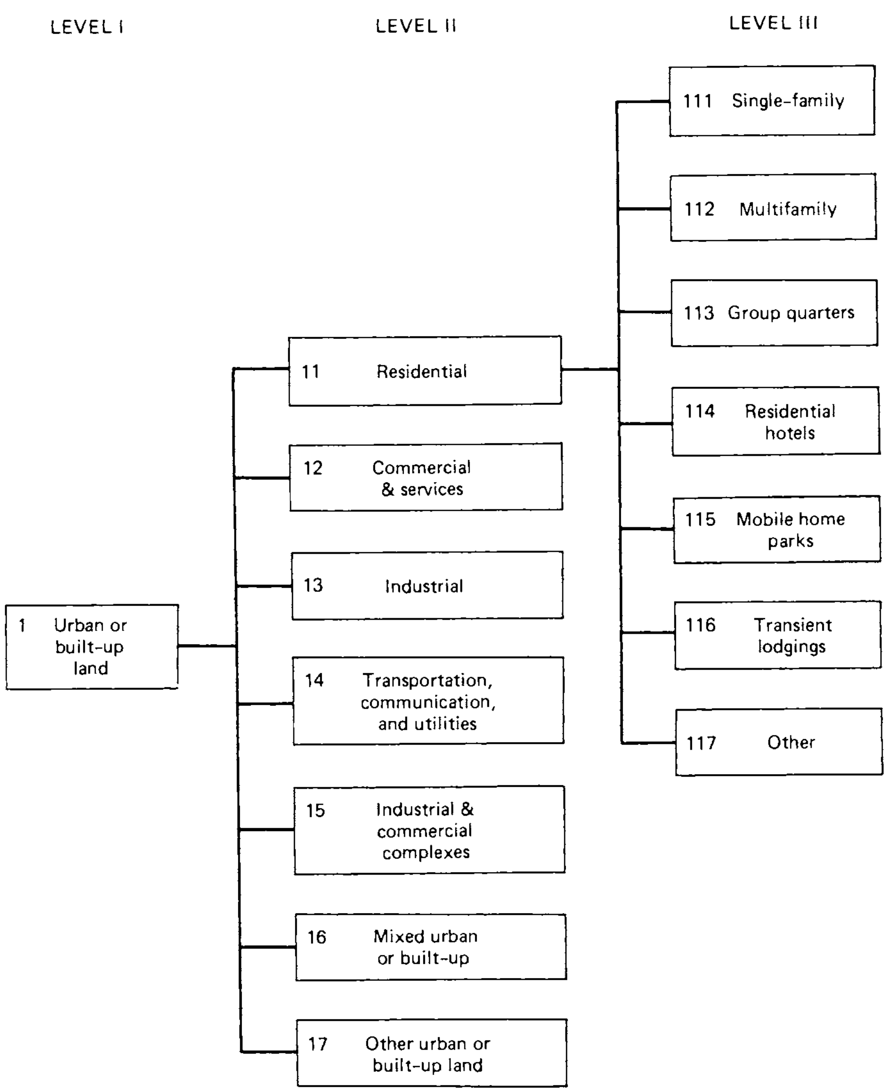


**Figure 4.9** An example aggregation of land use/land cover types.

est to users who desire information on a nationwide, interstate, or statewide basis. Levels III and IV can be utilized to provide information at a resolution appropriate for regional (multicounty), county, or local planning and management activities. Again, as shown in Table 4.3, Level I and II categories are specified by the USGS. It is intended that Levels III and IV be designed by the local users of the USGS system, keeping in mind that the categories in each level must aggregate into the categories in the next higher level. Figure 4.9 illustrates a sample aggregation of classifications for Levels III, II, and I.

Table 4.4 lists representative image interpretation formats for the four USGS land use and land cover classification levels (Jensen, 2000). Level I was originally designed for use with low to moderate resolution satellite data such as Landsat Multispectral Scanner (MSS) images. (See Chapter 6 for a description of the Landsat satellites and the other satellite systems mentioned below.) Image resolutions of 20 to 100 m are appropriate for this level of mapping.

Level II was designed for use with small-scale aerial photographs. Image resolutions of 5 to 20 m are appropriate for this level of mapping. The most widely used image type for this level has been high altitude color infrared photographs. However, small-scale panchromatic aerial photographs (Figure 4.10), Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) data, SPOT satellite data, and Indian Remote Sensing Satellite (IRS) data are also representative data sources for many Level II mapping categories.

The general relationships shown in Table 4.4 are not intended to restrict users to particular data sources or scales, either in the original imagery or in the final map products. For example, Level I land use/land cover information, while efficiently and economically gathered over large areas by the Landsat MSS, could also be interpreted from conventional medium-scale photographs or compiled from a ground survey. Conversely, some of the Level II categories have been accurately interpreted from Landsat MSS data.

**TABLE 4.4 Representative Image Interpretation Formats for Various Land Use/Land Cover Classification Levels**

| Land Use/Land Cover Classification Level | Representative Format for Image Interpretation |
|---|---|
| I | Low to moderate resolution satellite data (e.g., Landsat MSS data) |
| II | Small-scale aerial photographs; moderate resolution satellite data (e.g., Landsat TM data) |
| III | Medium-scale aerial photographs; high resolution satellite data (e.g., IKONOS data) |
| IV | Large-scale aerial photographs |

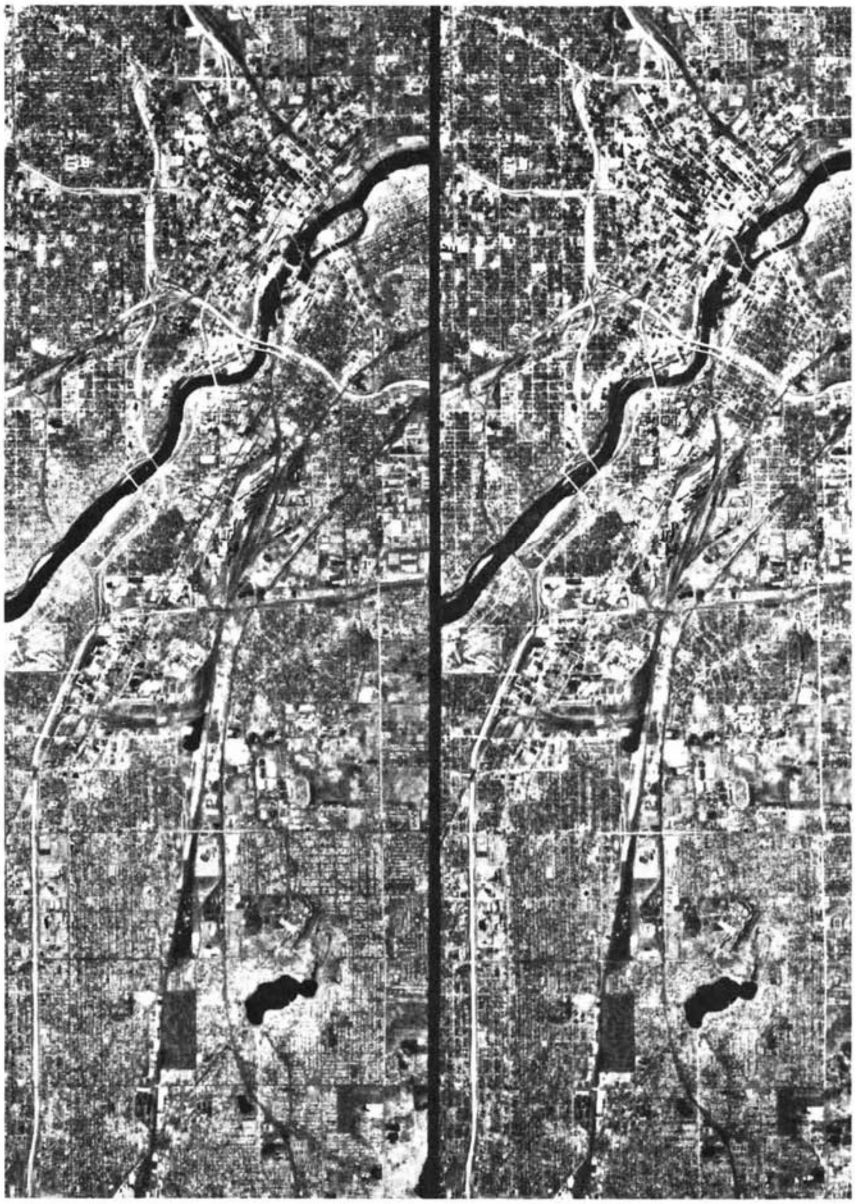

**Figure 4.10** Small scale panchromatic aerial photographs, Minneapolis-St. Paul, MN. Scale 1 : 94,000. (North to right.) Stereopair. (Courtesy Mark Hurd Aerial Surveys, Inc.)

For mapping at Level III, substantial amounts of supplemental information, in addition to that obtained from medium-scale images, may need to be acquired. At this level, a resolution of 1 to 5 m is appropriate. Both aerial photographs and high resolution satellite data can be used as data sources at this level.

Mapping at Level IV also requires substantial amounts of supplemental information, in addition to that obtained from aerial images. At this level, a resolution of 0.25 to 1.0 m is appropriate. Large-scale aerial photographs are often the most appropriate form of remotely sensed data for this level of mapping.

The USGS definitions for Level I classes are set forth in the following paragraphs. This system is intended to account for 100 percent of the earth's land surface (including inland water bodies). Each Level II subcategory is explained in Anderson et al. (1976) but is not detailed here.

*Urban* or *built-up land* is composed of areas of intensive use with much of the land covered by structures. Included in this category are cities; towns; villages; strip developments along highways; transportation, power, and communication facilities; and areas such as those occupied by mills, shopping centers, industrial and commercial complexes, and institutions that may, in some instances, be isolated from urban areas. This category takes precedence over others when the criteria for more than one category are met. For example, residential areas that have sufficient tree cover to meet *forest land* criteria should be placed in the urban or built-up land category.

*Agricultural land* may be broadly defined as land used primarily for production of food and fiber. The category includes the following uses: cropland and pasture, orchards, groves and vineyards, nurseries and ornamental horticultural areas, and confined feeding operations. Where farming activities are limited by soil wetness, the exact boundary may be difficult to locate and *agricultural land* may grade into *wetland*. When wetlands are drained for agricultural purposes, they are included in the *agricultural land* category. When such drainage enterprises fall into disuse and if wetland vegetation is reestablished, the land reverts to the *wetland* category.

*Rangeland* historically has been defined as land where the potential natural vegetation is predominantly grasses, grasslike plants, forbs, or shrubs and where natural grazing was an important influence in its precivilization state. Under this traditional definition, most of the rangelands in the United States are in the western range, the area to the west of an irregular north–south line that cuts through the Dakotas, Nebraska, Kansas, Oklahoma, and Texas. Rangelands also are found in additional regions, such as the Flint Hills (eastern Kansas), the southeastern states, and Alaska. The historical connotation of rangeland is expanded in the USGS classification to include those areas in the eastern states called brushlands.

*Forest land* represents areas that have a tree-crown areal density (crown closure percentage) of 10 percent or more, are stocked with trees capable of producing timber or other wood products, and exert an influence on the climate or water regime. Lands from which trees have been removed to less than 10 percent crown closure but that have not been developed for other uses are also included. For example, lands on which there are rotation cycles of clearcutting and blockplanting are part of the forest land category. Forest land that is extensively grazed, as in the southeastern United States, would also be included in this category because the dominant cover is forest and the dominant activities are forest related. Areas that meet the criteria for forest land and also urban and built-up land are placed in the latter category. Forested areas that have wetland characteristics are placed in the *wetland* class.

The *water* category includes streams, canals, lakes, reservoirs, bays, and estuaries.

The *wetland* category designates those areas where the water table is at, near, or above the land surface for a significant part of most years. The hydrologic regime is such that aquatic or hydrophytic vegetation is usually established, although alluvial and tidal flats may be nonvegetated. Examples of wetlands include marshes, mudflats, and swamps situated on the shallow margins of bays, lakes, ponds, streams, and artificial impoundments such as reservoirs. Included are wet meadows or perched bogs in high mountain valleys and seasonally wet or flooded basins, playas, or potholes with no surface water outflow. Shallow water areas where aquatic vegetation is submerged are classified as *water* and are not included in the *wetland* category. Areas in which soil wetness or flooding is so short-lived that no typical wetland vegetation is developed belong in other categories. Cultivated wetlands such as the flooded fields associated with rice production and developed cranberry bogs are classified as *agricultural land*. Uncultivated wetlands from which wild rice, cattails, and so forth are harvested are retained in the *wetland* category, as are wetlands grazed by livestock. Wetland areas drained for any purpose belong to the other land use/land cover categories such as urban or built-up land, agricultural land, rangeland, or forest land. If the drainage is discontinued and wetland conditions resume, the classification will revert to *wetland*. Wetlands managed for wildlife purposes are properly classified as *wetland*.

*Barren land* is land of limited ability to support life and in which less than one-third of the area has vegetation or other cover. This category includes such areas as dry salt flats, beaches, bare exposed rock, strip mines, quarries, and gravel pits. Wet, nonvegetated barren lands are included in the wetland category. Agricultural land temporarily without vegetative cover because of cropping season or tillage practices is considered *agricultural land*. Areas of intensively managed forest land that have clear-cut blocks evident are classified as *forest land*.

*Tundra* is the term applied to the treeless regions beyond the geographic limit of the boreal forest and above the altitudinal limit of trees in high mountain ranges. In North America, tundra occurs primarily in Alaska and northern Canada and in isolated areas of the high mountain ranges.

*Perennial snow* or *ice* areas occur because of a combination of environmental factors that cause these features to survive the summer melting season. In so doing, they persist as relatively permanent features on the landscape.

As noted above, some parcels of land could be placed into more than one category, and specific definitions are necessary to explain the classification priorities. This comes about because the USGS land use/land cover classification system contains a mixture of land activity, land cover, and land condition attributes.

Several land use/land cover mapping efforts that have been undertaken in the United States and elsewhere use the USGS land use/land cover classification system, or variations thereof. A representative subset of these efforts is summarized below (new initiatives continue to develop given the importance of such data).

The USGS land use/land cover classification system was used to prepare Level I and II land use/land cover maps for most of the conterminous United States and Hawaii at a scale of 1 : 250,000. For most categories, a minimum mapping unit of 16 ha was used. A limited number of maps are available at a scale of 1 : 100,000. Digital land use/land cover data have been compiled from these maps by the USGS in vector format and are available for the conterminous United States and Hawaii. Polygons delineating "natural" areas have a minimum size of 4 ha with a minimum feature width of 400 m. The minimum size of polygons representing cultural features (e.g., urban areas, highways) is also 4 ha, with a minimum feature width of 200 m. The data are also available in raster (grid-cell) format. The digital data use the Universal Transverse Mercator (UTM) coordinate system and can be transformed into other map projections. In digital form, the land use/land cover data can be combined with other data types in a GIS. These data are available from the USGS EROS Data Center (see Appendix B) at no cost when downloaded over the Internet.

Traditionally, land cover mapping activities in the United States, as well as a variety of natural resource mapping activities, have used topographic base maps produced by the USGS, at scales generally ranging from 1 : 24,000 to 1 : 250,000, for their base maps. Over time, mapping activities have become increasingly digitally based. In response to this, the USGS will be providing, on the Internet, current, accurate, and nationally consistent digital data and topographic maps derived from those data. The resulting product, *The National Map*, will be a seamless, continuously maintained set of geographic base data that will serve as a foundation for integrating, sharing, and using other data easily and consistently. The National Map will include the following: (1) high resolution digital orthorectified imagery that will provide some of the feature information now symbolized on topographic maps; (2) high resolution surface elevation data, including bathymetry, to derive contours for primary series topographic maps and to support production of accurate orthorectified imagery; (3) vector feature data for hydrography, transportation (roads, railways, and waterways), structures, government unit boundaries, and publicly owned land boundaries; (4) geographic names for physical and cultural features to support the U.S. Board on Geographic Names, and other names, such as those for highways and streets; and, (5) extensive land cover data. Data will be seamlessly and consistently classified, enabling users to extract data and information for irregular geographic areas, such as counties or drainage basins. For further information, see http://nationalmap.usgs.gov.

The USGS and the EPA are cooperating on a North American Landscape Characterization Project (NALC) that has completed production of a standardized digital data set for the contiguous 48 states and Mexico that contains Landsat MSS satellite data (Chapter 6) from the 1970s, 1980s, and 1990s. This data set allows researchers to inventory land use and land cover and to conduct land cover change analysis using a standardized data set.

The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) conducts a statistically based National Resources Inventory (NRI) at 5-year intervals. The NRI is an inventory of land use and land cover, soil erosion, prime farmland, wetlands, and other natural resource characteristics of nonfederal rural land in the United States. It provides a record of the nation's conservation accomplishments and future program needs. Specifically, it provides valuable information concerning the effect of legislative actions on protecting land from erosion and slowing the rate of loss of wetlands, wildlife habitat diversity, and prime agricultural land. The NRI data are also used by federal and state agencies in regional and state environmental planning to determine the magnitude and location of soil and water resource problems. With each 5-year cycle of data gathering, the NRI places increasing emphasis on remote sensing data acquisition and computer-based data analysis.

As part of NASA's Earth Observing System (EOS) Pathfinder Program, the USGS, the University of Nebraska-Lincoln, and the European Commission's Joint Research Centre are involved with a Global Land Cover Characterization study that has generated a 1-km resolution global land cover database for use in a wide range of environmental research and modeling applications. The global land cover characteristics database was developed on a continent-by-continent basis and each continental database contains unique elements based on the geographical aspects of the specific continent. The initial remote sensing data source for this study was Advanced Very High Resolution Radiometer (AVHRR) data (Chapter 6) spanning April 1992 through March 1993. These global land cover data are available from the USGS EROS Data Center (see Appendix B) at no cost when downloaded over the Internet.

The USGS National Gap Analysis Program (GAP) is a state-, regional-, and national-level program established to provide map data, and other information, about natural vegetation, distribution of native vertebrate species, and land ownership. Gap analysis is a scientific method for identifying the degree to which native animal species and natural communities are represented in our present-day mix of conservation lands. Those species and communities not adequately represented in the existing network of conservation lands constitute conservation "gaps." The GAP data sets are produced at a nominal scale of 1 : 100,000. A minimum mapping unit (MMU) of 30 × 30 m (the resolution of the Landsat TM data typically used for data acquisition and analysis) is generally used. (Some GAP data sets use a larger MMU.)

The Multi-Resolution Land Characteristics (MRLC) Consortium was established as an interagency initiative to provide a consistent national Landsat TM data set and, ultimately, a 30-m national land cover classification for the conterminous United States. The original members of the MLRC were the USGS, the EPA, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Forest Service (USFS). Later joining the MLRC were the National Aeronautics and Space Administration (NASA) and the Bureau of Land Management (BLM). This consortium of agencies developed a common set of requirements and specifications for Landsat TM data acquisition and data processing. The initial result of MRLC was a multitemporal geocoded Landsat TM data set for the 48 conterminous states, with dates of data acquisition centered on 1992. The ultimate purpose of this data set was the development of the land cover database needed by each of the participating projects and programs. Several complementary land cover databases are being developed from the MRLC coverage. For additional information, see the MRLC website at http://www.epa.gov/mlrc.

Land use and land cover mapping is also being addressed by various groups outside of the United States. For example, the Land Cover Working Group of the Asian Association on Remote Sensing is involved with the preparation of a 1-km-resolution land cover database of Asia based on AVHRR satellite data.

The Coordination of Information on the Environment (CORINE) land cover initiative is led by the European Environment Agency. The CORINE land cover database provides a pan-European inventory of biophysical land cover, using a 44-class nomenclature. It is made available on a 250 by 250 m grid database. CORINE land cover is a key database for integrated environmental assessment across Europe. For additional information, see http://www.eea.eu.int.

The Africover project of the United Nations Food and Agriculture Organization has as its goal the establishment, for the whole of Africa, of a digital geo-referenced database on land cover, the *Multipurpose Africover Database for Environmental Resources*, at a 1 : 200,000 scale (1 : 100,000 for small countries and specific areas). This project has been prepared in response to a number of national requests for assistance on the implementation of reliable and geo-referenced information on natural resources (e.g., "early warning" of potential agricultural problems, forest and rangeland monitoring, watershed management, wildlife monitoring, natural resource planning, production statistics, biodiversity and climate change assessment) at subnational, national, and regional levels. The land cover information is mainly derived from visual interpretation of recent high resolution satellite images that have been enhanced digitally. Additional information about the Africover database is available at http://www.africover.org.

## 4.5 GEOLOGIC AND SOIL MAPPING

The earth has a highly complex and variable surface whose topographic relief and material composition reflect the bedrock and unconsolidated materials that underlie each part of the surface as well as the agents of change that have acted on them. Each type of rock, each fracture or other effect of internal movement, and each erosional and depositional feature bear the imprint of the processes that produced them. Persons who seek to describe and explain earth materials and structures must understand geomorphological principles and be able to recognize the surface expressions of the various materials and structures. Through the processes of visual image interpretation and geologic and soil mapping, these materials and structures can be identified and evaluated. Geologic and soil mapping will always require a considerable amount of field exploration, but the mapping process can be greatly facilitated through the use of visual image interpretation. Here, we briefly describe the application of visual image interpretation to geologic and soil mapping. Section 4.16 provides a more detailed coverage of this application and contains stereoscopic aerial photographs illustrating visual image interpretation for landform identification and evaluation.

### Geologic Mapping

The first aerial photographs taken from an airplane for geologic mapping purposes were used to construct a mosaic covering Bengasi, Libya, in 1913. In general, the earliest uses of airphotos were simply as base maps for geologic data compilation, especially as applied to petroleum exploration. Some interpretive use of aerial photographs began in the 1920s. Since the 1940s, the interpretive use of airphotos for geologic mapping and evaluation has been widespread.

Geologic mapping involves the identification of landforms, rock types, and rock structures (folds, faults, fractures) and the portrayal of geologic units and structures on a map or other display in their correct spatial relationship with one another. Mineral resource exploration is an important type of geologic mapping activity. Because most of the surface and near-surface mineral deposits in accessible regions of the earth have been found, current emphasis is on the location of deposits far below the earth's surface or in inaccessible regions. Geophysical methods that provide deep penetration into the earth are generally needed to locate potential deposits and drill holes are required to confirm their existence. However, much information about potential areas for mineral exploration can be provided by interpretation of surface features on aerial photographs and satellite images.