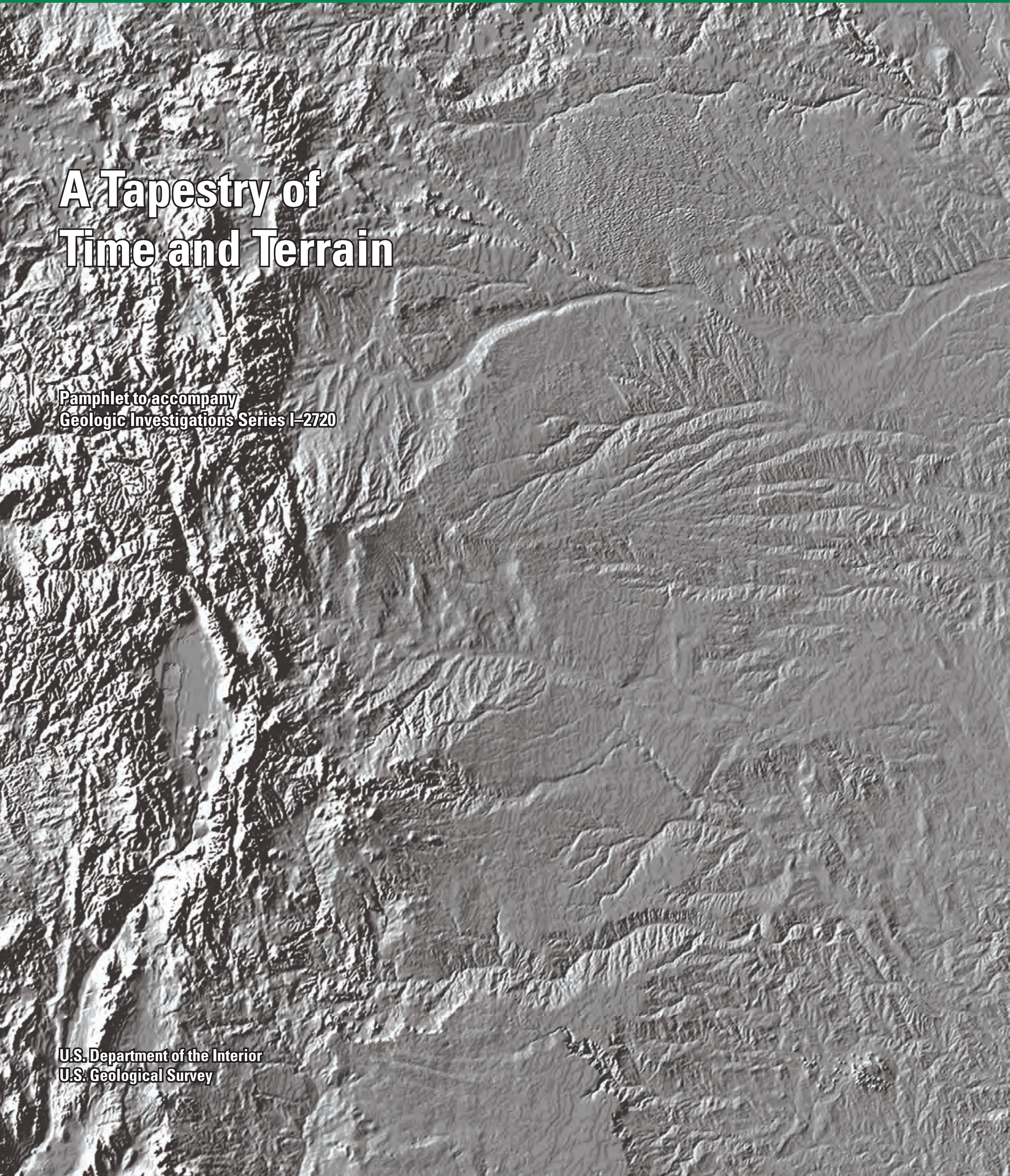
USGS
science for a changing world



A Tapestry of Time and Terrain

Pamphlet to accompany
Geologic Investigations Series I–2720

U.S. Department of the Interior
U.S. Geological Survey

This page left intentionally blank

A Tapestry of Time and Terrain

By José F. Vigil, Richard J. Pike, and David G. Howell

Pamphlet to accompany
Geologic Investigations Series I–2720

U.S. Department of the Interior
Bruce Babbitt, Secretary

U.S. Geological Survey
Charles G. Groat, Director

United States Government Printing Office: 2000
Reprinted with minor corrections: 2008

For additional copies please contact:

USGS Information Services
Box 25286
Denver, CO 80225

For more information about the USGS and its products:

Telephone: 1–888–ASK–USGS
World Wide Web: http://www.usgs.gov/

Text edited by Jane Ciener
Layout and design by Stephen L. Scott
Manuscript approved for publication, February 24, 2000

Introduction

Through computer processing and enhancement, we have brought together two existing images of the lower 48 states of the United States (U.S.) into a single digital tapestry. Woven into the fabric of this new map are data from previous U.S. Geological Survey (USGS) maps that depict the topography and geology of the United States in separate formats. The resulting composite is the most detailed and accurate portrait of the U.S. land surface and the ages of its underlying rock formations yet displayed in the same image. The new map resembles traditional 3-D perspective drawings of landscapes with the addition of a fourth dimension, geologic time, which is shown in color. This union of topographic texture with the patterns defined by units of geologic time creates a visual synthesis that has escaped most prior attempts to combine shaded relief with a second characteristic shown by color, commonly height above sea level (already implicit in the shaded relief). In mutually enhancing the landscape and its underlying temporal structure, this digital tapestry outlines the geologic story of continental collision and break-up, mountain-building, river erosion and deposition, ice-cap glaciation, volcanism, and other events and processes that have shaped the region over the last 2.6 billion years. The map and the many features described in this pamphlet are online at **http://tapestry.usgs.gov.**

The terrain

[Most terms that may be unfamiliar to a general readership are italicized where first mentioned]

One of this map's two components is a *digital shaded-relief image* that shows the shape of the land surface by variations in brightness. The degree of light and dark artificially mimics the intensity of the Sun's light on different types of topography. This technique, called *chiaroscuro*, dates back some 400 years to sketches of the Tuscan landscape by Leonardo da Vinci. Because manual (artistic) portrayals of terrain can practicably show only small areas both accurately and in detail (Raisz, 1931), the technique has been automated by the computer to cover large regions. The resulting digital shaded-relief map of the lower 48 states (Thelin and Pike, 1991) succeeded the unique, if less accurate, hand-drawn landform map by master cartographer Erwin Raisz (1939).

The shaded-relief image of U.S. hills and dales is made up of some 12,000,000 minute squares—each one about 1/100 of an inch (0.25 mm) on a side. The gray tone of each square is a brightness value computed from a mathematical relation that includes steepness of the local ground, the direction that its slope faces, and the positions of the observer and a simulated Sun. Light and dark tones show steeper areas; intermediate tones indicate gentler terrain. No actual shadows are included. The angle of surface slope and its sun-facing direction were computed from a *digital elevation model*, or DEM, a square-grid array of terrain heights spaced about 1/2-mile (800 m) apart on the ground. These elevations were derived by semi-automated means from the height contours (at 50-, 100-, or 200-foot intervals) of older 1:250,000-scale USGS topographic maps. Further information about the shaded-relief technique, with details of the map's construction, are given in Thelin and Pike (1991). Systematic descriptions of the terrain features shown on this tapestry, as well as the geology on which they developed, are available in Thornbury (1965), Hunt (1974), and other references on *geomorphology*, the science of surface processes and their resulting landscapes (Graf, 1987; Bloom, 1997; Easterbrook, 1998).

Landscape features contain many of the clues needed to understand the Earth and the agents that have shaped it (Pike, 1991). Finding and decoding these clues enables scientists to learn more about natural hazards, the events of Earth history, and resources of land, water, energy, and minerals. Many methods of landscape portrayal are used to view surface features, but shaded-relief imaging by computer is unique in the following respects:

- It provides fine-scale detail over a wide area, a combination not possible in other techniques of illustration;
- It shows terrain accurately and in its true complexity, two properties commonly lost in sketches and diagrams of large areas;
- Unlike mosaics of aerial photos and radar images, the view—limited only by extent of the digital data set—is continuous across the country;
- Relief shading is free of distortion and the vegetation and cultural features that conceal topographic form on satellite images.

Geologic time

The second component of this tapestry, color, represents geologic time and is simplified from the *geologic map* of King and Beikman (1974a). Rocks contain information essential to an intelligent understanding of the Earth and its long natural history. Geologists determine the location, geographic extent, age, and physical and chemical characteristics of rocks and unconsolidated (loose) materials. To express these attributes geologists have developed a unique method of portrayal, the geologic map, which has the following properties:

- It recognizes similarities and differences among materials that comprise the Earth's crust and classifies them by type of rock or surficial deposit;
- It ascribes Earth materials to a specific environment or mode of origin—for example, volcano, river deposit, wind-blown dune, limestone reef, or alteration at depth by heat or pressure;
- It identifies rock formations of distinctive materials and ages that are the three-dimensional building blocks of the Earth's crust; it further shows the relative position of one formation to another at the Earth's surface;
- It arranges rock formations of different ages into a time sequence from which the geologic history of the planet can be deciphered.

The original 161 colors and line patterns used by King and Beikman (1974a,b) to portray the age, location, and extent of materials that make up the lower 48 states are here reduced to 52 colors that show just the geologic ages of rocks and surficial deposits at the Earth's surface. Combined colors and patterns were retained only for a few altered (*metamorphic*) rocks of uncertain age. Lines representing *faults* (for example, the San Andreas in California) were omitted. The map is a necessary compromise in that it emphasizes time intervals defined by bedrock rather than surficial materials. In areas affected by continental glaciation, for example, the ages shown are of underlying rocks, not the veneer of glacial (surficial) deposits.

Geologists subdivide time variously by *eras* (Precambrian to Cenozoic), *periods* (Cambrian to Quaternary), and *epochs*—only Pleistocene (early Quaternary) and Holocene (late Quaternary) are used here (see column on map). These units are quite uneven in elapsed time, the older intervals generally being of much longer duration. Rocks in the U.S. range in age from early Precambrian (2.6 billion years ago) to Holocene, which includes the present. The orderly sequence of Earth materials, from oldest to youngest, is represented by an equally well-ordered sequence of "prismatic" colors (based on the rainbow). To improve the color balance of the tapestry, the Holocene is represented by two hues, light gray in the East and beige in the West.

The King and Beikman geologic map of the U.S. was compiled from many detailed maps that describe the rocks of smaller areas. The constituent maps were made by many individuals from field and laboratory observations. These geologic maps distinguish among types of rocks that form in different ways: *igneous* granite and basalt; *sedimentary* sandstone, shale, and limestone; and *metamorphic* slate, marble, gneiss, and schist. From several converging lines of evidence—fossils, the layered sequence of strata, and the systematic radioactive decay of certain minerals—geologists have been able to place the rock formations in their correct time order, and from that arrangement construct a sequence of likely geologic events. Further information about the U.S. geologic map, including details of its compilation and descriptions of the major rock formations that occupy the time intervals shown here, are given in the four related reports by King (1976) and King and Beikman (1974b, 1976, 1978).

What this tapestry shows

The face of the United States has not always appeared as it does today. The land has been a shifting geologic battleground for well over two billion years, and the tapestry presented here records traces of many of the contributing skirmishes. Constructional forces, fueled by heat from the Earth's interior, have built and rebuilt the North American continent from roving pieces of the planet's exterior shell, only to give way before the processes of erosion, led by gravity and atmospheric moisture. Mountains raised episodically by *tectonic* (crustal stress and strain) and *magmatic* (melting at depth) activity are reduced to sediment and dispersed into the oceans by the ceaseless work of rainfall and rivers. The surface on which we live today is only one snapshot in time of the constantly shifting balance, or *dynamic equilibrium*, between opposing geologic agents of construction and decay.

The geologic story of the U.S. told by the new map begins with *tectonic plates*, large segments of the Earth's outer rigid layers that move about, or "drift", on the plastic material beneath. The thinner *oceanic* plates are composed largely of denser (*basaltic*) rock; the thicker *continental* plates are rich in lighter (*granitic*) rocks. All the continental U.S. except its far west coast lies within the North American Plate. Continuous creation and recycling of plates—through the spreading of fresh sea-floor formed at oceanic ridges, *subduction* (descent and consequent melting) of one plate beneath another, and other broad-scale processes of *plate tectonics*—builds the planet's largest features, its continents, and then redistributes and eventually reduces or destroys them. At least twice, all of Earth's continental plates are believed to have collided and remained connected, forming a single landmass. The older of these proposed supercontinents, *Rodinia* (1.3 billion years ago), was followed much later by *Pangaea* (200-300 million years ago). Rocks and geologic structures in the lower 48 states still bear traces of both events. Ice-cap glaciation during the Pleistocene Epoch (about 1.8 million to 10,000 years ago), which created much of the topographic detail in the tapestry, is the most recent major chapter in the story.

These and many other contending processes and events have given rise to the myriad of physical features portrayed in the new digital map. Forty-eight examples are described below in brief sketches, emphasizing phenomena—large and small—that owe their prominence on the tapestry to a combination of topographic texture and the color patterns defined by units of geologic time. The features are discussed in roughly chronological order, starting with the oldest, but no continuous narrative is intended. The discussion is intentionally non-technical. Detailed information on these and the many other features is available in the books and articles and their bibliographies listed in the appendix. We invite viewers of the new map to let their curiosity lead them where it may and to pursue whatever geologic and topographic questions strike their fancy.

An interpretative tool that can help make sense out of the large amount of information contained in the new map is the regional classification shown on figure 1. Geomorphic, or *physiographic*, regions are broad-scale subdivisions based on terrain texture, rock type, and geologic structure and history. Nevin Fenneman's (1928) three-tiered classification of the United States—by *division*, *province*, and *section*—has provided an enduring spatial organization for the great variety of physical features (see Graf, 1987, and other publications on geomorphology listed in the references). The composite image presented here clearly shows the topographic textures and generalized geology (by age) from which the physical regions were synthesized. The highlighted features represent many of these subdivisions. A second small map (figure 2) shows state boundaries and the numbered locations of specific features discussed below to further assist interpretation of the tapestry.

General features

The two major tectonic regimes of the U.S. contrast vividly in surface roughness, structural and coastline patterns, and freshness of relief: the *active plate-margin* of the West (exemplified by California's San Andreas Fault Zone) and the *static mid-plate* East and Southeast (the eastern edge of the North American Plate lies at the Mid-Atlantic Ridge, not the east coast of the U.S.). The geologic youth of the West is evident in its many high mountains, fragmented terrain textures, and steep coast and continental shelf—indicated by absence of long, thin *barrier islands* just offshore. Geologic age reveals another broad-scale contrast. The eastern portion of the United States is dominated by continuous tracts of Paleozoic and Precambrian rocks. In the West, such older rocks appear only in isolated patches—exhumed by erosion, as in the ancient metamorphic rocks of the Grand Canyon's Inner Gorge, or uplifted and exposed in the cores of ranges in the Rocky Mountains, for example, the billion-year-old Pike's Peak Granite. The many types of mountains shown on the tapestry are complex features that form in different ways. Somewhat counterintuitively, they can arise from broad-scale forces either pushing on the crust (*compression*) or, oppositely, pulling it apart (*extension*). The architecture of the California Coast Ranges and the tightly folded Appalachians, for example, reflects compressional forces (although implemented in different ways and at different times), whereas that of the faulted mountain blocks in Utah and Nevada reveals an extensional origin.

Specific features

[Bracketed numbers in bold type locate features on the state index map, figure 2]

[1] The Superior Upland of Wisconsin and Minnesota is the largest U.S. surface exposure of the ancient (2.6 to 1.6 billion years old) core of the North American continent, known geologically as the Canadian Shield. (Even older rocks have been recognized in northwest Canada.) Now an area of low topographic relief, these metamorphic rocks once themselves formed mountains—located at the margin of a continent, as once were their later Appalachian and Rocky Mountain counterparts. Some of these highly altered rocks have been important sources of iron, copper, and other industrial metals.

[2] The Llano Uplift is conspicuous as a red and tan blotch in central Texas. A structural high, it provides a window into the underlying uplifted Precambrian rocks that formed a margin of the ancient supercontinent of Rodinia. These 1.0-1.3 billion-year-old metamorphic rocks belong to a long, now poorly exposed, mountain belt that once included what are parts of Scandinavia and Antarctica today. Similar rocks also appear in New York's Adirondack Mountains.

[3] The Adirondack Mountains form most of northern New York state. They are an uplifted complex of Precambrian metamorphic rocks—like the Llano Uplift in Texas, a part of an ancient (Grenville) continental province. The Paleozoic sedimentary strata that now flank these older rocks once covered them. The intersecting faults and joints responsible for the rectilinear surface texture of the Precambrian rocks developed from release of pressure on this once deeply buried metamorphic complex.

[4] Another window into an ancient continent, the Baraboo Range in southern Wisconsin, appears as a small east-west-trending patch of tan about 25 miles (40 km) long. The resistant Precambrian quartzite that gives the Baraboos their topographic prominence today formed an erosional remnant, or *monadnock* (named for an isolated mountain in New Hampshire), as long ago as the late Precambrian. These ancestral mountains were buried by Paleozoic sedimentary strata and are still being exhumed by erosion of the softer overlying rocks.

[5] The winding course of the Colorado River through northern Arizona's mile-deep Grand Canyon is well marked on the new map by a vivid contrast in pattern and color. A narrow ribbon of red differentiates the ancient granites and tilted metamorphic rocks along the river banks from the younger, overlying horizontal Paleozoic sedimentary rocks in the canyon walls and at the rim (blue). Abundant water from melting Pleistocene glaciers probably is responsible for the most recent episode of erosion that has deepened the canyon.

[6] Across the continent, alternating beds of hard and soft Paleozoic sedimentary rocks, folded like the wrinkles in a kicked floor rug, are the hallmark of the Appalachian Valley and Ridge Province. Extending some 900 miles (1500 km) from New York to Alabama, and flanked by flat-lying sedimentary strata to the west and Precambrian metamorphic rocks to the east, this famous belt of parallel structures reflects the several great continental collisions that formed the Appalachian chain and the Pangaea supercontinent some 300 to 400 million years ago.

[7] Sequences of folded Paleozoic rocks in the southern Appalachians of Alabama and Tennessee match those in the eastern Ouachita Mountains of Arkansas, across the deep Mississippi River Embayment. Because these crustal wrinkles date to the same period of continental-scale collision, the two ranges once were almost certainly continuous. The gap, a 160-million-year-old structural trough, is a legacy from the time when the collided masses of North and South America parted company and opened the Gulf of Mexico.

[8] Complex north-south patterns in the six New England states mirror a convoluted geologic story. This northern part of the Appalachians consists of several *terranes*, fault-bounded slices of the crust that have a tectonic history distinct from adjacent rocks. The terranes, which include rocks similar to those in the British Isles, originated elsewhere but were joined (*accreted*) to eastern North America in the Paleozoic during the formation of Pangaea. A Paleozoic fault zone comparable to the San Andreas, intrusion of Mesozoic igneous-rock masses, and later opening of the Atlantic Ocean have further complicated this New England portrait.

[9] A giant incomplete bulls-eye is centered on the state of Michigan. Extending into Illinois, Ohio, Indiana, Wisconsin, and Ontario, this annular pattern outlines the Michigan Basin, a bowl-shaped structure of uncertain origin that contains over 4 km of inward-dipping Paleozoic strata and a veneer of Jurassic sedimentary rocks. This mysterious basin is located in the tectonically less active interior of the continent, between the Appalachians and the Rocky Mountains. It subsided rapidly from Cambrian to Silurian time as it filled with shallow-water marine sediments, some of which host deposits of petroleum, coal, and salt.

[10] Nature is said to abhor a straight line, and geology is no exception. Why, then, the several north-south linear contacts between different Late Cretaceous ages in North Dakota, Minnesota, and Iowa? The reasons are complex and reflect vagaries of the geologic-mapping process rather than the geology itself: in this case, the bedrock formations defining time periods are so thin and discontinuous (and also overlain by glacial deposits), that their true contacts have yet to be located and thus were drawn arbitrarily—along nearby state, county, or even map-sheet boundaries, which often are straight lines.

[11] Other Mesozoic-age features are less ambiguous. The (green) hook-shaped N-S ridge just north of New York's Long Island is a *cuesta* or *hog-back* ridge, one of several tilted and eroded lava flows in the Connecticut Valley. It is contained within coarse Triassic-Jurassic sediments that were deposited rapidly during rift-faulting of North America, about 180-200 million years ago, as the supercontinent of Pangaea was pulled apart and Europe and Africa separated from North America. When you are visiting Normandy in western France, look for the matching rocks!

[12] Florida is one of the many add-on appendages to eastern North America. Evidence of its overseas origin lies hidden beneath a cover of Tertiary and Quaternary sediments. The underlying rocks, unrepresented on this map but known from cores brought to the surface from drill holes, are an upper-Precambrian to lower-Paleozoic piece of western Africa that was added to the continent during formation of Pangaea and left behind in early Mesozoic time, when Pangaea broke up and created the Atlantic Ocean.

[13] The wide Coastal Plain belt of Late Cretaceous to Holocene deposits, extending from New Jersey to Texas, is one of the tapestry's outstanding patterns. These sedimentary rocks, deposited mostly in a marine environment, were later uplifted and now tilt seaward; part of them form the broad, submerged Atlantic Continental Shelf. Coastal Plain deposits overlap the older, more distorted, Paleozoic and Precambrian rocks immediately to the north and west.

[14] The Fall Line is a low east-facing cliff paralleling the Atlantic coastline from New Jersey to the Carolinas. It separates hard Paleozoic metamorphic rocks of the Appalachian Piedmont to the west from the softer, gently dipping Mesozoic and Tertiary sedimentary rocks of the Coastal Plain. This erosional scarp, the site of many waterfalls, hosted flume- and water-wheel-powered industries in colonial times and thus helped determine the location of such major cities as Philadelphia, Baltimore, Washington, and Richmond.

[15] The Late Cretaceous and Early Tertiary periods were geologically more eventful in the West. The Rocky Mountains, which were uplifted about 50 to 100 million years ago, extend from southern Colorado northwest to the Canadian border. Their rocks and topography are diverse and highly complex. Many of the individual ranges that make up the Rocky Mountains appear on the map as variously shaped bull's-eyes surrounding a red-hued center. Each crudely ringed pattern was created by the Tertiary erosion of Paleozoic and Mesozoic sedimentary rocks that once overlay and now surround a core of uplifted Precambrian granite.

[16] Rising topographically from the Great Plains in eastern Wyoming and western South Dakota, the Black Hills are conspicuous on the map by the (red) outcrop of Precambrian granite. The upturned and eroded Paleozoic and Mesozoic strata of this structural dome surround the ancient granite on which the four faces of the Mt. Rushmore presidential monument were carved. Geologically, the Black Hills represent the easternmost outpost of the Rocky Mountains.

[17] The Great Plains Province, a broad yellowish band down the center of the map, is a vast east-tilted surface formed by deposition of sediment eroded from the uplifting Rocky Mountains in Early Tertiary time, beginning about 65 million years ago. This upraised region now is being eroded, especially on its eastern margin, by many east-flowing rivers that expose the older rocks beneath. To the west, these older, largely Cretaceous, sedimentary rocks contain some of the Nation's most spectacular dinosaur fossils.

[18] A north-northwest-trending terrain texture, or grain, evident as aligned ridges and valleys carved by segments of streams, pervades the northern and central Great Plains. This widely distributed pattern disappears north and east of the Pleistocene glacial margin. Both regional tectonism (fine-scale fracturing in the Earth's crust induced by opposing horizontal forces) and surface processes (late-glacial wind action) have been suggested for the origin of this widespread texture.

[19] The Llano Estacado ("Staked Plains") of west Texas and eastern New Mexico marks the southernmost extent of the High Plains. One of the largest expanses of near-featureless terrain in the U.S., it is an uplifted surface of porous, uneroded Late Tertiary river sediments veneered by late Pleistocene and Holocene wind-blown sand. The region was named by early

European settlers who placed marker stakes to avoid losing their way on the flat land. (The faint, evenly-spaced wavy north-south lines on the map are a false artifact of the computer-processed terrain.)

[20] The Nation's Far West is geologically younger and much more active than its East and Midcontinent. The northwest-southeast-trending Olympic-Wallowa Line across southern Washington state, for example, is a structural zone that includes active earthquake faults. This trend was first described from aerial photographs by Erwin Raisz (1939). Other northwest-trending alignments to the southeast, west of the central Rocky Mountains, perhaps are related geologically to this feature.

[21] The mountains in the Olympic Peninsula of northwest Washington State, which describe a backwards "C" on the map in yellow and light orange, also are quite young. This crescentic pattern took form in Tertiary time as the western margin of North America—much like its earlier Appalachian counterpart—grew through the accretion of several geologic terranes, bits and pieces of drifting oceanic crust that collided with and became joined to the continent.

[22] Centered on the state of Nevada and extending from southern Oregon to western Texas, the Basin and Range Province is an immense region of alternating, north-south-trending, faulted mountains and flat valley floors. It has no counterpart elsewhere in the U.S. The province was created about 20 million years ago as the Earth's crust stretched, thinned, and then broke into some 400 mountain blocks that partly rotated from their originally horizontal positions. These mountains of late Precambrian and Paleozoic rock continue to erode and fill the intervening valleys with fresh sediment.

[23] California's Sierra Nevada ("snow-capped mountain") is a west-tilting 350-mile (560-km)-long block of granite. Extending from 14,494 feet (Mt. Whitney, the highest peak in the lower 48 states) in the east to near sea level in the west, it contains the spectacular Yosemite and Sequoia National Parks (not indicated on the map). The massive granite intruded the crust in Mesozoic time and was uplifted and faulted in the Tertiary during formation of the Basin and Range province to the east. Eroded residue from the Sierra Nevada has filled the Central Valley of California, giving rise to both extensive agriculture and the 1849 Gold Rush.

[24] California's Central Valley resembles a great elongate bath tub. Its present, remarkably flat surface consists largely of material eroded from the rising Sierra Nevada and Coast Ranges to the east and west, respectively, and deposited in low alluvial fans. On more than one occasion the valley impounded a large lake, which left behind a veneer of muddy deposits. About 650,000 years ago, rising waters of the most recent lake carved a gap through the mountain range to the west and drained into the Pacific Ocean through a low pass just south of the city of San Francisco.

[25] The topographic texture of western California is controlled by the San Andreas fault system, the tectonic expression of the Pacific Plate sliding northwestward along the western margin of the North American Plate. Hundreds of miles long and in places up to a mile wide, the San Andreas Fault Zone has been active since its origin in the Tertiary. About 10 percent of the present plate motion is *compressional*, shortening and wrinkling the crust to create the parallel coastal northwest-southeast mountain ranges. Comparatively quiet after the 1906 San Francisco earthquake until the 1989 Loma Prieta event, the fault is again showing activity.

[26] The intersection of the San Andreas and Garlock Faults in southern California reflects two different tectonic forces: northwest-southeast sliding along the Pacific and North American plate boundaries and roughly east-west crustal extension within the North American Plate. The relative westward movement of crust north of the Garlock Fault bends the San Andreas system into a lazy "S" pattern. This deflection results in a jamming of rocks to the south, expressed by the San Gabriel Mountains and other east-west-trending Transverse Ranges north of Los Angeles.

[27] Walker Lane is a linear north-northwest-trending depression extending some 500 miles (800 km) north from the Garlock Fault-Las Vegas area to south-central Oregon. Within it are Walker, Goose, and Pyramid Lakes (shown on the tapestry). This trough is part of the Walker Lane Fault Zone, a major tectonic system that includes Owens and Death Valleys and several prominent faults. It is the site of current earthquakes. Located at the juncture of two contrasting tectonic styles, the Sierra Nevada and the Basin and Range, the Walker Lane region is deforming in a complex way by both extensional and *transcurrent* (sliding) fault movements.

[28] The Nation's active tectonism is not confined to the Far West. In at least one place, the mid-section of the continent is beginning to be pulled apart by extensional forces. Volcanism accompanies this activity. The upper Rio Grande River flows southward through New Mexico within a long fault-bounded basin, the Rio Grande Rift, where lava from a source deep in the *mantle* periodically spreads across the surface. In the near geologic future, several million years or so, a youthful ocean basin may occupy this area.

[29-31] Thousands of volcanoes erupted throughout the western U.S. in the last 60 million years, but most individual craters are too small to show up clearly in the tapestry. Among the larger volcanoes, although still small at this scale, are two broad collapse cauldrons—Valles (a beige and yellow patch in the northwest Rio Grande Rift) **[29]** and Crater Lake (southwest Oregon) **[30]**. These two *calderas* formed in different ways. Mount St. Helens **[31]**, which erupted catastrophically in 1980 (by yet a third mechanism), is smaller still and lies largely hidden among the many peaks in the Cascade Range of southwest Washington.

[32] The great length and strong north-south linearity of the Cascade Range, a narrow yellow band extending from southern Washington to northern California, contrasts sharply with the varied directional trends of other mountain groups to the east and northeast. The Cascades arose through the plate collisions that have enlarged the western continent in Tertiary-to-Holocene time. This mountain range contains such large and geologically recent active volcanoes as Rainier, Hood, and Shasta.

[33] Interpreted by geologists as the southernmost volcano in the Cascade Chain, the now-inactive and highly dissected Sutter Buttes show up on the map as a small circular bump that contrasts sharply with its flat surroundings in California's Central Valley. It erupted in Late Tertiary time—punching through flat-lying young sediments eroded from the rising Sierra Nevada to the east.

[34-35] Low basalt shields **[34]** appear as even smaller bumps on the lava-flooded Snake River Plain, a kidney-shaped expanse in southern Idaho. The apparent decrease in age of these tiny Holocene volcanoes from west to east over the last 16 million years marks the movement of the North American Plate westward across a source of magma. Such *hot spots* or *plumes* rise into the Earth's crust from many miles deep in the underlying mantle. (A different one formed the Hawaiian Islands.) Yellowstone National Park **[35]** in northwest Wyoming currently lies above this particular source. The giant volcanic depression that contains the park and its geysers and hot springs (for example, Old Faithful) formed about 100,000 to 5 million years ago.

[36] Late Cenozoic ice-cap glaciation and its many geomorphic effects mark a chapter in U.S. Earth history that began some 2.0 million years ago and ended about 10,000 years ago. A subtle but widespread feature remarkable for its exposure on this composite image is the overall textural contrast created by the last of the several ice-sheet advances from Canada. Particularly in the mid-continent, topography north of the highly irregular line **[36]** marking the glacial limit is muted and smooth and lacks the strong river-carved grain characteristic of unglaciated terrain to the south.

[37] Isolated patches of rough terrain in the unglaciated Driftless Area of southwestern Wisconsin and northwestern Iowa stand out from the surrounding, smoothed glaciated ground. Thoroughly dissected by tributaries of the Mississippi River, the topography within these "islands" was engulfed but never overridden by the ice. The appearance of the Driftless Area landscape today probably is much like that of adjacent glaciated landscapes prior to the first Pleistocene ice advance.

[38] The north-pointing, flatiron-shaped Coteau des Prairies in eastern South Dakota is arguably the most conspicuous landform of the U.S. Midcontinent shown on this map. Some 200 miles (320 km) long, the low plateau of thick glacial deposits is underlain by a small ridge of resistant Cretaceous shale. Moving south along pre-glacial stream valleys just to the west and east, respectively, the James River and Des Moines Lobes of the last Pleistocene ice sheet probably parted at the stream divide preexisting the present Coteau ("hill" in French) and further deepened its flanking lowlands—which then drained meltwater as the glaciers retreated to the north.

[39] The low, arc-shaped ridges just west of the "thumb" region of northeast Michigan are *recessional moraines* composed of glacial rubble that overlie the Pennsylvanian-age bedrock shown on the map. They mark the northeastward retreat of the Huron Lobe of the last Pleistocene ice sheet from Saginaw Bay about 10,000 years ago (Lake Huron is not shown). Similar moraines south of Lake Michigan, west of Lake Ontario, and in eastern Wisconsin (Green Bay) are not well represented by the rather coarse terrain data available to make the shaded relief map.

[40] Festoons of *terminal moraines* marking the southern limit of Pleistocene glaciation were deposited on a submarine ridge of Tertiary rocks off the coasts of Massachusetts and Connecticut 15,000 to 20,000 years ago. These hummocky piles of clay-rich, poorly-sorted glacial material, and the smoother plains of sandy *outwash* deposits immediately south of them, form much of Long Island, Cape Cod, Martha's Vineyard, and Nantucket Island. They also controlled the post-glacial development of beaches, offshore islands, and other Holocene coastal landforms.

[41] Traces of an old east-west drainage system, buried by glacial deposits not shown on the map, are conspicuous across northern Ohio and Indiana. Presence of the pre-Pleistocene Teays River is revealed as a sinuous, branching pattern of Ordovician rocks (pink) surrounded by overlying Silurian strata (violet). The old river channel was abandoned when its course was diverted southward to the Ohio River drainage by the movements of early Pleistocene ice and the emplacement of glacial deposits, probably about 2 million years ago.

[42] The seven large Finger Lakes in central New York state were formed when the last Pleistocene ice cap melted back and flooded valleys previously overdeepened by scouring of the advancing glacial ice. A thick veneer of glacial debris, not shown here, overlies the lower Paleozoic bedrock indicated on the map. The native American Iroquois believed that the fan-shaped array of lakes are marks from the hand of the Great Spirit.

[43] Trail Ridge, the largest of several long, low north-trending ridges in central Florida, is among the most distinctive landforms in this area of low topographic relief. The ridges are complexes of sand dunes formed during the Pleistocene, when the coastline was some 300 feet lower than it is today. The sandy sediments were eroded from rocks of the Appalachian highland to the north. Some of the ridges are mined for the industrial minerals rutile and ilmenite, sources of the titanium metal used in the spacecraft operated at Cape Canaveral on Florida's east coast.

[44] The largest field of sand dunes in the Western Hemisphere is located southeast of the Black Hills region and occupies much of western Nebraska. The Sand Hills, developed on the northernmost occurrence of Late Tertiary High Plains deposits (light yellow), are evident on the map as a fine-scale hummocky texture. The dunes formed as recently as 10,000 years ago, during and after Pleistocene time. Under modest changes in climatic conditions, these dormant features could shed their vegetative cover and again become active.

[45] Events of the Pleistocene also left their mark on major U.S. rivers. A conspicuous band of alternating Pleistocene (pale yellow) and Holocene (gray) deposits characterizes the broad, flat alluvial plain of the Mississippi River Embayment, its tributaries to the west, and coastal Texas. The irregularly striped pattern owes its origin to extensive and accelerated deposition by streams during interglacial phases of the Pleistocene, followed by erosion of these materials by Holocene river systems, over the last 1-2 million years.

[46] Crowleys Ridge, evident on the map in eastern Arkansas as a long yellow-orange ribbon against a gray background, is an erosional remnant of 40- to 50-million-year-old sedimentary rock in the upper Mississippi River Embayment. The ridge formed late in the Pleistocene as the river, gorged with glacial meltwater, continually shifted course and broadened its floodplain at the expense of Tertiary rock forming its banks. Crowleys Ridge is located near the site of the great 8+ magnitude New Madrid earthquakes of 1811-1812.

[47] The giant bird's foot delta, featuring a large middle toe, that terminates the lower Mississippi River in southern Louisiana marks the seaward growth of land into the Gulf of Mexico. The Mississippi-Missouri River system collects eroded debris from the entire central half of the U.S. Upon reaching the Gulf the river's velocity slows, abruptly reducing its capacity to carry suspended mud and sand, and the sediment is deposited in vast alluvial fans not visible on the map. These submarine fans are major sources of petroleum, natural gas, and sulfur.

[48] A large lake located by the scouring of Pleistocene ice hosts a geographical curiosity. The Northwest Angle, a 150 square mile (390 square km) tract separated from the rest of Minnesota by the Lake of the Woods, is the northernmost point in the United States exclusive of Alaska. The peninsula is connected to Manitoba and can be reached overland only by going through Canada. It was acquired in the 1783 Treaty of Paris, through an earlier surveying error made while attempting to locate the source of the Mississippi and other rivers. Most of the land is uninhabited and held in trust by the Red Lake Indian Reservation.

Technical details

Combining the existing images of terrain and geologic time posed challenges not encountered in previous digital compilations. The constituent maps differ dramatically in scale, type of color, and the spatial structure of their digitized information. The gray-scale (monochrome) shaded-relief map, at a uniform 1:3,500,000 scale, is arrayed in a *raster* (regular rectangular-grid) structure (Thelin and Pike, 1991). The geologic map is in multi-color, has a non-uniform scale of 1:2,500,000, and is *vector* structured (irregular lines and polygons). The geologic map had been transformed earlier from the original paper product to a computer database by digital scanning and vectorizing (Schruben and others, 1998). About 35 large lakes (shown in black) were added to aid in feature recognition.

The two maps were combined by converting the geologic map from vector to raster structure and overlaying the resulting data file on the shaded-relief file. The non-uniform scale of the geologic map posed difficulties in fitting it to the uniform scale of the shaded-relief map. Extraneous data cells were removed digitally with a global selection tool, and various procedures were applied where needed to adjust and "clean up" the combined image. (In such areas as the Basin and Range Province, registration of the two maps still is not perfect.) Transparency (opacity), color levels, and contrast of the geologic map were adjusted to attain an aesthetic and visual balance between shaded relief and geologic time. This was a trial-and-error process because colors on the computer screen differed substantially from those plotted on paper. Several test plots were made in RGB (color addition mixing) mode, at 72 and 300 dpi (dots per inch). Final prints, at image size 56 by 40 inches and sheet size 58 by 42 inches, were rendered in CMYK (color-subtraction mixing) mode at 2400 dpi. The data are registered to an Albers Equal-Area Conic projection (standard parallels at 29.5° N. and 45.5° N; central meridian at 96.0° W., and latitude of projection's origin at 23.0° N.). Scale of the tapestry is slightly over 1:3,500,000, or about 55 miles to the inch.

The composite map was created by Vigil on an Apple Computer PowerMacintosh G3 450-MHz machine running under the Mac OS 8.6 operating system, with one GB (billion bytes) of RAM (random access memory), a 9-GB internal hard disk, and a 47-GB external disk. The size of the first composite image-file was 1.3 GB; the file prepared for final printing was much smaller, requiring scarcely 700 MB (million bytes). The software applications by which the two constituent maps were combined are Adobe Illustrator (version 8.1) and Adobe Photoshop (version 5.5). The test prints were made on a Hewlett-Packard HP 3500CP drum plotter.

PHYSIOGRAPHIC REGIONS OF THE LOWER 48 UNITED STATES

after Fenneman (1928)

LAURENTIAN UPLAND
- 1. Superior Upland

ATLANTIC PLAIN
- 2. Continental Shelf (not on map)
- 3. Coastal Plain
  - a. Embayed section
  - b. Sea Island section
  - c. Floridian section
  - d. East Gulf Coastal Plain
  - e. Mississippi Alluvial Plain
  - f. West Gulf Coastal Plain

APPALACHIAN HIGHLANDS
- 4. Piedmont province
  - a. Piedmont Upland
  - b. Piedmont Lowlands
- 5. Blue Ridge province
  - a. Northern section
  - b. Southern section
- 6. Valley and Ridge province
  - a. Tennessee section
  - b. Middle section
  - c. Hudson Valley
- 7. St. Lawrence Valley
  - a. Champlain section
  - b. Northern section (not on map)
- 8. Appalachian Plateaus province
  - a. Mohawk section
  - b. Catskill section
  - c. Southern New York section
  - d. Allegheny Mountain section
  - e. Kanawha section
  - f. Cumberland Plateau section
  - g. Cumberland Mountain section
- 9. New England Province
  - a. Seaboard Lowland section
  - b. New England Upland section
  - c. White Mountain section
  - d. Green Mountain section
  - e. Taconic section
- 10. Adirondack province

INTERIOR PLAINS
- 11. Interior Low Plateaus
  - a. Highland Rim section
  - b. Lexington Plain
  - c. Nashville Basin
- 12. Central Lowland
  - a. Eastern Lake section
  - b. Western Lake section
  - c. Wisconsin Driftless section
  - d. Till Plains
  - e. Dissected Till Plains
  - f. Osage Plains
- 13. Great Plains province
  - a. Missouri Plateau, glaciated
  - b. Missouri Plateau, unglaciated
  - c. Black Hills
  - d. High Plains
  - e. Plains Border
  - f. Colorado Piedmont
  - g. Raton section
  - h. Pecos Valley
  - i. Edwards Plateau
  - k. Central Texas section

INTERIOR HIGHLANDS
- 14. Ozark Plateaus
  - a. Springfield-Salem plateaus
  - b. Boston “Mountains”
- 15. Ouachita province
  - a. Arkansas Valley
  - b. Ouachita Mountains

ROCKY MOUNTAIN SYSTEM
- 16. Southern Rocky Mountains
- 17. Wyoming Basin
- 18. Middle Rocky Mountains
- 19. Northern Rocky Mountains

INTERMONTANE PLATEAUS
- 20. Columbia Plateau
  - a. Walla Walla Plateau
  - b. Blue Mountain section
  - c. Payette section
  - d. Snake River Plain
  - e. Harney section
- 21. Colorado Plateaus
  - a. High Plateaus of Utah
  - b. Uinta Basin
  - c. Canyon Lands
  - d. Navajo section
  - e. Grand Canyon section
  - f. Datil section
- 22. Basin and Range province
  - a. Great Basin
  - b. Sonoran Desert
  - c. Salton Trough
  - d. Mexican Highland
  - e. Sacramento section

PACIFIC MOUNTAIN SYSTEM
- 23. Cascade-Sierra Mountains
  - a. Northern Cascade Mountains
  - b. Middle Cascade Mountains
  - c. Southern Cascade Mountains
  - d. Sierra Nevada
- 24. Pacific Border province
  - a. Puget Trough
  - b. Olympic Mountains
  - c. Oregon Coast Range
  - d. Klamath Mountains
  - e. California Trough
  - f. California Coast Ranges
  - g. Los Angeles Ranges
- 25. Lower California province

Acknowledgments: We thank USGS colleagues Andrei Sarna-Wojcicki and King Huber for comments that improved content and presentation, Eleanore Jewel for assistance with the digital cartography, and Jane Ciener for editing the pamphlet.

References

Bloom, A.L., 1997, Geomorphology, a systematic analysis of late Cenozoic landforms: Englewood Cliffs, N.J., Prentice Hall, 482 p.

Easterbrook, D.J., 1998, Surface processes and landforms: Englewood Cliffs, N.J., Prentice Hall, 560 p.

Fenneman, N.M., 1928, Physiographic divisions of the United States: Annals of the Association of American Geographers, v. 18, p. 261-353.

Graf, W.L., ed., 1987, Geomorphic systems of North America: Geological Society of America, Centennial Special Volume 2, 643 p.

Hunt, C.B., 1974, Natural regions of the United States and Canada: San Francisco, W.H. Freeman, 725 p.

King, P.B., 1976, Precambrian geology of the United States; an explanatory text to accompany the geologic map of the United States: U.S. Geological Survey Professional Paper 902, 85 p.

King, P.B., and Beikman, H.M., compilers, 1974a, Geologic map of the United States (exclusive of Alaska and Hawaii): Reston, Va., U.S. Geological Survey, three sheets, scale 1:2,500,000.

King, P.B., and Beikman, H.M., 1974b, Explanatory text to accompany the geologic map of the United States: U.S. Geological Survey Professional Paper 901, 40 p.

King, P.B., and Beikman, H.M., 1976, The Paleozoic and Mesozoic rocks; a discussion to accompany the geologic map of the United States: U.S. Geological Survey Professional Paper 903, 76 p.

King, P.B., and Beikman, H.M., 1978, The Cenozoic rocks; a discussion to accompany the geologic map of the United States: U.S. Geological Survey Professional Paper 904, 82 p.

Pike, R.J., 1991, Surface features of central North America; A synoptic view from computer graphics: GSA Today, v. 1, no. 11, p. 241, 251-253.

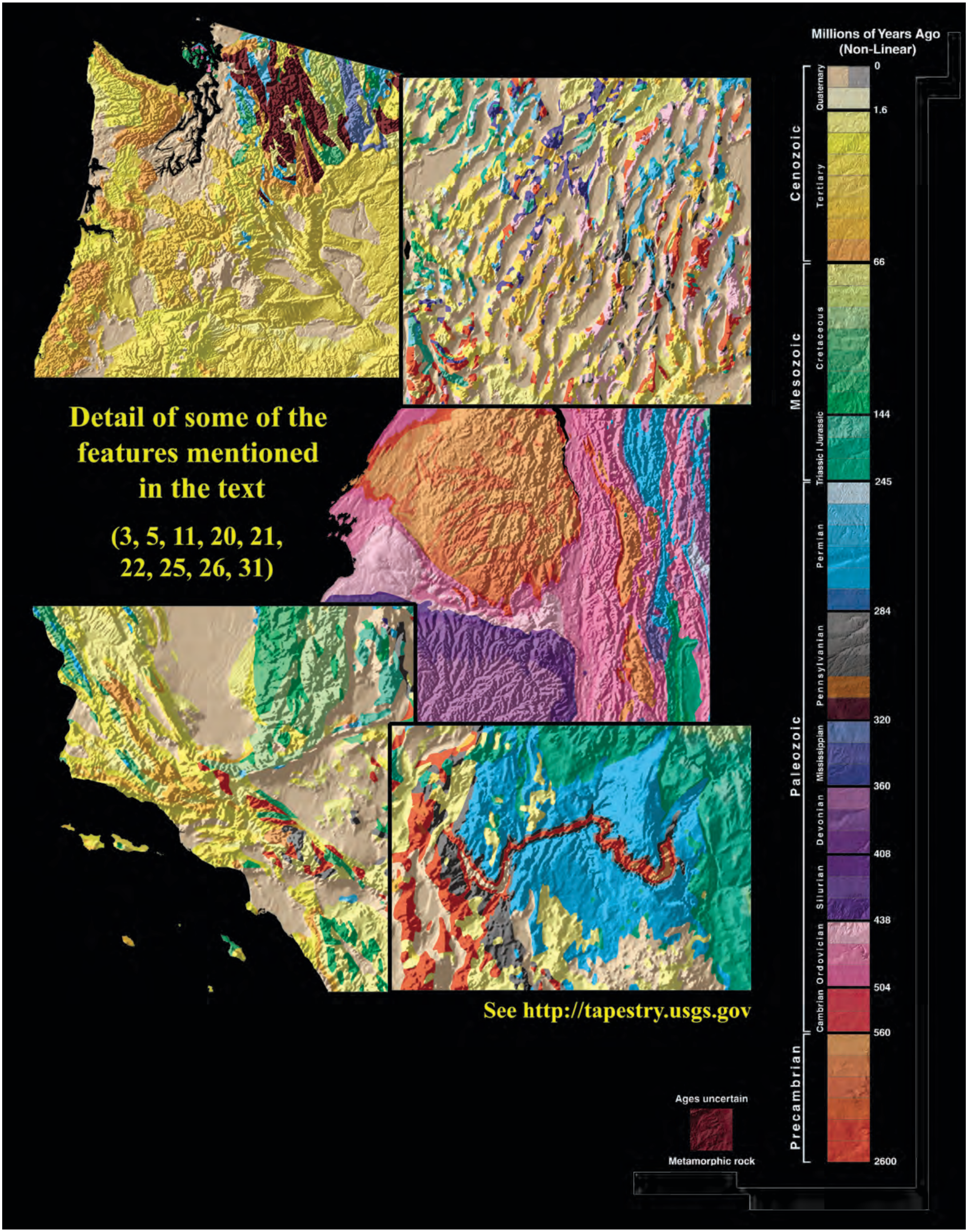
Raisz, Erwin, 1931, The physiographic method of representing scenery on maps: Geographical Review, v. 21, no. 2, p. 297-304.

Raisz, Erwin, 1939, Landforms of the United States, *in* Atwood, W.W., 1940, The physiographic provinces of North America: New York, Blaisdell, scale about 1:4,500,000.

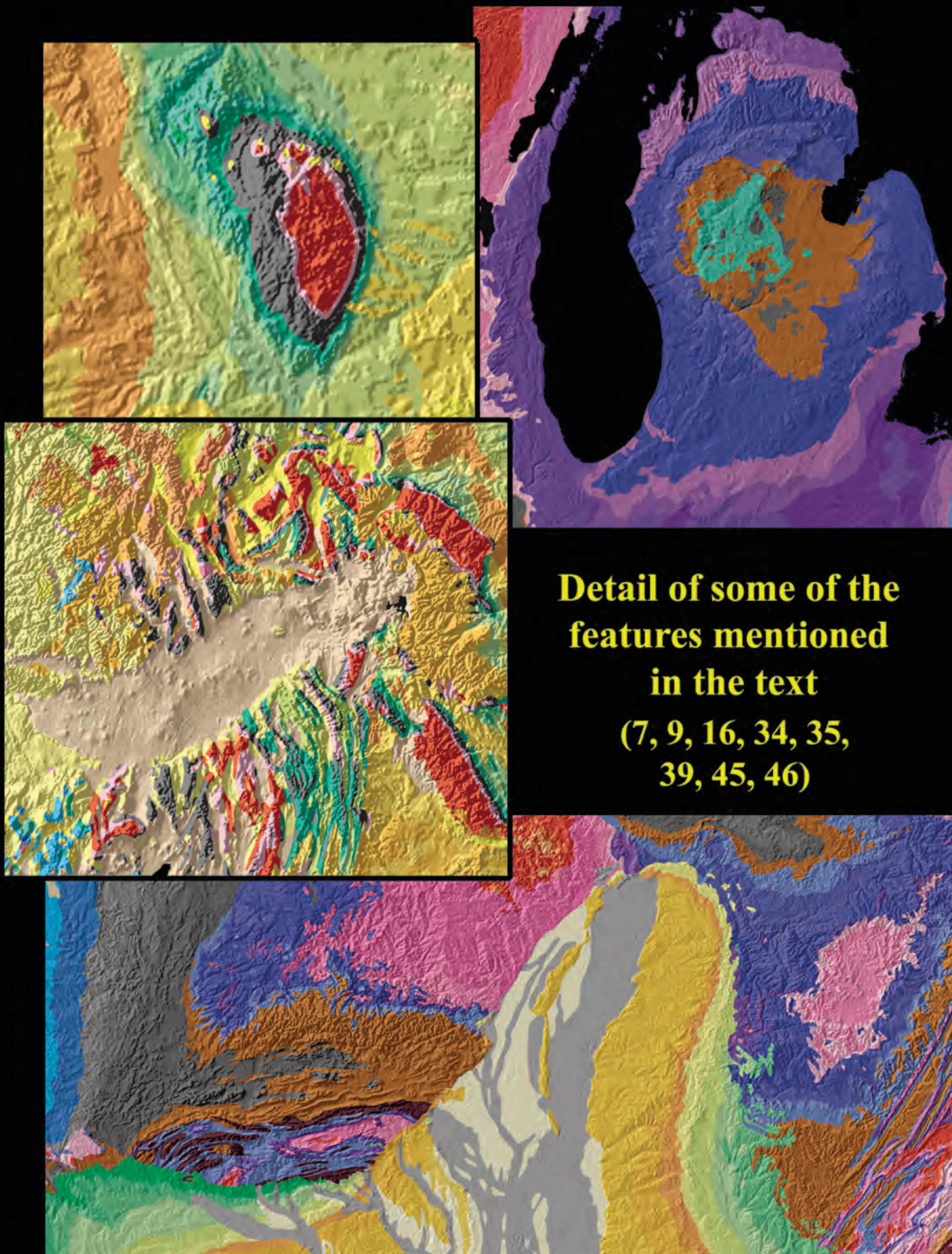
Schruben, P.G., Arndt, R.E., and Bawiec, W.J., 1998, Geology of the conterminous United States at 1:2,500,000 scale—A digital representation of the 1974 P.B. King and H.M. Beikman map: U.S. Geological Survey Digital Data Series DDS-11, Release 2, one CD-ROM. **(http://pubs.usgs.gov/dds/dds11/)**

Thelin, G.P., and Pike, R.J., 1991, Landforms of the conterminous United States; A digital shaded-relief portrayal: U.S. Geological Survey Miscellaneous Investigations Map I-2206, scale 1:3,500,000. **(http://pubs.usgs.gov/imap/i2206/)**

Thornbury, W.D., 1965, Regional geomorphology of the United States: New York, John Wiley, 609 p.

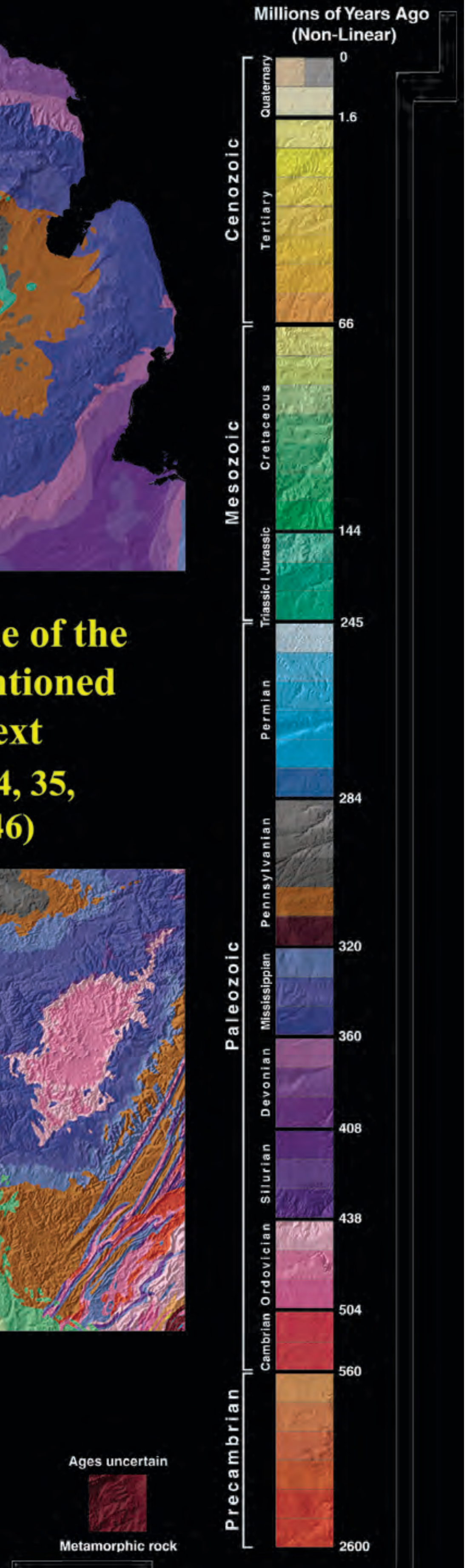


Detail of some of the features mentioned in the text
(3, 5, 11, 20, 21, 22, 25, 26, 31)
See http://tapestry.usgs.gov
Millions of Years Ago (Non-Linear)
Cenozoic
Quaternary
Tertiary
Mesozoic
Cretaceous
Triassic | Jurassic
Paleozoic
Permian
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Cambrian
Precambrian
0
1.6
66
144
245
284
320
360
408
438
504
560
2600
Ages uncertain
Metamorphic rock



Detail of some of the features mentioned in the text (7, 9, 16, 34, 35, 39, 45, 46)

See http://tapestry.usgs.gov



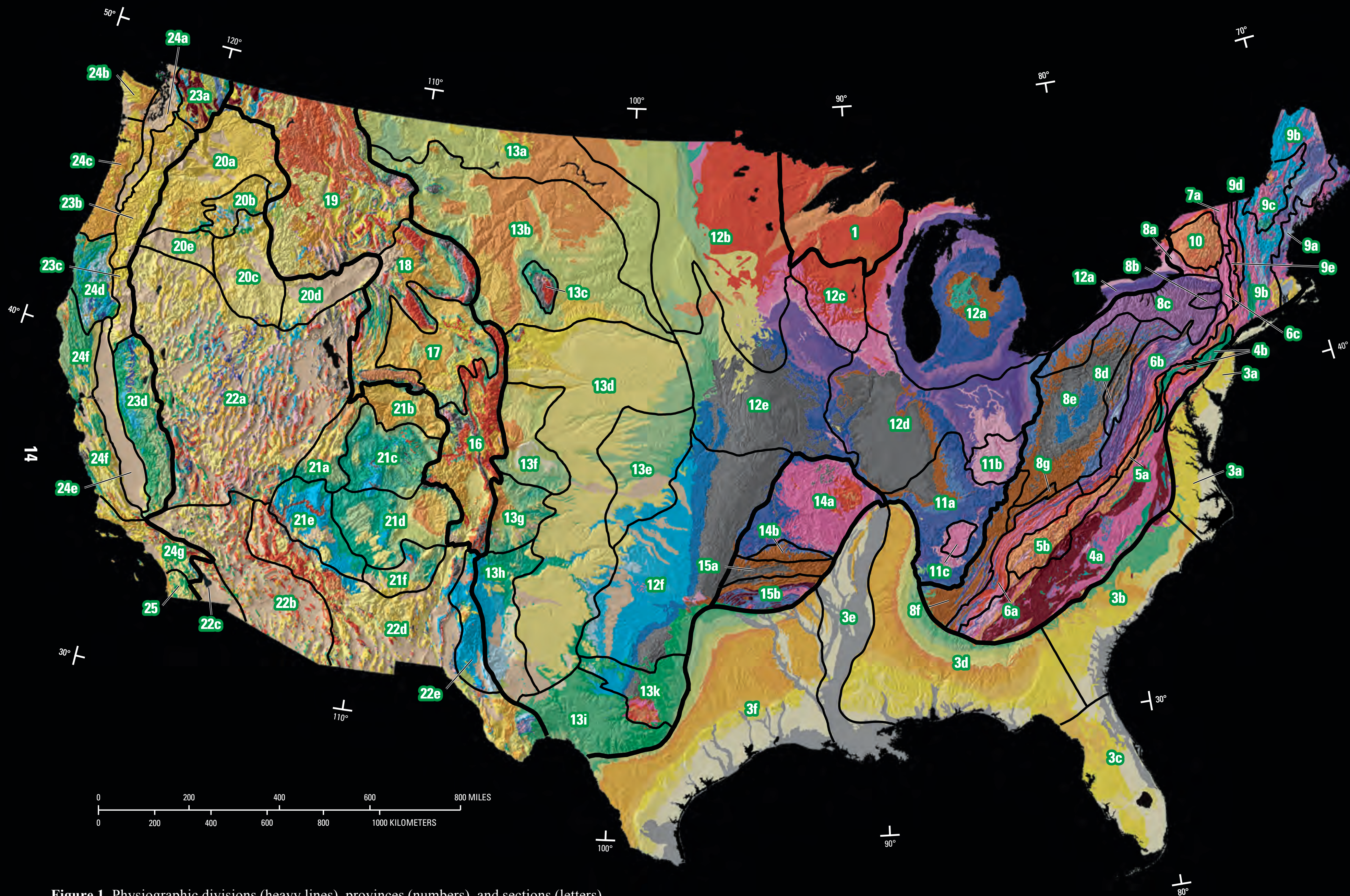


Figure 1. Physiographic divisions (heavy lines), provinces (numbers), and sections (letters) of the lower 48 states (from Fenneman and Johnson, 1946).

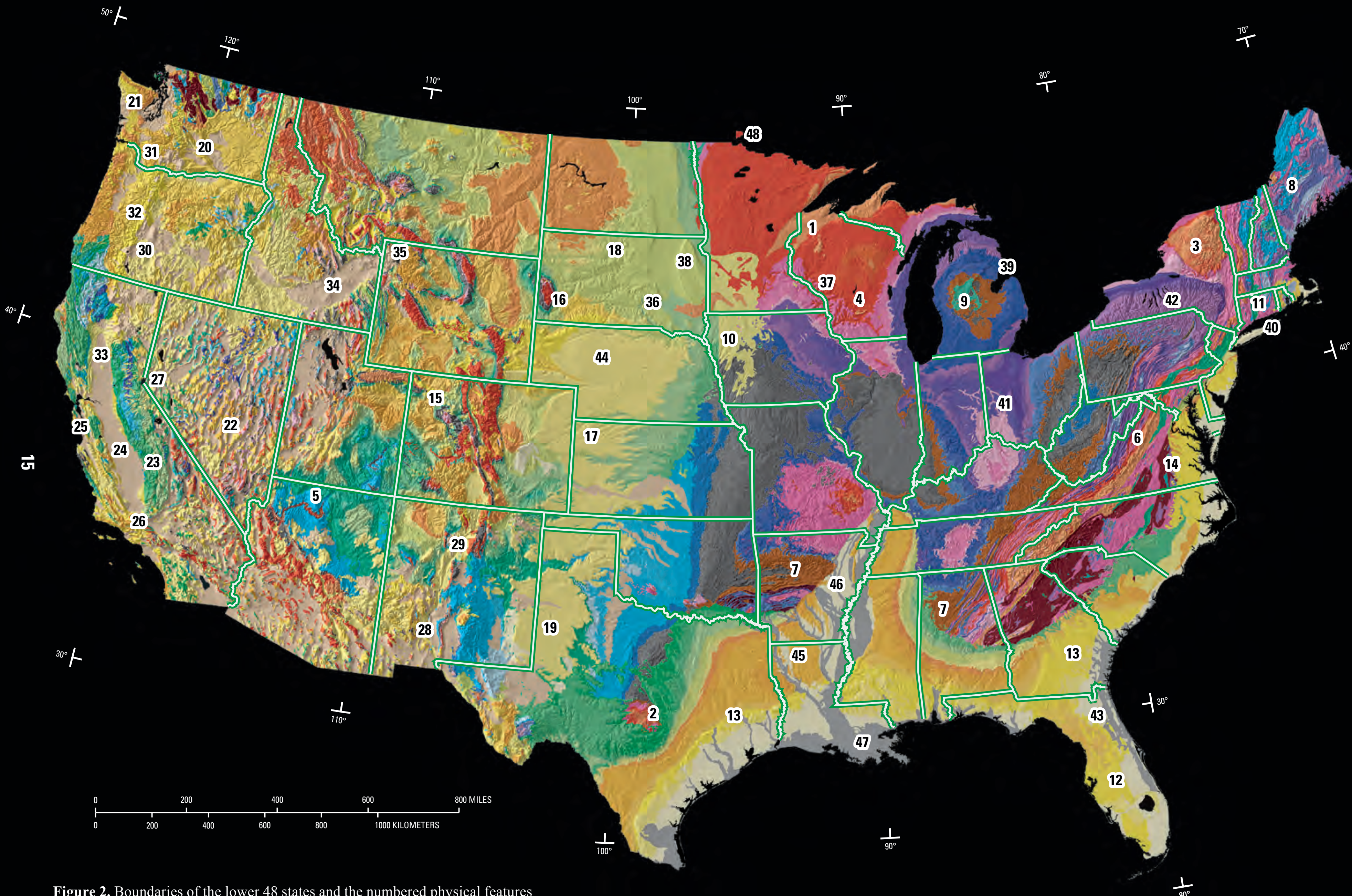


Figure 2. Boundaries of the lower 48 states and the numbered physical features cited in this pamphlet.

ISBN 978-1-4113-2282-0
9 781411 322820