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INSIDE

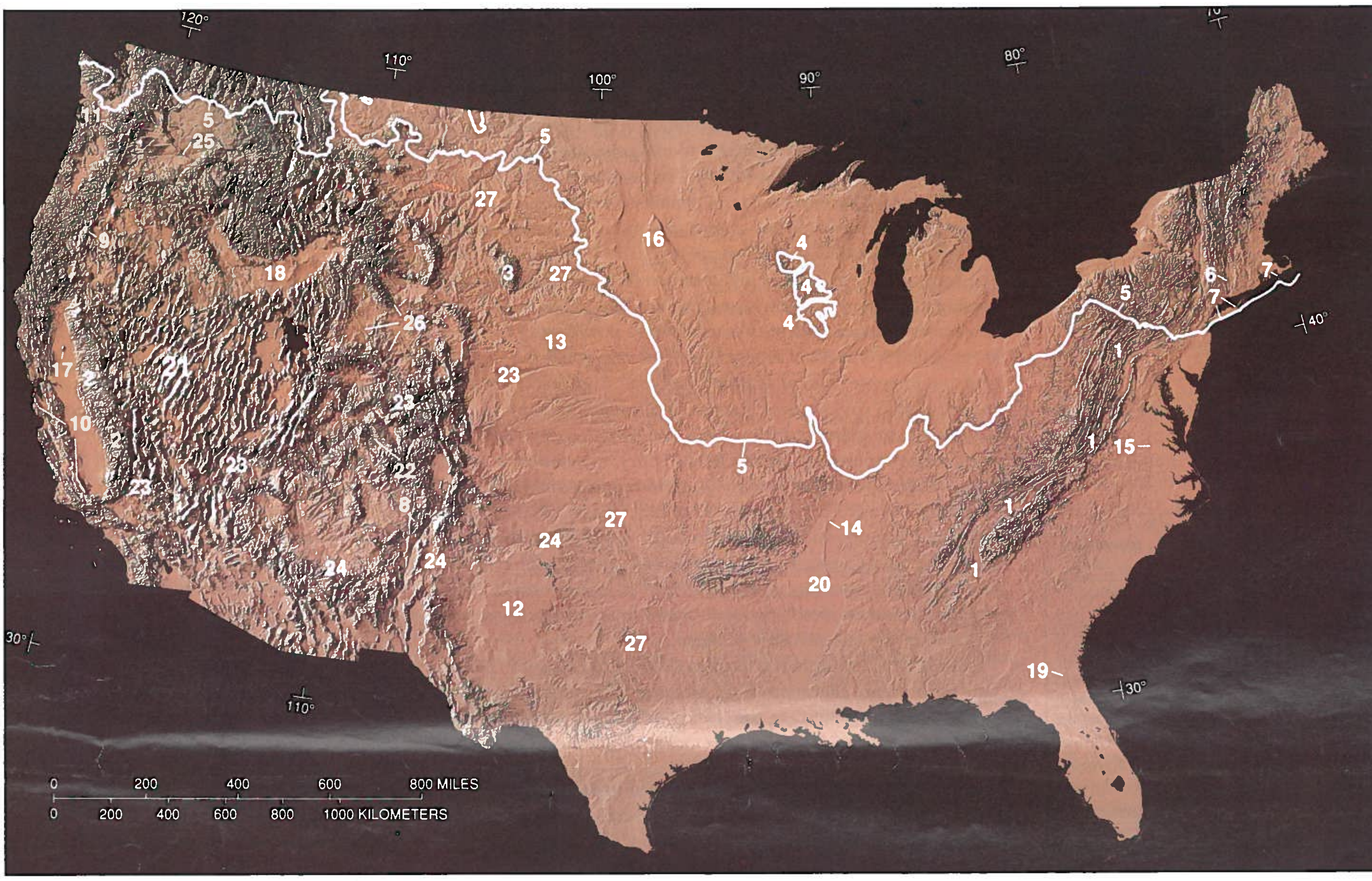

Figure 1 (above). The conterminous United States in computer-shaded relief (see large version on p. 252–253). Light source is 25° above the horizon at 300° azimuth. Numbers indicate topographic features cited in text (after Thelin and Pike, 1991): 1—folded Appalachian Mountains; 2—Sierra Nevada; 3—Black Hills; 4—driftless area; 5—southern limit of Pleistocene continental glacial deposits; 6—basalt ridges in the Connecticut River valley; 7—terminal moraines on Long Island and Cape Cod; 8—Valles caldera; 9—Crater Lake caldera; 10—San Andreas fault zone; 11—Mount St. Helens; 12—Llano Estacado; 13—Nebraska Sand Hills; 14—Crowleys Ridge; 15—Fall Line; 16—Coteau des Prairies; 17—Sutter Buttes; 18—low volcanic shields on Snake River plain; 19—Trail Ridge; 20—Mississippi alluvial plain; 21—Basin and Range province; 22—west-trending lineaments in Rocky Mountains; 23—extension of Garlock fault zone; 24—linear trend following Gila, Salt, and Canada rivers; 25—Olympic-Wallowa lineament; 26—northwest trends in Rocky Mountains; 27—north-northwest grain on High Plains.

Surface Features of Central North America: A Synoptic View From Computer Graphics

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ABSTRACT

A digital shaded-relief image of the 48 contiguous United States shows the details of large- and small-scale landforms, including several linear trends. The features faithfully reflect tectonism, continental glaciation, fluvial activity, volcanism, and other surface-shaping events and processes. The new map not only depicts topography accurately and in its true complexity, but does so in one synoptic view that provides a regional context for geologic analysis unobscured by clouds, culture, vegetation, or artistic constraints.

MECHANIZED MAPPING OF RELIEF

The techniques of visualization provided by computer graphics offer a fresh look at Earth's landform patterns. Hill shading, which shows topographic form by intensity of the sun's shadows, was adapted for digital execution (Yoeli, 1967; Batson et al., 1975) because manual (artistic) methods can economically portray only small areas both accurately and in detail. Large areas have been mapped by mechanized shading, but spatial resolution has remained low (Moore and Simpson, 1982; Loughridge, 1986). This paper briefly reviews a sampling of landforms depicted in a digital relief map of the entire conterminous United States that shows features as small as 2.5 km across.

Machine-shaded maps resemble cloudless aerial photographs but are actually large arrays of minute gray squares. Each square represents a brightness value computed from a mathematical relation between ground slope and azimuth and position of the observer and a simulated sun (Yoeli, 1967; Batson et al., 1975). Light and dark tones show steep areas; intermediate tones are gentle terrain. The maps are created from dense square-grid matrices of terrain heights, or digital elevation models, that sample topography normally observed in the field or viewed on photographs and satellite images.

A NEW MAP OF U.S. TOPOGRAPHY

The map (p. 252–253) is the most detailed and accurate synoptic view of U.S. relief forms yet made (for similar maps of some western states at 1:1 000 000 scale see Edwards and Batson, 1990). It resembles Harrison's (1969) vertical-perspective map in concept and execution but contains much more information than either that map or Raisz's (1940) near-vertical panorama of the same area. The new image was computed from 12 000 000 elevations (spaced 0.8 km apart) read from 1:250 000-scale topographic sheets. The 1:3 500 000-scale map (Thelin and Pike, 1991) gives specifics on the computer technique, digital dataset, and applications (see also Pike

Surface *continued on p. 251*

Surface *continued from p. 241*

and Thelin, 1989). Among highlights of the map, shown here at reduced scale (Fig. 1), are the following.

Large Features

Major topographic styles contrast vividly on the map. Two tectonic regimes, the static eastern United States —a passive continental margin—and the active plate margin of the west, differ in surface roughness, structural and coastline patterns, and freshness of relief. Topography north of the Pleistocene ice limit (5 in Fig. 1) is muted and lacks the strong, mature fluvial texture characteristic of unglaciated terrain to the south. Rough islands of the unglaciated driftless area in Wisconsin (4) stand out sharply from surrounding glaciated ground.

Physiographic units of the United States are based largely on topography (Fenneman and Johnson, 1946). Particularly distinctive in Figure 1 are the lithologic and structurally controlled folded Valley and Ridge province of the Appalachian Mountains (1), the Basin and Range province (21)—a complex region of fault-block structures formed by extension of a thin continental crust, the west-tilted Sierra Nevada fault block (2), the eroded domed strata of the Black Hills (3), and such sharp boundaries as the Fall Line (15)—which divides dramatically unlike rocks of the Piedmont and Coastal Plain provinces. Statistics of elevation and slope angle (Pike and Thelin, 1989) indicate that some Fenneman and Johnson (1946) boundaries (for example, that delimiting California's Central Valley) are so generalized that they do not accurately follow topographic contrasts. This new map and its raw data may aid in visualizing, refining, and interpreting such boundaries.

Small Features

Small but distinct features in Figure 1 include the southernmost volcano in the Cascade chain, the Pleistocene Sutter Buttes (17)—erupted through Upper Cretaceous and Tertiary sedimentary strata that fill the Central Valley; the many low Quaternary shields on the basalt-flooded Snake River plain (18)—which mark the tracks of two time-transgressive volcanic systems (Christiansen and McKee, 1978); and Trail Ridge (19, a major source of ilmenite and zircon) and other north-trending ridges in Florida —evidently coast-parallel transgressive complexes of Pleistocene dunes (Force and Rich, 1989).

Somewhat subtler are cuesta ridges of the Connecticut Valley (6)—eroded basalt flows intercalated in tilted redbeds during Mesozoic rifting; late Pleistocene terminal moraines that controlled much of the geomorphic evolution of Long Island and western Cape Cod (7); such late Cenozoic caldera-forming volcanoes as Valles (New Mexico; 8) and Crater Lake (Oregon; 9); and the complex, diffuse, and long-active San Andreas transform-fault zone (California; 10). Mount St. Helens (11) lies mostly hidden among the many peaks in the Cascade Range (southwestern Washington).

Midcontinent

The map is unique in its clear portrayal of low-relief features in the central United States. Among these are the broad and extraordinarily flat Pleistocene and Holocene alluvial plain of the Mississippi River (20) and the Llano Estacado of western Texas and eastern New Mexico (12)—an uplifted High Plains surface on permeable and virtually undissected fluvial sediments (Miocene) and their eolian veneer (Quaternary); the fine hummocky texture of Nebraska's late Holocene Sand Hills (13)—the largest dune field in the Western Hemisphere; and Crowleys Ridge (14)—a late Pleistocene erosional remnant in the upper Mississippi Embayment near the epicenter of the 1811–1812 New Madrid earthquakes.

An intriguing midcontinent landform, the Coteau des Prairies, is "a flat-iron-shaped plateau some 200 miles (300 km) long, pointing north" (Flint, 1955) in and near eastern South Dakota (16). The ice-scoured lowlands that flank this feature hosted the James and Des Moines lobes of the last ice sheet and then drained ice meltwater and ice-dammed lakes during deglaciation. The lowlands and intervening plateau bear remarkable resemblance in size and shape to Martian outflow channels with associated point bars observed on spacecraft images (Kehew and Lord, 1986). However, the Martian features usually are attributed to erosion by water, not ice (Mars Channel Working Group, 1983).

Linear Trends

Discontinuous linear features form throughgoing patterns on the map. Three of them are seen clearly perhaps for the first time here. An unmapped west-trending lineament in the Rocky Mountains (lat 38°30'N, long 105°–109°W) includes the Morrow Point–Blue Mesa Reservoir segment of the Gunnison River (22) and marks the northern edge of the Tertiary San Juan volcanic field. The other two lineaments parallel the Murray fracture zone, an inactive transform-fault zone system on the eastern Pacific sea floor. One seems to extend the trend of the Garlock fault zone east-northeast from Death Valley; the alignment persists as far as the Colorado Front Range near Fort Collins (23). The second is an east-northeast alignment (24) of parts of the Gila and Salt rivers (Arizona) and the Canada River (Texas). Better known are the northwest-trending Olympic-Wallowa lineament (25), which may include currently active faults (Mann, 1989), and many alignments subparallel to it in the Rocky Mountains to the southeast (26).

A 325°-striking grain characterizes erosional topography in the central part of the map (27), but its geological interpretation on an image such as this requires caution. Oblique illumination can enhance, subdue, or artificially create the appearance of terrain lineaments (Wise, 1969; Howard and Larsen, 1972). The 300° lighting of this map could be expected to emphasize linear features that lie at symmetrical acute angles to this azimuth—e.g., at 325°. The pattern is evident as aligned discontinuous ridges and valleys carved by north-northwest–striking segments of streams, especially on the Great Plains.

The grain may be a real geologic feature, on the basis of its abrupt disappearance or muting north and east of the glacial margin (5), its presence on the manually shaded 1:500 000-scale U.S. Geological Survey state map of South Dakota, its persistence on images using a different sun azimuth (360°), faintness of a complementary acute (275°-striking) linear pattern, and Wise's (1969) analysis of lineaments in the Black Hills area. The great extent of the pattern suggests a regional rather than a local cause and thus points toward tectonic rather than surface processes. If the aligned stream segments reflect preferentially etched bedrock fractures, it is noteworthy that they strike normal to the greatest principal horizontal compressive stress now prevailing in the western midcontinent (Zoback and Zoback, 1980, Fig. 5).

CONCLUSIONS

Topographic features shown on this new U.S. map highlight several advantages of computer-visualization methods for the synoptic interpretation of geology. Mechanized relief shading portrays landforms accurately and discloses their real complexity (here at 0.8 km resolution), two properties often lost in small-scale sketches and diagrams. Surface features are viewed continuously in a broad context limited only by size of the digital dataset— unlike plastic relief models, aerial photographs, and radar images. The map is without distortion and is free of the vegetation and culture that mask topographic form on satellite images. Finally, lighting conditions and viewer location can easily be varied for a different perspective on a landform or to enhance subtle physiographic features.

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