DIGITAL SHADED-RELIEF IMAGE OF ALASKA

By J.R. Riehle[1], M.D. Fleming[2], B.F. Molnia[3], J.H. Dover[1], J.S. Kelley[1], M.L. Miller[1], W.J. Nokleberg[4], George Plafker[4], and A.B. Till[1]

INTRODUCTION

One of the most spectacular physiographic images of the conterminous United States, and the first to have been produced digitally, is that by Thelin and Pike (1991). The image is remarkable for its crispness of detail and for the natural appearance of the artificial land surface. Our goal has been to produce a shaded-relief image of Alaska that has the same look and feel as the Thelin and Pike image. The Alaskan image could have been produced at the same scale as its lower 48 counterpart (1:3,500,000). But by insetting the Aleutian Islands into the Gulf of Alaska, we were able to print the Alaska map at a larger scale (1:2,500,000) and about the same physical size as the Thelin and Pike image. Benefits of the 1:2,500,000 scale are (1) greater resolution of topographic features and (2) ease of reference to the U.S. Geological Survey (USGS) (1987) Alaska Map E and the statewide geologic map (Beikman, 1980), which are both 1:2,500,000 scale.

Manually drawn, shaded-relief images of Alaska's land surface have long been available (for example, Department of the Interior, 1909; Raisz, 1948). The topography depicted on these early maps is mainly schematic. Maps showing topographic contours were first available for the entire State in 1953 (USGS, 1:250,000) (J.H. Wittmann, USGS, written commun., 1996). The Alaska Map E was initially released in 1954 in both planimetric (revised in 1973 and 1987) and shaded-relief versions (revised in 1973, 1987, and 1996); topography depicted on the shaded-relief version is based on the 1:250,000-scale USGS topographic maps. Alaska Map E was later modified to include hypsometric tinting by Raven Maps and Images (1989, revised 1993) as copyrighted versions. Other shaded-relief images were produced for The National Geographic Magazine (LaGorce, 1956; 1:3,000,000) or drawn by Harrison (1970; 1:7,500,000) for The National Atlas of the United States. Recently, the State of Alaska digitally produced a shaded-relief image of Alaska at 1:2,500,000 scale (Alaska Department of Natural Resources, 1994), using the 1,000-m digital elevation data set referred to below.

An important difference between our image and these previous ones is the method of reproduction: like the Thelin and Pike (1991) image, our image is a composite of halftone images that yields sharp resolution and preserves contrast. Indeed, the first impression of many viewers is that the Alaskan image and the Thelin and Pike image are composites of satellite-generated photographs rather than an artificial rendering of a digital elevation model.

A shaded-relief image represents landforms in a natural fashion; that is, a viewer perceives the image as a rendering of reality. Thus a shaded-relief image is intrinsically appealing, especially in areas of spectacular relief. In addition, even subtle physiographic features that reflect geologic structures or the type of bedrock are visible. To our knowledge, some of these Alaskan features have not been depicted before and so the image should provide earth scientists with a new "look" at fundamental geologic features of Alaska.

METHOD OF IMAGE GENERATION

The first step in producing the image was the creation of a statewide, digital elevation model (DEM) using data produced in 1°x1° blocks by the Defense Mapping Agency Topographic Center. These same data are currently available from the Earth Science Information Center, USGS (507 National Center, Reston, VA 20192; 703–648–6045). The original DEMs have a resolution of 3x6 arc-seconds in the horizontal (approximately 90x90 m); vertical values were interpolated to the nearest meter from digitized 200-ft contours. The 1°x1° blocks were spliced together in 1:250,000-scale quadrangles, most of which are 1°x3°. Visible flaws in the spliced data set were repaired using techniques such as data inversion, replacement of missing data lines, and correction of geometric distortions.

The individual data sets for 153 quadrangles were then sampled at a spacing of 30x30 arc-seconds (a ground resolution of approximately 900x450 m). Several remaining omissions in the data were filled using hypsography from the Digital Chart of the World (Defense Mapping Agency, 1992) together with surrounding DEM data.

Manuscript approved for publication on July 26, 1996

Author affiliation
[1] U.S. Geological Survey, 4200 University Dr., Anchorage, AK 99508
[2] Hughes STX Corporation, U.S. Geological Survey, EROS Alaska Field Office, 4230 University Dr., Anchorage, AK 99508. Work performed under U.S. Geological Survey contract #1434–92–C4004
[3] U.S. Geological Survey, 12201 Sunrise Valley Dr., Reston, VA 20192
[4] U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025

This patched data set was reprojected and interpolated to form a statewide data set in Albers Equal-Area Conic projection having a grid-cell size of 300 m (standard parallels at 55° and 65° N.; central meridian at 154° W.; and latitude of projection's origin at 50° N.). The Aleutian Island inset was reprojected and interpolated using the same parameters except for the central meridian (176° E. for the midpoint of the inset). The final step in generating the base DEM was to delimit the elevation data at sea level by adding a coastline digitized from 1:250,000-scale USGS quadrangles. This 300-m data set achieves a degree of resolution suitable for the creation of a sharp, high-resolution shaded-relief image at 1:2,500,000 scale.

The original quadrangle data sets were sampled previously at a broader spacing (lower resolution) of 30x60 arc-seconds, which is approximately 900x900 m, and joined as a mosaic. Missing data for the 900-m data set were added using ETOPO5 data (Fleming and Binnian, 1990) and reprojected and resampled to 1,000 m in Albers Equal-Area Conic projection. The 1,000-m data set proved insufficient for the creation of a high-resolution, shaded-relief image at 1:2,500,000 scale. However, this lower resolution data set has been used effectively elsewhere, such as for the shaded-relief base image used in the map of Alaskan transportation corridors published by the Alaska Department of Natural Resources (1994).

The shaded-relief image was generated from the DEM using procedures and algorithms generally similar to those employed by Thelin and Pike (1991, see Computation and Production). A difference between the images is that, owing to the wide variation of topographic trends across Alaska, the Alaska image is a composite of three different azimuth or illumination directions, but all having the same sun angle of 25° above the horizon. The three azimuths are northeast (for southeastern Alaska), north (for south-central and southwestern Alaska), and northwest (for the remainder of the State). Preferred azimuths were selected by visual inspection of trial images. After digitally combining the regions into a single image, the final image was produced by applying a nonlinear stretch to the illumination values to take advantage of the full range of intensity values available on the output device, and by adding a vertical exaggeration of 2x. Another difference from Thelin and Pike's (1991) methodology is a slightly different method of computing the amount and direction of slope for each pixel.

Preparation of the final image involved several steps. Inland water bodies larger than about 20 acres were obtained from 1:2,000,000-scale Digital Line Graph (DLG) files of the USGS. The lakes were combined with the image files as a digital overlay and are shown in black for ease of recognition. Five black plates were created for the printing process: three contain imagery information and two contain text information. Initial image rotation and translation into a Scitex-readable data file were accomplished on a Macintosh computer; the data file was then transferred to a Scitex Imager System. The single greytone image was then subdivided into a three-layer (tritone) composite image. Stretches were applied individually to each of the layers to create the black plates emphasizing shadow, midtone, and full-range data.

A layout file containing non-imagery data was generated by compositing linework files generated by ARC/INFO, Macintosh, and Scitex systems. ARC/INFO was used to generate digitized extensions of Russia and Canada to fill to Alaska Map E neatline extensions. Text and scale-bar information was generated by a Macintosh computer. The Scitex system was then used to composite all linework files and generate masks and traps for printing. The image and layout files were combined in the publication-quality negatives, which were created on the Scitex system.

The published image has two manual modifications. First, a "glitch" (data loss) in the 300-m DEM data set was corrected by airbrushing a roughly circular area of about 500 km², just west of the Alaska-Yukon border between the Bagley Icefield and the Chitina River fault valley (see fig. 2, nos. 20 and 24, respectively). Second, the shoreline at the head of Icy Bay (see fig. 2, no. 17) was manually drawn from 1996 oblique aerial photography. The Icy Bay glaciers have retreated nearly 20 km between 1954, the age of the shoreline used to delimit the rest of the image, and 1996.

TYPES OF PHYSIOGRAPHIC FEATURES

AREAS OF CONTRASTING RELIEF

An obvious feature of the Alaskan shaded-relief image is the contrast between flatlands and mountains. Wahrhaftig's (1965) classic physiographic divisions of Alaska—areas that differ in topographic appearance from adjacent areas (fig. 1)—are nicely illustrated by the image.

Physiographic and geographic features discussed in the text are shown on figure 2 (centerfold) to assist with identification of features on the image. The numbers are arranged sequentially from southeastern Alaska through south-central Alaska to the Aleutian Islands, then along the west coast to the Seward Peninsula, east to the Yukon border, and then north to the Brooks Range and the coast of the Beaufort Sea. Another useful aid for locating features is the Alaska Map E (USGS, 1987).

Areas of low relief are chiefly glaciers and icefields; unconsolidated deposits; or young, flat-lying bedrock. For example, the two largest piedmont glaciers in the world, the Malaspina (16) and Bering Glaciers (21), are readily apparent where they emerge from the mountains near sea level in south-central Alaska, and the Juneau Icefield (6) stands out as a relatively smooth surface above 1,500-m elevation, among the fractures in the Coast Mountains northeast of Juneau. The Arctic Coastal Plain (fig. 1; 109) of the North Slope, a virtually featureless area on the shaded-relief image, is underlain by unconsolidated deposits. Some Alaskan physiographic divisions coincide with structural basins (compare figs. 1 and 3; Kirschner, 1994): areas that, in the recent geologic past, have tectonically

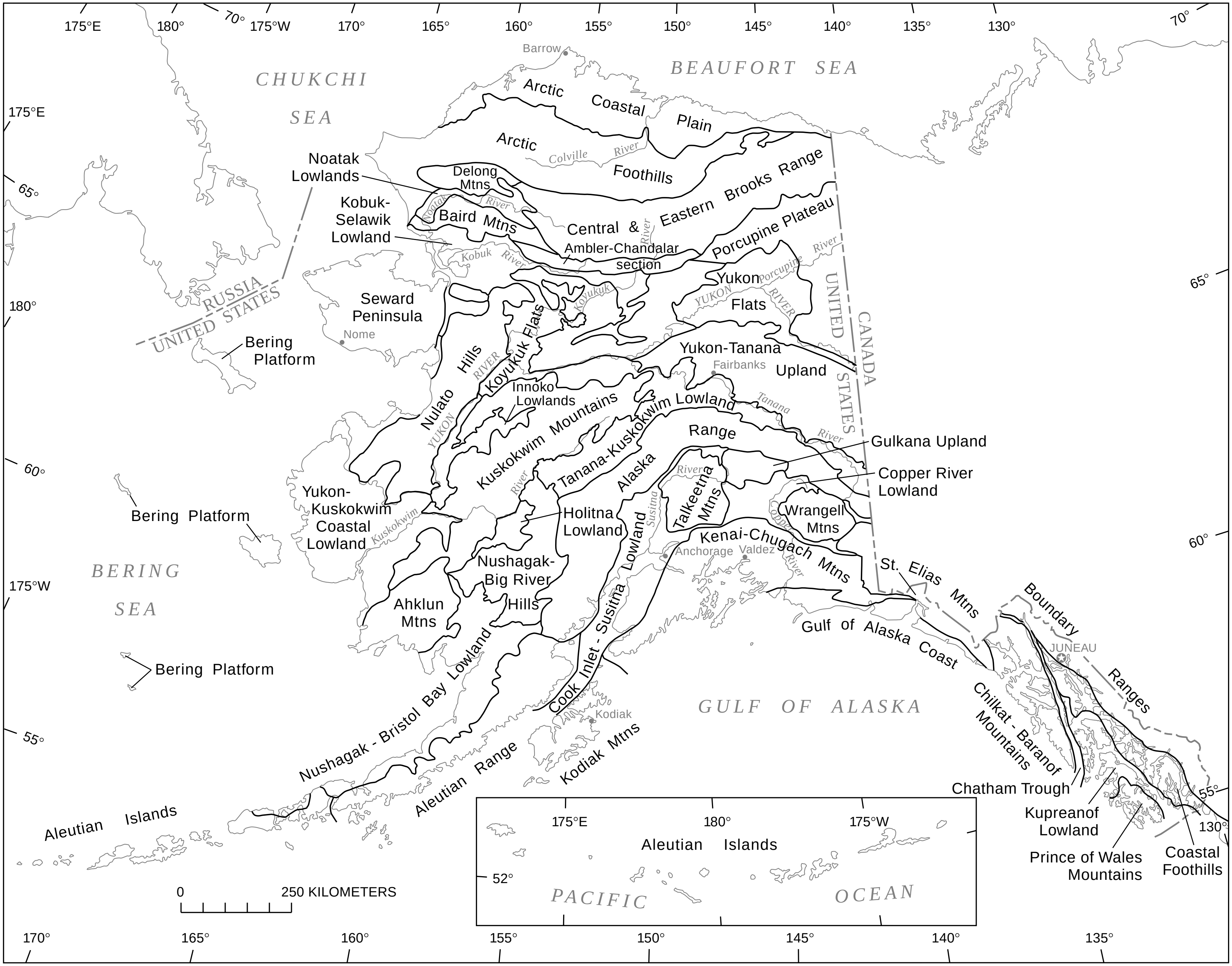

Figure 1. Physiographic divisions of Alaska (generalized from Wahrhaftig, 1965); main divisions labeled.

subsided and received sediments eroded from nearby, actively rising highlands. The young sedimentary rocks that partly fill these basins are distinguishable from the adjacent highlands by their low relief and low density of fractures. An example is the Cook Inlet basin (46), between the Kenai Mountains and the Aleutian Range in south-central Alaska.

FAULT-CONTROLLED VALLEYS

Linear valleys are another type of physiographic feature that is obvious on the shaded-relief image. Many of these valleys have been eroded along, or adjacent to, faults (fig. 3) or fracture zones. Generally, the more recent the movement on the fault and the steeper the fault plane, the more sharply defined the valley. So, for example, the trace of the Fairweather fault (12)—the transcurrent boundary between the North American and Pacific plates—is strikingly obvious in southeastern Alaska. This fault is still active, having had large earthquakes as recently as 1958 (Lituya Bay, *M*=7.7) and 1972 (Sitka, *M*=7.6; Plafker and others, 1994), and has had hundreds of kilometers of right-lateral offset since its formation about 30 million years ago.

LINEAMENTS

In addition to fault-controlled valleys, other linear physiographic features—lineaments—are visible on the image as well. To our knowledge, many of these lineaments have not been previously identified and cannot be readily attributed to specific geologic features. In the area from the Copper River basin (29) east to the Canadian border, for example, valley segments define a faint but pervasive, north-south alignment. West of the Copper River basin (29), from north of the Denali fault (35) to the south end of the Kenai Peninsula (32), a similar pervasive alignment of lineaments is more northwesterly. In the Aleutian Range on the west side of Cook Inlet (46), a subtle but pervasive northwest-trending alignment of lineaments occurs in addition to the northeast-striking major faults. These lineaments correspond to no specific faults, although many minor faults and fractures that have a northwesterly strike have been mapped near one of the most prominent lineaments (69) (B.M. Gamble, USGS, written commun., 1996). In southwestern Alaska, a predominantly northeast alignment of lineaments is parallel to major through-going faults (66 and 67).

DISCUSSION OF SELECTED FEATURES BY AREA

One of the benefits of a shaded-relief image is to illustrate physiographic features that, for reasons of scale, tone, or directional bias, are not as apparent in other media. As noted by Thelin and Pike (1991, p. 3), "A major strength of [their] new map is not so much its expression of the obvious, but rather its depiction of features that are subtler or less familiar." Toward this end, we discuss selected physiographic features visible on the shaded-relief image, which both earth scientists and lay persons alike may find interesting. The features we discuss are only examples; many features are left to viewers to identify for themselves.

Readers seeking a single source of more detailed information about Alaska's geology are referred to the review papers compiled by Plafker and Berg (1994a); most of the concepts referred to in this report are discussed in one or more of these review papers. Citations included here are either for original sources of specific information that are not cited in Plafker and Berg (1994a), or for other sources on particularly interesting, major facts and interpretations. Readers who are interested in definitions of geologic terms are referred to the Glossary of Geology (Bates and Jackson, 1987).

SOUTHEASTERN ALASKA: PRINCE OF WALES ISLAND TO ICY BAY

The physiography of southeastern Alaska is dominated by northwest-trending fault valleys such as those of the Chatham Strait fault in Chatham Strait fiord (3), the Fairweather fault (12), and possible splays of the Denali fault near Juneau (5). The most active of these faults at present is the Fairweather fault (fig. 3), the boundary between the Pacific and North American plates; the Fairweather fault occupies a prominent, ice- and alluvium-filled trough between Icy Cape (10) on the south and the head of Yakutat Bay (14) on the north. Faults on the northern part of Baranof Island (Peril Strait and Sitkoh Bay faults; 8) extend from the Chatham Strait fault to the Fairweather fault. Other linear valleys such as the one on the Canadian border (15) northeast of Yakutat Bay may be inactive splays of nearby named faults.

Through-going, linear fault valleys are conspicuously absent from the highlands along the border with Canada. Instead, these rocks—the Coast plutonic complex (2)—are characterized by a crosshatched pattern of pervasive, north- and northwest-striking fractures. There are no major through-going faults because the plutonic rocks of the complex, intruded about 50 million years ago, obscure any older faults. In contrast, rocks to the southwest of the Coast plutonic complex are mainly older and have through-going, northwest-trending fault valleys.

Fragments of the Earth's crust, or terranes (Plafker and Berg, 1994b), have slowly migrated, some great distances, along some of the northwest-striking faults of southeastern Alaska and along other Alaskan faults. The terranes have collected over geologic time into a collage that forms the present geologic framework of much of southeastern and south-central Alaska.

Flat-lying areas in southeastern Alaska are the result of different causes. Local areas of low relief on Kupreanof

Island (1) may reflect in part a type of bedrock that is less resistant to erosion. The southern part of Kruzof Island (4) is underlain by young, flat-lying volcanic rocks and deposits; the volcanic cone of Mount Edgecumbe is visible on the image, as well. The Juneau Icefield (6) is one of the largest icefields in Alaska. Glacial deposits underlie the east headland at the entrance of Glacier Bay (7), which has formed just since the late 1700's by more than 100 km of retreat of tidewater glaciers. Coastal lowlands between the Alsek River (13) and Yakutat Bay have formed in the past 2,000 years by northwestward littoral transport of sediment carried by the Alsek River.

Brady Glacier (9) is the largest outlet glacier in the Fairweather Range and occupies the valley of the Border Ranges fault. Lituya Bay (11) is a T-shaped fiord that has formed since the 1600's by retreat of tidewater glaciers. Earthquakes on the Fairweather fault (12), which underlies the valley that forms the cross-arm of Lituya Bay, have caused landslides and icefalls into the bay several times in the past 200 years; giant destructive waves resulting from

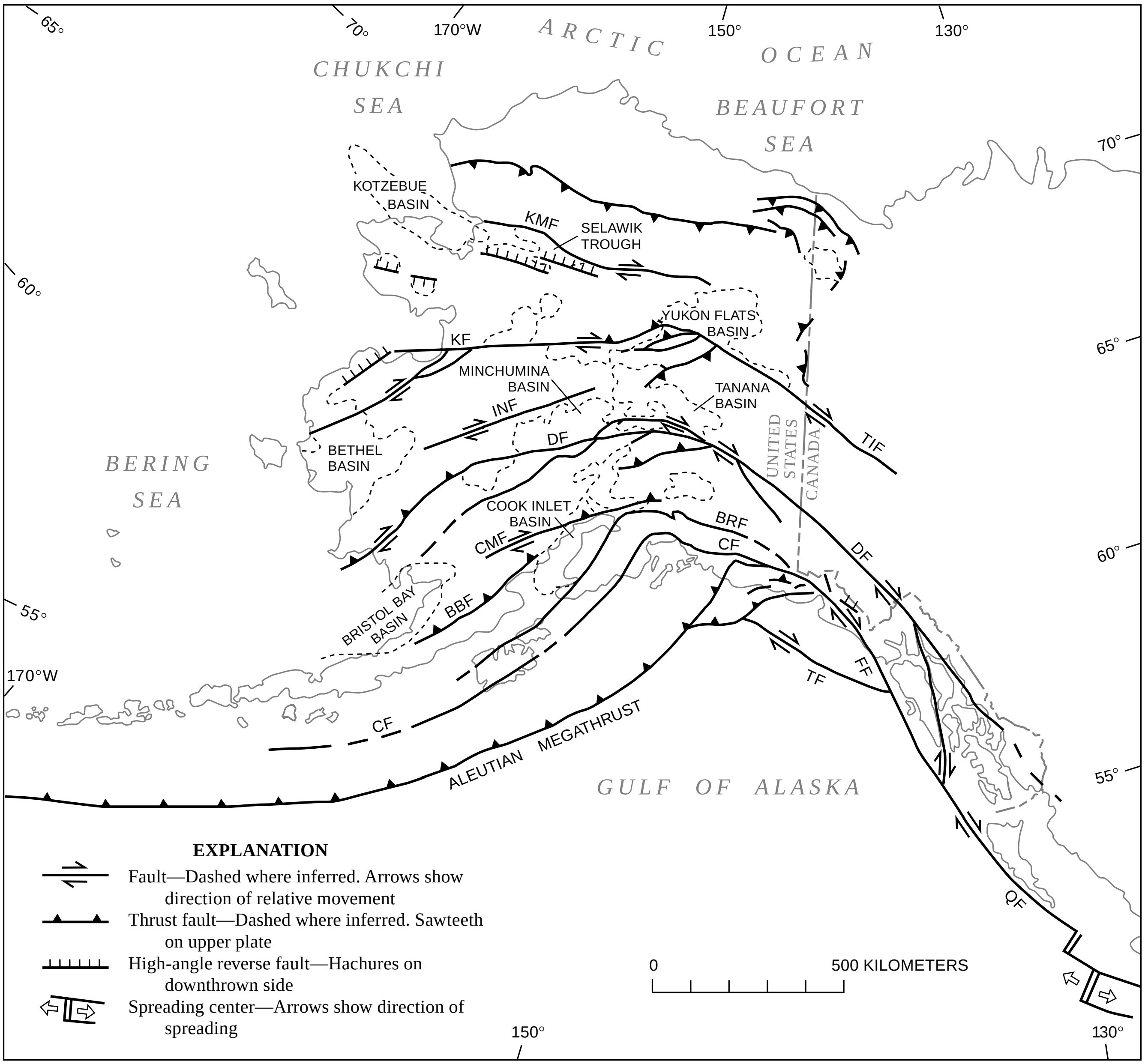

Figure 3. Major faults of Alaska and their extensions into Canada (from Plafker and others, 1994) and sedimentary basins, that is, areas of flat-lying, typically young sedimentary rocks and deposits (from Kirschner, 1994). BBF, Bruin Bay fault; BRF, Border Ranges fault; CF, Contact fault; CMF, Lake Clark-Castle Mountain fault; DF, Denali fault; FF, Fairweather fault; INF, Iditarod-Nixon Fork fault; KF, Kaltag fault; KMF, Kobuk-Malamute fault system; TF, Transition fault; TIF, Tintina fault; QF, Queen Charlotte fault.

Figure 2 Graphic
(centerfold)
Shaded-relief index of Alaska

Figure 2 Graphic
(centerfold)
Shaded-relief index of Alaska

the landslides have swept down the length of the bay, most recently in 1958 (Miller, 1960). Yakutat Bay (14) and its southeastward extension, Russell Fiord, were filled by an advanced Hubbard Glacier as recently as 1,000 years ago. In 1986 Hubbard Glacier advanced to block the entrance to Russell Fiord, resulting in temporary formation of a large freshwater lake in the fiord. Retreat of Guyot Glacier during the first half of the 20th century has lengthened Icy Bay (17) by more than 30 km.

SOUTH-CENTRAL ALASKA: ICY BAY TO COOK INLET AND NORTH TO THE ALASKA RANGE

The second and third tallest mountains in North America are located within 50 km of one another near the Canadian border north of Icy Bay (17). Mount Logan (not shown) is Canada's highest mountain (19,850 ft) and Mount Saint Elias (18) is the United States' second tallest peak (18,008 ft).

The major fault valleys in south-central Alaska are those of the Denali fault (35), the glacier-filled valley of the Contact and Bagley faults (19) in the Chugach Mountains, the Chitina River fault (24) that bounds a short segment of the north flank of the Chugach Mountains, and the Castle Mountain fault (44). Of these faults, only the Denali and Castle Mountain faults are currently active (fig. 3). Other, unnamed faults probably underlie many of the linear valleys in the Chugach Mountains east and north of Prince William Sound. A short segment of the Patton Bay thrust fault is exposed on the southeastern part of Montague Island (30); movement on this fault caused 7.9 m of uplift of the island during the great Alaska earthquake in 1964 (M=9.2; the digitized shoreline shown on the map predates the uplift) (Plafker, 1967).

An obvious aspect of the Denali and Castle Mountain faults in south-central Alaska is the progressive change in their orientation from east to west. Originally these strike-slip faults were nearly linear, northwest-striking features along the west margin of North America. Beginning about 65 million years ago, much of Alaska began to rotate counterclockwise at least partly because of a collision between North American and Eurasian crustal plates (see summary by Plafker and Berg, 1994b). After as much as 60° of rotation, which ended by about 40 million years ago, these faults had been deformed to their present, southward-concave traces (fig. 3).

The Bering Glacier (21) is the major outlet of the Bagley Icefield (20), which occupies in part the trench of the Bagley fault. Okalee Spit (22) is actively growing westward as a result of littoral (wave- and current-driven) transport of sediment carried to the Gulf of Alaska by the Bering Glacier and other Chugach Mountains glaciers east of the spit. The barrier islands at the mouth of the Copper River (23) are built of sediment delivered by the Copper River, one of Alaska's largest braided streams. As these islands migrate westward, they are replaced by new ones. The Chitina River follows the north margin of the Chugach Mountains from near the Chitina River fault (24) to a junction with the Copper River. The Copper River (28) then turns sharply south and cuts directly across the Chugach Mountains. The crosscutting is the result of downcutting by the Copper River in a course that predates uplift of the Chugach Mountains.

The volcanic Wrangell Mountains stand in sharp relief on the north side of the Copper River. The volcanoes Mount Sanford (25), Mount Drum (26), and ice-covered Mount Wrangell (27) are readily apparent in the western part of the Wrangell Mountains. Note the radial drainage from these volcanoes, in contrast with the linear erosional pattern that reflects faults and fractures in rocks of the Chugach Mountains and in the older volcanic rocks in the northeastern part of the Wrangell Mountains. The Copper River basin (29) is identifiable by its low relief developed on glacial and lake deposits of Quaternary age.

The trace of the Rainy Creek thrust fault (34), a north-dipping thrust fault south of the Denali transform fault (35), is marked by a valley over part of its extent. The Granite Mountain pluton (39) north of the Denali fault is recognizable as a subcircular area of high relief. The north-flowing Delta River (36) originates south of the Alaska Range and, like the Tok (37) and Nenana (38) Rivers, may constitute an ancestral drainage that maintained its course as North America's highest mountain range rose. Mount McKinley (40), North America's highest peak (20,320 ft), and Mount Foraker (41; 17,400 ft) are prominent peaks in the Alaska Range that are adjacent to the Denali fault just south of its trace.

The Columbia Glacier (31) is the largest tidewater glacier in Prince William Sound. The intricate shoreline of Prince William Sound and the southeastern Kenai Peninsula is the result of submergence of glacially eroded fiords and cirques (32). Tazlina Lake (33), which extends in depth to nearly 1,000 ft below sea level, was exposed by the retreat of the north-flowing Tazlina Glacier. The Elmendorf moraine (45), faintly visible across Knik Arm at the north end of upper Cook Inlet, marks the advanced terminal positions of the Knik and Matanuska glaciers (43) about 14,000 years ago.

The Cook Inlet structural basin (46) and its northward extension, the Susitna Lowland (fig. 1), are marked by the subdued relief of Tertiary sedimentary rocks and glacial deposits that partly fill the basin, in contrast with the highlands of older rocks to the east and west. The prominent linear front of the Kenai Mountains, on the east side of the Cook Inlet basin, approximately follows a concealed segment of the Border Ranges fault (47) (MacKevett and Plafker, 1974). The rocks along this segment of the Border Ranges fault presently are down on the northwest side of the fault (the Kenai Lowlands). Where exposed in the southern part of the Kenai Peninsula and north of Prince William Sound, however, rocks along the Border Ranges fault are up on the northwest side. Thus, the Kenai Mountains segment of the fault may coincide with a flexure caused by subsidence of the Cook Inlet basin in response to its sedimentary infilling. Perhaps the flexure, in part, reactivated the Border Ranges fault.

The north margin of the Matanuska Valley follows the trace of the Castle Mountain fault (44), which extends westward and then southwestward across the Susitna Valley. In contrast, the northwest-flowing Sheep and Talkeetna Rivers (42) are incised across the Talkeetna Mountains at nearly right angles to the Matanuska River. Such a drainage pattern developed on a land surface that sloped northwest away from the Matanuska Valley; the Sheep and Talkeetna Rivers maintained their ancestral courses by downcutting as the northern part of the Talkeetna Mountains rose.

The cone-shaped peaks of some of the northeasternmost Aleutian-arc volcanoes—Spurr (48), Redoubt (49), Iliamna (50), and Augustine (51)—are visible on the west side of Cook Inlet. The most obvious structural feature in the northern part of the Aleutian Range is the trace of the Lake Clark fault (52), the southwestward extension of the Castle Mountain fault (fig. 3).

ALASKA PENINSULA, KODIAK ISLAND, AND ALEUTIAN ISLANDS

The rugged Pacific coastline of the Alaska Peninsula contrasts markedly with the shoreline of the Nushagak-Bristol Bay Lowland (fig. 1) on the northwest side. The lowland is underlain largely by unconsolidated Quaternary deposits, whereas the Pacific coastline is glacially eroded bedrock. Geologically young faults in the southeastern part of Kodiak Island (58) are easily discerned.

The larger and (or) more isolated of the Aleutian-arc volcanoes are visible along the crest of the Aleutian Range, for example, Mount Douglas volcano (54); Mount Katmai volcano (caldera; 56) and, immediately to the northwest, Griggs Volcano; Mount Peulik volcano (59); Aniakchak Crater (caldera; 60); and Mount Veniaminof volcano (61). The radial drainage pattern and nonfractured volcanic rocks of young volcanoes such as Okmok Caldera—90 km southwest of Makushin Volcano (65) on Unalaska Island—contrast strongly with the dense pattern of fractures in older volcanic rocks south and east of Makushin Volcano.

The north-northeasterly alignment of the volcanoes west of Cook Inlet clearly differs from the northeasterly alignment of the volcanoes on the northernmost Alaska Peninsula. Most Aleutian-arc volcanoes are between 80 and 110 km above the top of the subducting Pacific plate (Kienle and others, 1983). Thus, the different alignment of the volcanoes in different sectors of the arc means that the underlying Pacific plate is broken into segments. Because the dip of the Pacific plate increases from the northern part of Cook Inlet to the Alaska Peninsula, the distance of the volcanoes from the Aleutian trench or megathrust (fig. 3) progressively decreases to the southwest.

The glacial moraines that form the large lakes of the Alaska Peninsula are visible through close inspection of the image. For example, Iliamna Lake (53) and Becharof Lake (57) are glacial troughs dammed at their west ends by deposits of glaciers, which flowed through lows in the Aleutian Range from an ice sheet on the Pacific continental shelf. In contrast, Naknek Lake (55) was occupied only by valley glaciers that formed in local cirques in the Aleutian Range to the east. The Aleutian Range east of Naknek Lake blocked westward movement of ice from the continental shelf, and the moraines at the outlet of Naknek Lake are not as prominent as those on Iliamna and Becharof Lakes. Another example of landforms resulting from northwestward flow of ice from the continental shelf are the narrow isthmuses on Cold Bay (63) and Morzhovoi Bay (64). Note in comparison the small but well-defined valleys and moraines (62) of glaciers that formed locally in cirques west of Mount Veniaminof volcano (61).

SOUTHWESTERN ALASKA

The Yukon-Kuskokwim Coastal Lowland (71) is a dominant feature in southwestern Alaska (fig. 1). Other interior lowlands, such as that of the Holitna Lowland (68) structural basin, are less obvious. The actively prograding delta of the Yukon River (75), a classic lobate (sediment-dominated) delta, is readily seen on the south shore of Norton Sound. In contrast, the Kuskokwim River terminates in a marine estuary (70). At various times in the geologic past, both rivers shifted their courses throughout the lowlands. Thus, the uninterrupted extent of the combined Yukon-Kuskokwim Coastal Lowland means that at some time the two rivers may have been joined in a single outlet.

The important structural features of southwestern Alaska that are visible on the image are the Goodnews fault (66), the Denali-Farewell faults (67), and the Iditarod-Nixon Fork fault (74). Some of these faults are southwesterly extensions of faults from the Alaska Range. Small knobs in southwestern Alaska mark outcrops of more resistant, volcanic and intrusive rocks (72) that have intruded, or been deposited upon, the surrounding sedimentary rocks. Other small knobs on Nunivak Island (73) are geologically young basaltic cinder cones.

The subdued relief of southwestern Alaska differs markedly from that of the adjacent Alaska Range and Alaska Peninsula. This, in part, reflects the different rock types: geologically young, little deformed sedimentary rocks underlie much of southwestern Alaska, in contrast to the mixture of sedimentary and more resistant igneous and metamorphic rocks that underlie the west side of Cook Inlet and the Alaska Peninsula.

SEWARD PENINSULA AND WESTERN INTERIOR ALASKA

The major structural feature visible in western Alaska is the Kaltag fault (77), a geologically young, right-lateral strike-slip fault that is the extension of the Tintina fault (90) in east-central Alaska (fig. 3). A faint, northeasterly alignment of valleys and ridges in the Nulato Hills (76) reflects folds and unnamed faults in the sedimentary rocks.

The prominent area of low relief east of the northern part of the Nulato Hills is the Koyukuk Flats (78; fig. 1).

The barrier islands on the northwest edge of the Seward Peninsula (79), formed by northeastward littoral transport of sand, are readily identified on the image. The Kigluaik and Bendeleben Mountains (80) are geologically young ranges bounded by east-striking, active normal faults along which these mountains have been uplifted. The structural trend in the eastern Seward Peninsula (81) is north-south; this trend reflects inactive, north- to north-east-striking faults, parallel to those in the Nulato Hills to the east.

The Baldwin Peninsula (82) in the eastern part of Kotzebue Sound was formed by deposition and (or) shoving of sediments by west-flowing glaciers that originated in the Brooks Range.

EAST-CENTRAL AND EASTERN INTERIOR ALASKA

The Koyukuk Flats (78) extend discontinuously from the east side of the Nulato Hills (76) to the south side of the Brooks Range (fig. 1). Local areas of more rugged relief (83) are typically underlain by plutons, which have intruded the less resistant sedimentary rocks, and by surrounding metamorphic rocks (Patton and Box, 1989). The flats are bordered on the east by more resistant metamorphic rocks (84) of the Ruby geanticline.

The right-lateral Tintina fault (90) is a major structural feature of east-central Alaska (fig. 3). Like faults farther to the south in Alaska, the Tintina fault was deformed to its present, southward-concave trace by counterclockwise rotation of Alaska between about 65 and 40 million years ago. Other major faults include the Tozitna fault (85) and the Kaltag fault (77). The Minook Creek fault (86) is a north-striking, high-angle fault that has modern earthquake activity and so is probably active. Two other fault-controlled lineaments cross the resistant metamorphic rocks of the Yukon-Tanana Upland (fig. 1) and merge with the Tintina fault. One may be a splay of the Tintina (87) and the other is the left-lateral Shaw Creek fault (88).

The prominent, smoothly curving boundary (91) between the Yukon Flats (fig. 1) and the flat, loess-covered uplands to the south may be fault controlled, judging from its faint linear extension into uplands to the southeast and from its parallelism with the Tintina fault system. Other, northeast-trending lineaments in the Yukon-Tanana Upland (89) are parallel to known fractures and mapped faults in the area and may represent additional faults in this area of low relief and thick loess deposits.

BROOKS RANGE AND NORTH SLOPE

The Brooks Range is a 1,200-km-long, east-west-trending continuation of geologic belts found in the Rocky Mountain region of Canada and the conterminous United States. The continental divide extends the length of the range and separates north- from south-flowing rivers. Glacially sculpted valleys visible on the image include those of the north-flowing Itkillik (92), Anaktuvuk (93), and Killik Rivers (94) and the south-flowing east fork of the Chandalar River (95).

The Brooks Range is bordered on the south by the Kobuk-Malamute fault system (96) and a parallel fault system (97) south of the Kobuk-Malamute system (fig. 3). Both fault systems extend east to where their physiographic expression is obscured in the Yukon Flats; the fault systems may in part converge (98) west of the Yukon Flats. The Bear Mountain (99) and Ammerman Mountain (100) plutons are visible as small circular patches near the Yukon border. The prominent Noatak Lowlands (101), in the western part of the Brooks Range, are bounded on their east side by a normal fault (Karl, 1992) and so, at least in part, may be a structural basin.

The rocks of the main part of the Brooks Range generally are older, more resistant, and more complexly deformed than rocks of the Arctic Foothills (fig. 1) on the north flank of the range. Discontinuous, west-northwest topographic trends in the north-central part of the Brooks Range (104) reflect the present orientation of structural basins that began to develop between 370 and 360 million years ago. The rocks that fill these basins, as well as younger rocks, were faulted (thrust) northward toward rocks that form the Arctic Foothills starting about 120 million years ago. This faulting resulted in the east-west trend of the present range front. Prominent Leffingwell ridge (105) marks the northeast-trending contact between less resistant rocks under the Arctic Coastal Plain to the northwest and rocks that underlie the Brooks Range. The northeasterly trend is a complex result of younger folding and faulting that began about 60 million years ago and which has produced the east-trending fold ridges in the Arctic Foothills (102). A reverse-Z-shaped ridge (103) marks one such pair of east-trending folds that plunge slightly to the east, resulting in a Z pattern.

Among the youngest deformational features in northern Alaska are the Sadlerochit Mountains (106), which were produced by uplift related to folding and thrusting at the east end of the Brooks Range. Historic earthquakes beneath nearby Camden Bay (107) may also be the result of active mountain building in this area.

The Arctic Coastal Plain on the North Slope of Alaska, an area approximately equal to that of Kentucky, is underlain by perennially frozen, unconsolidated deposits. Most of the area is poorly drained and the ground surface has local relief principally due to thaw lakes, pingoes (ice-cored frost mounds), or dunes. The scale of the shaded-relief image is inadequate to show many physiographic details; however, northeast-oriented, stabilized sand dunes (108) are sufficiently large and extensive on the west side of the Colville River to be just visible. These dunes were active during the last ice age. From the dunes north to the coast of the Beaufort Sea is an area of interbedded marine deposits, small dunes, and fluvial deposits (109). The largest of the barrier islands along the

Beaufort coastline (110) are just visible at the scale of the image.

ACKNOWLEDGMENTS

D.A. Brew, William Brosgé, L.D. Carter, P.J. Haeussler, T.E. Moore, and F.H. Wilson read an early version of the manuscript and made numerous suggestions to improve it. We are grateful to these technical reviewers for lending their regional expertise. S.M. Stone edited the report and coordinated the publication team; G.M. Schumacher prepared the pamphlet and illustrations; L.G. Matheson performed the final image processing and map layout with assistance from T.R. Kiser, E.N. Moser, and D.P. Dee; R.F. James and L.G. Utz coordinated final map production operations.

REFERENCES CITED

Alaska Department of Natural Resources, 1994, RS 2477 Project: Historic Transportation Routes Status: Fairbanks, Alaska, scale 1:2,500,000.

Bates, R.L., and Jackson, J.A., eds., 1987, Glossary of geology (3d ed.): Falls Church, Va., American Geological Institute, 788 p.

Beikman, H.M. (compiler), 1980, Geologic map of Alaska: U.S. Geological Survey, scale 1:2,500,000. [Reprinted as pl. I *in* Plafker, George, and Berg, H.C., eds., 1994, The geology of Alaska, v. G–1 *of* The geology of North America: Boulder, Colo., Geological Society of America.]

Defense Mapping Agency, 1992, Digital chart of the world: Fairfax, Va., Department of Defense, Plans and Requirements Directorate.

Department of the Interior, 1909, Alaska *with* shaded relief, scale 1:3,800,000.

Fleming, M.D., and Binnian, E.F., 1990, Alaska—digital elevation model mosaic, *in* ARC/INFO maps 1990: Redlands, Calif., Environmental Systems Research Institute, p. 3.

Harrison, R.E., 1970, Shaded relief of Alaska, *in* The National Atlas of the United States of America: U.S. Geological Survey, scale 1:7,500,000, p. 58.

Karl, S.M., 1992, Age and extensional basin geochemical and tectonic affinities for the Maiyumerak basalts in the western Brooks Range, *in* Bradley, D.C., and Ford, A.B., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1990: U.S. Geological Survey Bulletin 1999, p. 141–155.

Kienle, Jurgen, Swanson, S.E., and Pulpan, Hans, 1983, Magmatism and subduction in the eastern Aleutian arc, *in* Shimozuru, D., and Yokoyama, I., eds., Arc volcanism: physics and tectonics: Tokyo, Terra Scientific Publishing Co., p. 191–223.

Kirschner, C.E., 1994, Interior basins of Alaska, *in* Plafker, George, and Berg, H.C., eds., The geology of Alaska, v. G–1 *of* The geology of North America: Boulder, Colo., Geological Society of America, p. 469–493.

LaGorce, J.O., ed., 1956, Alaska: Washington, D.C., The National Geographic Magazine, scale 1:3,000,000.

MacKevett, E.M. Jr., and Plafker, George, 1974, The Border Ranges fault in south-central Alaska: U.S. Geological Survey Journal of Research, v. 2, no. 3, p. 323–329.

Miller, D.J., 1960, Giant waves in Lituya Bay: U.S. Geological Survey Professional Paper 354–C, 86 p.

Patton, W.W. Jr., and Box, S.E., 1989, Tectonic setting of the Yukon-Koyukuk basin and its borderlands, western Alaska: Journal of Geophysical Research, v. 94, p. 15,807–15,820.

Plafker, George, 1967, Surface faults on Montague Island associated with the 1964 Alaska earthquake: U.S. Geological Survey Professional Paper 543–G, 42 p.

Plafker, George, and Berg, H.C., eds., 1994a, The geology of Alaska, v. G–1 *of* The geology of North America: Boulder, Colo., Geological Society of America, 1055 p.

Plafker, George, and Berg, H.C., 1994b, Overview of the geology and tectonic evolution of Alaska, *in* Plafker, George, and Berg, H.C., eds., The geology of Alaska, v. G–1 *of* The geology of North America: Boulder, Colo., Geological Society of America, p. 989–1021.

Plafker, George, Gilpin, L.M., and Lahr, J.C., 1994, Neotectonic map of Alaska, pl. 12 *in* Plafker, George, and Berg, H.C., eds., The geology of Alaska, v. G–1 *of* The geology of North America: Boulder, Colo., Geological Society of America, scale 1:2,500,000.

Raisz, Erwin, 1948, Landform map of Alaska for Office of the Quartermaster General: Department of the Interior, scale 1:2,500,000.

Raven Maps and Images, 1989 (revised 1993), Alaska: Medford, Oreg., scale 1:2,500,000.

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, 16 p.

U.S. Geological Survey, 1987, Alaska Map E, scale 1:2,500,000.

———1996, Alaska Map E *with* shaded relief, scale 1:2,500,000.

Wahrhaftig, Clyde, 1965, Physiographic divisions of Alaska: U.S. Geological Survey Professional Paper 482, 52 p.

ORDERING INFORMATION

Both the 1,000-m (10 Mb) and 300-m (193 Mb) topographic data sets that are described in this report are available from the U.S. Geological Survey, EROS Alaska Field Office (4230 University Dr., Anchorage, AK 99508; 907–786–7020) World Wide Web site: http://www-eros-afo.wr.usgs.gov/agdc.

Paper copies of this report, which includes the image and pamphlet, are available from the U.S. Geological Survey Information Services (Denver Federal Center, Box 25286, Denver, CO 80225; 1–800–HELP–MAP).

Continuous-tone, photographic prints or negatives can be ordered from the EROS Data Center (Mundt Federal Bldg., Sioux Falls, SD 57198; 605–594–6151) or through the Alaska Earth Science Information Center (4230 University Dr., Anchorage, AK 99508; 907–786–7011).

Black-and-white, 35-mm slides of the image can be ordered from the U.S. Geological Survey Photographic Library (Denver Federal Center–M/S 914, Box 25046, Denver, CO 80225; 303–236–1010). Two versions of the slide are available—one has only title information and the other also has a brief explanation of the image.

For current product, price, and ordering information for I–2585, Digital shaded-relief image of Alaska, and associated products call the listed telephone numbers or 1–800–USA–MAPS.