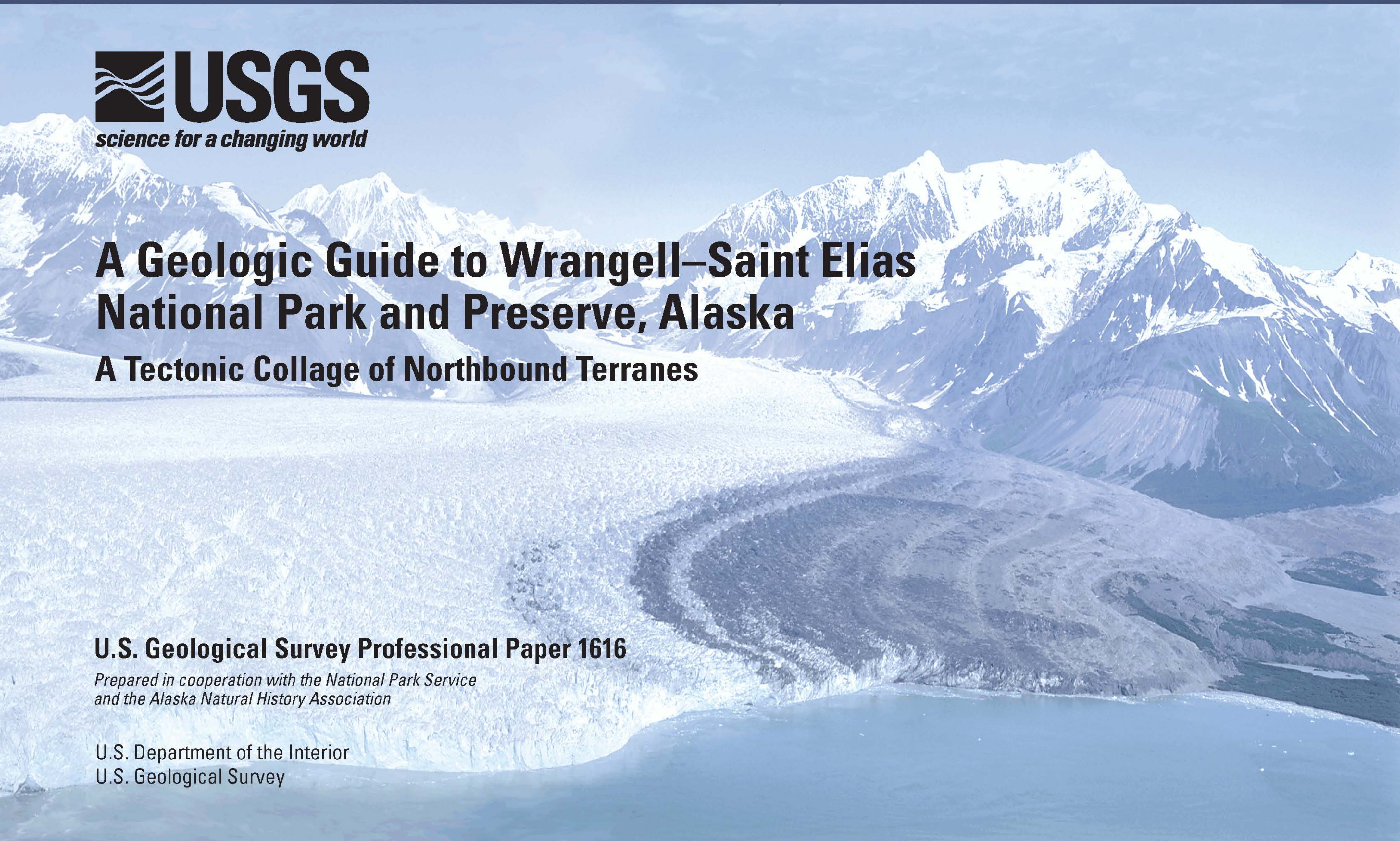

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A Geologic Guide to Wrangell–Saint Elias National Park and Preserve, Alaska

A Tectonic Collage of Northbound Terranes

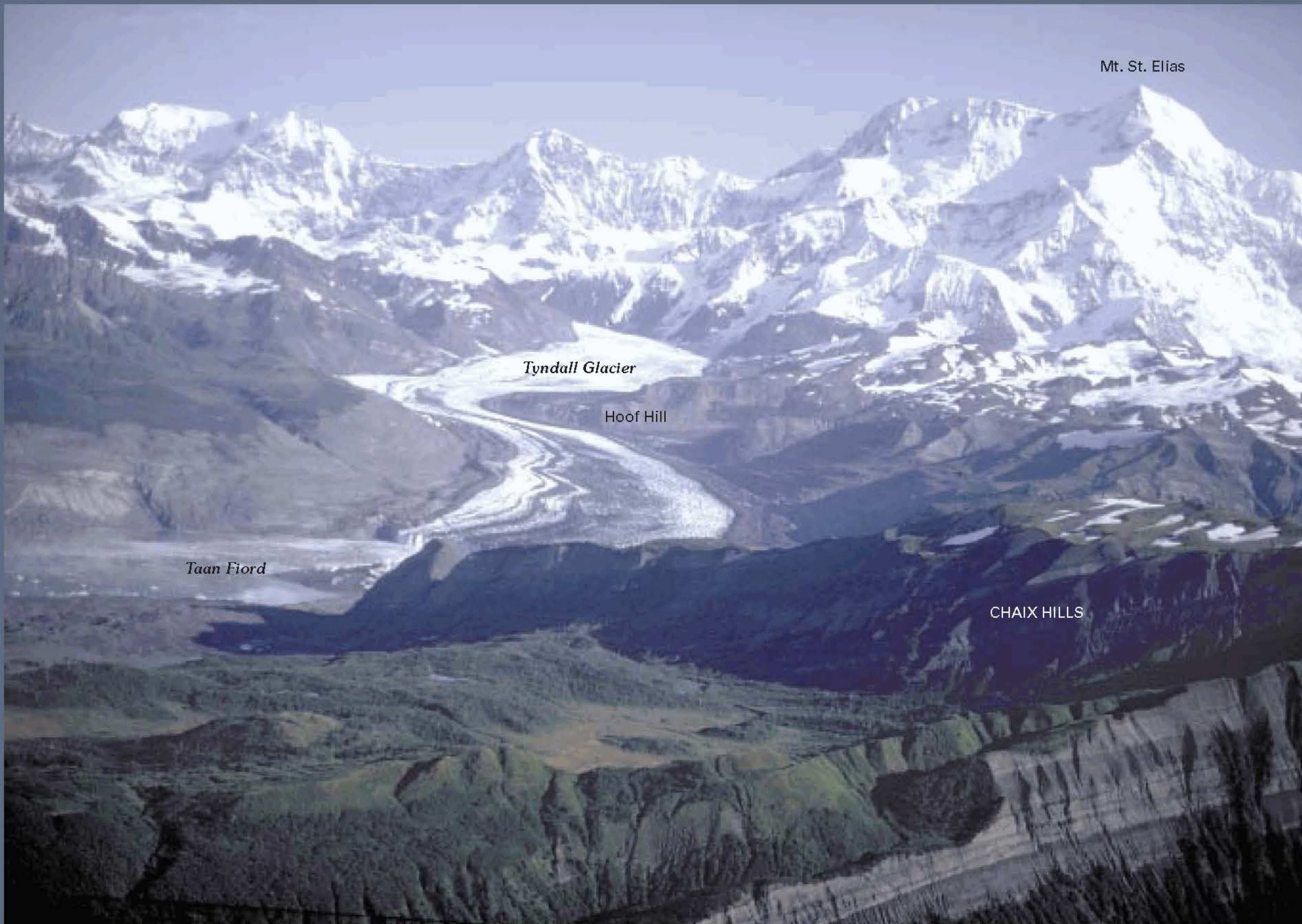
U.S. Geological Survey Professional Paper 1616

*Prepared in cooperation with the National Park Service
and the Alaska Natural History Association*

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

Wrangell-Saint Elias National Park and Preserve, Alaska

Figure 1. Mt. St. Elias (18,008 ft) and Tyndall Glacier looking north over the Chaix Hills. Bedded marine Tertiary rocks of the Yakutat terrane underlie the foothills in the foreground, and Upper Cretaceous metamorphosed sedimentary and volcanic rocks of the Chugach terrane underlie snow-covered parts of Mt. St. Elias and the ridge to its left. At the base of the mountains, the Tertiary strata are tightly folded as a result of post-Oligocene underthrusting of the Chugach terrane along the Chugach–St. Elias fault system. Continuing deformation is manifested by active seismicity, by more than 3,000 ft of emergence of marine rocks of Pliocene age in the foreground, and by uplift of as much as 0.4 in./yr of coastal terraces. Vertical relief from the summit of Mt. St. Elias to the tidewater terminus of Tyndall Glacier at the head of Taan Fiord is nearly 3.4 mi in a horizontal distance of less than 15 mi, making the slope one of the most abrupt of the world's high mountains. Note the well-expressed trimline between unvegetated and vegetated slopes above Taan Fiord, a clear indication that Tyndall Glacier filled the fiord to that depth until very recent recession and thinning of the ice. Between 1981, when this photograph was taken, and 1996, Tyndall Glacier receded to the vicinity of Hoof Hill (the prominent reentrant in the east side of the glacier), a distance of approximately 6 miles. *(George Plafker)*


Mt. St. Elias
Tyndall Glacier
Hoof Hill
Taan Fiord
CHAIX HILLS

Kennicott and Bonanza Ridge

Figure 2. View of Kennicott and Bonanza Ridge as they appeared in 1964. Kennicott was the mill-site for concentrating copper ore from the Bonanza, Jumbo, Mother Lode, Erie, and Glacier mines. The Bonanza (B) and Jumbo (J) mines were located nearly 4,000 ft above the mill. Tramlines 16,000 ft in length descended from each mine to deliver ore to crushing facilities located in the highest buildings in the center foreground. The Bonanza vein cropped out at the crest of a steep-sided ridge; material that eroded from it formed two unique surficial ore bodies. A body of high-grade talus or slide ore on the southeast side of the ridge was mined by surface scrapers, and more than 90,000 tons were trammed to the mill along with ore from the underground workings at the Bonanza mine. The location of the slide ore is concealed by the ridge in this view. On the northwest side of the ridge, the Glacier mine (G) was formed by blocks of ore from the outcropping Bonanza vein, which tumbled down a cirque headway to be incorporated in glacier ice below. Inasmuch as most of the ore was encased in compact ice, standard underground mining methods—including blasting and timbering—were used. More than 220,000 tons of high-grade material from this deposit descended by separate tramline to join ore from the Jumbo mine at a junction station below. Between 1911 and 1938, the mill at Kennicott treated more than 4 million tons of ore, concentrating it for shipment via railroad and steamship to a smelter in Tacoma, Wash. Ultimately about 1/2 million tons of copper and about 100 tons of silver were produced. The mill is located on the edge of an older lateral moraine of the Kennicott Glacier, which provided a stable foundation for the mill-site. Just a few tens of feet downhill, however, is an active, ice-cored moraine—an unstable foundation, due to seasonal melting and downglacier movement. *(G.R. Winkler)*


J
G
B

Chitina Valley

Figure 3. View to the east of the upper Chitina valley, which is entirely filled by the moraine-covered Logan and Chitina Glaciers. The Logan Glacier is joined by a tributary, the Baldwin Glacier, in the right-hand middle ground. Geologist in the left foreground is walking on platy outcrops of fossiliferous Cretaceous sandstone that unconformably overlie Pennsylvanian and Permian volcanic rocks of the Skolai Group, the older parts of which are intruded by a Pennsylvanian pluton. These upper Paleozoic rocks of the Wrangellia terrane form the dark ridges on the left. Much of the background in this view lies in Canada. The massif in the center skyline, partially obscured by clouds, is Mt. Logan (19,850 ft), the highest mountain in Canada. The summit ridge is continuously above 15,000 ft for more than 12 mi, making it the largest mountain in North America. Mt. Logan is flanked on the left by McArthur Peak (14,200 ft) and on the right by King Peak (16,971 ft). *(E.M. MacKevett, Jr.)*


Mt. Logan
King Peak
McArthur Peak
Logan Glacier
Baldwin Glacier
Chitina Glacier

Figure 4. Ice-covered Mount Blackburn (16,390 ft) and the Nabesna Glacier. Mt. Blackburn is the eroded remnant of a large shield volcano that was active 3.5–4.5 m.y. (million years) ago. To the left of Mt. Blackburn are the twin Atna Peaks and Parka Peak, both of which are probably old volcanic edifices. A series of lava flows more than 3,000 ft thick makes up the ridges in the foreground. The Nabesna Glacier is a 75-mi-long alpine glacier that has its principal source on the slopes of Mount Wrangell volcano, out of sight to the right of Mt. Blackburn. It is the longest inland glacier in North America. Debris eroded from the many nunataks (bedrock knobs projecting above the glacier's surface) in the background forms dark-colored surface deposits on the glacier, called medial moraines. *(D.H. Richter)*


Mt. Blackburn
Parka Peak
Atna Peaks
Nunatak
NABESNA GLACIER


Mt. Vancouver
Mt. Foresta

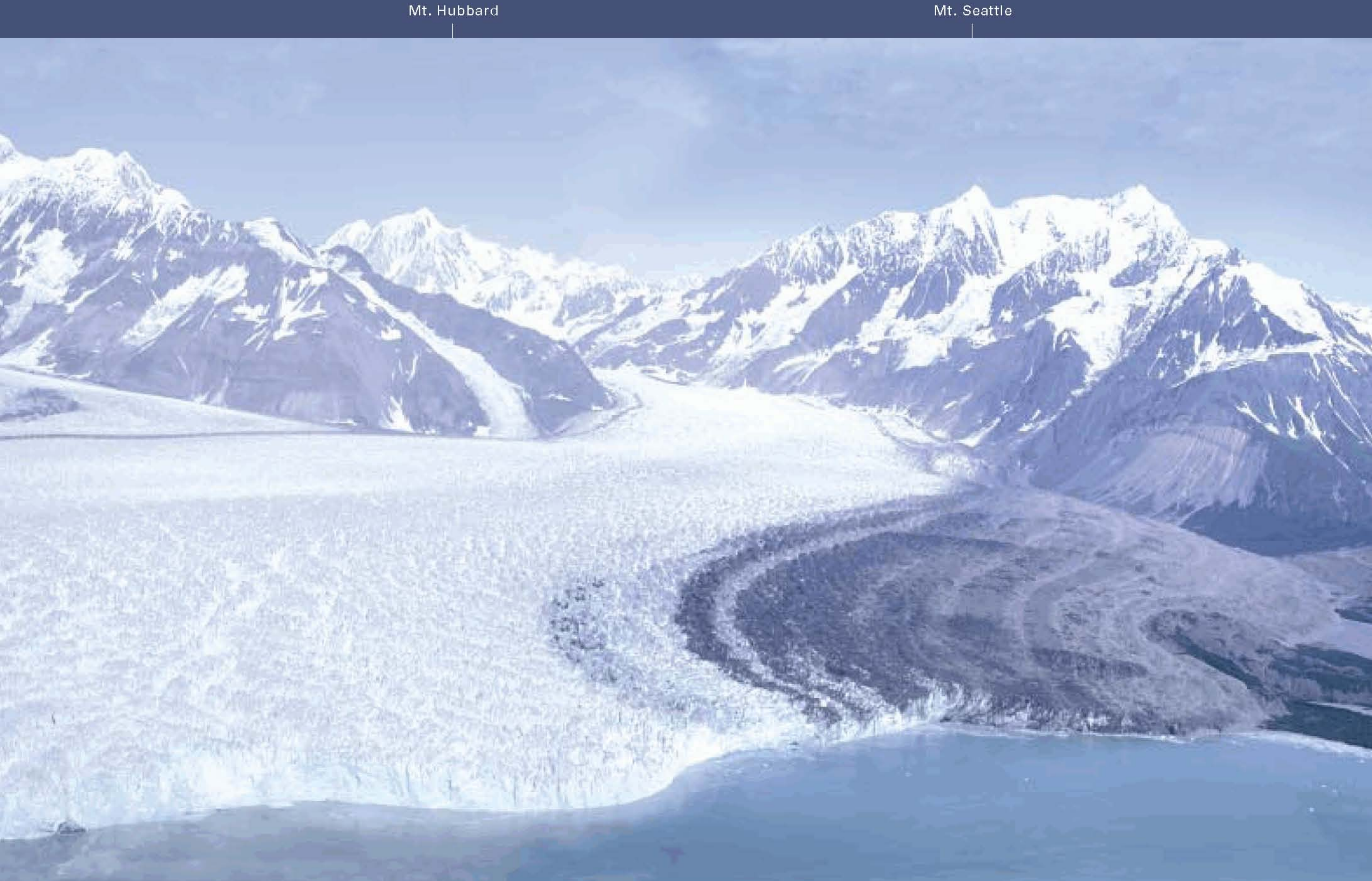
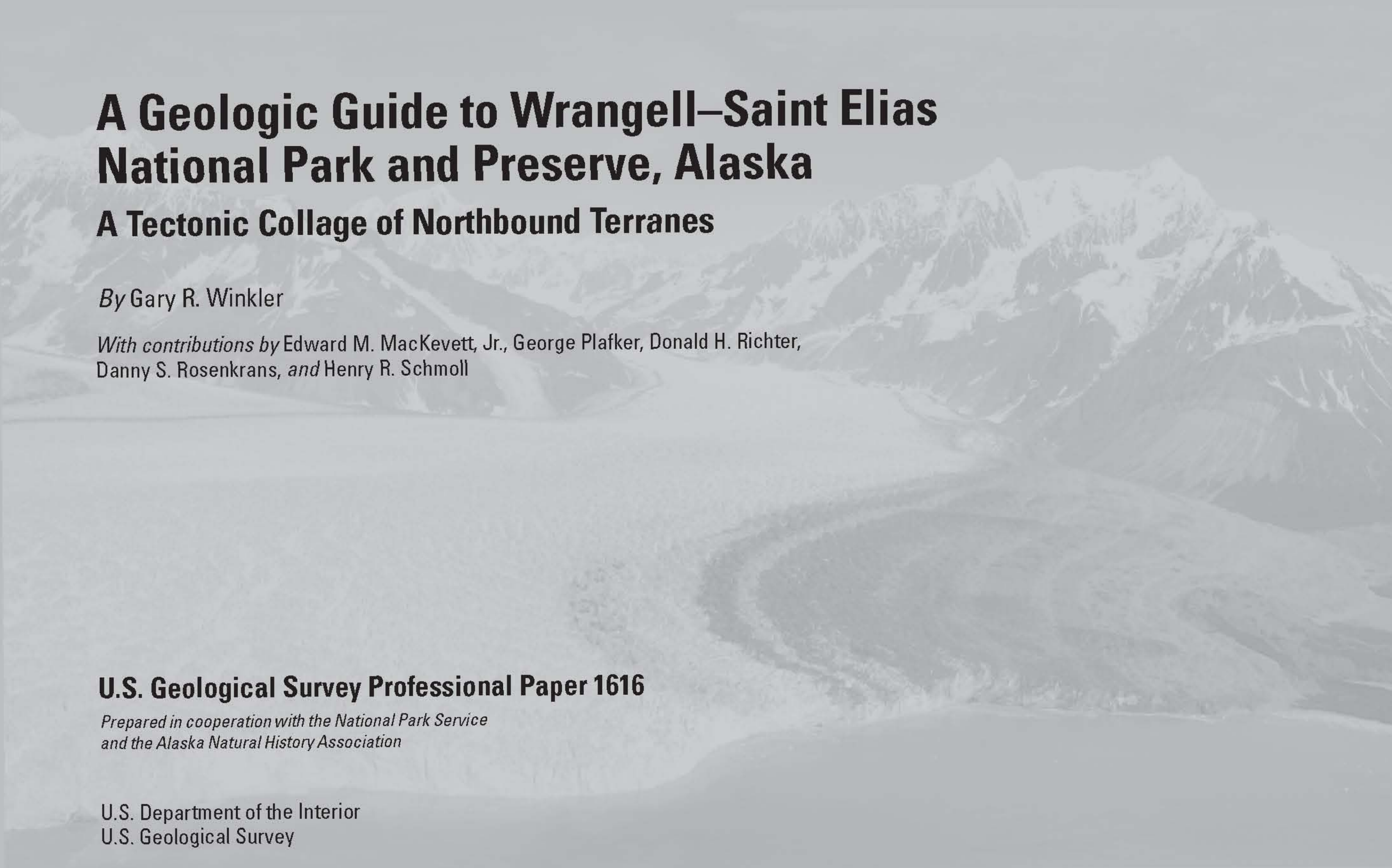

Mt. Hubbard
Mt. Seattle

Figure 5 (previous pages). Hubbard Glacier, North America's largest tidewater glacier, at the head of Disenchantment Bay near Yakutat. The arcuate face of the glacier is more than 6 mi wide and 300 ft high. Hubbard Glacier extends more than 60 mi northward into the Yukon Territory, being fed by ice fields that mantle much of the Saint Elias Mountains. It has little cover of surface moraine because so little bedrock is exposed up the glacier. Hubbard Glacier has been actively advancing during much of the 20th century, a condition that leads to a thoroughly crevassed upper surface and abundant calving at the glacier's terminus. The high background mountains in this panoramic view are, from left to right, Mt. Vancouver (15,700 ft), Mt. Foresta (11,040 ft), Mt. Hubbard (14,950 ft), and Mt. Seattle (10,070 ft). Mt. Cook (13,760 ft) is just off the view to the left. *(George Plafker)*



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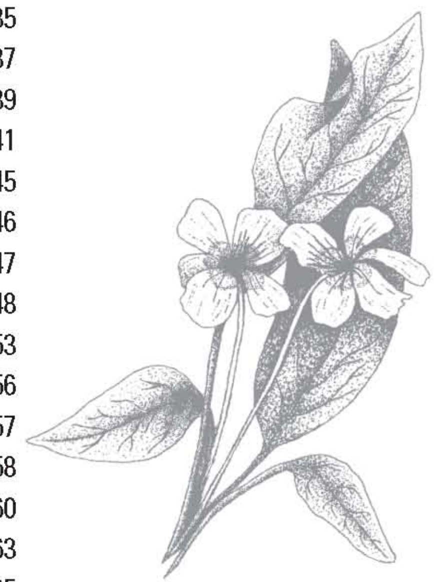

METRIC CONVERSION FACTORS

Multiply	By	To obtain metric units
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot (ft^3)	0.028	cubic meter
cubic mile (mi^3)	4.17	cubic kilometer

Wrangell-Saint Elias National Park and Preserve, Alaska

A Geologic Guide to Wrangell–Saint Elias National Park and Preserve, Alaska

A Tectonic Collage of Northbound Terranes

By Gary R. Winkler[1]

With contributions by Edward M. MacKevett, Jr.,[2] George Plafker,[3] Donald H. Richter,[4] Danny S. Rosenkrans,[5] *and* Henry R. Schmoll[1]

Introduction

Wrangell–Saint Elias National Park and Preserve (fig. 6), the largest unit in the U.S. National Park System, encompasses nearly 13.2 million acres of geological wonderments. Furthermore, its geologic makeup is shared with contiguous Tetlin National Wildlife Refuge in Alaska, Kluane National Park and Game Sanctuary in the Yukon Territory, the Alsek-Tatshenshini Provincial Park in British Columbia, the Cordova district of Chugach National Forest and the Yakutat district of Tongass National Forest, and Glacier Bay National Park and Preserve at the north end of Alaska's panhandle—shared landscapes of awesome dimensions and classic geologic features. In 1978, the United Nations recognized the global importance of Wrangell–Saint Elias and Kluane by designating them as "World Heritage" sites; Glacier Bay and Alsek-Tatshenshini were similarly designated in 1992, unifying some 24 million acres of international parklands. The array of geologic features makes these parklands an impressive outdoor laboratory. Within Wrangell–Saint Elias are displayed features that indicate (1) how the southern Alaskan continental margin has more than doubled in size in approximately the past 200 million years by incremental addition of far-traveled geologic fragments; (2) how *underthrusting* by the Pacific *oceanic plate*[6] has prompted rapid uplift, voluminous volcanism, and powerful earthquakes; and (3) how uplift of the coastal mountains adjacent to the storm-brewery of the Gulf of Alaska has engendered large and scenic systems of alpine, *piedmont*, and tidewater glaciers.

In 1892, glaciologist Israel C. Russell, writing of one of the earliest scientific probes of the Wrangell–Saint Elias region—his explorations of Malaspina Glacier and Mt. St. Elias—characterized the vast mountains and glaciers whose realms he invaded with a sense of astonishment. His descriptions are filled with superlatives. In the ensuing 100+ years, earth scientists have learned much more about the geologic evolution of the parklands, but the possibility of astonishment still is with us as we unravel the results of continuing *tectonic* processes along the south-central Alaska continental margin. Russell's superlatives are justified: Wrangell–Saint Elias is, indeed, an awesome collage of geologic *terranes*. Most wonderful has been the continuing discovery that the disparate terranes are, like us, invaders of a sort with unique trajectories and timelines marking their northward journeys to arrive in today's parklands.

This geologic guide includes six parts: the first part briefly notes the 150-year history of exploration in the Wrangell–Saint Elias region that preceded the 20th century and summarizes the ensuing 100-year history of earth-science investigations that have brought us to our present understanding of the geologic makeup of the parklands.

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[4]U.S. Geological Survey, Anchorage, AK 99508-4667.

[5]National Park Service, Copper Center, AK 99573.

[6]Terms in *italics* are defined in a glossary that begins on page 150.

The second part describes that geologic makeup, interpreting features of the Wrangell–Saint Elias region in the context of *plate tectonics* and *accretionary terranes*. (It was earth-science studies in this part of south-central Alaska, after all, that sparked development of, or provided early tests for, some fundamental tectonic and terrane concepts.) This second part sets the Wrangell–Saint Elias region within a present framework of a tectonically active continental margin straddling part of the boundary between major crustal plates—the North American *continental* and Pacific *oceanic plates*. It is the contemporary *convergence* between these plates that engenders some of the park's most notable features—its volcanoes, lofty coastal mountains, and network of major crustal breaks along which occur frequent damaging earthquakes.

This present is also key to the parkland's past, for geologic terranes have been converging on—and accreting to—Alaska's continental margin for much of the past 200 million years. The sequential *accretion* of these terranes has accumulated a vast collage in the Wrangell–Saint Elias region, and the third part of the guide characterizes each geologic terrane in the collage—proceeding from north to south, the same sequence by which the terranes were accreted to the Alaska continental mass.

The fourth part recapitulates the geologic dynamism of the parklands, describing how earthquakes, volcanoes, and glaciers continuously reshape the landscapes of the park.

A stampede of gold-seekers toward the rich *placer* diggings of the Klondike first brought prospectors to the Wrangell–Saint Elias region. However, it was discovery of fabulously rich copper deposits in the McCarthy area that led to the major industrial developments along the southern flank of the Wrangell Mountains in the early 20th century, including construction of a major railway and creation of a major integrated mining company. The fifth part of this guidebook characterizes the copper and gold resources of the parklands, including the exceptionally large and rich deposits of the Kennecott-type. It was development of these resources that created the infrastructure still in use in today's parklands.

The sixth part is a series of geological sketches of outstanding places within Wrangell–Saint Elias National Park and Preserve. It includes descriptions of locales where some of the plate tectonic processes of part two are exemplified best or where particular features of the geologic terranes of part three are most clearly displayed.

Some previous exposure to geological ideas will be helpful, because many technical terms are used in what follows. However, a glossary of geologic terms is included near the end of this guidebook that briefly defines what may be unfamiliar terms. A term that is defined in the glossary is *italicized* the first place where it appears in the text or in a figure caption.

Many place names and geographic terms also are used. Thus, a topographic map of Wrangell–Saint Elias National Park and Preserve and a dictionary of Alaska place names will be valuable companions to this guidebook.

Citations have not been inserted in the text to indicate sources for geologic data and interpretations. However, the following principal sources could have been cited repeatedly, for they are original, authoritative, and thorough. Published geologic maps of the Nabesna quadrangle (Richter, 1976) and the McCarthy quadrangle (MacKevett, 1978) and unpublished geologic mapping of the Bering Glacier, Icy Bay, Mt. St. Elias, and Yakutat quadrangles by George Plafker depict the fundamental geologic setting of terranes in the parklands and are accompanied by text that describes the rock units, interprets their genesis, and summarizes the tectonic evolution of large regions of southern Alaska. These geologic maps provide the basic data from which hundreds of more detailed interpretive reports have been derived. A multi-chaptered compendium on the geology of Alaska produced by the Geological Society of America in 1994 contains statewide and regional syntheses (Plafker and Berg, 1994), including definitive papers on the southern Alaska continental margin (Plafker, Moore, and Winkler, 1994) and south-central Alaska (Nokleberg and others, 1994) that cover all areas within the parklands. Important precursory descriptions and interpretations of the lithologic and structural complexities of terranes marginal to the Gulf of Alaska include Plafker (1987) and Plafker, Nokleberg, and Lull (1989). A report by Richter and others (1990) provides the most complete discussion of volcanism in the Wrangell Mountains, but numerous additional reports by Richter and his colleagues also could be referenced here, including an important guide to the principal volcanoes in the parklands (Richter, Rosenkrans, and Steigerwald, 1995). MacKevett and others (1997) provided the definitive summary of the remarkably high grade copper deposits of the Kennecott-type, the presence of which provoked, directly or indirectly, many of the earth-science studies that have brought us to today's state of geological understanding of the Wrangell–Saint Elias region.

Figure 6 (facing page). Location and setting of Wrangell–Saint Elias National Park and Preserve. (*National Park Service*)

Slana
District Ranger Station
MENTASTA MOUNTAINS
Noyes Mountain 8147ft 2483m
TETLIN LOWLANDS
TETLIN NATIONAL WILDLIFE REFUGE
DAWSON RANGE
Chistochina
NATIONAL PRESERVE
Nabesna Road
Fish Lake
Ewan Lake
Crosswind Lake
Capital Mountain 7731ft 2356m
Copper Lake
Tanada Lake
Jack Lake
Nabesna
Caution: Private property interspersed with public lands.
Wellesley Mountain 4960ft 1512m
Beaver Creek
Wellesley Lake
Gulkana
Gakona
Tanada Peak 9358ft 2852m
NUTZOTIN MOUNTAINS
Cooper Pass
Mt Allen 9480ft 2883m
Mt Sanford 16237ft 4949m
Tolsona Lake
Glennallen
To Anchorage
Mt Drum 12010ft 3661m
Mt Gordon 9040ft 2755m
NATIONAL PRESERVE
NISLING RANGE
Mt Zanetti 13009ft 3965m
Mt Jarvis 13421ft 4091m
Chisana
Braye Lakes
Park Headquarters
Copper Center
Tazlina Lake
Mt Wrangell 14163ft 4317m
NATIONAL PRESERVE
Wiki Peak 7655ft 2333m
St. Anne Lake
WRANGELL MOUNTAINS
Alaska Highway
Willow Lake
Solo Mountain 5875ft 1791m
Ptarmigan Lake
Rock Lake
Edgerton Highway
Mt Blackburn 16390ft 4996m
13860ft 4225m
13600ft 4145m
Atna Peaks
Regal Mountain 13845ft 4220m
Tonsina
Liberty Falls
Dixie Pass
Castle Mountain
Skolai Pass
Mt Sulzer 10926ft 3330m
Chitina
District Ranger Station
Strelna
Donoho Peak 6696ft 2041m
Chitistone Peak
Mt Natazhat 13435ft 4095m
KLUANE GAME SANCTUARY
Chokosna
Kennicott
McCarthy
Caution: Private property interspersed with public lands.
McCarthy Road
Sourdough Peak 6201ft 1890m
Dan Creek
May Creek
Mt Bona 16421ft 5005m
Mt Churchill 15638ft 4767m
UNIVERSITY RANGE
YUKON TERRITORY ALASKA
UNITED STATES CANADA
Burwash Landing
Destruction Bay
Valdez
Richardson Highway
Spirit Mountain 7267ft 2221m
Nelson Mountain 5457ft 1663m
NATIONAL PRESERVE
University Peak 14470ft 4411m
Mt Bear 14831ft 4521m
Mt Wood 15885ft 4842m
Mt Macauly 15405ft 4695m
Mt Slaggard 15575ft 4747m
Mt Steele 16644ft 5073m
MACCOLL RIDGE
SAINT
Hanagita Peak 8504ft 2592m
NATIONAL PARK
Mt Lucania 17147ft 5226m
Mt Walsh 14780ft 4505m
CHUGACH MOUNTAINS
Baldy Mountain 7230ft 2204m
ELIAS
KLUANE NATIONAL PARK
GRANITE RANGE
Mt Hawkins 10395ft 3168m
Mt Tom White 11210ft 3417m
CHUGACH NATIONAL FOREST
Cordova
HAWKINS ISLAND
Juniper Island
BAGLEY ICEFIELD
King Peak 16971ft 5173m
McArthur Peak 14400ft 4389m
Mt Logan 19850ft 6050m
ICEFIELD RANGES
MOUNTAINS
Mt Steller 10617ft 3236m
WAXELL RIDGE
Mt Miller 8875ft 2705m
COPPER RIVER DELTA
BERING GLACIER
Mt St. Elias 18008ft 5489m
Mt Augusta 14070ft 4289m
Mt Vancouver 15700ft 4785m
Mt Alverstone 14565ft 4439m
Mt Hubbard 15015ft 4577m
Mt Kennedy 13093ft 3991m
ROBINSON MOUNTAINS
Katalla
Haydon Peak 11945ft 3641m
Pt Glorious 5000ft 1524m
Mt Cook 13760ft 4194m
Mt Seattle 10070ft 3069m
SUCKLING HILLS
Cape Suckling
Cape Yakataga
GULF OF ALASKA
YUKON TERRITORY
BRITISH COLUMBIA
Mt Jette 8460ft 2579m
MALASPINA GLACIER
Malaspina Lake
KAYAK ISLAND
Point Manby
SITKAGI BLUFFS
YAKUTAT BAY
N
ALASKA
AREA OF MAP
Wrangell–St. Elias National Park
Native corporation lands
Wrangell–St. Elias National Preserve
Unpaved road
0 10 20 KILOMETERS
0 10 20 MILES

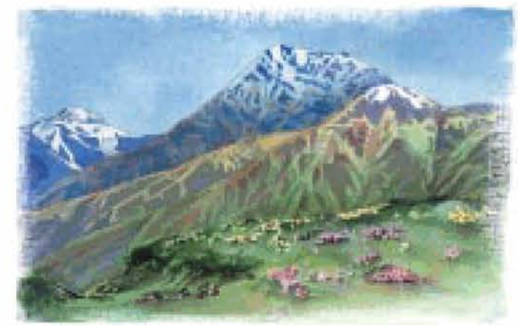
A categorized list of sources of information for this guidebook, including those just cited, and suggested additional reading, including geologic and topographic maps, is included beginning on page 158. The list is not intended to be comprehensive, but many of the included references contain extensive bibliographies that can be used to guide more detailed investigations of topics that are touched upon herein. An index map showing the localities of photographs used in this guidebook also is included near the end (fig. 78).

In preparing this geologic guide, the authors and contributors acknowledge the invaluable work of Fred H. Moffit, whose geologic studies in Alaska—and particularly south-central Alaska—spanned nearly five decades. His sustained efforts in the Wrangell–Saint Elias region provided a broad foundation for all who followed.

Exploration

On July 16, 1741, after an arduous voyage from the Russian Far East, Vitus Bering finally glimpsed the mountainous mainland of southern Alaska, a prominent ice-clad summit many leagues distant rising above thick stormy banks of clouds. Desperate to secure fresh water and whatever resources land might offer, the navigator sailed in its direction, passing a conspicuous cape at the southwest end of Kayak Island on July 20, and making a hurried landfall nearby. In honor of the patron saint of the day, the island was named Saint Elias, the name subsequently applied to the headland and the towering mountain also. Georg Steller, a naturalist on the expedition, was included in this first Alaskan landing party, spending a tantalizing few hours ashore collecting floral and faunal specimens, briefly examining evidence of native inhabitants, and geologically noting “only sand and gray rock.” Mt. Steller, on the boundary of Wrangell–Saint Elias National Park and Preserve about 60 mi to the northeast, named for the naturalist, commemorates this first fleeting scientific investigation. Bering’s initial landmark, Mt. St. Elias, at 18,008 ft, is the second highest mountain in Alaska and the highest in the park. It is the most conspicuous summit in the remote expanse of massive peaks and glaciers that constitute the southeastern part of the park in the Chugach and Saint Elias Mountains.

This Russian voyage of exploration inaugurated more than a century of investigation by notable English, French, Spanish, Russian, and American mariners and merchants. The coastal waters were teeming with marine life, local native peoples might participate in trade or be conscripted as labor, and a fabled direct passage from Europe to Asia still might be discovered in such a little-known region. Thus, by the late 1800’s, the expeditions of Cook, La Pérouse, Dixon, Malaspina, Shelikov, and Vancouver, among many others, had charted the coasts of southern Alaska with considerable accuracy; and a few coastal rivers had been tentatively probed as routes to Alaska’s interior. Fortified trading posts were established by Russian traders at Nuchek on Hinchinbrook Island in Prince William Sound in 1793 and at Yakutat in 1795. Between 1796 and the 1850’s, traders of the Russian American Company ascended the rugged canyons of the Copper River to penetrate the Copper River Basin, establishing a temporary trading post at Taral near the mouth of the Chitina River and possibly others elsewhere. Serebrennikov’s expedition in 1848 may have reached the headwaters region of the Copper River, but the group was annihilated by Ahtna natives, probably near the village of Batzulnetas. Aside from providing the first description of Mt. Wrangell, these commercial expeditions to the vicinity of today’s parklands added little scientific knowledge to the miniscule amount then known about the imposing peaks, glaciers, and resources of the Chugach, Wrangell, and Saint Elias mountain ranges. However, they did report spear points, knives, and utensils of pure copper being used by the natives of the Copper River region, and confirmed that copper nuggets and implements were an item of barter between interior and coastal peoples.



First Geologic Probes

Subsequent to the acquisition of Alaska from Russia in 1867, the U.S. Congress authorized geographical and geological surveys of the new Territory. Responding to pressure of maritime commercial interests, Federal coastal surveys immediately began charting navigable waters, requiring virtually all of the small annual survey appropriations. The first inland surveys of the Wrangell–Saint Elias region, however, were delayed until the 1880's. In 1882, George Holt became the first American to ascend the lower Copper River, reaching the mouth of the Chitina River in his search for trading opportunities. In 1884, John Bremner began the first real prospecting, examining several of the lower tributaries of the Copper River before wintering in Taral. Also in 1884, Lt. W.R. Abercrombie, U.S. Army, led an inconclusive sortie to test the navigability of the Copper River canyon inland from its delta. Although Abercrombie's party was stopped by rapids on the lower Copper River, they reported an alternative route via Valdez Glacier to the Copper River Basin. In 1885, a second military exploring expedition under the direction of Lt. H.T. Allen successfully ascended the Copper River to Taral and, hoping to contact the native leader Nicolai, ascended the Chitina and Nizina Rivers to the mouth of Dan Creek. Like Russian traders before them, the party noted copper implements in use by Nicolai's band and named the river near Nicolai's encampment on Dan Creek (today's "Nizina River") the Chitistone River "on account of the copper ore found by the Natives near it." ("Chiti" in Ahtna vernacular means copper.) Returning to Taral, the Allen expedition then ascended the Copper River to Batzulnetas, naming Mounts Blackburn, Drum, and Sanford, and utilizing aboriginal trails that—although upgraded—remain principal routes of access to the parklands today. At times, the party was accompanied by the prospectors Peder Johnson and John Bremner, vanguards of a coming rush to the region. After leaving the Copper River drainage, Allen's expedition followed the Tetlin, Tanana, and Yukon Rivers to the Bering Sea in a single season—an unparalleled epic of Alaskan exploration.

In 1886, Lt. Frederick Schwatka, U.S. Army, led an expedition sponsored by the New York Times to explore the Icy Bay region and climb Mt. St. Elias. The 10 days allowed were insufficient and no systematic surveys were completed, although anecdotal accounts were published and place names were attached to prominent features.

In 1890 and again in 1891, glaciologist I.C. Russell, with the support of the National Geographic Society and the U.S. Geological Survey (USGS), led expeditions in the Yakutat Bay region in renewed attempts to climb Mt. St. Elias. Although the expeditions failed to reach the summit, they yielded a wealth of geographic and geologic knowledge of the Malaspina and Hubbard Glacier regions.

In 1891, Lt. Schwatka and C.W. Hayes, USGS, accompanied by prospector Mark Russell, entered Alaska from the east, ascended the White River to its source in the large glacier that Hayes named in honor of I.C. Russell (fig. 7). Crossing Skolai Pass, the expedition then descended the Nizina, Chitina, and Copper Rivers to the coast near Cordova. This expedition, like those of Abercrombie and Allen, primarily evaluated routes to Alaska's interior. Nonetheless, it also expressly supported geologic studies of a general character and filled a geographic blank, connecting explorations of the Yukon River in 1883 with the headwaters of the Tanana and Copper Rivers and with Allen's 1885 chart of the Chitina and Copper River drainages.

By the late 1890's, the lure of gold discoveries in the Klondike region of Canada's Yukon had irresistibly drawn thousands of argonauts inland from Alaska's coasts, despite a paucity of reliable geographic information. Most stampeders followed a principally Canadian route over Chilkoot Pass near Skagway to the headwaters of the Yukon River, which they descended to the Klondike. However, unscrupulous promoters circulated stories of an easy, "all-American" passage from Prince William Sound to the interior, luring many would-be miners to Port Valdez. Stampeders tried many paths through the coastal mountains in the Wrangell–Saint Elias region, undergoing severe hardships and suffering. In attempts to investigate and publicize the most reliable routes, military exploring expeditions under W.R. Abercrombie were launched in 1898 and 1899. In 1898, F.C. Schrader, USGS, accompanied the expedition, which explored a large circuit from Valdez to the Copper River Basin and back via Valdez Glacier and the Klutina, Copper, Tasnuna, and Lowe River valleys. Concurrently, a separate expedition, led by USGS geologists W.J. Peters and A.H. Brooks, investigated overland routes from the White River to the Tanana River. In 1899, Oscar Rohn, USGS, accompanied a second military expedition, which explored both the southern and northern flanks of the Wrangell Mountains. Rohn was the first to report copper-bearing float on the Kennicott Glacier, although he did not track it to nearby bedrock sources. Rohn's work, in particular, laid the groundwork for many subsequent geologic investigations in what later became Wrangell–Saint Elias National Park and Preserve. Like earlier expeditions, these government parties benefitted from the company of prospectors and natives, who already had acquired working knowledge of routes and conditions to be encountered, as well as locations of gold-bearing placers and gold- and copper-bearing *lodes*.

The scattered prospecting of the late 1880's and the early 1890's and the more concentrated surge of prospectors impelled by the Klondike gold rush led directly to the discovery of the fabulously wealthy copper deposits in the McCarthy area. A few of the estimated 4,000 stampeders who landed at Valdez in the fall of 1897 and the spring of 1898 remained in Prince William Sound to pursue occurrences of copper reported by local natives. Of the estimated 3,000 stampeders who made it across the formidable barrier of the coastal mountains to the Copper River Basin, many stopped short of the Klondike to pursue rumoured copper and gold occurrences in the Wrangell Mountains. Prospectors located widespread copper claims in the region of the Kotsina, Kluvesna, and Kuskulana Rivers in 1898 and 1899, and located the Nikolai mine (named for the Taral native leader) in 1899. By 1900, two prospectors, Clarence Warner and Jack Smith, who worked intermittently at the Nikolai mine were searching for the source of the copper float on the Kennicott Glacier that Rohn had reported in 1899, and located the Bonanza lode. Within weeks, A.C. Spencer, USGS, independently discovered the copper-stained talus marking the Bonanza lode, and was surprised to discover fresh claim markers on what he thought was unprospected territory. Prospectors located several other significant copper lodes along the southern flank of the Wrangell Mountains and by 1902 had located workable gold placers in the Bremner and Nizina districts. Prospectors also were active in the Nabesna region along the northern flank, discovering numerous occurrences of both copper and gold. Results in the Nabesna area, however, were not as encouraging as those to the south.

By the late 1890's, persistent prospecting of beach sands had uncovered only traces of placer gold along the Gulf of Alaska coastline. However, numerous oil and gas seeps had been discovered, particularly around the shores of Controller Bay and near Cape Yakataga. In places along the lower Katalla River, the flow of gas was so strong that observers claimed to hear and smell it from several hundred feet away. Numerous small lakes in the area also had oily sheens. Expanding the search for indications of petroleum northeastward into the Bering and Nichawak River drainages, explorers by this time also had discovered thick, discontinuous seams of coal on the ridges adjacent to Kushtaka Lake. In the Wrangell–Saint Elias region, these demonstrated resources of petroleum and coal were to influence the commercial developments and the politics of the early 20th century. They ultimately sparked renewed pulses of exploration between 1954 and 1986, and influenced the location of the southern boundary of Wrangell–Saint Elias National Park and Preserve that was legislated in late 1980.

Russell Glacier

Figure 7 (facing page). Looking west across Russell Glacier toward Castle Mountain and Skolai Pass in the summer of 1914. Having originated in McCarthy, the pack train is enroute to the glacier's terminus, source of the White River, in support of geologic explorations by a USGS party. The White River joins the Yukon River about 70 mi upstream from Dawson. According to Oscar Rohn (USGS), the route from Valdez to Dawson via Skolai Pass and the White River was followed by a few stampeders in the Klondike gold rush of 1898–99. *(S.R. Capps)*

Twentieth Century Geologic Studies

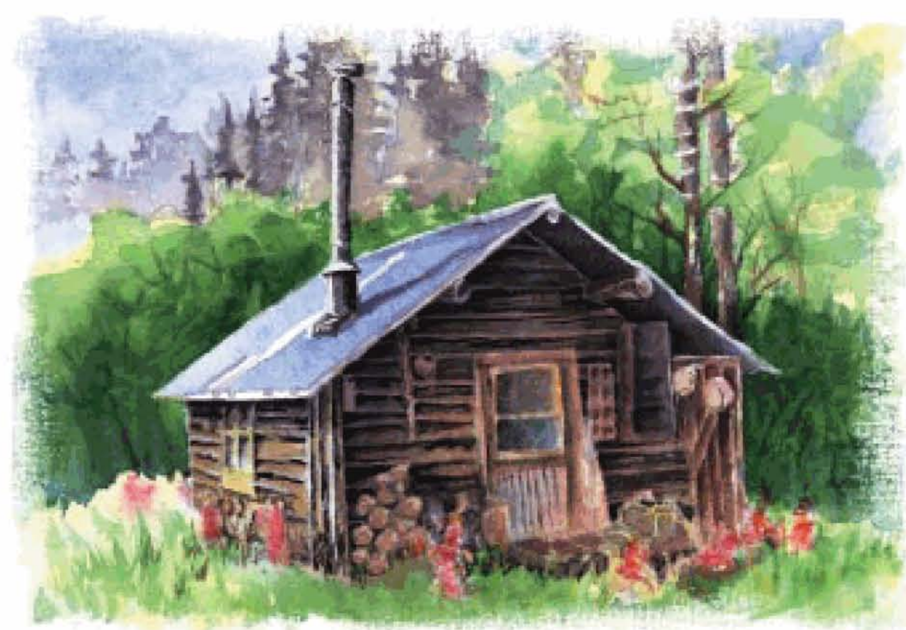
By the early 1900's, a push to consolidate mining claims, develop the rich copper lodes, and complete production and transportation infrastructure marked the end of geological pioneering in the Wrangell Mountains (fig. 8). By 1905, systematic investigations to understand the geologic setting and to characterize the mineral resources were begun by the U.S. Government in the region. Soon, geologic maps and reports of mining district and regional scope began to appear, spurred by the success of the Kennecott Copper Company in the McCarthy area. The numerous studies of Fred H. Moffit and coworkers on the southern flank of the Wrangell Mountains were particularly noteworthy, establishing, by 1938, the basic characteristics and ages of rock units of the region extending from the upper Chitina River Valley on the east to the Tonsina River on the west and incorporating large areas of the Chugach Mountains as well.

On the northern flank of the Wrangell Mountains, government geologic studies continued until the major gold strike in the Chisana area played out in 1915. The lack of rich ore bodies and suitable transportation to move ore to market, however, thwarted development on the north flank in either the Nabesna or Chisana areas. Lacking commercial impetus, further geologic studies languished.

Along the Gulf of Alaska coastline, the first oil well was drilled near Katalla in 1901. Government and industry studies from 1902 to 1920 determined the general character and structural setting of the source and reservoir rocks in the Katalla and Cape Yakataga areas, then moved on to more promising energy resource occurrences elsewhere in Alaska. The Katalla field, however, was brought into production in 1903, yielding, on average, 30 barrels per day of high-quality paraffin-base, low-sulfur oil. Between 1903 and 1933, a small refinery at Katalla produced a total of 154,000 barrels—mostly used in the Cordova area. On Christmas Day in 1933, the refinery was destroyed by fire, and it was never rebuilt. Sporadic attempts to develop the Bering River coal fields ended in 1922 when larger and more accessible coal seams in the upper Matanuska Valley and the Healy area of the Alaska Range began production.

The shutdown of the Kennecott mines and the Copper River and Northwestern Railway in 1938 caused surface access to the Wrangell–Saint Elias region to revert nearly to its previous difficulty, and government geologists moved to other areas. However, during World War II, numerous airstrips were created in former wilderness and the Alaska and Glenn Highways were completed, greatly aiding the subsequent post-war "opening-up of the last frontier."

Rapid industrial expansion at the end of World War II engendered a rush to expand energy- and mineral-resource bases of the Territory, and Alaskan geologic studies were reinvigorated. In the Gulf of Alaska region, sustained programs to investigate the geologic setting for energy resources in the Tertiary sequences near the coast began in the mid-1940's, resulting by the mid-1980's in a thorough understanding of the *stratigraphy* and structure of the continental margin, and the completion of region-wide geologic map coverage. By the early 1960's, concern for the adequacy of domestic supplies of many strategic metals led to long-term projects to investigate the geologic controls for mineral resources in the historic Nabesna and McCarthy mining areas, resulting in detailed geologic mapping in the immediate vicinities of the camps that later was expanded to regional coverage of the Wrangell Mountains. After passage of the Alaska Native Claims Settlement Act in 1972, land and resource evaluations by the Federal government were greatly accelerated to provide contemporary information on which to base Federal, State, and Native land selections. In 1974, the Alaska Mineral Resource Assessment Program of the USGS began systematic statewide investigations of 1:250,000-scale quadrangles, ultimately including nearly all the lands in the Wrangell–Saint Elias region and providing much geologic data to guide the selection of new Federal parklands created by passage of the Alaska National Interest Lands Conservation Act of December 1980.



The Great Alaska earthquake of March 27, 1964, galvanized regional tectonic and *seismic* hazards investigations in southern Alaska. The breadth and magnitude of destruction wrought by this largest earthquake ever recorded in North America stimulated scientists in government agencies, private companies, and academia to undertake comprehensive investigations of causes and effects of the earthquake, aftershocks, and accompanying *tsunamis*. The results provided compelling evidence for crustal plate convergence and *subduction* in an *island arc* environment. Such evidence directly supported the mobilistic concepts of *sea-floor spreading* and plate tectonics that were to revolutionize earth science studies before the end of the decade. The southern Alaskan studies also provided major input to developing models of accretionary terranes. *Neotectonic*, *seismologic*, and earthquake hazards studies that began in the region of the 1964 earthquake *epicenter* in Prince William Sound were expanded to evaluate all major *fault systems* in southern Alaska and were accompanied by much new geologic mapping. In the Wrangell–Saint Elias region, major unrecognized fault systems, such as the Border Ranges fault, were defined, and *offset* histories of other major crustal breaks, such as the Fairweather and Denali faults, were greatly elucidated.

Discovery of the supergiant Prudhoe Bay oil field in 1968 on Alaska's North Slope had two stimulative effects on geologic investigations in southern Alaska. First, the need for a reliable trans-Alaska pipeline and an ice-free tidewater shipping port impelled a resurgence of geotechnical studies and surficial geologic mapping along the proposed nearly 800 mile long corridor for the pipeline, most particularly in the region from the Denali fault south through the Copper River Basin to the southern terminus and shipping facility near Valdez in Prince William Sound. Investigations of the distribution and physical and thermal properties of *permafrost* in unconsolidated deposits near the pipeline corridor led to decisions to elevate rather than bury the pipeline in most permafrost areas. (Thus, along much of its route between Willow Lake and Gakona Junction near the western boundary of Wrangell–Saint Elias National Preserve, the pipeline is conspicuously above ground.) Second, a mood of post-discovery optimism engendered accelerated exploration of other possible oil provinces, including large areas of the offshore Gulf of Alaska Tertiary province. During the 1970's and early 1980's, the heady atmosphere was stimulated further by Federal and State lease sales on the *continental shelves* of southern Alaska and elsewhere, prompting many new *marine* geophysical and geological surveys of large areas of the submerged continental margin. The siting of drilling rigs and the possibility that coastal production and shipping facilities might be constructed led to numerous studies of coastal and seafloor processes and hazards, yielding much new evidence of the dynamic conditions in the southern Alaska nearshore environments. In addition, offshore sampling surveys by the Federal government and company drilling of 13 test wells on the outer continental shelf in the northern Gulf of Alaska yielded information that helped to define the geologic characteristics of the offshore part of the Yakutat block, confirming the oceanward boundary of this latest addition to the collage of displaced terranes that makes up southern Alaska.

In 1989–90, eruptions of Mt. Redoubt, an active volcano in the northeastern part of the Aleutian *arc*, seriously impacted air transportation and ground facilities and services over a large region of northern Cook Inlet, and 1992 eruptions of Mt. Spurr, even closer to Anchorage, had similar regional impacts. In response, the Alaska Volcano Observatory, established in 1988 in Anchorage, began to institutionalize studies of *volcanic* processes and hazards and to develop eruption prediction capabilities—principally for active volcanoes in the Aleutian Islands, the Alaska Peninsula, and Cook Inlet. Topical studies of the Wrangell volcanic field had been underway for many years, having begun in the early 1970's during the last stages of regional geologic mapping in the Nabesna and McCarthy quadrangles. Volcanic studies continued during the 1980's and early 1990's, producing large-scale maps of most of the volcanic edifices in the western Wrangell Mountains, including the quietly active Mt. Wrangell. From the outset of these studies, it was clear that explosive volcanism is not typical for Wrangell volcanoes and that their remoteness from major population centers minimized their hazard. However, the discovery that the volcanic activity apparently is induced by underthrusting of the combined Pacific oceanic plate and piggybacking crust of the Yakutat terrane beneath the continental margin provided an important link between volcanic hazards investigations and concurrent earthquake hazards studies of major fault systems. Studies of both the faulting and the volcanism have yielded integrative clues about the geometry and chronology of terrane convergence and collision and plate configuration in the northern Gulf of Alaska.

The Present Tectonic Setting of Southern Alaska—Key to the Past

It is a fundamental tenet of geology that an understanding of the present provides the key to interpreting the past. In few places is this principle more clearly displayed than in southern Alaska, where the North American *continental plate* and the Pacific oceanic plate presently converge at a dynamic boundary between an oceanic *trench* and a *transform fault system*, generating an inboard volcanic *arc*, the chain of active volcanoes stretching from the Aleutian island arc through Cook Inlet to the Wrangell Mountains (fig. 9). Today's continuing convergence and accretion of crustal fragments provide examples of comparable tectonic regimes that have affected southern Alaska's continental margin for much of the past 200 million years, and many of the effects are strikingly displayed within the parklands of Wrangell–Saint Elias.

In the southern Alaska region, contemporary subduction of dense, heavy *oceanic crust* and *lithosphere* of the Pacific plate beneath lighter *continental crust* and lithosphere of the North American plate maintains a landward-dipping zone marked by earthquakes near the continental margin and an active volcanic arc farther inland (fig. 10). Today's subduction zone and arc are superimposed on a broad zone of rocks, the Wrangellia and southern margin composite terranes, that were deformed by subduction, *underplating*, and accretion during earlier plate boundary tectonism.

At the present, the Pacific plate is moving northwestward relative to Alaska at about 2–2.5 in./yr along the Queen Charlotte–Fairweather transform fault system, converging with the North American plate almost at right angles in the eastern Aleutian trench and the Kayak Island–Pamplona structural zone (fig. 9). In between the trench and the transform fault system, a relatively buoyant fragment of continental crust known as the Yakutat terrane is coupled to the Pacific plate. The terrane is being *thrust* beneath continental crust that has approximately the same density as the terrane along the Chugach–St. Elias fault system; its uneasy subduction causes extreme uplift of the Chugach and St. Elias Mountains. Along its southern margin, the Yakutat terrane is separated from oceanic crust of the Pacific plate by the Transition fault system, which accommodates some oblique convergence—short-circuiting a little less than 10 percent of total Pacific plate motion. In effect, the Yakutat terrane is caught in a tectonic conflict between subduction and accretion. If Pacific plate motion is transferred completely to the Transition fault system (or to some other fault system seaward of the Yakutat terrane), subduction of the remaining part of the Yakutat terrane will cease and its accretion to the southern Alaskan margin will result.

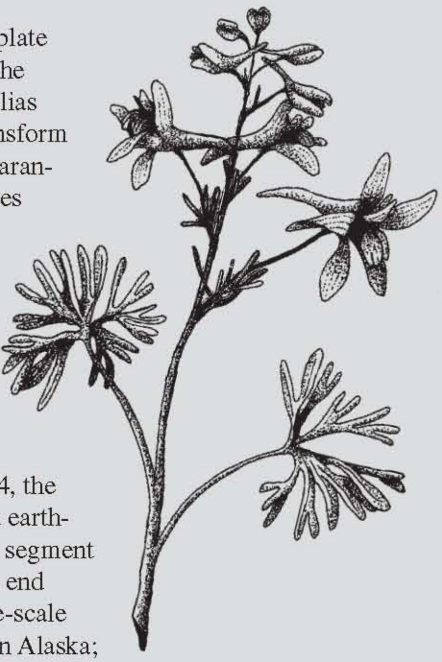
This relative plate motion has prevailed since mid-Eocene time about 50 m.y. ago, the time at which the modern Aleutian arc began to form (fig. 11). Thus, today's arc and associated trench are long-lived crustal features. Volcanism at various places in the Aleutian Islands, Alaska Peninsula, Cook Inlet region, Talkeetna Mountains, or the Wrangell Mountains, and subduction and underplating of crustal slabs in the inner wall of the trench have persisted through virtually all of Cenozoic time.

Copper River Basin

Figure 8 (previous pages). The Copper River and Northwestern Railway bridge (left) across the Copper River just upstream from its confluence with the Chitina River (coming in from right background). Taken in 1911, the view is from the river bluffs near Chitina to the northeast across the Copper River Basin toward the Wrangell Mountains. The bridge was completed on temporary wooden trestles in September 1910 and was reinforced during the winter of 1910–11, but a planned 10-span steel bridge never was completed. While the "temporary" bridge was in service between 1910 and 1938, portions of the structure were destroyed every spring during break-up and frequently during summer floods, as well. Bridge-building crews became adept at making rapid replacements in order to keep copper ore moving from the Kennecott mines to Cordova. Note the three steamships moored near the west end of the bridge. These sternwheelers, the *Chitina*, *Nizina*, and the *Tonsina*, were used between 1907 and 1910 for hauling freight in the upper canyons of the Copper River until the railroad line was completed beyond the Kuskulana River bridge about 10 mi to the east. The railroad greatly improved access to the southern flank of the Wrangell Mountains, providing a lifeline for residents of Kennicott, McCarthy, Chitina, and smaller intermediate camps that sprang up following its completion. *(F.H. Moffit)*

Prior to formation of the modern Aleutian arc, a predecessor to the Pacific plate—the Kula oceanic plate—was being subducted obliquely beneath the Alaska continental margin. Between about 60 and 55 m.y. ago, convergence rates between the oceanic plates and the Alaska continental margin may have been as rapid as 8 in./yr—faster than any known plate motions on Earth today. As the actively spreading oceanic ridge separating the Kula and Pacific plates reached the zone of rapid oblique convergence, intense tectonism, terrane fragmentation, crustal melting, and bending of an originally linear Alaska continental margin to its present concave southward configuration ensued, creating by 50 m.y. ago a tectonic setting that has persisted with only minor changes to the present time.

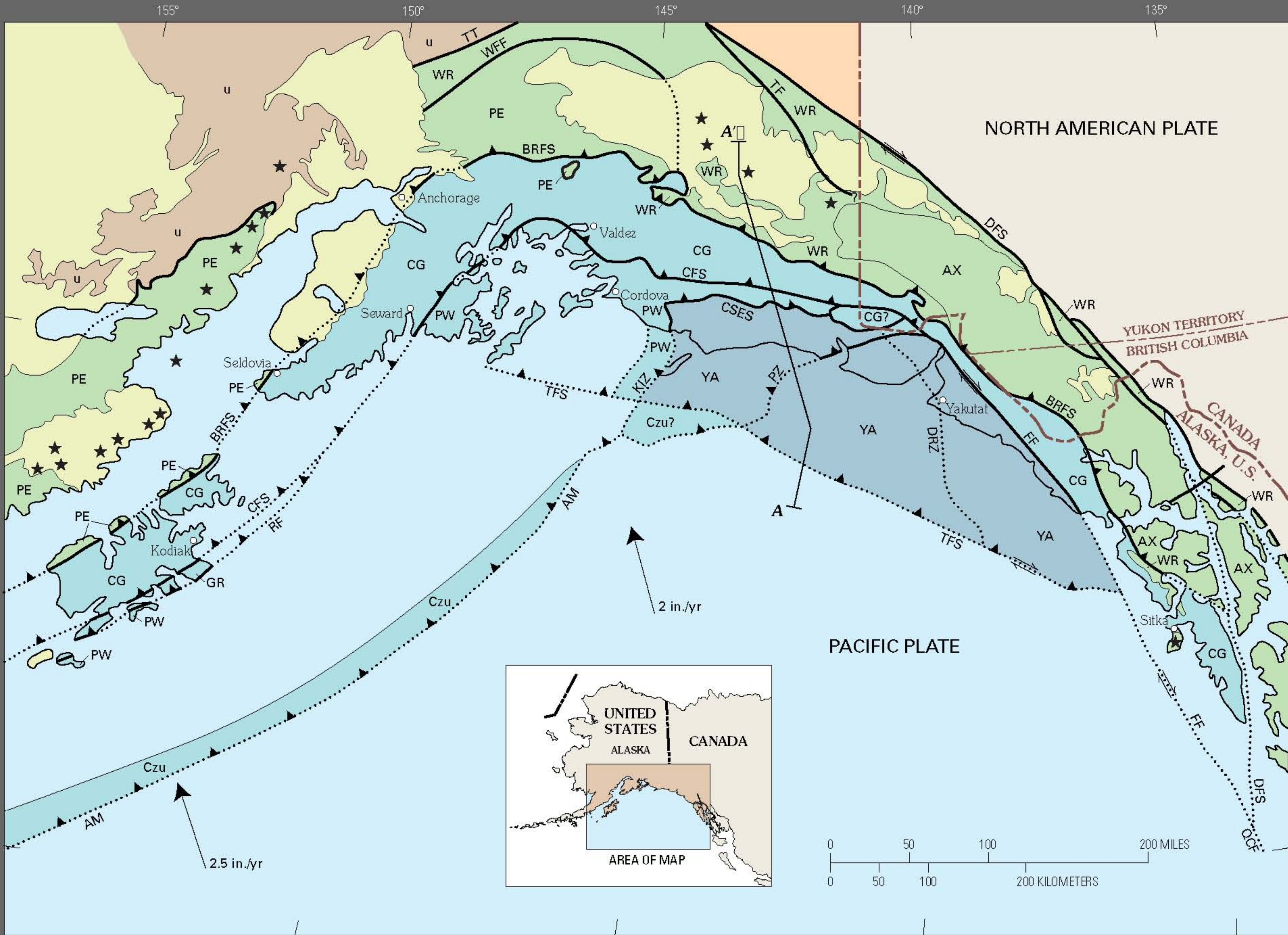
The southern Alaskan margin of the Pacific plate is one of the most active seismic regions in the world: the position of the Wrangell–Saint Elias region straddling a contemporary trench-transform junction and a currently accreting terrane guarantees continuing seismicity. Major earthquakes generated by plate boundary tectonism episodically rattle the parklands. In 1899 and 1958, for example, powerful earthquakes on the transform segment of the boundary between Lituya Bay and Yakutat Bay and on the oblique convergent margin between Yakutat Bay and Yakataga ruptured land surfaces, elevated shorelines, and triggered devastating landslides and tsunamis. In 1964, the great Alaska earthquake—the second largest earthquake ever recorded worldwide—ruptured a segment of the underthrusting boundary near the east end of the Aleutian trench. This resulted in large-scale vertical displacements over much of southern Alaska; subsidiary surface faulting occurred over a zone at least 90 mi wide. Displacement of the sea floor generated a trans-Pacific tsunami that caused destruction and death in Alaska and along the Pacific coast as far away as northern California. A complex zone of compressional folds and faults marks the convergent boundary where the Yakutat terrane has been thrust obliquely under the continental margin; this deformational zone is at least 60 mi wide, and it continues to widen today and to rupture in major seismic events such as the St. Elias earthquake of 1979.



Volcanic activity in southern Alaska also records the plate-tectonic processes. The Aleutian-Wrangell arc forms one link in the circum-Pacific "ring of fire"—the active volcanic arcs that girdle the Pacific plate wherever it is being subducted beneath adjacent plates. At a depth of about 60 mi, heating of the subducting slab of oceanic crust, as well as the overlying materials, creates *magma* that rises above the subduction zone through the overlying crustal plates. The magma may reach the surface to be erupted in a volcano or volcanic field, or it may cool and crystallize underground to form a *pluton*. Both volcanoes and subvolcanic plutons characterize *magmatic arcs* created by plate convergence. In the Alaska Peninsula and Cook Inlet, where the subduction zone steepens to about a 45° *dip* beneath the axis of the arc, episodic but widespread *magmatism* has characterized most of the last 50 million years, driven by orthogonal convergence of the Pacific plate beneath the continental margin since Eocene time. The subduction zone dips northward at a lower angle under the Wrangell Mountains and the axis of the arc is farther inland. Arc volcanism began in the Wrangell Mountains about 26 m.y. ago, when the northwestward-moving Pacific plate, with its piggyback load of the Yakutat terrane, reached sufficient depth in the subduction zone to generate magma.

These subduction-generated magmas have distinctive compositions. Thus, by analogy, plutonic-volcanic complexes in pre-Eocene rocks also provide compositional clues to their possible origins in magmatic arcs. Similar distinctive compositions in the older rocks enable geologists to decipher the magmatic arc settings and plate-tectonic histories of the pre-Eocene terranes that make up the majority of the Wrangell–Saint Elias region.

Figure 9 (following pages). Major lithotectonic terranes and geologic units of southern Alaska and nearby areas. *(Modified from Plafker, Moore, and Winkler, 1994.)*


155°
150°
145°
140°
135°
60°
55°
NORTH AMERICAN PLATE
PACIFIC PLATE
Anchorage
Valdez
Cordova
Seward
Seldovia
Kodiak
Yakutat
Sitka
YUKON TERRITORY
BRITISH COLUMBIA
CANADA
ALASKA, U.S.
2 in./yr
2.5 in./yr
UNITED STATES
ALASKA
CANADA
AREA OF MAP
0 50 100 200 MILES
0 50 100 200 KILOMETERS
u
TT
WFF
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BRFS
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CG
CFS
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PW
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AX
CG?
PZ
KIZ
TFS
Czu?
Czu
DRZ
FF
AM
RF
GR
QCF
A
A′

EXPLANATION

Cenozoic and Cretaceous basinal deposits, undifferentiated

North of Denali fault system (DFS)

Windy (Yukon-Tanana terrane)

North of Border Ranges fault system (BRFS)

Wrangellia composite terrane

- PE Peninsular terrane
- WR Wrangellia terrane
- AX Alexander terrane

Undifferentiated terranes (u)

South of Border Ranges fault system (BRFS)

Southern Margin composite terrane

- CG Chugach terrane
- PW Prince William terrane
- GR Ghost Rocks Formation

Yakutat terrane (YA)

Czu Upper Cenozoic accreted rocks

Contact or terrane boundary not obviously faulted

Water body

Holocene volcano

A A′ Line of section

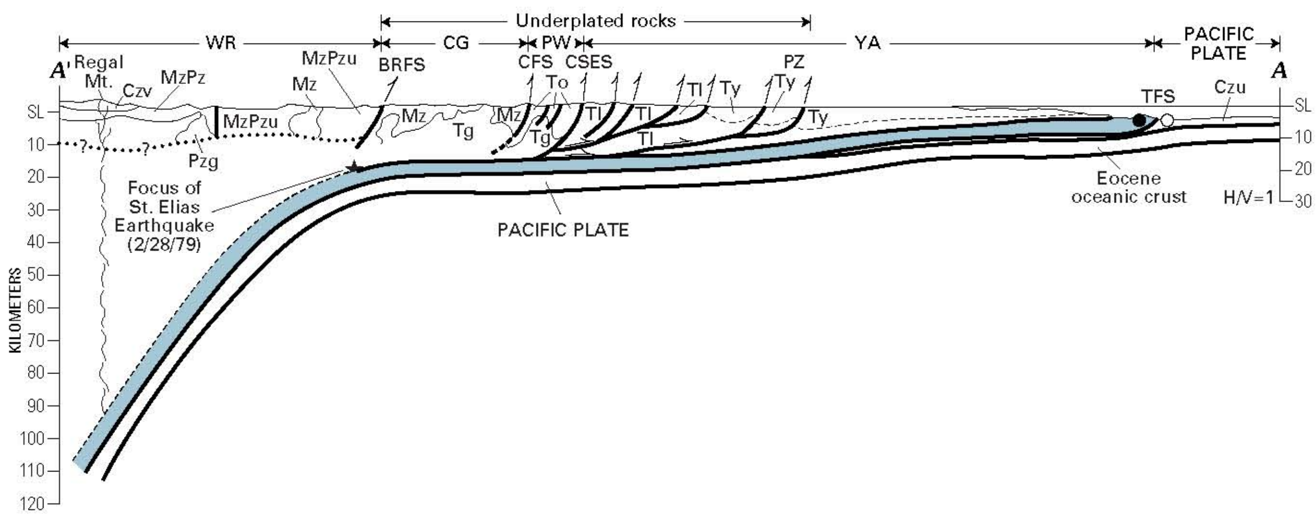
Faults—Dotted where concealed or inferred

- **Thrust fault**—Sawteeth on upper plate
- **Strike-slip fault**—Barbs indicate relative motion
- **Oblique thrust fault**
- **Fault displacement unknown**

2 in./yr **Present motion of Pacific plate relative to North America, showing rate in in./yr**

Major faults

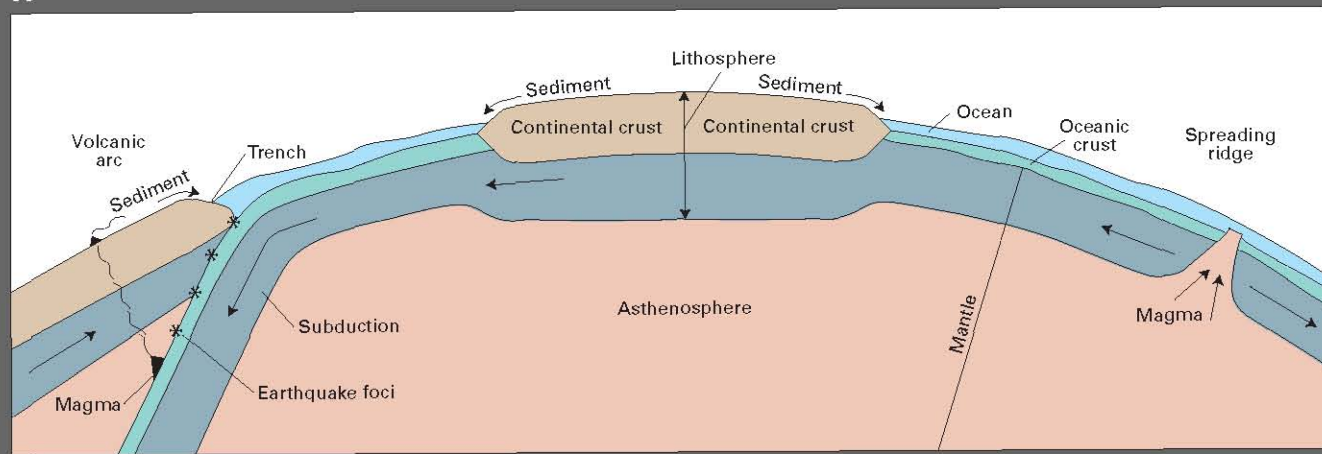
AM	Aleutian megathrust
BRFS	Border Ranges fault system
CFS	Contact fault system
CSES	Chugach-St. Elias fault system
DRZ	Dangerous River zone
DFS	Denali fault system
FF	Fairweather fault
KIZ	Kayak Island zone
PZ	Pamplona zone
QCF	Queen Charlotte fault
RF	Resurrection fault
TF	Totschunda fault
TFS	Transition fault system
TT	Talkeetna thrust
WFF	West Fork fault



EXPLANATION

Czv	Upper Cenozoic Wrangell Lava
Czu	Upper Cenozoic deep marine sedimentary rocks
Tg	Tertiary granitic rocks
Ty	Neogene Yakataga Formation
To	Eocene and Paleocene Orca Group
Tl	Paleogene sedimentary rocks
Mz	Cretaceous metaflysch and metamelange
Jg	Jurassic granitic rocks
MzPzu	Mesozoic and Paleozoic schistose rocks
Mzpz	Mesozoic and Paleozoic sedimentary and volcanic rocks
Pzg	Paleozoic plutonic rocks
●	Movement away from reader
○	Movement toward reader

A



EXPLANATION

Mantle—The zone of the Earth below the crust and above the core

Lithosphere—The solid part of the Earth (as opposed to atmosphere and hydrosphere). It includes the crust and part of the upper mantle and rides on the underlying asthenosphere

Asthenosphere—The part of the upper mantle that is weak and behaves more like a fluid than a solid

Subduction zone—Zone where one crustal plate overrides another along a convergent margin

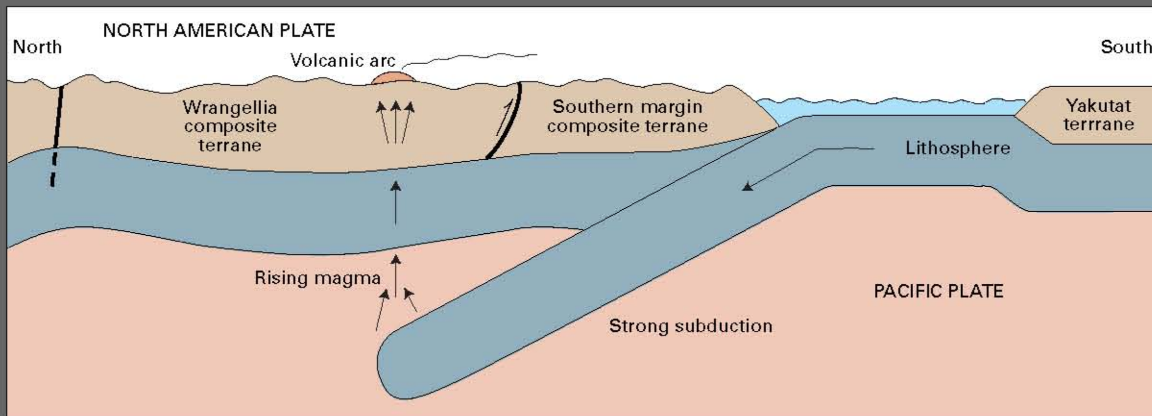
Trench—Depression of the sea floor, formed at convergent plate boundaries where an oceanic plate is subducted beneath a continental plate

Spreading ridge—Suboceanic zone where magma rises between two crustal plates and spreads them apart

Magma—Molten rock generated within the asthenosphere; the parent of all volcanic and plutonic rocks

Volcanic arc—A curved belt of volcanoes above a subduction zone where crustal plates converge

B



C

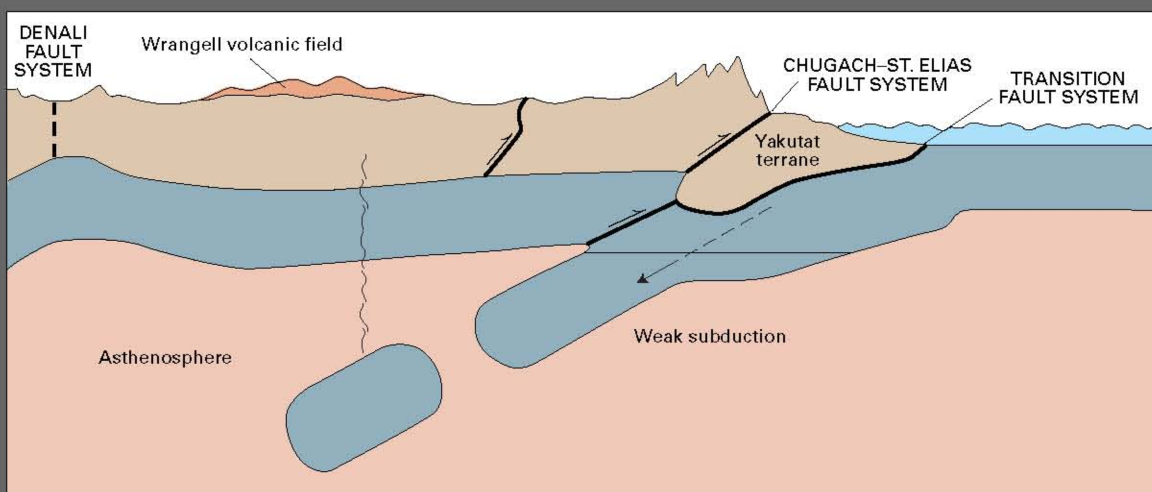


Figure 10. Diagrammatic cross sections through the Earth's crust and upper mantle, showing plate-tectonic features developed in ocean basins and at continental margins. *A*, General features and nomenclature. *B*, The Wrangell–Saint Elias region and the northern Pacific Ocean, about 26 m.y. ago, showing collision of oceanic and continental plates, the Pacific and North American plates, with strong subduction causing formation of an active volcanic arc. *C*, The Wrangell–Saint Elias region and the northern Pacific Ocean at the present time, showing that collision of continental plates, the Yakutat terrane and the North American plate, has jammed the subduction zone and quieted the volcanism. *(Modified from Richter, Rosenkrans, and Steigerwald, 1995.)*

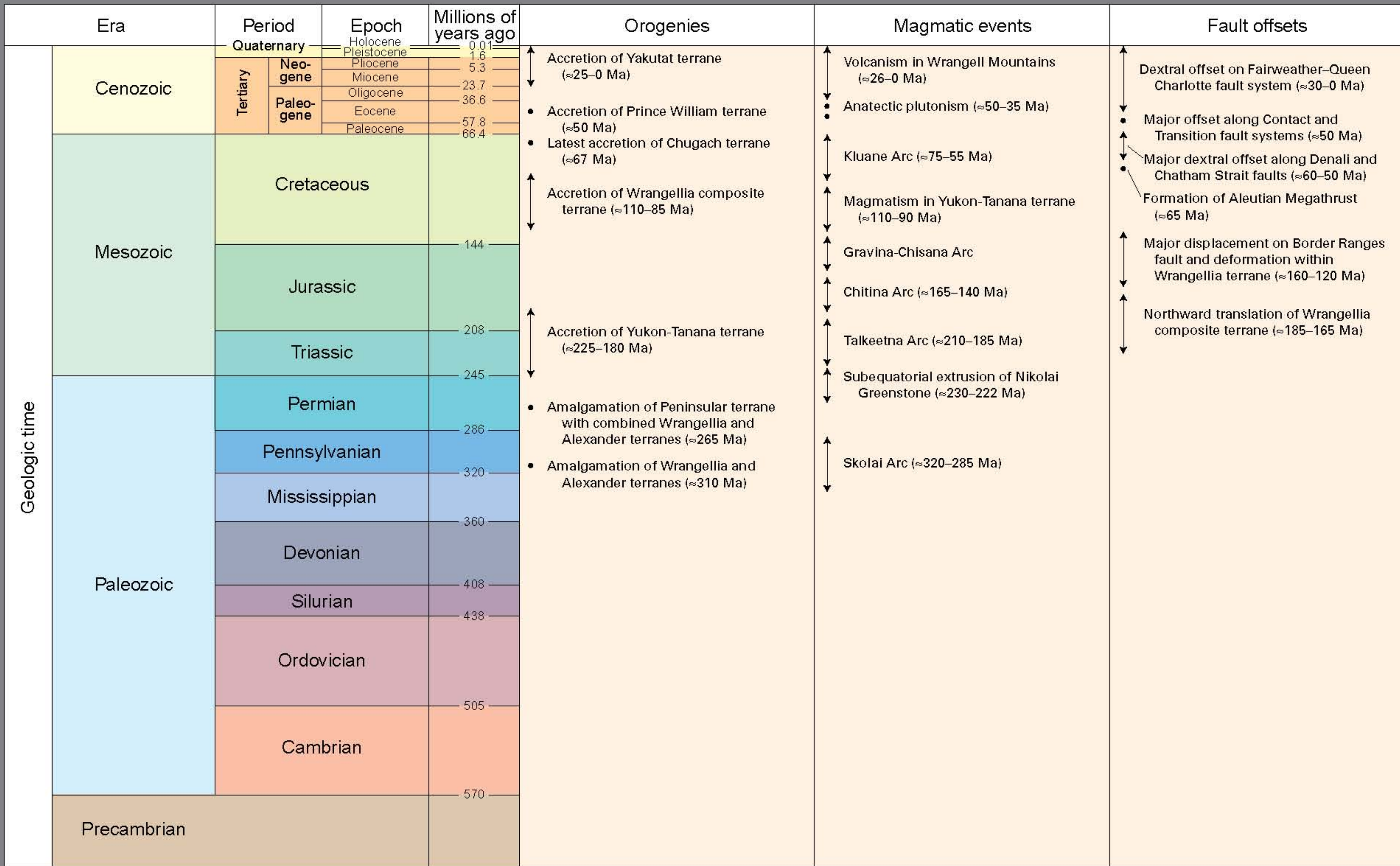


Figure 11. Geologic time scale, showing timing of major geologic events in the Wrangell–Saint Elias region. *(Time subdivisions and dates are from the Decade of North American Geology 1983 geologic time scale.)*

Wrangell–Saint Elias—A Collage of Geologic Terranes

Southern Alaska, and indeed much of the North American Cordillera, is a patchwork of geologically distinctive crustal fragments separated by major fault systems (fig. 12). These fragments exist in all shapes and sizes, but each has a history of development that differs from that of neighboring fragments. All are exotic—that is, they were formed elsewhere and transported to their present position by the motions of crustal plates. Some have been rotated relative to their neighbors, and some have been displaced vast distances compared to less traveled nearby fragments. Thus, adjacent fragments generally differ in the characteristics of the rocks which constitute them—their *lithologies*, and they differ in the structural modifications that those rocks have undergone—their tectonic histories. Thus, these fragments are called *lithotectonic* terranes—or, in shorthand, just *terranes*.

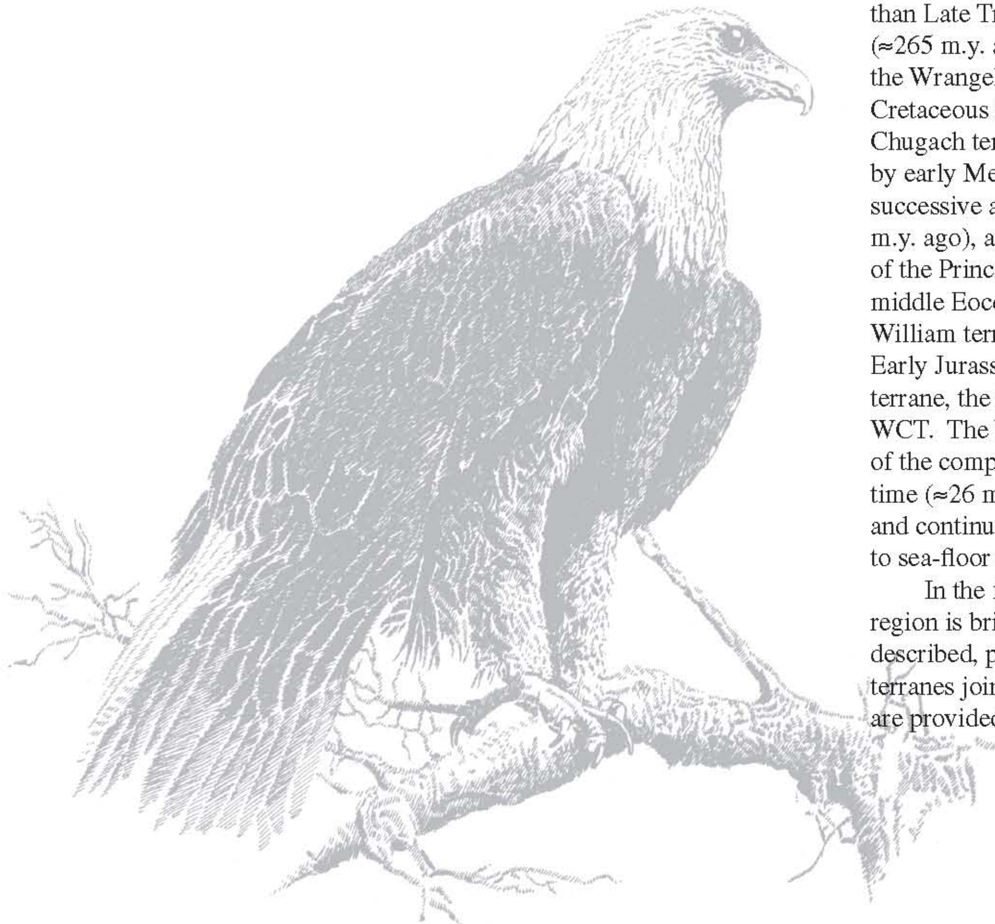
In southern Alaska, juxtaposition of disparate terranes has created a collage on a grand scale. Collectively, the processes by which the collage was assembled (by which south-central Alaska has grown by the addition of exotic terranes over the past 200 million years or so) are termed accretionary tectonics. Terrane assembly continues at the Alaska continental margin today: the latest terrane to accrete—the Yakutat terrane—still is being displaced, jamming against and beneath terranes to the north and west.

The makeup of these terranes is diverse: some represent pieces of old continental crust (probably the North American *craton*), whereas parts of others consist of oceanic crust. Some fragments represent island arcs formed in the open ocean (like the western Aleutian arc). Others represent arcs formed on the edge of a continent (like the eastern Aleutian arc or western South America). Some terranes consist almost totally of the *detritus* eroded from the edge of ancestral North America, such as the sediment eroding from today's continental margin that is filling the Aleutian trench. Where these Alaskan terranes were formed originally and how they came to be fragmented and brought to Alaska is obscure. Most are presumed to have been derived from in and around the proto-Pacific Ocean basin. Some may have been brought as "rafts" propelled on a conveyor belt of converging oceanic crust. Given sufficient time, oceanic crust created by sea-floor spreading has the potential to convey exotic terranes great distances from their places of origin. Other terranes may have been brought northward along *dextral transcurrent faults* near the continental margin. The Yakutat terrane provides a prime example, having been transposed 375 mi along the Queen Charlotte–Fairweather transform fault system in the last approximately 30 million years.

The designation of terranes in regional tectonic analysis received its greatest impetus in the mid-1970's from landmark papers on the Wrangellia terrane. *Paleomagnetic* data from 230 million-year-old Triassic basalts—the distinctive Nikolai Greenstone of the Wrangell Mountains (fig. 13)—provided quantitative evidence for post-Triassic northward displacement of the basalts for thousands of miles from where they formed near the Triassic equator. Subsequent studies of other nearby terranes in the Wrangell–Saint Elias region substantiated that they, too, were displaced, having been moved variable distances from their places of origin by tectonic processes. In fact, it has been shown that so much of Alaska consists of displaced terranes that only a small triangle-shaped area immediately north of the Tintina fault near the International Boundary, less than 1 percent of Alaska's total area, is an undisplaced part of the North American continental nucleus. It is against this ancient continental edge that all terranes to the south accreted, including all the rocks of Wrangell–Saint Elias National Park and Preserve.

The Wrangell–Saint Elias region includes parts of six terranes and one belt of *sedimentary* and volcanic rocks that lies between two adjacent terranes and may have been deposited on both of them, a so-called overlap assemblage (fig. 14). From north to south, they are the Windy (Yukon-Tanana?) terrane, the Gravina-Nutzotin belt, and the Wrangellia, Alexander, Chugach, Prince William, and Yakutat terranes. The Yukon-Tanana terrane was accreted to the continental margin by early Middle Jurassic time about 180 m.y. ago (fig. 11). The Early Cretaceous age (≈120 m.y. ago) of the youngest rocks in the Gravina-Nutzotin belt provides the approximate time by which the Yukon-Tanana and Wrangellia terranes were juxtaposed. The Wrangellia and Alexander terranes were joined by Early Pennsylvanian time (≈310 m.y. ago), and the combined Wrangellia and Alexander terranes were amalgamated with the Peninsular terrane by no later than Late Triassic time (≈210 m.y. ago) and possibly by Early Permian time (≈265 m.y. ago). Thus, by early Mesozoic time, or even earlier, the three formed the Wrangellia composite terrane (WCT), which was accreted as a unit by mid-Cretaceous time (≈110 m.y. ago). Initial accretion of the oldest parts of the Chugach terrane against the southern margin of the WCT may have begun also by early Mesozoic time, prior to its docking against the continental margin, with successive accretionary pulses continuing through latest Cretaceous time (≈67 m.y. ago), approximately 50 million years after the WCT had docked. Accretion of the Prince William terrane rapidly followed, and was completed by the early middle Eocene, about 50 m.y. ago. The rocks of the Chugach and Prince William terranes record repeated episodes of crustal convergence from at least Early Jurassic through middle Eocene time; together they form a composite terrane, the Southern Margin composite terrane, which is at least as large as the WCT. The Yakutat terrane, the latest to arrive, began to impact the south edge of the composited Chugach and Prince William terranes by early late Oligocene time (≈26 m.y. ago). The Yakutat terrane is coupled tightly to the Pacific plate and continues today to be propelled by northwestward plate motion in response to sea-floor spreading at oceanic ridges to the south.

In the following sections, each terrane or belt in the Wrangell–Saint Elias region is briefly characterized and some of its most conspicuous features are described, proceeding from north to south, mimicking the order in which the terranes joined the Alaskan geologic collage. In addition, more detailed reasons are provided for the geologic history just introduced.



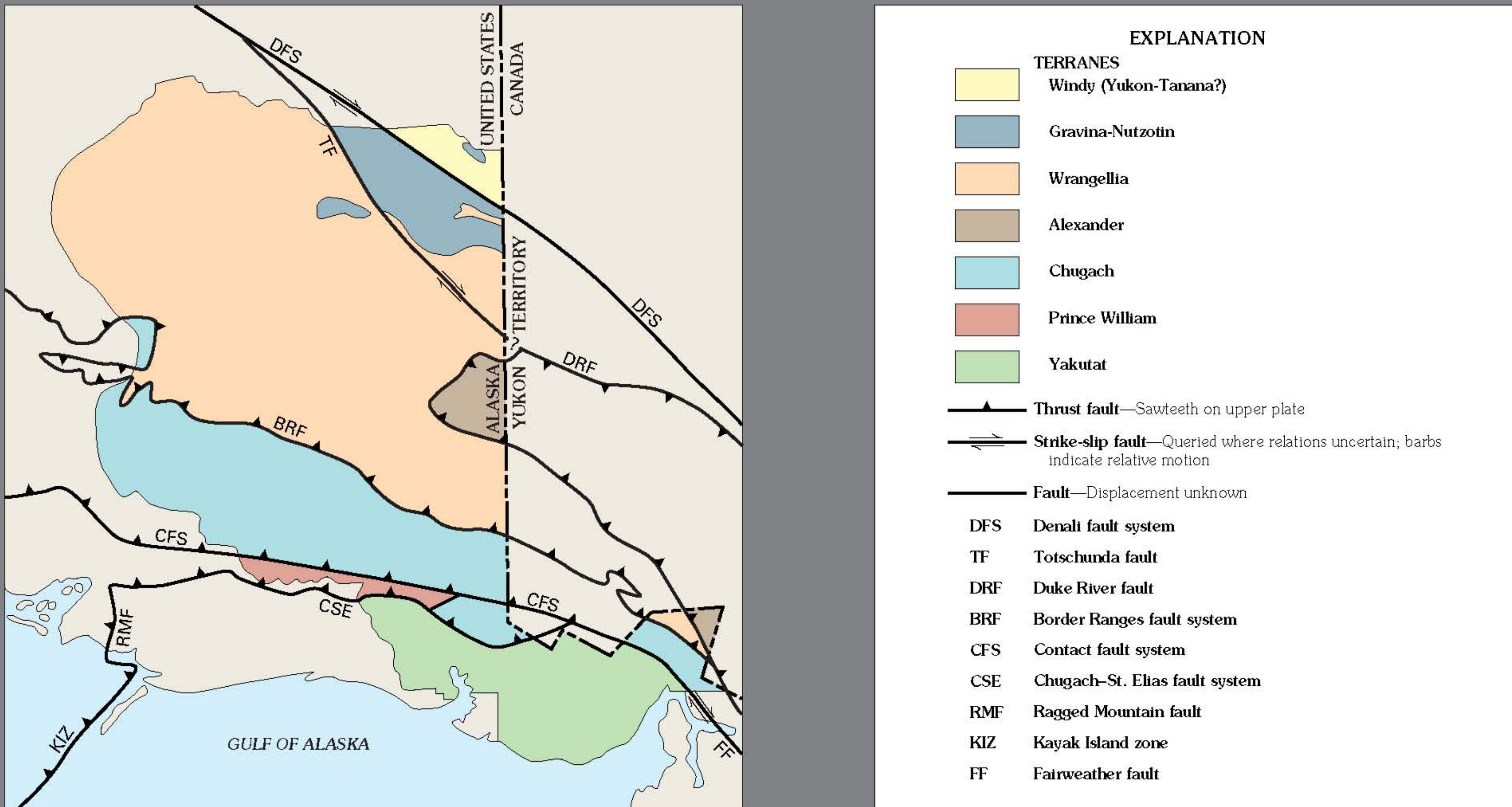
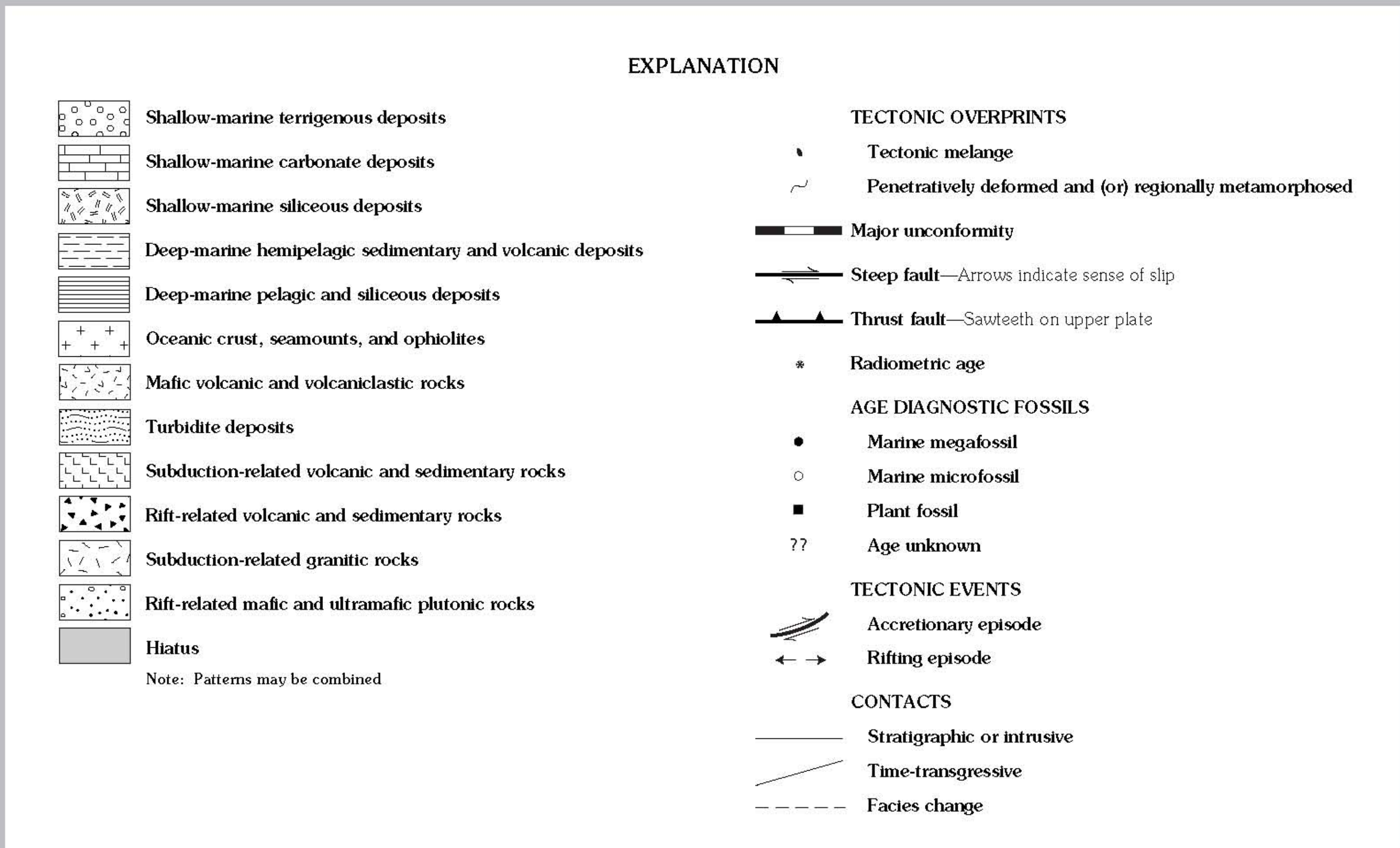


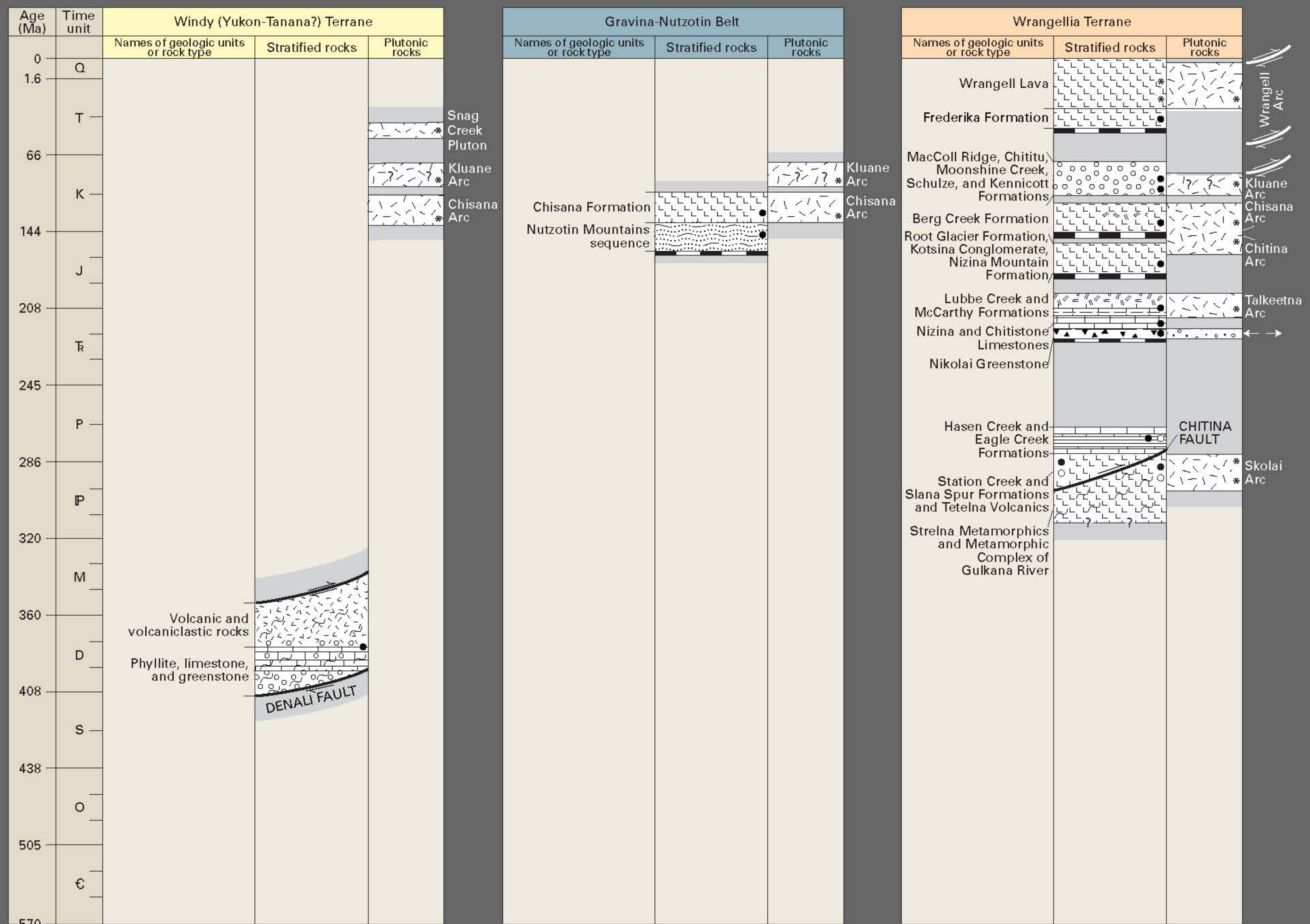
Figure 12. Map showing lithotectonic terranes and major faults of Wrangell-Saint Elias National Park and Preserve.

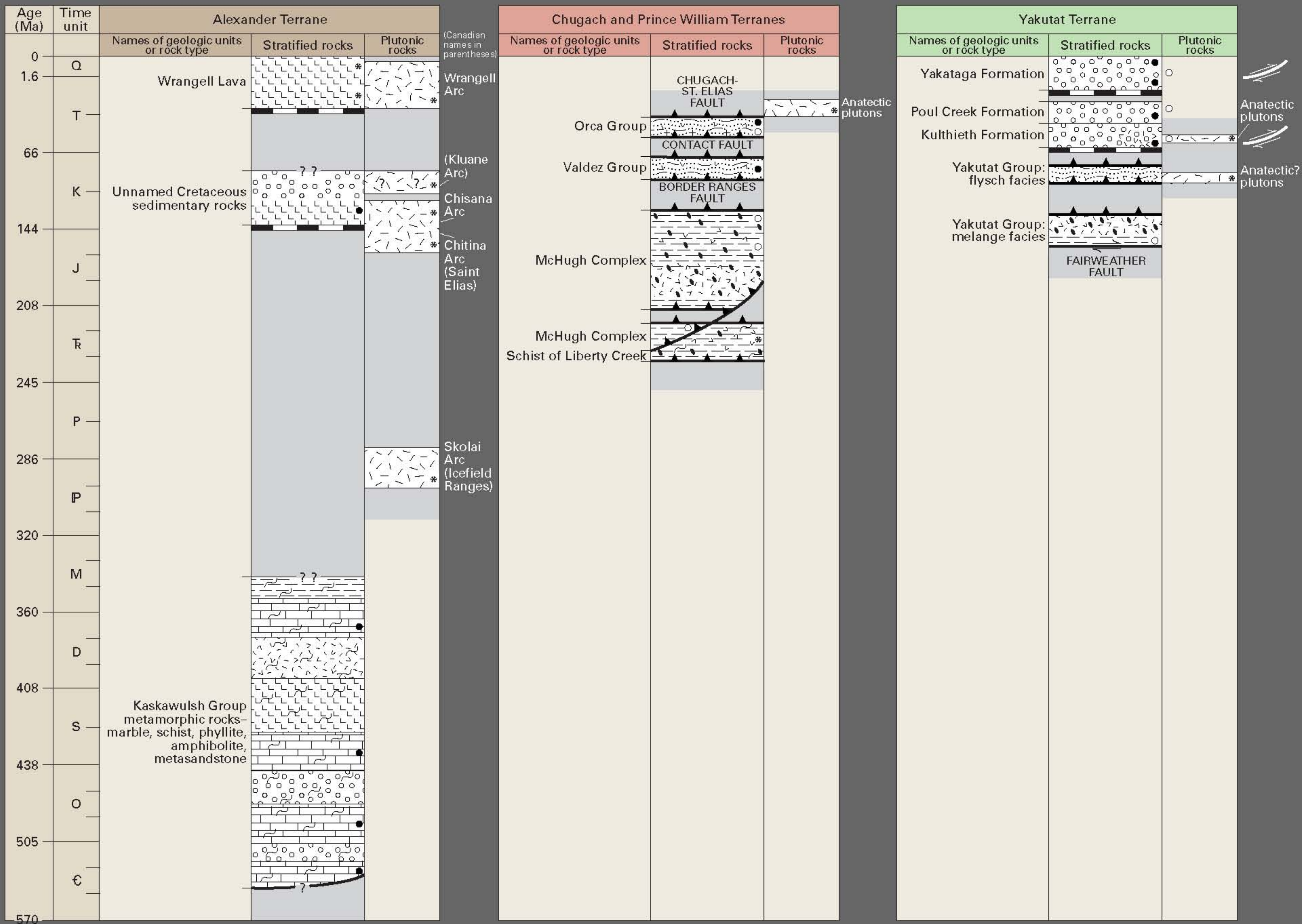
Mt. Blackburn (16,390 ft)
Donoho Peak
Chitistone Limestone
Nikolai Greenstone
Chitistone Limestone
Nikolai Greenstone
Tramline

Figure 13 (facing page). Remains of the tramline that carried copper ore from the Bonanza mine to the mill at Kennicott make a diagonal streak from upper right to lower left in this view. Mt. Blackburn rises above Kennicott Glacier in the background. The dark-brown-weathering ridges in the foreground consist of basaltic rocks of the Triassic Nikolai Greenstone. The paleomagnetic properties of these outcrops of Nikolai Greenstone and others near Kennicott indicate a near-equatorial latitude at the time the basalts formed. Thus, these outcrops have been displaced thousands of miles northward to their current position near lat 61°30′ N. The depositional contact with overlying light-gray marginal marine rocks of the Triassic Chitistone Limestone can be seen on the ridge on the right-hand skyline, as well as on Donoho Peak in the middle ground. Preserved in the lower part of the Chitistone Limestone are evaporative tidal-flat deposits, such as form in the Persian Gulf region today. Thus, the Chitistone also probably formed near the equator and has been displaced great distances northward. *(E.M. MacKevett, Jr.)*

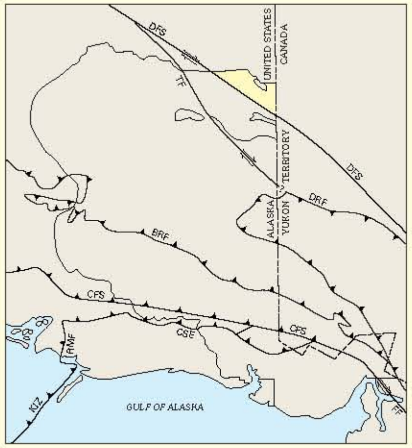
Figure 14 (below and pages 24–25). Geologic characteristics of lithotectonic terranes in the Wrangell–Saint Elias region. *(Modified from Nokleberg and others, 1994, and Plafker, Moore, and Winkler, 1994.)*




Age (Ma)
Time unit
Windy (Yukon-Tanana?) Terrane
Names of geologic units or rock type
Stratified rocks
Plutonic rocks
Gravina-Nutzotin Belt
Wrangellia Terrane
0
1.6
66
144
208
245
286
320
360
408
438
505
570
Q
T
K
J
Ꞧ
P
ℙ
M
D
S
O
Є
Snag Creek Pluton
Kluane Arc
Chisana Arc
Volcanic and volcaniclastic rocks
Phyllite, limestone, and greenstone
DENALI FAULT
Chisana Formation
Nutzotin Mountains sequence
Wrangell Lava
Frederika Formation
MacColl Ridge, Chititu, Moonshine Creek, Schulze, and Kennicott Formations
Berg Creek Formation
Root Glacier Formation, Kotsina Conglomerate, Nizina Mountain Formation
Lubbe Creek and McCarthy Formations
Nizina and Chitistone Limestones
Nikolai Greenstone
Hasen Creek and Eagle Creek Formations
Station Creek and Slana Spur Formations and Tetelna Volcanics
Strelna Metamorphics and Metamorphic Complex of Gulkana River
CHITINA FAULT
Wrangell Arc
Chitina Arc
Talkeetna Arc
Skolai Arc



Age (Ma)
Time unit
Alexander Terrane
Names of geologic units or rock type
Stratified rocks
Plutonic rocks
(Canadian names in parentheses)
0
1.6
66
144
208
245
286
320
360
408
438
505
570
Q
T
K
J
Ŧ
P
ℙ
M
D
S
O
Є
Wrangell Lava
Wrangell Arc
(Kluane Arc)
Chisana Arc
Chitina Arc (Saint Elias)
Unnamed Cretaceous sedimentary rocks
Skolai Arc (Icefield Ranges)
Kaskawulsh Group metamorphic rocks–marble, schist, phyllite, amphibolite, metasandstone
Chugach and Prince William Terranes
Names of geologic units or rock type
Stratified rocks
Plutonic rocks
CHUGACH-ST. ELIAS FAULT
Anatectic plutons
Orca Group
CONTACT FAULT
Valdez Group
BORDER RANGES FAULT
McHugh Complex
McHugh Complex
Schist of Liberty Creek
Yakutat Terrane
Names of geologic units or rock type
Stratified rocks
Plutonic rocks
Yakataga Formation
Poul Creek Formation
Kulthieth Formation
Anatectic plutons
Yakutat Group: flysch facies
Anatectic? plutons
Yakutat Group: melange facies
FAIRWEATHER FAULT



Windy Terrane—Diced Pieces of the Continental Backstop

In the northeast corner of Wrangell–Saint Elias National Park and Preserve, fault-bounded sequences of diverse *metamorphic rocks* occupy a small area north of the Denali fault in the foothills of the Nutzotin Mountains, the Carden Hills, and Wellesley Mountain. These metamorphic rocks are provisionally assigned to the Windy terrane (fig. 12), but they also have many similarities to rocks of the Yukon-Tanana terrane. They underlie only about 2 percent of the area of the parklands.

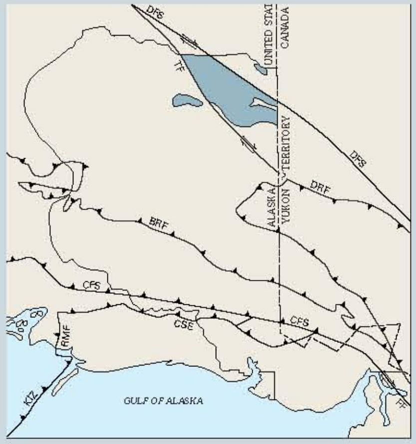
In the foothills of the Nutzotin Mountains, one of these sequences consists of *schistose* sedimentary and volcanic rocks of probable Devonian age containing conspicuous lenses of *metamorphosed conglomerate* and *limestone*. North of the parklands, in the Mentasta Mountains and the Black Hills, this sequence contains thicker lenses of *fossiliferous* recrystallized limestone containing mid-Devonian *corals*. The rocks have been deformed multiple times and are cut by numerous near-vertical faults of the Denali fault system. In the Carden Hills area (fig. 15), bedrock consists of weakly metamorphosed *mafic* volcanic *flows*, *tuffs*, and *volcaniclastic rocks* of uncertain Paleozoic age. These rocks may correlate with Devonian *greenstone* and *phyllite* that is widespread to the north and west (outside the parklands). These metamorphic rocks are in fault contact with layered *mafic* and *ultramafic intrusive rocks* of probable Paleozoic age. Both the intrusive and *extrusive* sequences in the Carden Hills are cut by numerous steep faults, but are less strongly *foliated* than rocks in the foothills of the Nutzotin Mountains. In the Wellesley Mountain area, Cretaceous or Tertiary sedimentary rocks *unconformably* overlie these metamorphic rocks and are intruded by the Eocene Snag Creek pluton.

Based on similarity of lithologies and structural features, some geologists have correlated these fault-bounded sequences with the Windy terrane of the Mt. McKinley area about 140 mi to the northwest. In the Mt. McKinley area, the Windy terrane consists of an assemblage of continental margin deposits, including reeflike limestone bodies, that formed along the edge of the North American craton during the early Paleozoic. Other geologists have correlated these rocks with the Yukon-Tanana terrane, which extends 170 mi northward across the uplands between the Tanana and Yukon Rivers. The Yukon-Tanana terrane also consists of deposits formed along the continental margin in early Paleozoic time, but contains much less limestone. In the Yukon-Tanana Upland, the rocks consist of multiply deformed *schists* and *gneisses* formed by metamorphism of diverse sedimentary, volcanic, and plutonic rocks. Collectively, the fault-bounded sequences of the Windy terrane that crop out in the Wrangell–Saint Elias parklands have *protoliths* and ages similar to those of the less dismembered rocks of the Yukon-Tanana terrane. Thus, these rocks may represent tectonic slices derived from the edge of the Yukon-Tanana terrane, or from continental margin sequences fringing it, and were interleaved between strands of the Denali fault system during Cenozoic *dextral* offset.

The Yukon-Tanana terrane was accreted to the margin of North America in Early Jurassic time, accompanied by intense deformation across the suture zone and plutonism and metamorphism of regional extent. This crustal heating and melting served to weld the terrane to the continental margin. During the remainder of Mesozoic and Cenozoic time, the Yukon-Tanana rocks served as a firm backstop to later arriving terranes as they continued to collide with and be accreted to the Alaskan continental margin south of the Denali fault. Although they were broken and crumpled episodically during subsequent accretionary events, they were lodged firmly enough to bring the giant, northward-moving Wrangellia composite terrane to a halt.

Windy Terrane

Figure 15 (facing page). Carden Lake in the Carden Hills north of the Denali fault; view is to the south. The rounded hills in the foreground are underlain by Devonian phyllite and greenstone. The higher peaks of the Nutzotin Mountains in the background are underlain chiefly by sedimentary rocks of the Jurassic-Cretaceous Nutzotin Mountains sequence. Trumpeter swans are using the lake as a stopover on their migratory flight south. *(D.H. Richter)*



Gravina-Nutzotin Belt—Jurassic and Cretaceous Adhesive

An Upper Jurassic and Lower Cretaceous sequence of marine sedimentary and volcanic rocks nearly 20,000 ft thick makes up most of the Nutzotin and Mentasta Mountains southwest of the Denali fault. This sequence underlies about 6 percent of the parklands (fig. 12). On the opposite side of the Denali fault system, widespread but discontinuous exposures of rocks of similar ages and lithologies occur in the Dezadeash Basin of the Yukon Territory and in an elongate belt in southeastern Alaska, extending from Gravina Island near Ketchikan to the vicinity of Juneau. In the Nutzotin and Mentasta Mountains, rocks of the Gravina-Nutzotin belt include sparsely fossiliferous volcanogenic sedimentary rocks and volcanic flows, *breccias*, and tuffs. Locally, the sedimentary rocks may include impure limestone, carbonaceous strata, and conglomerate. The older, predominantly sedimentary part of the sequence consists principally of graded and rhythmically bedded *flysch*, and is known informally as the Nutzotin Mountains sequence. Although principally Late Jurassic in age, it may include strata of earliest Cretaceous age. West of the Totschunda fault near Noyes Mountain, the lower part of the Nutzotin Mountains sequence includes shallow marine and perhaps partly nonmarine conglomeratic rocks containing fragments of coalified wood and conspicuous limestone *clasts* derived from the Wrangellia terrane to the south as well as schist and gneiss clasts probably derived from the Yukon-Tanana terrane to the north (fig. 16). South of the Nabesna mine, the upper part of the Nutzotin Mountains sequence also contains nearshore and nonmarine strata. In the Chathenda Creek area, tuffaceous *mudstone* at the top of the sequence is overlain conformably by fragmental *andesitic* volcanic rocks, which define the transition to the Chisana Formation. The Chisana Formation contains marine and subaerial andesitic and basaltic volcanic and volcaniclastic rocks as much as 9,500 ft thick, which contain minor intercalated marine sedimentary rocks in the lower part. Both the textures and chemistry of the volcanic rocks are characteristic of an island arc assemblage. Locally, the marine sedimentary rocks contain numerous *pelecypods* and *ammonites*, which indicate the Early Cretaceous age of the Chisana Formation.

The Gravina-Nutzotin belt in the Wrangell–Saint Elias region is intruded by mid-Cretaceous *granitic* plutons, such as the Klein Creek and Chisana plutons, which are presumed to represent the roots of the island arc for which the Chisana Formation is the volcanic carapace. As in most magmatic arcs, the mid-Cretaceous *radiometric ages* of the deep-seated intrusive rocks are somewhat younger than the Early Cretaceous *paleontologic* and radiometric ages of the correlative shallow volcanic rocks. Millions of years are required for the intrusive rocks to cool sufficiently for their constituent minerals to crystallize, finally "locking in" *isotopic* ratios of radioactive elements that are used to determine their absolute ages. In contrast, the volcanic rocks are quenched nearly instantly upon extrusion at the Earth's surface.

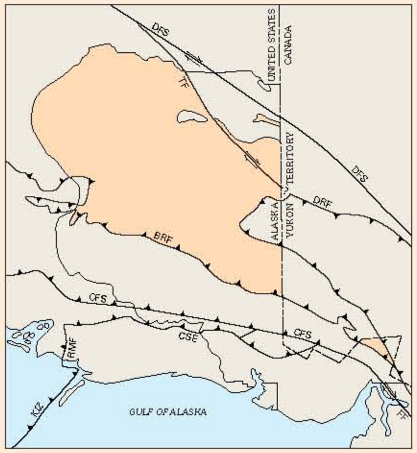
Apparently, the flysch of the Nutzotin Mountains sequence was deposited along the north edge of the Wrangellia composite terrane as it approached the continental margin, close enough that the basin also received some detritus from the Yukon-Tanana terrane. The Chisana arc is interpreted to have formed on the leading (north) edge of Wrangellia as subduction of oceanic crust was occurring along Wrangellia's southern margin. At Wellesley Mountain, conglomeratic rocks that may be coeval with the latest stages of the Chisana arc lie unconformably on the Yukon-Tanana terrane. Thus, at least locally, basin-margin facies of the youngest part of the Gravina-Nutzotin belt may have overlapped terranes to both north and south. However, subsequent structural telescoping of the basin—particularly its northern margins where all contacts are faults—makes this interpretation tentative.

Gravina–Nutzotin Belt

The flysch and the arc assemblage both were strongly deformed during the ensuing collision of Wrangellia with the continental margin. In a way, these rocks are the adhesive that glues the two terranes together. The mid-Cretaceous collision resulted in intense folding, structural imbrication, and deep underthrusting of the Gravina-Nutzotin belt, as well as plutonism and metamorphism in the tectonically thickened crust above the collisional zone. Major Late Cretaceous and early Tertiary dextral displacement on the Denali fault and and younger slip on the Totschunda fault have occurred in approximately this same zone, further adding to the structural complexity along the northern flank of the Wrangell and Nutzotin Mountains.

The regional extent of the Gravina-Nutzotin belt provides evidence for substantial Late Cretaceous and early Tertiary dextral offset along the terrane-bounding Denali fault. Rocks of the Nutzotin Mountains sequence south of the Denali fault in the northeastern part of Wrangell–Saint Elias are nearly identical to the Dezadeash flysch north of the Denali fault near the Ruby Mountains in the Yukon Territory. If these two flysch sequences formed a continuous basin, as seems likely, a dextral displacement along the Denali fault of a minimum of 190 mi is required to restore them directly opposite one another. In fact, total displacement of other units not exposed in Wrangell–Saint Elias may be as much as 250 mi. This magnitude of displacement along the Denali fault clearly indicates that it is not only a terrane boundary, but also one of the major tectonic features of western North America.

Figure 16. Conglomerate in the Jurassic and Cretaceous Nutzotin Mountains sequence. Light-colored clasts are quartz indicating that the sequence was receiving sediment from a stable crystalline terrane to the north (containing abundant quartz veins), which likely was the Yukon-Tanana terrane; distinctive limestone clasts in the conglomerate can have been derived only from the Wrangellia terrane to the south, which was advancing northward upon the Gravina-Nutzotin basin, eventually closing it completely. *(D.H. Richter)*



Wrangellia—The First of its Type

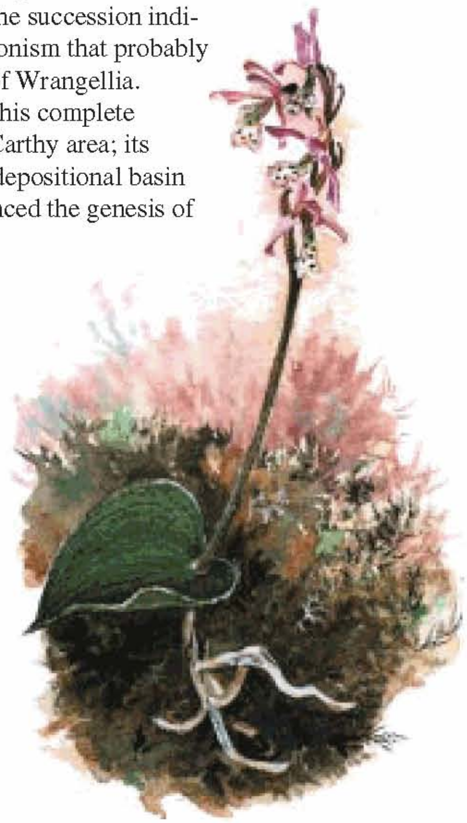
The original recognition of Wrangellia as a far-traveled terrane, the first to receive name recognition, was founded on its distinctive stratigraphy and molluscan fauna, which contrasted strongly with nearby terranes having rocks of similar ages. These contrasts were ascribed to Wrangellia's displacement with respect to its neighbors. However, it was the study of *paleomagnetism* that first provided a semiquantitative means to measure relative displacements with respect to the North American craton. Under certain conditions, rocks retain a remanent magnetism that records the Earth's magnetic field at the time they formed, and thus the latitude where they formed can be determined. Paleomagnetic poles from the interior (and presumably stable) part of North America define a frame of reference for comparison with measured paleolatitudes for samples of known age from accreted terranes in southern Alaska and elsewhere. In the 1960's and 1970's, the Nikolai Greenstone (fig. 13) near McCarthy was extensively sampled and analyzed: the average paleolatitude measured for 50 lava flows was at least 27° south of the predicted Triassic latitude for the region. Thus, the Nikolai Greenstone had been displaced poleward at least 1,800 mi relative to interior North America. The interpretation that sabkha facies in the overlying Chitistone Limestone indicated its formation near the Late Triassic equator now seemed credible. Subsequent additional measurements on the Nikolai in Alaska and the correlative Karmutsen Formation in British Columbia confirmed the anomalously low paleolatitudes of Wrangellia, supporting the concept of far-traveled terranes elsewhere in the Cordillera of western North America. The provocative results from the paleomagnetic study of the Nikolai Greenstone stimulated rapid acquisition of paleomagnetic data from other Alaskan terranes over the next several years. It has turned out that the rocks forming large areas of Alaska also were once located at lower latitudes with respect to the North American craton and had been displaced long distances northward since they formed.

The rugged mountain ridges surrounding Kennicott and Root Glaciers and the canyons of the Chitistone and Nizina Rivers expose in nearly continuous outcrops the most characteristic rocks of Wrangellia (fig. 17). The distinctive maroon-weathering slopes of the Nikolai Greenstone contrast conspicuously with the light-gray-weathering cliffs and ledges of the overlying Chitistone and Nizina Limestones. The color contrast can be seen easily from a distance, and by the late 1800's, the contact zone had gained the attention of prospectors and geologists, who discovered that copper lodes were concentrated in its proximity. By 1900, the fabulous Bonanza lode east of Kennicott Glacier had been located. By 1905, probably every linear foot of the contact zone in the southern Wrangell Mountains had been scrutinized, where it was accessible, and all major known copper deposits of the region had been staked.

The Nikolai Greenstone (fig. 14) consists of Triassic basalt flows whose aggregate thickness is nearly 10,000 ft. The greenstone formed a vast volcanic field; today's remnants cover large tracts on both north and south flanks of the Wrangell Mountains and the south flank of the eastern Alaska Range, as well as adjacent parts of Canada at least as far as the Kluane Lake region. Correlative basalts are known as far west as the Alaska Peninsula and at least as far east as the Chilkat Peninsula near Haines, Alaska. Large areas of Triassic basalt on the Queen Charlotte and Vancouver Islands in British Columbia, known as the Karmutsen Formation, probably are offset continuations of the same volcanic field, although displaced by post-Triassic movement along the Denali, Queen Charlotte, or other major transcurrent fault systems. The Nikolai Greenstone was extruded during a 7–8 million year interval onto a mostly subaerial volcanic plateau; near the perimeters of its outcrops, however, submarine flows have been identified. Volumetric estimates for the Nikolai Greenstone exceed a staggering 60,000 mi^3, enough to bury the entire State of Oregon with a quarter mile of basalt! The Nikolai Greenstone is overlain by as much as 3,600 ft of Upper Triassic limestone and *dolomite* in the area between the Kennicott Glacier and the Chitistone River canyon, but the *carbonate* rocks thin rapidly westward, eastward, and northward. The lower part of the Chitistone Limestone in the McCarthy area contains *stromatolites*, relicts of *evaporites*, and algal-mat chips,

Wrangellia

which collectively indicate deposition in a tidal-flat *sabkha* environment. Sabkhas are widespread in the Middle East today. The upper part of the Chitistone Limestone, and the overlying Nizina Limestone, were deposited in progressively deepening seawater, culminating, by latest Triassic time, in deposition of *spiculite*, muddy limestone, and *shale* of the McCarthy Formation. The McCarthy Formation makes up the thin-bedded, dull-brown-weathering, slope-forming units above the cliff- and ledge-forming Triassic limestones throughout the region. Between Kennicott and Nizina Glaciers, an overlying Jurassic sedimentary succession more than 5,200 ft thick forms the higher ridges and consists primarily of marine *sandstone*, shale, and conglomerate. Locally, the succession includes spiculite and minor *coquina*; some beds contain abundant ammonites and *mollusks* that substantiate ages ranging from Early to Late Jurassic. Thin lava flows and beds of volcanic ash in the Middle and Upper Jurassic parts of the succession, as well as abundant primary volcanic detritus in the clastic rocks, indicate arc magmatism from about 170 to 150 m.y. ago in Wrangellia (the so-called Chitina arc). Lenses of conglomerate and *disconformities* within the upper part of the succession indicate episodic uplift and subsidence—tectonism that probably is an early manifestation of the docking of Wrangellia. Within the Wrangell–Saint Elias region, this complete Jurassic sequence occurs only in the McCarthy area; its presence indicates the deepest parts of a depositional basin whose hydraulic regime may have influenced the genesis of Kennecott-type copper deposits.



In a few widely scattered localities, remnants of fossiliferous marine *siltstone*, shale, and limestone of Middle Triassic age, as much as 300 ft thick, intervene between the Nikolai Greenstone and underlying rocks. These strata contain the distinctive age-diagnostic pelecypod, *Daonella*, and provide biostratigraphic timing of the onset of basaltic volcanism represented by the overlying Nikolai Greenstone.

These distinctive Triassic and Jurassic rocks were deposited unconformably upon the remnants of an upper Paleozoic assemblage (fig. 14), consisting of andesitic volcanic flows and volcaniclastic rocks; shallow-marine shale, sandstone, and limestone; and *alkalic* plutonic rocks. The stratified rocks may represent the remnants of an intraoceanic island arc; their base is not exposed. On the southern slopes of the Wrangell Mountains, the stratified rocks are collectively named the Skolai Group, after the locality where they are exposed most completely along Skolai Creek (fig. 18), and the conceptual arc also has been given the name, "Skolai" (fig. 11). At the Golden Horn, the limestone forms reeflike lenses near the top of the Skolai Group that are as much as 800 ft thick and contain abundant corals, *crinoids*, *bryozoans*, and *brachiopods* of Early Permian age. The limestone is underlain by a Permian sedimentary sequence as much as 2,000 ft thick, which is underlain in turn by Permian and Pennsylvanian volcaniclastic and volcanic rocks as much as 6,500 ft thick. Nearly complete exposures of the Skolai Group also occur in the areas of Chitistone Gorge, Hawkins Glacier, and the head of the White River.

Large plutons of mid-Pennsylvanian age (≈300 million years old) invade the lower strata of the Skolai Group in the Hawkins, Barnard, and Chitina Glacier areas (fig. 3) and consist principally of *granite*, *monzonite*, and *syenite*, rock types that have relatively elevated levels of potassium compared to average plutonic rocks. These plutons probably are correlative with the more extensive Icefield Ranges plutonic suite 20 mi to the east in Kluane National Park, Yukon Territory. More than 50 mi to the west in the Gilahina River area, alkalic *gabbro* and *orthogneiss* of probable Pennsylvanian age intrude the Skolai Group; these plutons may be more mafic phases of the same intrusive suite. Metamorphosed plutons of these ages also are known in the Dadina River area on the west slopes of Mt. Wrangell, where they intrude foliated metasedimentary and metavolcanic rocks that are presumed to correlate with other less metamorphosed rocks formed in the Skolai arc.


Nizina Limestone
Chitistone Limestone
Nikolai Greenstone
CHITISTONE RIVER CANYON

On the northern slopes of the Wrangell Mountains, the upper Paleozoic stratified rocks of Wrangellia are called the Pennsylvanian and Permian Tetelna Volcanics and the Permian Mankomen Group (fig. 19). The stratigraphy is generally equivalent to units on the southern flank, but individual units vary markedly in thickness from place to place. The lower volcaniclastic and volcanic part of the sequence, the Tetelna Volcanics, is more than 3,300 ft thick, and is well exposed north of the Nabesna Road in the Boyden Hills and on the ridge north of Natat and Caribou Creeks. The upper sedimentary part of the sequence, consisting of the Slana Spur and Eagle Creek Formations, is from 300 to 1,600 ft thick. Outcrops are most accessible in the Camp Creek area east of the Nabesna River; excellent exposures also are present between the toe of the Nabesna Glacier and Camp Creek. Isolated, incomplete sequences of both the Tetelna Volcanics and Mankomen Group also occur in fault-bounded blocks within the Nutzotin Mountains sequence near the International Boundary. In the eastern Alaska Range, these upper Paleozoic stratified sequences are intruded by foliated and nonfoliated mafic and intermediate alkalic plutons of mid-Pennsylvanian age. However, none of the plutonic rocks occur within the parklands; the nearest outcrops are on the divide between Suslota and Suslositna Creeks about 6 mi north of the preserve boundary.

The late Paleozoic Skolai arc sequence, the Triassic Nikolai Greenstone, and the overlying Triassic-Jurassic shallow marine sedimentary rocks are the units that typify Wrangellia. Although they are widely and strikingly displayed along the entire southern flank of the Wrangell Mountains, they also are widespread in other parts of the parklands, underlying at least 50 percent of the Wrangell–Saint Elias region (fig. 12) and forming one of the larger terranes in southern Alaska. Upper Paleozoic and Mesozoic units that are broadly correlative with the units of Wrangellia extend westward through the Talkeetna Mountains and southwestward along the Alaska Peninsula for more than 600 mi, forming the Peninsular (Alaska Peninsula) terrane. The Peninsular terrane is faulted against Wrangellia, but the similarities between upper Paleozoic and Mesozoic sedimentary and volcanic units in the two terranes have been interpreted to indicate that they were juxtaposed by no later than the Late Triassic, and possibly by the late Paleozoic. Only one small area of rocks that have been assigned to the Peninsular terrane occurs within the parklands: on the north bank of the Copper River near the mouth of the Cheshnina River, layered gabbroic rocks crop out that are the easternmost occurrence of a Middle Jurassic ultramafic-mafic assemblage. These rocks continue westward to Bernard Mountain near Tonsina, where layered *ultramafic* rocks weather a conspicuous rusty brown. Viewed on a sunny day from near Mile 80 on the Richardson Highway, their dun-colored tint contrasts markedly with surrounding dark, somber rocks.

Chitistone River

Figure 17 (facing page). View of the mouth of Chitistone River canyon looking north from the east bank of the Nizina River. The "Triassic Trinity" of the maroon-weathering Nikolai Greenstone (lowest unit), the light-gray-weathering Chitistone Limestone, and the dark-gray-weathering Nizina Limestone form the right half of the view, dipping northward into the Chitistone River canyon. Cliffs on the north side of the Chitistone River are eroded entirely from the Chitistone and Nizina Limestones, which here are more than 3,600 ft thick. Caves and solution-collapse features are present locally in the limestones, particularly in their lower parts. At the Kennecott mines, similar brecciated features are associated with major copper orebodies. *(G.R. Winkler)*

Chimney Mountain
President's Chair
Qtw
TRng
TRd
Pgh
Phc
Pgh
Phc
PIPsc
PIPsc

Figure 18 (page 34). View of the north side of Skolai Creek, the type locality of volcanic and sedimentary rock units of the Pennsylvanian and Permian Skolai Group. The ridge in the left foreground and the lighter colored rocks on the background ridge are composed of fossiliferous marine carbonate rocks of the Golden Horn Limestone Lentil of the Hasen Creek Formation (Pgh). Strata in the upper half of the Golden Horn contain numerous Early Permian brachiopods, *gastropods*, crinoids, and bryozoans. The Golden Horn forms *bioclastic*, reeflike accumulations within the upper, sedimentary part of the Skolai Group, which is called the Hasen Creek Formation (Phc). The sedimentary sequences apparently formed aprons surrounding a volcanic arc, represented in the center of this view by poorly bedded volcaniclastic rocks and andesitic flows, called the Station Creek Formation (PIPsc), that crop out in the gorge of Skolai Creek. In most places where it occurs in the region, the sedimentary part of the Skolai Group is overlain unconformably by basalts of the Triassic Nikolai Greenstone (Ꞧng), which forms the west-dipping somber rocks north of Skolai Creek. At this location, however, a thin remnant of Middle Triassic pelecypod-bearing strata (Ꞧd) intervenes between the Golden Horn Limestone and the Nikolai Greenstone. On the skyline, the Paleozoic and Mesozoic rocks are overlain unconformably by nearly flat lying andesitic *tephra* and flows of the Miocene and younger Wrangell Lava (QTw). Wrangell Lava also underlies Chimney Mountain on the left edge of this view and the ice-clad summits in the background, including the President's Chair (10,372 ft). *(E.M. MacKevett, Jr.)*

Figure 19 (page 35). *Hydrothermal* alteration in Pennsylvanian and Permian Tetelna Volcanics along Cross Creek in the northern Wrangell Mountains. Gaudy colors are due to the oxidation of the mineral pyrite (FeS_2) and other sulfide minerals. The Tetelna Volcanics along the north side of the Wrangell Mountains are approximately equivalent to the Station Creek Formation on the south side of the range. *(D.H. Richter)*

Figure 20 (facing page). View to the east from near the Lakina River, showing tightly folded thin-bedded rocks of the Lower Jurassic and Upper Triassic McCarthy Formation. The deformation manifests a Late Jurassic–Early Cretaceous mountain-building event that affected the entire region of the southern Wrangell and Saint Elias Mountains. The geometry of the folds indicates compression from the south (right to left in this view), apparently related to subduction along the southern margin of the Wrangellia composite terrane. The light-colored dikes (Ti) intruding the McCarthy Formation cut across the deformational fabric. They probably fed andesitic flows of the Wrangell Lava, which unconformably overlie the McCarthy just beyond the left edge of this view. *(G.R. Winkler)*


Ti
Ti
Ti
Ti
Ti
Ti
Ti
Ti
Ti
Ti
Ti
Direction of compression

In the southeastern part of the Wrangell Mountains, the mid-Pennsylvanian Barnard Glacier pluton intrudes both the volcanic cover of the upper Paleozoic magmatic arc (represented by rocks of the Skolai Group) and older *marble*, schist, phyllite, and *amphibolite* of the Kaskawulsh Group. These older rocks constitute the westernmost known exposures of the Alexander terrane and are described in the next section. Their presence, however, indicates that the eastern part of the Skolai arc was built upon older, submerged continental crust. Similar arcs occur today in the southwestern Pacific Ocean; the arcs of the Solomon and Fiji Islands, for example, are constructed upon a platform of continental crust. However, the western part of the Skolai arc may have been built upon oceanic crust. The isotopic composition of the intrusive and extrusive rocks of this part of the arc indicates that the magmas formed from oceanic *mantle* uncontaminated by older continental crust. Thus, the Skolai arc may have straddled a contact between oceanic and continental rocks.

In the southern Wrangell Mountains and along the northern flank of the Chugach Mountains, Jurassic granitic plutons are widespread and intrude all older rocks of the Wrangellia and Alexander terranes. Several nonfoliated, crosscutting *granodioritic* plutons occur north of the Chitina Valley between Granite Peak and the Gilahina River. South of the Chitina Valley, voluminous elongate and foliated plutons consisting of *tonalite*, *quartz diorite*, and granodiorite are broadly parallel with older country rocks. One pluton stretches from the Tana River at least as far as the Canadian border and probably is continuous with the Late Jurassic *batholith* that underlies Mt. Logan in Canada and extends eastward to Mt. Vancouver on the International Boundary, a total distance of more than 90 mi. Other Jurassic plutons are widespread in the Saint Elias Mountains, giving rise to the name, "Saint Elias plutonic suite," applied by Canadian geologists to plutons of this age in the Yukon Territory. In fact, in the Wrangell–Saint Elias region, most of the southern margin of the Wrangellia terrane may be underlain by Jurassic plutonic rocks. The plutons are interpreted to represent a magmatic arc formed above a subduction zone during initial collision of the Chugach terrane (the McHugh Complex and correlative units—see next section on the Chugach and Prince William terranes) between about 170 and 150 m.y. ago along the south edge of Wrangellia. So voluminous are the plutons in the vicinity of the Chitina Valley that Alaskan geologists have borrowed the name—hence, Chitina arc.

Chitistone Mountain

Figure 21 (facing page). Chitistone Mountain and the north side of the Chitistone River at the mouth of Grotto Creek. Gray cliffs and ledges are formed from Triassic marine carbonate rocks of the Chitistone and Nizina Limestones, which overlie Triassic nonmarine basalt of the Nikolai Greenstone. Near the right skyline, the Chitistone and Nizina are overlain by brown-weathering thin-bedded rocks of the McCarthy Formation. Note in the center of the view how the Nikolai Greenstone and Chitistone Limestone have been arched over into a recumbent *anticlinal* fold, which is broken in turn by a *thrust fault*, emplacing Nikolai above Chitistone. The fold outline is dashed where it is reconstructed to project above the present surface; on the fault, sawteeth are on the overriding block. The geometry of this broken fold indicates southwest to northeast (left to right) compression. *(E.M. MacKevett, Jr.)*


RECUMBENT ANTICLINE
Chitistone and Nizina Limestones
Direction of compression
McCarthy Formation
Chitistone and Nizina Limestones
Nikolai Greenstone
THRUST FAULT

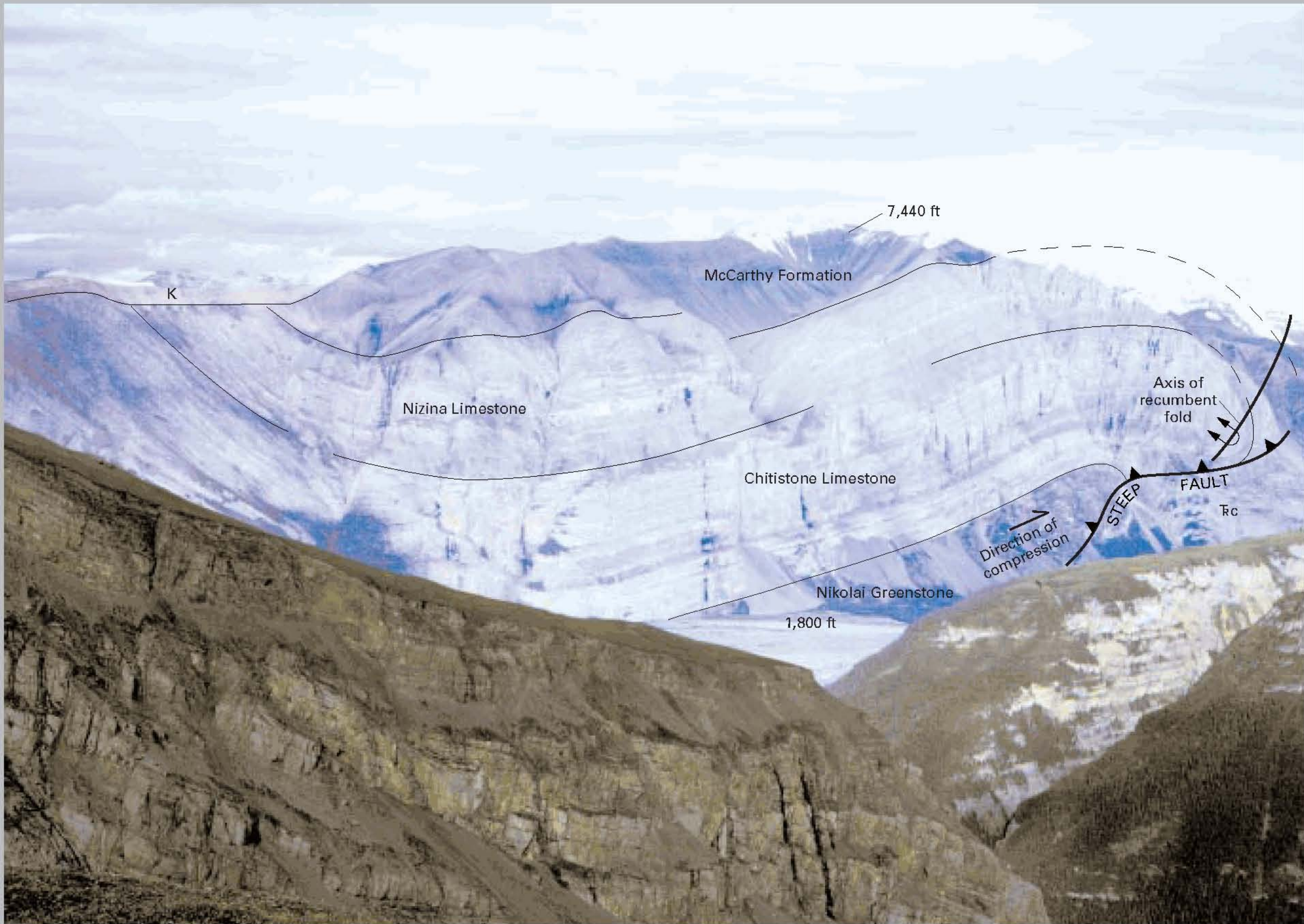
Curiously, the axis of this Late Jurassic arc is roughly parallel to, and only about 60 mi south of, the Early Cretaceous Chisana arc that formed along the north edge of the Wrangellia composite terrane. As the composite terrane began to impinge on the continental margin, subduction of the younger part of the McHugh Complex was intensified along its southern margin, engendering renewed magmatism in the Chisana arc.

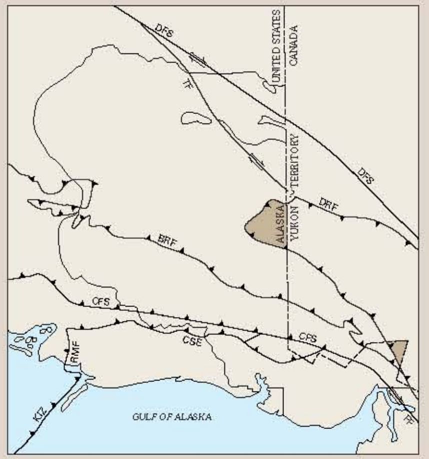
These Late Jurassic and Early Cretaceous crustal melting events are concurrent with regional deformation of Wrangellian rocks (figs. 20, 21), a mountain-building event that presages mid-Cretaceous collapse of the Gravina-Nutzotin belt between the continental margin and the accreting Wrangellia composite terrane. Cretaceous marine sedimentary rocks that are widespread in local basins along the southern flank of the Wrangell Mountains were deposited above major *unconformities* that reflect the mountain-building event (fig. 22). These Cretaceous conglomerates, sandstones, shales, and bioclastic limestones reach thicknesses of more than 6,500 ft locally, and form much of Fireweed Mountain and Sourdough Peak near McCarthy, as well as all of the ridges between Dan Creek and the Chitina River including Williams Peak and Mt. Holmes. On MacColl Ridge, a sequence of marine sandstones 2,500 ft thick forms prominent ledges and cliffs rising abruptly above the Chitina River. On both west and east sides of the Nizina Glacier, nearly 5,000 ft of fossiliferous marine sedimentary rocks accumulated. Locally—particularly along Moonshine Creek—these rocks contain rich accumulations of ammonites, pelecypods, and fossil logs, reflecting a nearshore marine environment. Recycled volcanic detritus in the Cretaceous clastic rocks indicates the proximity of episodically active volcanic arcs—the Chisana and Kluane arcs (fig. 14).

In the area of today's parklands, accretion of the Wrangellia composite terrane had been completed by Late Cretaceous time, no later than 85 m.y. ago. Subsequently, tectonic activity was driven by accretion of terranes south of the Border Ranges fault. The most conspicuous features of today's Wrangell Mountains, the lofty young volcanoes that dominate the skyline in so many views, began to form about 26 m.y. ago, long after Wrangellia had docked. Their formation is attributable to interaction of other terranes to the south. Thus, although the volcanic field formed principally on subjacent Wrangellia, large parts of the field also formed on the Alexander terrane and the Gravina-Nutzotin belt. The volcanic field will be discussed further in subsequent sections.

"Mile-high Cliffs"

Figure 22 (facing page). The "Mile-high Cliffs" rising above the west side of the Nizina River. The cliffs are composed of a *synclinal* fold more than 3 mi across in Triassic rocks. (Outline is dashed where reconstructed to project above the current land surface.) From the base of the cliffs (at 1,800 ft elevation) to the top of the ridge (at 7,440 ft), the sequence consists of the Triassic Nikolai Greenstone (TRng), Chitistone Limestone (TRc), Nizina Limestone (TRn), and the McCarthy Formation (JTRm). At the right edge of the view, the northern limb of the *syncline* is folded back on itself (recumbently) and broken by a steep fault. (Sawteeth are on the overriding block.) The geometry of this paired fold and fault indicates compression from south to north, a result of mountain building that began in the region in Late Jurassic time. On the left, the ridge is capped by Cretaceous marine sedimentary rocks (K) resting nearly horizontally above an angular unconformity upon the folded Triassic sequence. Clearly, the Cretaceous rocks are younger than the mountain building. Rocks exposed in the foreground ridges are Triassic marine carbonate sequences identical to those in the "Mile-high Cliffs." *(E.M. MacKevett, Jr.)*


7,440 ft
K
McCarthy Formation
Nizina Limestone
Axis of recumbent fold
Chitistone Limestone
STEEP
FAULT
Ћc
Direction of compression
Nikolai Greenstone
1,800 ft

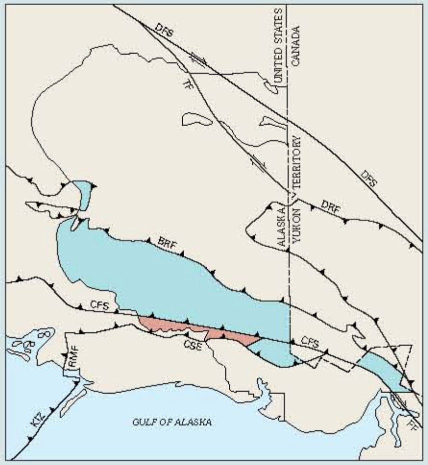


Alexander Terrane—Basement for the Archipelago

Folded and refolded schistose marble, greenstone, *graywacke*, phyllite, and *argillite* occupy a large area in the remote eastern part of the parklands between Klutlan, Barnard, and Walsh Glaciers and a small segment east of the Hubbard Glacier near Mt. Alverstone and Mt. Hubbard. These rocks, assigned to the Alexander terrane, underlie about 2 percent of the Wrangell–Saint Elias region (fig. 12). In Alaska, they consist of about two-thirds marble and about one-third noncalcareous metamorphosed sedimentary and volcanic rocks that are strongly foliated and kink-banded. These units are at least several thousand feet thick and continue eastward in the Yukon Territory, Canada, as the widespread early to middle Paleozoic sequence called the Kaskawulsh Group (named for typical exposures along the Kaskawulsh Glacier near Kluane Lake). Poorly preserved tabulate horn corals of probable Devonian age are present in marble outcrops along the Klutlan Glacier, the only fossils known in the Kaskawulsh Group in Alaska. In the Yukon Territory, however, numerous fossils of Devonian age are present, and Ordovician and probable Mississippian fossil collections also are known from the Kaskawulsh. Farther southeast, the Kaskawulsh is coextensive with the older part of the widespread Alexander terrane of Alaska's panhandle.

The Alexander terrane forms the *basement* not only for today's archipelago of southeastern Alaska, but also for the late Paleozoic Skolai island arc of Wrangellia. In the southeastern Wrangell Mountains, the Middle Pennsylvanian Barnard Glacier pluton stitches the Alexander and Wrangellia terranes, indicating that the Alexander and Wrangellia terranes had been joined at least 310 m.y. ago. Thereafter, Wrangellia and Alexandria acted as a unified mass—the Wrangellia composite terrane—traveling together on their long northward journey to be accreted to North America.

Alexander



Chugach and Prince William Terranes—Accretionary Processes on Edge

The Border Ranges fault system marks the southwest edge of the Wrangellia composite terrane (fig. 12). The fault system is a crustal suture south of which sequences of deep-sea rocks known as the Chugach and Prince William terranes were successively accreted. Remnants of the fault surface that dip 45° to 50° to the north underlie the summit ridge of Spirit Mountain south of Chitina and are well exposed on ridges adjacent to the Tana River about 3 mi south of Towhead Mountain. Elsewhere, the Border Ranges fault trace is entirely in remote ridges south of the Chitina River or is concealed beneath icefields and glaciers in the Saint Elias Mountains (fig. 23); thus, the fault cannot be viewed from normal routes of access to the parklands. Immediately east of the Copper River, the top of Spirit Mountain—the upper plate above the fault system—consists of metamorphosed rocks of the Wrangellia terrane. The lower slopes of Spirit Mountain—the lower plate—consists of rocks of the Chugach terrane, which are *ductilely* deformed beneath the fault. In many areas of the northern Chugach Mountains and the Saint Elias Mountains, the Border Ranges fault has been modified by younger, *brittle* and *ductile strike-slip* displacements, which are manifested in rocks on both sides of the fault.

Episodic accretion of fault-bounded slabs of deep-sea rocks against and beneath the Wrangellia composite terrane records Early Jurassic through mid-Eocene underplating on the inner side of a subduction zone. These fault-bounded slabs are called accretionary wedges and their successive underplating from the south has lifted up, placed on edge, or locally even tipped beyond vertical large segments of the Chugach and Prince William terranes, yielding remarkably complete cross-sectional or edgewise views of both terranes.

The deep-sea rocks south of the Border Ranges fault system constitute one of the thickest and most extensive subduction-related accretionary complexes in the world. The Chugach and Prince William terranes together form a composite terrane—the Southern Margin composite terrane—that extends more than 1,300 mi along the Alaska continental margin from as far west as the Sanak Islands to Chichagof Island on the east. These rocks form an outcrop width (including submerged parts of the continental shelf) of as much as 125 mi. Their total volume exceeds 800,000 mi^3 (an estimate that does not include material already removed by erosion)—enough material to cover all of Alaska south of the Alaska Range to a depth of more than 2 mi. The Southern Margin composite terrane underlies roughly 25 percent of Wrangell–Saint Elias National Park and Preserve (fig. 12).

In the Wrangell–Saint Elias region, the Chugach terrane includes three accretionary sequences of Mesozoic age, and the Prince William terrane includes one of Paleogene age. From north to south (and in order of decreasing age), these are (1) the schist of Liberty Creek; (2) the McHugh Complex and *melange* of the Yakutat Group; (3) the Valdez Group and flysch and basalt of the Yakutat Group, as well as their metamorphosed equivalents in the Chugach and Saint Elias Mountains; and (4) the Orca Group.

Chugach and Prince William

The schist of Liberty Creek does not occur in Wrangell–Saint Elias National Park and Preserve, but is present immediately to the west, cropping out along the Edgerton Highway from near Lower Tonsina to Second Lake, north of Chitina. The strongly foliated rocks are chiefly *greenschist* and *blueschist*, but also include gray-weathering micaceous, siliceous, and calcareous schist. Where the schist contains a high proportion of sodic-amphibole, a characteristic bluish hue is imparted to the rocks. On a sunny day, a look at the rocks near the waterfall in Liberty Falls State campground 7.5 mi northwest of Chitina reveals them to be surprisingly blue! These schistose rocks formed by metamorphism of mixed lithologies: *pillow basalt*, basaltic breccias and tuffs, and volcaniclastic sedimentary rocks, limestone, and *mudstone*. Such lithologies form in marine environments on *oceanic crust*. The presence of blueschist is particularly notable: such rocks are created only by rapid, deep underthrusting in a convergent continental margin. Thus, the blueschist-bearing rocks substantiate the presence of a subduction zone along the south edge of the Wrangellia composite terrane.

Isotopic dating of metamorphic minerals in the schistose rocks indicate Early Jurassic ages in the Chugach Mountains. The rocks occur in close proximity to Upper Triassic oceanic rocks, which include paleontologically dated *radiolarian cherts*. This association suggests a possibility that the schistose rocks may be part of the same Upper Triassic mixture of marine lithologies that was more deeply subducted.

Blueschist-bearing metamorphic rocks have been recognized at scattered locations south of the Border Ranges fault system from the Kodiak Islands on the west to Chatham Strait in southeastern Alaska on the east. Interestingly, blueschist clasts have been found in moraines on the surface of Hubbard Glacier and in moraines along Russell Fiord, but the outcrops from which they were eroded have not been located.

In the vicinity of Chitina, the schist of Liberty Creek is emplaced against rocks of the McHugh Complex along the Second Lake fault zone. In the parklands of Wrangell–Saint Elias east of the Copper River, the McHugh Complex is not widely exposed, but is present only in discontinuous, fault-bounded outcrops south of the Border Ranges fault. These fault-bounded outcrops of the McHugh Complex (fig. 24) extend eastward from near the Tana River almost to the International Boundary. The McHugh Complex also is present in a narrow and remarkably linear belt along the Tana fault to the north, where it is juxtaposed between rocks of the Wrangellia terrane. In effect, along the Tana fault, we are looking through a *window* in the Wrangellia terrane into the structurally underlying younger rocks.

The McHugh Complex is a melange assemblage: it consists of a pervasively disrupted and variably metamorphosed array of deep-sea lithologies. The dominant McHugh rocks are dark-weathering pillow basalt and related fragmental volcanic rocks, green-weathering altered volcanic tuff, and dark-gray argillite. In many places, the McHugh contains subordinate lenses of medium-gray sandstone, milky-gray, green, or maroon radiolarian chert, and light-gray limestone. The presence of volcanogenic sandstone and andesitic tuff in the sedimentary units indicates that an active arc was a source for some of the sediment. Generally, the green tuff and dark argillite are chaotically mixed and intensely sheared, forming a *cataclastic matrix* within which are suspended lenses of the other lithologies (fig. 25). Extraformational or exotic lithologies also are included in the melange as clasts or blocks ranging in size from fractions of inches to miles. Limestone or marble blocks with Pennsylvanian, Permian, or Late Triassic fossils are known from scattered areas outside the parklands, and ultramafic and mafic plutonic rocks also are present in several areas as conspicuous and large blocks. These blocks are derived from the adjacent Wrangellia and Peninsular terranes, which must have been located near the melange during its formation.

On the west shore of Disenchantment Bay near the terminus of Turner Glacier, outcrops of melange also are present and are structurally interleaved in the Yakutat Group. These rocks correlate in part with the McHugh Complex but occupy a structural setting in the Yakutat terrane seaward of the Fairweather fault. Similar melange assemblages extend discontinuously southeastward at least as far as the east side of Chichagof Island, where they are truncated by the Chatham Strait fault.

Paleontologic ages of radiolaria from beds within the melange range from Middle Triassic to mid-Cretaceous, indicating multiple episodes of formation between about 230 and 90 m.y. ago. The mixing of oceanic crustal rocks, arc-derived detritus, and fragments of older rocks derived from the southern margin of the Wrangellia composite terrane indicates disruption and accretion at a convergent plate margin during times of active subduction beneath Wrangellia. Thus, the paleontologic ages correspond in general with the radiometric ages of rocks produced during magmatism in the adjacent evolving arcs.

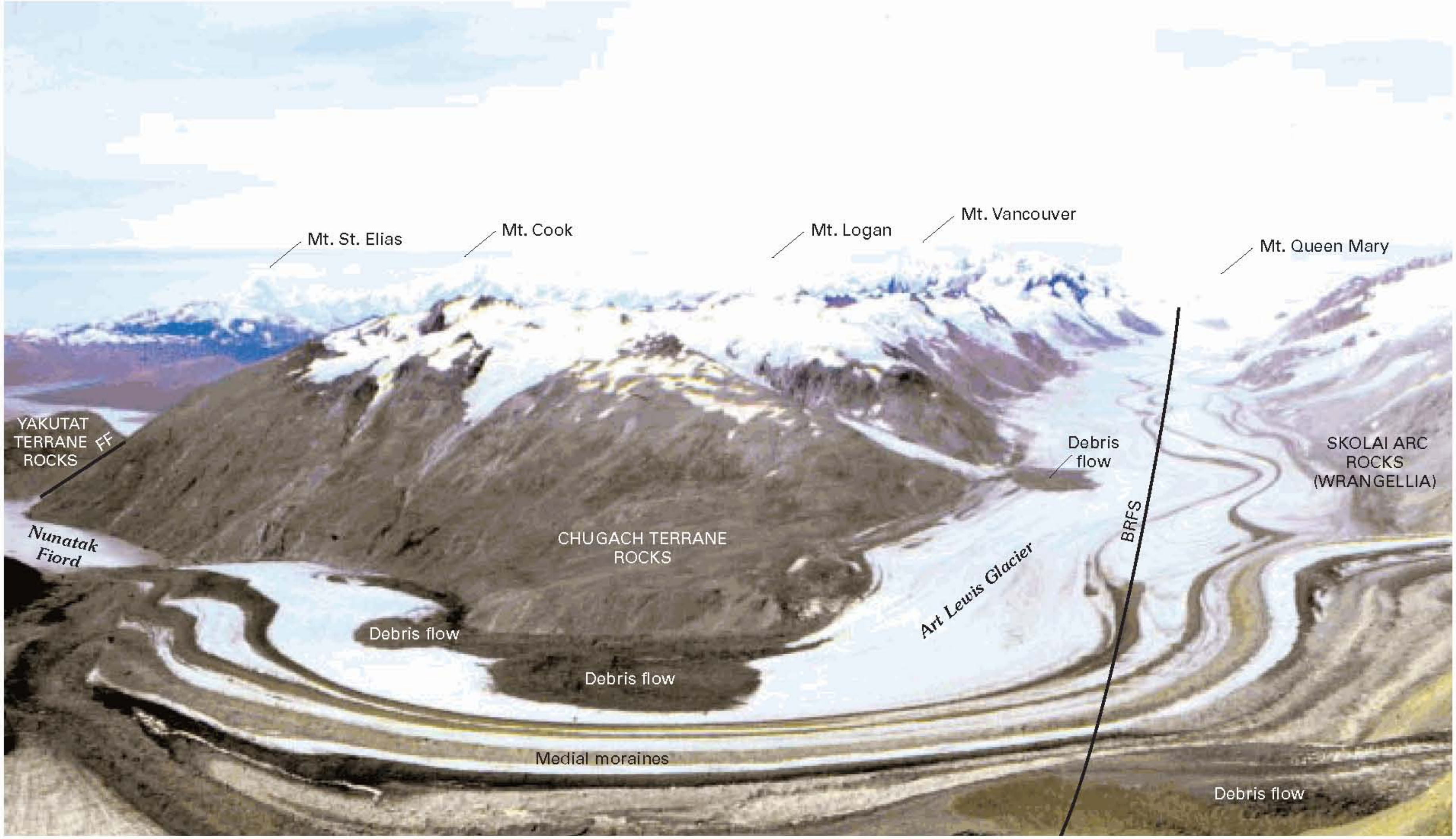


Figure 23. The Border Ranges fault system (BRFS) underlies the trough of Art Lewis Glacier, on the right; Nunatak Fiord is on the left; view is to the northwest from near the extreme southeast corner of Wrangell–Saint Elias National Park and Preserve. Here, the Border Ranges fault separates upper Paleozoic rocks of the Skolai arc (the Wrangellia terrane) on the right from metamorphosed sedimentary and volcanic rocks of the Mesozoic Chugach terrane on the left. The Fairweather fault (FF) is located at the base of the mountain front near the left edge. The Fairweather fault currently acts as the boundary between the North American and Pacific crustal plates. The high peaks in the background are, from left to right, Mt. St. Elias (18,008 ft), Mt. Cook (13,760 ft), Mt. Logan (in Canada, 19,850 ft), Mt. Vancouver (15,700 ft), and Mt. Queen Mary (in Canada, 12,800 ft). Note the strongly curving *moraines* near the right edge of Art Lewis Glacier, deformed by *surges* in tributary glaciers entering the valley glacier from the east. Note also several patches of brown-colored debris on the surface of Art Lewis Glacier near its edges. These may have formed as earthquake-induced debris flows (landslides) along the oversteepened margins of the glacier, but have now moved downglacier from their sources. If their age of formation were known, approximate rates of glacier movement could be determined. *(M.D. Wilson)*


Mt. Logan
MCHUGH COMPLEX

The deeply incised canyon of the Copper River between Chitina and the Miles Glacier and the highest ridges of the Chugach Mountains to the east expose nearly continuous outcrops of rocks of the Chugach terrane that dip shallowly to steeply northward (fig. 26). At river level between the mouth of Canyon Creek and The Peninsula (near the mouth of the Bremner River), these rocks consist entirely of strongly folded and penetratively deformed flysch: lithologically monotonous, rhythmically alternating thin beds of argillite and fine-grained sandstone. Locally, thick-bedded sandstone containing minor argillite interbeds forms bold outcrops. On high ridges east of the river, a few thin lenses of basaltic tuff are intercalated in the flysch, but none reach the level of the river. These volcanic rocks increase in thickness and abundance eastward, forming a belt of basaltic flows, breccias, and tuffs about 3 mi across in the eastern part of the Bagley Ice Field near Table Mountain. The flysch and basalt assemblage is named the Valdez Group, for the area of Port Valdez, where it was first described. Despite stratigraphic thicknesses of more than 2 to 2.5 mi, the assemblage is thought to have been deposited over a relatively short time span between about 75 and 70 m.y. ago.

The chemistry of the basaltic rocks indicates that they formed in a primitive island arc above oceanic crust. As this primitive intraoceanic arc migrated toward the continental margin, locally derived basaltic sediments and tuff were mixed with an enormous volume of flysch derived from the continental margin. *Provenance* of the flysch indicates that the continental margin consisted of an evolving magmatic arc, much like today's Andes Mountains. Inasmuch as Upper Cretaceous magmatic rocks, the probable sources of the flysch, are widely exposed in the Kluane Lake area, geologists have coined the name, "Kluane arc."

Figure 25. Melange of the McHugh Complex. A crude layering, which is defined by the alignment of clasts, dips into the outcrop from upper right to lower left. This fabric is parallel to intense shearing at all scales. At this location on Goat Creek Glacier south of the Chitina River Valley, the clasts consist principally of metamorphosed plutonic rocks similar to those that occur in the nearby southern margin of the Wrangellia terrane. The matrix of the melange is principally granulated mafic volcanic material, probably derived from oceanic crust. At other locations, the clasts may be much larger, in some cases exceeding a mile in maximum dimension, and the matrix may consist of dark argillite. (*G.R. Winkler*)

Goat Creek Glacier

Figure 24 (facing page). Goat Creek Glacier in the eastern Chugach Mountains. Maroon-weathering rocks on the foreground spur are the Mesozoic McHugh Complex, the melange facies of the Chugach terrane; the maroon color is imparted by iron-bearing radiolarian chert, a rock type that forms in many places above the basalt of oceanic plates. The McHugh was formed by tectonic mixing of lithologies within an active subduction zone along the southern margin of the Wrangellia terrane. The glacier-clad mountain on the skyline is Mt. Logan; it is eroded from a Late Jurassic batholith, part of a magmatic arc formed about 150 m.y. ago. Concurrently, parts of the McHugh were being assembled and deformed in the subduction zone associated with the arc. (*G.R. Winkler*)

This assemblage of flysch and basalt is in fault contact to the north with either the melange assemblage described previously or with rocks of the Wrangellia composite terrane. The flysch and basalt have been metamorphosed to *greenschist* facies and a strong *foliation* has been superimposed on them; primary sedimentary or volcanic features are difficult to decipher in most outcrops. This metamorphism is superimposed across regional structural trends in the Valdez Group, indicating that it occurred after the flysch and *basalt* assemblage was deformed against and amalgamated with the melange assemblage to the north. The age of metamorphism has been dated at about 50 m.y. ago and overlaps the age of region-wide magmatism. Plutons of Eocene age (≈50 million years old) intrude rocks of both the Chugach and Prince William terranes at numerous locations in the eastern Chugach Mountains, underlying 5–10 percent of the outcrop area of the accretionary assemblage. These light-colored plutons are conspicuous near Mt. Tom White, at the terminus of the Tana Glacier, along Granite Creek, and along the north side of Jefferies Glacier. In most places, the plutonic contacts are strongly discordant, but at deeper structural levels, they are gradational and *migmatitic*. Such features indicate that the plutons probably formed by partial melting of the accretionary assemblage, a process called *anatexis*. Isotopic ratios measured from the plutons also indicate that they likely formed by melting of a mixture of flysch and basalt.

The source of the heat necessary to melt the accretionary assemblage is uncertain. Some geologists have suggested that subduction of one or more still-active ridges on the Kula or Farallon oceanic plates (fig. 10) could have provided the thermal drive; others have suggested that the subducting oceanic plate actually broke and separated as it bowed downward into the subduction zone, opening a "window" into the hot *mantle* beneath.

Flysch and basalt that have been metamorphosed to *epidote-amphibolite grade* make up an east-west-trending structurally bound block 50 mi long and as wide as 10 mi that underlies the highest part of the Saint Elias Mountains in Alaska, including Mt. St. Elias. These highly metamorphosed rocks are emplaced against lower grade metamorphic rocks of the Valdez Group (Chugach terrane) to the north along extensions of the Contact and Fairweather fault systems where they apparently merge beneath the icefields of Columbus and Seward Glaciers. To the south, the block is bounded by the Chugach and St. Elias faults, which emplace the block above unmetamorphosed Cretaceous and Tertiary rocks of the Yakutat terrane (see next section). The metamorphosed flysch and basalt of the St. Elias structural block are similar lithologically and structurally to rocks of the Chugach terrane south of the Alsek River in Glacier Bay National Park. If this correlation is correct, the structural block has been displaced approximately 200 km northwestward by dextral offset along the Fairweather fault.

Between the Copper River and the vicinity of Mt. St. Elias, the Contact fault system marks the south edge of the Mesozoic Chugach terrane. Within the parklands, the fault is not exposed, but is strongly expressed topographically, underlying the nearly linear, glacier-filled trough of the Bagley Ice Field (fig. 27). West of the parklands, the Contact fault is well exposed in the Prince William Sound region, where it forms sinuous traces suggestive of oblique underthrusting followed by minor dextral offset. The 50 million-year-old Tom White pluton intrudes both upper and lower plates of the Bagley segment of the Contact fault system, indicating that little if any post-Eocene displacement has occurred along the fault system in the eastern Chugach Mountains.

Chugach Mountains

Figure 26 (pages 48–49). View westward along the crest of the Chugach Mountains in the vicinity of the Little Bremner River. Much of the central Chugach Mountains consists of Upper Cretaceous flysch of the Valdez Group, which, in this view, is mostly thick bedded sandstone dipping northward (from left to right). The mountains have been tipped on edge by episodic underplating from the south of additional fault-bounded slabs of flysch. These so-called accretionary wedges have jacked up the Chugach terrane until it has reached a structural thickness of more than 9 mi, and there is an additional structural thickness of at least 6 mi of accretionary wedges of the Paleogene Prince William terrane outboard (south) of the Chugach terrane. *(G.R. Winkler)*

Seaward of the fault system, upper Paleocene through lower middle Eocene flysch and basalt of the Orca Group form the succeeding accretionary assemblage, the so-called Prince William terrane, which is named for its typical exposures in the Prince William Sound region west of the parklands. Within the National Park, monotonous sequences of repetitively interbedded sandstone, siltstone, and mudstone form about 80 percent of Waxell and Barkley Ridges south of the Bagley Ice Field; interbedded submarine basaltic flows, breccia, and tuff make up about 20 percent of these outcrops. The sedimentary rocks of the Orca Group were deposited on westward-sloping deep-sea fans adjacent to a continental margin that was undergoing rapid uplift and erosion. Sediment deposited on today's Astoria fan off the mouth of the Columbia River may provide a less voluminous analog. (In total volume, the Orca Group is closer to the size of the Bengal fan, which is formed seaward of the mouths of the Ganges and Brahmaputra Rivers by sediment derived from the Himalaya Mountains.) Sedimentation of the Orca between about 60 and 50 m.y. ago coincides with a main phase of uplift of the Coast Mountains of British Columbia and southeastern Alaska, the dissection of which provided the bulk of the detritus. Coeval submarine volcanism from *seamounts* or active ridges on the Kula oceanic plate resulted in interlayering of tabular masses of ocean-floor basalt within rapidly accumulating prisms of *terrigenous* sediment. These discontinuous lenses of basaltic rocks may represent fragments of submarine ridges or chains of seamounts that were detached from the rapidly moving Kula plate as it was being subducted beneath the Alaska continental margin. A contemporary analogy is provided on the Pacific oceanic plate within the Gulf of Alaska, where volcanic edifices such as the Kodiak and Bowie Seamounts are moving directly toward the subduction zone in the Aleutian trench. When the seamounts enter the trench, they likely will be detached from the Pacific Oceanic plate to be incorporated within accreting prisms of terrigenous sediment derived from the Alaska continental margin.

The stratigraphic thickness of the Orca Group in Prince William Sound is at least a couple of miles, but pervasive tight folding, imbricate faulting, and poor fossil control preclude representative measurements. The entire Orca Group was affected by the same regional thermal event at about 50 m.y. ago that metamorphosed and partially melted rocks of the Chugach terrane. However, regional metamorphic grades are generally less than for rocks of the Chugach terrane. Thus, the entire thickness of the Prince William terrane had been deposited, deformed, intruded, and accreted to the Chugach terrane within a span of no more than 10 million years. This remarkably dynamic interval represents a two- to four-fold increase in the pace of accretion, coinciding with a period of rapid convergence of the Kula and North American crustal plates.

Bagley Ice Field

Figure 27 (facing page). View to west on Bagley Ice Field north of Natural Arch, taken in early July 1959 by USGS geologist Don J. Miller during the second known crossing of the ice field on foot. Nearby Mount Miller on Barkley Ridge is named for one of a pair of prospectors (the other being James Barkley) who first crossed the ice field in 1906 or 1905. The Bagley fault (of the Contact fault system) follows the ice-filled trough, separating Paleogene flysch and ocean-floor basalt of the Orca Group on the left from metamorphosed Cretaceous basaltic flows, breccia, tuff, and minor flysch of the Valdez Group on the right. At this location, the Bagley Ice Field is more than 8 mi across and feeds the enormous south-flowing piedmont lobe of the Bering Glacier, out of view to the left, as well as the north-flowing Tana Glacier, out of view to the right. In this view, geologists Art Kimball and Earl Brabb are preparing to continue the day's traverse; note the long aluminum pole to which they attach themselves when crossing crevassed areas of the ice. *(D.J. Miller)*

Yakutat Terrane— The Latest to Arrive

The Yakutat terrane lies seaward of the composited Chugach and Prince William terranes (fig. 12). It is bounded on the north and east by the Chugach–St. Elias and Fairweather fault systems, and underlies all of Wrangell–Saint Elias National Park between Mt. Miller and the head of Disenchantment Bay, perhaps 15 percent of total parklands. It is bounded on the west, outside the park, by the Kayak Island structural zone and the Ragged Mountain fault, and on the south, near the base of the *continental slope,* by the submerged Transition fault system. Two other structural zones, the Dangerous River and Pamplona zones, divide the Yakutat terrane into three segments that have distinct lithologic and structural features.

The west margin of the Yakutat terrane is the Kayak Island zone, an irregular series of west-dipping thrust faults beneath the Prince William terrane that are inferred to merge with the Aleutian *megathrust*, which is the present Pacific plate boundary, in the Aleutian trench (fig. 9). The Chugach–St. Elias fault system is the northern boundary of the Yakutat terrane, the northernmost of a series of thrust faults along which unmetamorphosed Upper Cretaceous and Paleogene strata are thrust beneath variably metamorphosed rocks of the Chugach and Prince William terranes. On the southern slopes of Barkley Ridge, one of the few places where the fault is well exposed, it dips northward between 30° and 45°. It also dips shallowly northward beneath the massif of Mt. St. Elias (fig. 28). The St. Elias earthquake of 1979 (magnitude 7.5) indicates that the Chugach–St. Elias fault system currently is a source of earthquakes related to underthrusting along the Pacific–North American plate boundary. To the west, the Chugach–St. Elias fault system terminates against the Ragged Mountain fault—an onshore extension of the Kayak Island structural zone. To the east, it terminates against the Fairweather fault, which is the northeastern boundary of the Yakutat terrane. The Transition fault system (fig. 9) marks the southern boundary for most of the Yakutat terrane, separating it from the Pacific plate, and apparently has sustained 125 mi of oblique underthrusting during Cenozoic time. The Transition fault system intersects the Fairweather fault seaward of Chichagof Island in southeastern Alaska. The nearly vertical dextral strike-slip Fairweather fault marks the northeast boundary of the Yakutat terrane. It is not exposed in the park, but between Hubbard Glacier and Cross Sound, its surface trace is marked by broad shear zones in bedrock and a topographic trench as much as 0.6 mi wide (fig. 29). Holocene scarps and dextrally offset drainages occur along the trace in many places, and dextral and vertical displacements of 10 ft and 3 ft, respectively, occurred during the 1958 Lituya Bay earthquake. The Fairweather fault forms part of a transform fault system between the Pacific and North American crustal plates and has undergone at least 375 mi of dextral displacement in the late Cenozoic. South of its intersection with the Transition fault system, the Fairweather fault (and its southern continuation in British Columbia, the Queen Charlotte fault) accommodates all displacement between the two plates. North of the intersection, displacement may have been shared between the Fairweather and Transition fault systems during parts of the late Cenozoic. Today, however, the Yakutat terrane is moving mostly with the Pacific plate (that is, along the Fairweather fault) at about 2 in./yr relative to North America and possibly only at about 0.16 in./yr relative to the Pacific plate (that is, along the Transition fault).

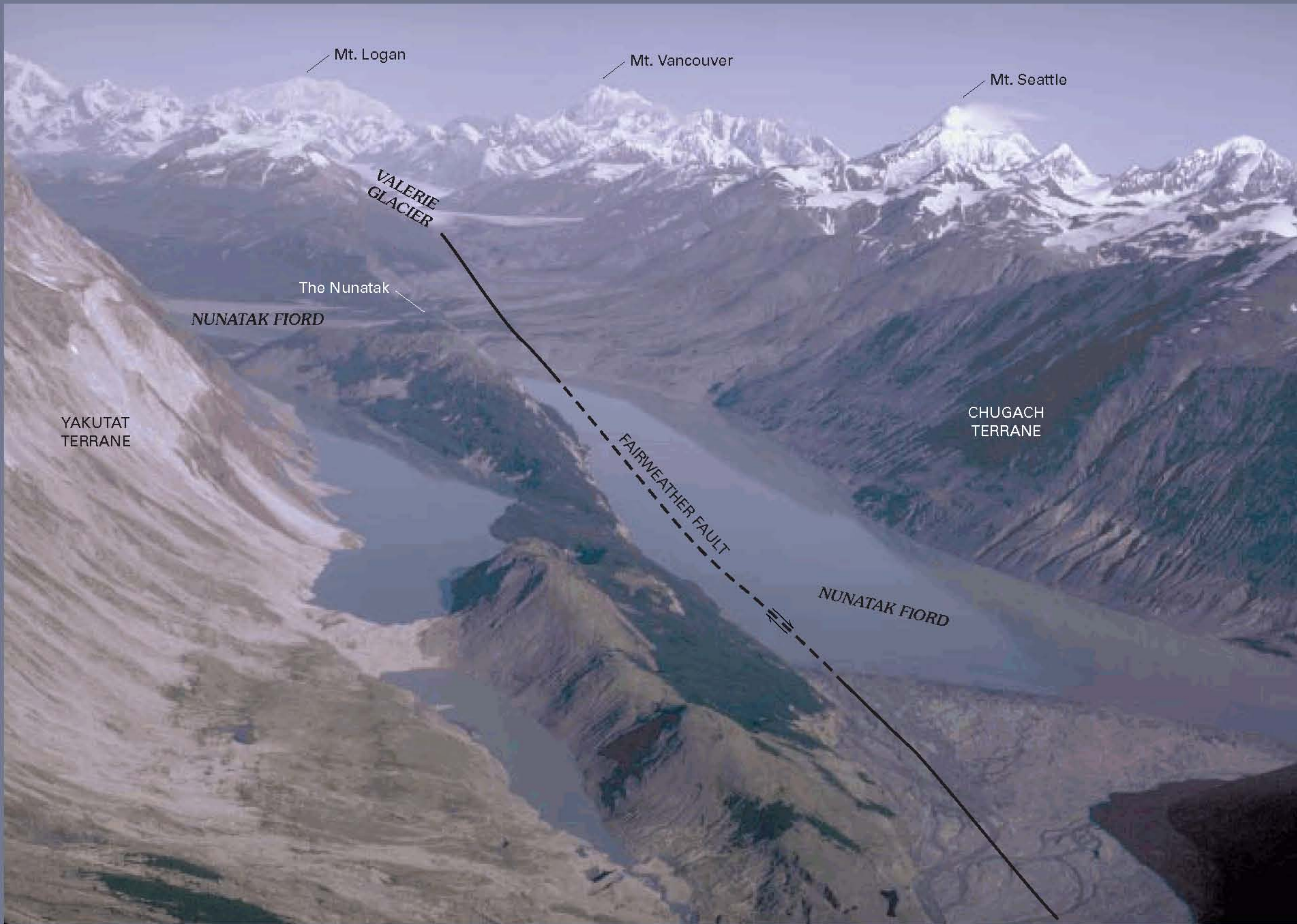
East of the Dangerous River zone, basement rocks for the Yakutat terrane (fig. 30) are Mesozoic flysch, basalt, and melange of the Yakutat Group and diverse Eocene intrusive rocks that are similar in composition and age to plutons in the Chugach terrane. These rocks crop out extensively between Tyndall Glacier and Russell Fiord and extend southeastward nearly to Cross Sound. Unlike rocks of the Chugach terrane, rocks of the Yakutat Group generally are only weakly metamorphosed. However, lithologies of the Yakutat Group otherwise are indistinguishable from those of the Chugach terrane, against which they are juxtaposed along the Fairweather and St. Elias faults. Apparently, rocks of the Yakutat Group are a displaced fragment of the late Mesozoic accretionary complex that makes up the Chugach terrane. Removal of late Cenozoic dextral-displacement along the Fairweather-Queen Charlotte transform fault system (see p. 63–64) restores the Yakutat Group to an original position along the continental margin southeast of Chatham Strait—perhaps near the present location of the Queen Charlotte Islands.

West of the Dangerous River zone, basement rocks for the Yakutat terrane are Paleogene oceanic basalt, as determined from several dredge samples on the outer continental shelf, and the Yakutat Group is not present. Immediately overlying rocks are lower Eocene through Oligocene clastic sequences containing minor coal and volcanic rocks. The composite thickness of this section is nearly 19,700 ft, whereas the correlative section east of the Dangerous River zone is less than 6,600 ft thick and has different units in its lower part. These Paleogene sequences of the Yakutat terrane have no analogs in the inboard terranes. They are overlapped by Miocene to Holocene marine and *glacial-marine* clastic strata as much as 16,400 ft thick, which also overlap the Prince William terrane to the west and the Chugach terrane to the east.

Figure 28 (page 56). The St. Elias fault is well exposed east of the Libbey Glacier, emplacing dark-colored metamorphosed Cretaceous flysch and basalt of the Chugach terrane (Kc) above lighter colored virtually unmetamorphosed Cretaceous flysch that is part of the Yakutat Group (Ky). Thus, this shallowly north dipping underthrust fault emplaces rocks of the Yakutat terrane beneath rocks of the Chugach terrane that are of approximately the same age, but are higher metamorphic grade. This fault currently forms part of the boundary between the North American tectonic plate and the Pacific plate. The steeply dipping rocks in the lower half of this view are coupled to the Pacific oceanic plate and are being thrust beneath the dark rocks in the upper half, which were accreted to North America more than 60 m.y. ago. The St. Elias earthquake of 1979 ruptured a continuation of this fault surface approximately 20 mi to the west of here at a shallow depth, which indicates that the fault (and plate boundary) still is actively adjusting. *(George Plafker)*

Figure 29 (page 57). View to the northwest along the Fairweather fault from a position southeast of The Nunatak. The dextral strike-slip fault underlies the pronounced topographic depression that is followed by Nunatak Fiord in the foreground, as well as Valerie Glacier in the distance. The fiord makes a dextral jog where it is crossed by the broad shear zone of the fault, a clear indication that its location is influenced by dextral offset across the zone. The Fairweather fault is the current plate boundary between the Pacific plate (on the left) and the North American plate (on the right), separating northward-moving weakly metamorphosed rocks of the Yakutat terrane from coeval schistose rocks of the Chugach terrane. Prominent mountains in the background include, from left to right, Mt. Logan (19,850 ft), Mt. Vancouver (15,700 ft), and Mt. Seattle (10,070 ft). *(George Plafker)*


Kc
Ky


Mt. Logan
Mt. Vancouver
Mt. Seattle
VALERIE GLACIER
The Nunatak
NUNATAK FIORD
YAKUTAT TERRANE
CHUGACH TERRANE
FAIRWEATHER FAULT
NUNATAK FIORD


Mt. St. Elias
Mt. Newton
ST. ELIAS
FAULT
CHUGACH TERRANE
Haydon Peak
CHAIX HILLS
FAULT
(not visible)
COAL GLACIER
FAULT
TERTIARY ROCKS
OF YAKUTAT TERRANE
CRETACEOUS ROCKS
OF YAKUTAT TERRANE
YAKUTAT GROUP

Samovar Hills

Figure 30 (facing page). Mt. St. Elias (18,008 ft) from the Samovar Hills. The southeastern part of the Samovar Hills is underlain by strongly deformed marine flysch of the Mesozoic Yakutat Group—the lighter colored rocks in the right foreground. The Yakutat is faulted against, and also overlain unconformably by, nonmarine rocks of the Paleogene Kulthieth Formation, which makes up the somber-colored ridges in the left middle ground. The Samovar Hills are capped by marine siltstone, sandstone, and *diamictite* of the Miocene and Pliocene part of the Yakataga Formation—deposited below sea level, but now uplifted at least 6,000 ft. The massif of Mt. St. Elias, consisting of schistose rocks of the Mesozoic Chugach terrane, has overridden all these rocks along the thrusts of the Chaix Hills, Coal Glacier, and St. Elias faults. Haydon Peak (11,945 ft) and Mt. Newton (13,811 ft) rise to the left and right of Mt. St. Elias, respectively. *(George Plafker)*

Striped Ridge

Figure 31 (pages 60–61). View to the northwest of Striped Ridge between Libbey and Agassiz Glaciers. The ridge in the foreground is about 2 mi wide. Prominent peaks in the background are Haydon Peak and Mt. St. Elias. The ridge is underlain by interbedded terrestrial to marginal-marine sandstone and mudstone of the Paleogene Kulthieth Formation. The strata are lenticular, interfingering, and locally coal bearing. They were deposited on *alluvial* plains, deltas, barrier beaches, and nearshore marine environments under subtropical climatic conditions. They are typical of the lower part of the Tertiary sequences deposited on the Yakutat terrane. The folds and faults in the middle part of the ridge are related to underthrusting along the Coal Glacier and St. Elias faults, which separate the sequences of Striped Ridge from the structurally higher rocks on Haydon Peak and Mt. St. Elias. The dark, complexly folded rocks underlying Haydon Peak are flysch and melange of the Upper(?) Jurassic and Cretaceous Yakutat Group; the massif of Mt. St. Elias is underlain by metamorphosed flysch and basalt of the Chugach terrane. *(George Plafker)*


Haydon Peak
Mt. St. Elias

The Cenozoic stratigraphy of the Yakutat terrane may be divided into three sequences (fig. 14). The lower sequence consists of upper Paleocene and Eocene nonmarine to marine coal-bearing sandstone, siltstone, and *claystone*, and lower to middle Eocene basalt (fig. 31). These units crop out in a belt extending from the west side of Yakutat Bay to the western margin of the Yakutat terrane near Kayak Island. They reach their greatest thickness, at least 10,000 ft, in the vicinity of Cape Yakataga, and generally indicate subtropical climatic conditions and warm seas. Coal beds are numerous in one of the units, the Kulthieth Formation, particularly in thick sections in the Samovar Hills north of Malaspina Glacier and west of the parklands. The siltstone units also are rich in organic material, and numerous oil and gas seeps that occur in the Samovar Hills area produce an iridescent sheen on the surface of Oily Lake. The basalt unit may be as much as 1,000 ft thick and crops out only in the Hubbs Creek area of the Samovar Hills. A medial sequence of Oligocene and lower Miocene marine sedimentary and tuffaceous strata is exposed discontinuously along a coastal belt from Icy Bay westward, largely outside the parklands. These rocks reach thicknesses of as much as 5,900 ft, and one of the units, the Poul Creek Formation, characteristically weathers a distinctive rusty-brown color, owing to its richness of organic material and alkalic basaltic detritus. The Poul Creek Formation also contains *glauconite*, a conspicuously green iron-rich mineral that forms only in conditions of restricted circulation and slow sedimentation. An upper sequence consists of middle Miocene to Holocene detritus shed from the Chugach and Saint Elias Mountains onto the adjacent continental margin. This enormous volume of material, principally composed of the Yakataga Formation (fig. 32), overlaps all older units and the boundaries of the Yakutat terrane with adjacent terranes.

The Yakataga Formation is widely distributed onshore and underlies much of the continental shelf and slope. It forms striking outcrops in the Robinson Mountains west of Icy Bay (fig. 33), the Guyot, Karr, and Chaix Hills surrounding Icy Bay (fig. 34), and parts of the Samovar and Pinnacle Pass Hills at the northern margin of the Malaspina Glacier (fig. 35). The Yakataga Formation is as much as 15,000 ft thick onshore and thickens southward to more than 16,400 ft offshore. It is characterized by glacial-marine tillite-like diamictite and laminated siltstone containing ice-rafted dropstones, particularly in its lower and upper parts (see fig. 40). Although the formation contains numerous fossils that indicate an open marine environment, the lithology, sedimentary structures, and cool-water molluscan fauna (see fig. 41) suggest that active tidal glaciers and possibly an ice shelf were present, at least intermittently, along the northern margin of the basin by mid-Miocene time (about 20 m.y. ago). The stratigraphic distribution of dropstones indicates that tidewater glaciers were present through much of the late Pliocene and Pleistocene. Numerous channels, local unconformities, *diamictite* exhibiting soft-sediment deformation, and rare *grooved pavements* indicate that grounded glaciers may have extended across the continental shelf during parts of the Pleistocene. Lithologically similar deposits of conglomeratic sandy mud and pebbly mud continue to accumulate locally near tidal glaciers along the northern Gulf of Alaska today. When these deposits are lithified, they will look just like the rocks of the Yakataga Formation. In fact, the Yakataga Formation preserves the most complete, and probably earliest, sedimentary record of late Cenozoic glaciation in North America—a record that continues to accumulate today.

Chaix Hills

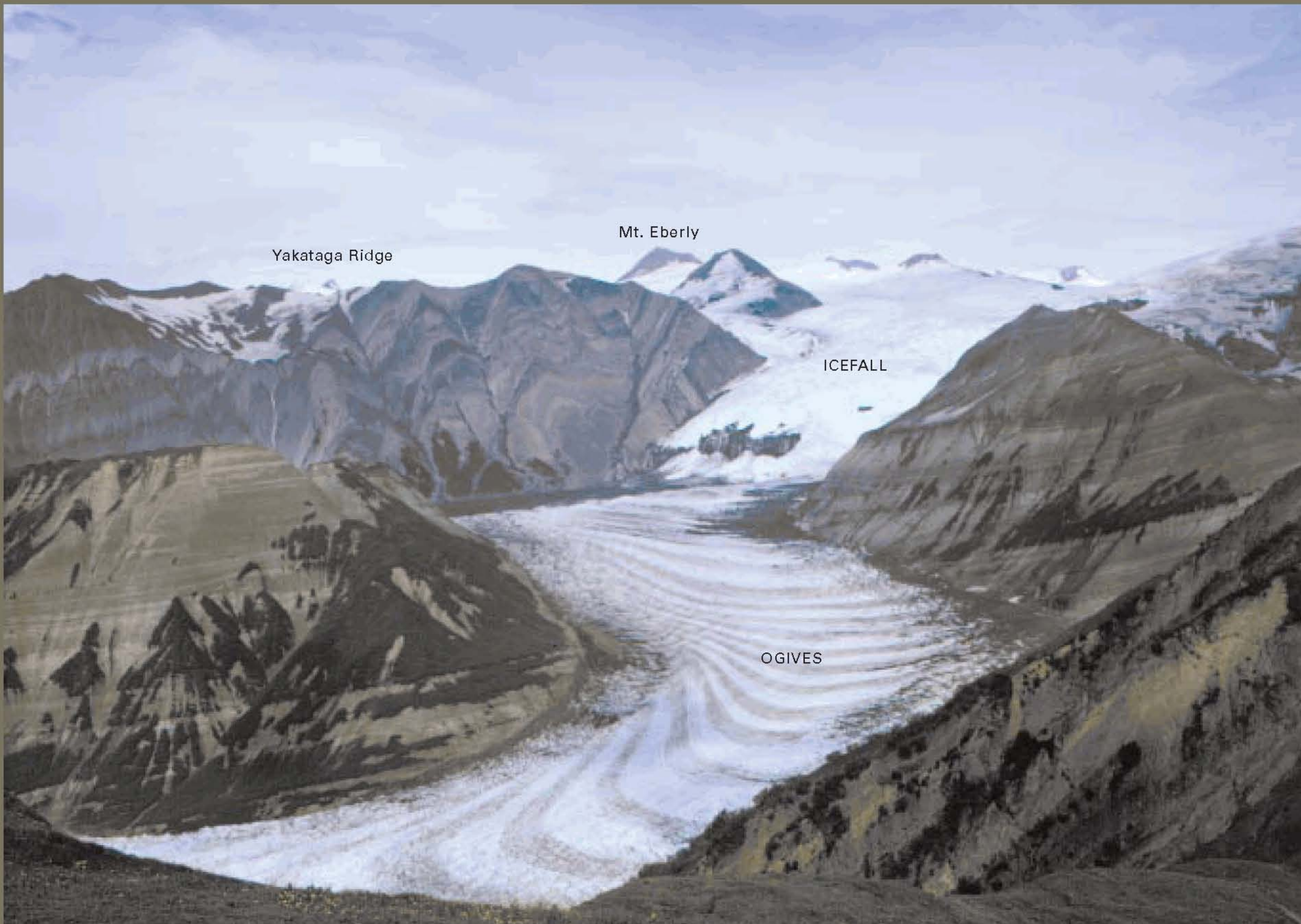
Figure 32 (facing page). Outcrops of the Yakataga Formation in the Chaix Hills, showing interbedded marine siltstone, sandstone, *tillite*, and deformed strata. Note numerous *dropstones* in the section, which are etched in relief above the weathered outcrops. The "swirly" lens in the lower half of the view ("s") may be a wad of sediment that slumped off the side of a channel, or it may have been pushed by grounded ice. (Lens is approximately 120 ft long by 20 ft thick.) The lenticularity of strata in this part of the section indicates that the sediment was deposited on very irregular surfaces. *(George Plafker)*

Impingement of the Yakutat terrane against, and partial underthrusting of it beneath, terranes to the north produced rapid uplift, forming the Chugach and Saint Elias Mountains. The regional unconformity at the base of the Yakataga Formation, the onset of glaciation, and the greatly accelerated rate of sedimentation of locally derived material all manifest arrival of the Yakutat terrane. Local multiple angular unconformities within the Yakataga (figs. 34, 35) record continuing deformation as the Yakutat terrane was driven northwestward during the last 20 million years. The terrane was displaced about 375 mi along the Queen Charlotte–Fairweather transform fault during the late Cenozoic and has been thrust at least 125 mi beneath the Prince William terrane along its northwest boundary. The Yakutat terrane must have been thrust at least 140 mi along its northern boundary beneath the Wrangell Mountains by Miocene time, the amount required for it to reach 60 mi depth and institute crustal melting and andesitic volcanism that began about 26 m.y. ago (see later section). As a result of this convergence, a wide fold-and-thrust belt has formed in the Cenozoic sequences and extends from the Pamplona zone to the north and west margins of the terrane (fig. 9). The Yakataga anticline, which extends westward from the Guyot Hills through Mt. Eberly to the toe of Yakataga Glacier, is a conspicuous fold in this zone (fig. 33). To its south, the Sullivan anticline is faulted along its crest, and strata on the seaward (south) side of the fault have been overturned so that they dip north. Such structural complexity reflects continued convergence across the widening zone. As folds grew and tightened in response to a continuing push of the Yakutat terrane from the south, in many places their crests broke and their seaward parts below the break were driven beneath their landward parts, in some places being overturned by the drag of the overriding plate. In addition, the fold-and-thrust belt migrated seaward over time. Faulted anticlines in a sedimentary section that is as young as Pleistocene are present near the seaward edge of the Pamplona zone, indicating growth of young structures beneath the outer continental shelf. They were targets for unsuccessful exploratory oil drilling in the northern Gulf of Alaska in the 1980's.

As a consequence of at least 375 mi of northwestward displacement and subduction, less than half the Yakutat terrane remains. This remaining part consists of the eastern segment of the terrane that has a relatively thick basement of Mesozoic rocks. These rocks are light and buoyant compared to oceanic crust. As the extreme elevations of the coastal mountains attest, this eastern segment of the terrane is not being subducted easily. Instead, it is jamming in the angular zone between the Aleutian trench and the Queen Charlotte–Fairweather transform fault system. The complex pattern of active deformation that characterizes the late Cenozoic history of the Wrangell–Saint Elias region will continue until the remainder of the Yakutat terrane either is completely subducted or is accreted by transferring current Pacific–North American displacement to another fault system outboard of the Yakutat terrane.

White River Glacier

Figure 33 (facing page). White River Glacier flowing from the slopes of Mt. Eberly (7,030 ft) on the boundary of Wrangell–Saint Elias National Park; view is to the north. The ridges are composed of thick sequences of the Yakataga Formation, consisting largely of laminated marine siltstone and sandstone containing much ice-rafted detritus, including dropstones. These indications of tidewater glaciers along the Gulf of Alaska are present in rocks as old as Miocene, probably the earliest record of glaciation in North America. Note the tilting of strata at the east end of Yakataga Ridge, as well as the tilting of sequences along the right edge of the view. These structures were formed during convergence of the Yakutat terrane against the continental margin. The conspicuous bands on the glacier are known as *ogives*, formed at the base of the *icefall* in the background by increased flowage each summer season. The ogives are convex downslope owing to faster flow in the center of the glacier. *(M.D. Wilson)*


Mt. Eberly
Yakataga Ridge
ICEFALL
OGIVES


Unconformity 4
Unconformity 3
Unconformity 2
Unconformity 1
A
ANTICLINAL FOLD

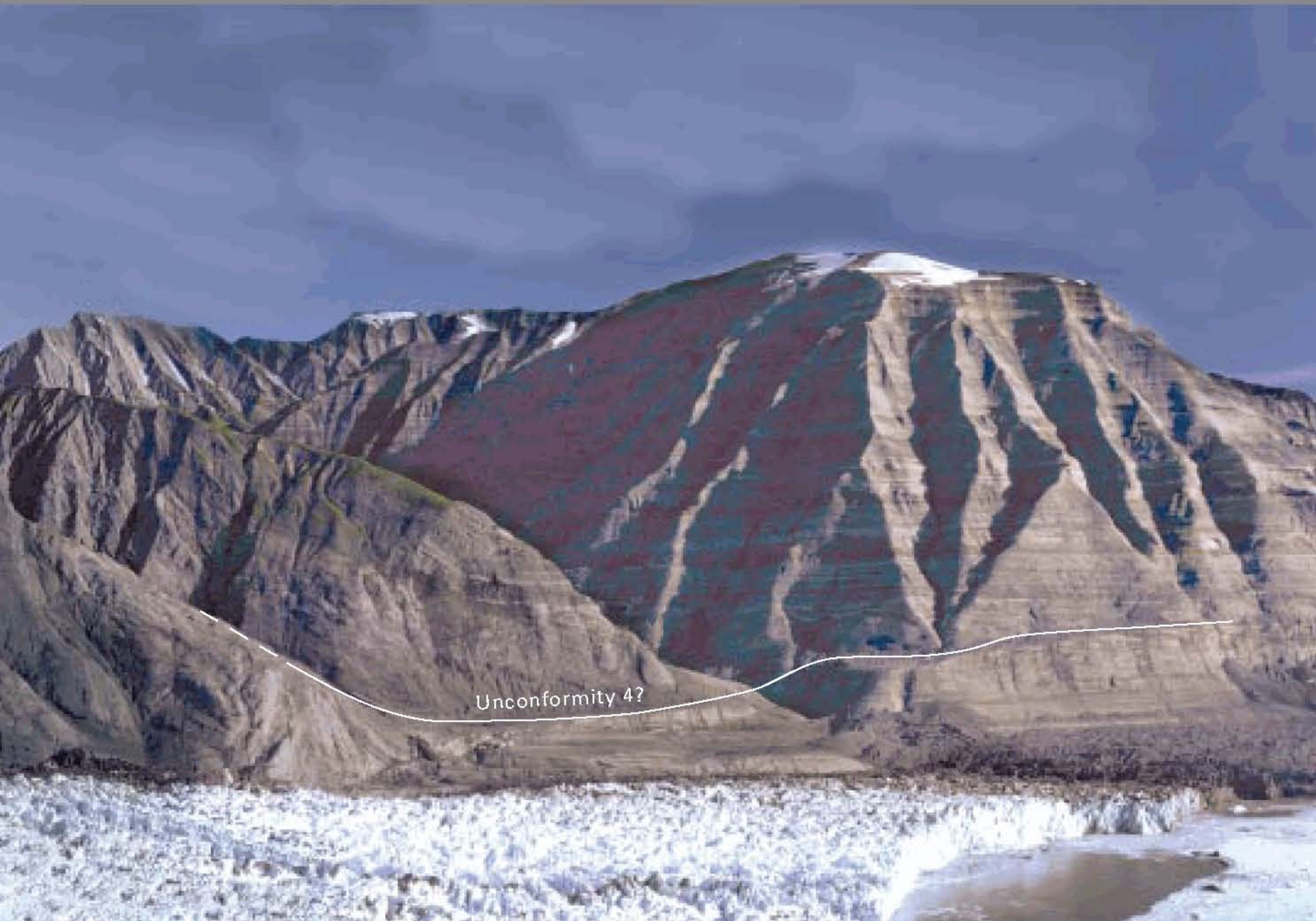


Figure 34. Folded and channeled part of the Yakataga Formation in the Karr Hills on the east side of the Yahtse Glacier. All outcrops in this view are of latest Miocene or Pliocene age, no more than 6 million years old. They expose at least four intraformational unconformities (from oldest to youngest, unconformity 1, 2, 3, and 4) that truncate strata, as well as an anticlinal fold (A). These features indicate active deformation and uplift during deposition of the Yakataga Formation—a dynamic tectonic regime that persists today as the Alaskan continental margin continues to absorb the northwestward motion of the accreting Yakutat terrane. *(George Plafker)*

Karr Hills


Mt. Cook
POUL CREEK
FORMATION
CHAIX HILLS FAULT
YAKATAGA
FORMATION
Discontinuous strata
Discontinuous strata
Unconformity

The Dynamic Parklands—Continually Reshaped by Earthquakes, Volcanoes, and Glaciers

Earthquakes

The location of Wrangell–Saint Elias National Park and Preserve straddling a zone of convergence between the Pacific and North American crustal plates guarantees continuing earthquakes. The area of the Wrangell Mountains is relatively quiet seismically, although the north edge of the parklands contains portions of the Denali and Totschunda fault systems. The Denali displays no evidence of slip during the last 200 years, but calculated dextral strike-slip rates over the last 10,000 years range from 0.3 to 0.4 in./yr. Thus, the fault is judged capable of generating infrequent but large earthquakes that may rupture segments more than a hundred miles in length and have horizontal displacements of 25 to 50 ft. Similarly, the dextral strike-slip Totschunda fault, a major splay from the Denali system, has low seismicity and shows no evidence of an event during the last 200 years. However, calculated slip rates for the last 10,000 years average between 0.4 and 0.8 in./yr, suggesting that infrequent large earthquakes may rupture all of the Totschunda and possibly adjacent parts of the Denali fault. The southern part of the parklands in the Chugach and Saint Elias Mountains is seismically very active and has generated several powerful earthquakes historically.

In the eastern Gulf of Alaska, the approximate 45° angle of convergence between a north-northwest-moving Pacific oceanic plate (and the tightly coupled Yakutat terrane) and a northwest-trending continental margin has resulted in complex patterns of late Cenozoic deformation and buckling of the plate boundary in the region of the parklands. The configuration of the plate boundary that dips northward beneath the parklands (known to seismologists as the *Benioff zone*) is indicated by earthquake seismograph records in southern Alaska (fig. 36). Orthogonal underthrusting along the Aleutian megathrust and the Kayak Island zone to the west is transferred to dextral strike-slip along the Queen Charlotte–Fairweather fault system on the east (fig. 9) through a complicated network of faults partitioning lesser amounts of oblique dextral displacement along their surfaces. Thus, during late Cenozoic time, faults as far inboard as the Denali and Totschunda faults near the north edge of the Wrangell–Saint Elias region and faults in outboard positions, such as the Transition fault and the seaward end of the Pamplona zone, have ruptured, sharing part of the relative motion between the Pacific and North American plates. Faults in intermediate positions, such as the Chugach–St. Elias fault, the Castle Mountain fault north of Anchorage, and the Patton Bay fault in Prince William Sound, also have ruptured in response to the plate motions.

Faults along the primary boundary between the Pacific and North American plates have broken at several places during the past 100 years. In September 1899, four major earthquakes (estimated *moment magnitudes* between 7.0 and 8.0) apparently ruptured the plate boundary segment between Yakutat Bay and Yakataga (fig. 36). At least two of these shocks were roughly the same magnitude as the great San Francisco earthquake of 1906. A wave-cut platform in the vicinity of Bancas Point on the north side of Yakutat Bay was uplifted as much as 46 ft during those events (see fig. 77).

Figure 35 (facing page). Intraformational unconformity, highlighted by dashed line in the lower part of the view, in the glacial-marine Yakataga Formation, Pinnacle Pass Hills, north of Malaspina Glacier. Mt. Cook (13,760 ft) is in the right background. The banded alternation of dark pebbly mudstones and lighter siltstones and sandstones is characteristic of the Yakataga Formation. Note that many sandstone strata, particularly in the middle of the view, are internally deformed and discontinuous. In part, these strata may be so-called "push moraines," soft sediment deformed on the ocean floor by the overriding of grounded ice, and, in part, slumps from rapidly accumulating water-laden sediment in a tectonically active environment. The intraformational unconformity may be an unusually large channel, scoured from a soft, water-saturated seabed, but elsewhere, strongly angular unconformities in the Yakataga unequivocably indicate the presence of growing structures within the depositional basin—no doubt induced by contemporaneous impingement of the Yakutat terrane against and beneath the continental margin. The rusty-weathering knob on the left skyline is eroded from the Poul Creek Formation. Its normal stratigraphic position is beneath the Yakataga Formation; here, the Yakataga has been thrust beneath it along the Chaix Hills fault. (Sawteeth on line marking the fault surface are on the upper plate.) *(M.D. Wilson)*

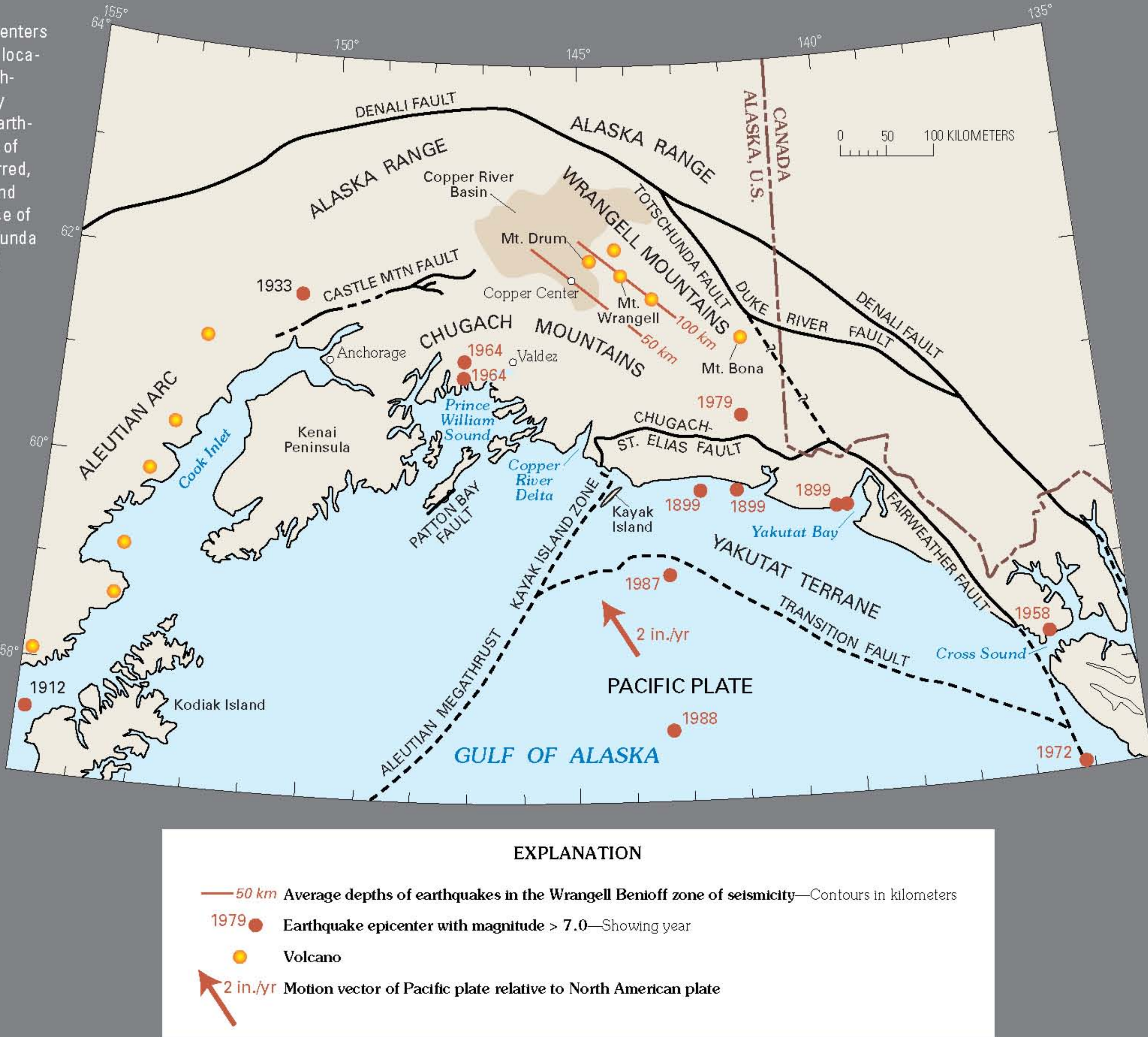


Figure 36. Map of earthquake epicenters in eastern southern Alaska showing locations and dates of historic large earthquakes, major faults with Quaternary movement, and average depths of earthquakes in the Wrangell Benioff zone of seismicity. Fault dashed where inferred, queried where uncertain. Dashed and queried line shows approximate trace of inferred connection between Totschunda and Fairweather faults. (See p. 102.)

In July 1958, the transform segment between Cross Sound and Yakutat Bay broke in the magnitude 7.7 Lituya Bay earthquake, causing horizontal and vertical surface displacements of 11.5 ft and 3.3 ft, respectively, along the Fairweather fault and triggering enormous landslides from surrounding glacially oversteepened slopes. The Fairweather fault broke again in July 1972 (magnitude 7.6), in a submerged segment 25 mi west of Baranof Island near Sitka.

In the Good Friday earthquake of March 1964, the convergent plate boundary west of Kayak Island ruptured and had shoreline uplift of as much as 37 ft and subsidence of as much as 6.5 ft. The shock (magnitude 9.2) was the second largest earthquake of this century worldwide and was accompanied by regional warping along at least 500 mi of the Gulf of Alaska from the Bering Glacier area to southern Kodiak Island. The devastation by seismic shaking, ground failure, subsidence (and inundation), tsunamis, and *seiches* was even more widespread. Although the Wrangell–Saint Elias region was located 100 or more miles east of the epicenter in Prince William Sound, snowslides and landslides were numerous, and ground cracking—particularly in areas of unconsolidated deposits—was ubiquitous. In broad river flats, networks of cracks were particularly conspicuous. Wind- and water-borne seeds quickly lodged in the cracks, sprouting to form well-defined polygonal vegetation patterns. In the area of the upper Chitina River, patterned ground defined by dwarf fireweed still is visible more than 30 years after the causative earthquake.

In February 1979, the St. Elias earthquake (magnitude 7.5) ruptured the plate boundary at about 14 mi depth beneath the Jefferies Glacier, approximately at the inflection where the Benioff zone buckles to dip more steeply beneath the continental margin. The shock triggered a large landslide from outcrops of Yakutat Group rocks in the vicinity of Cascade Glacier (fig. 37) and caused extensive ground cracking in unconsolidated deposits along the margin of Malaspina Glacier.

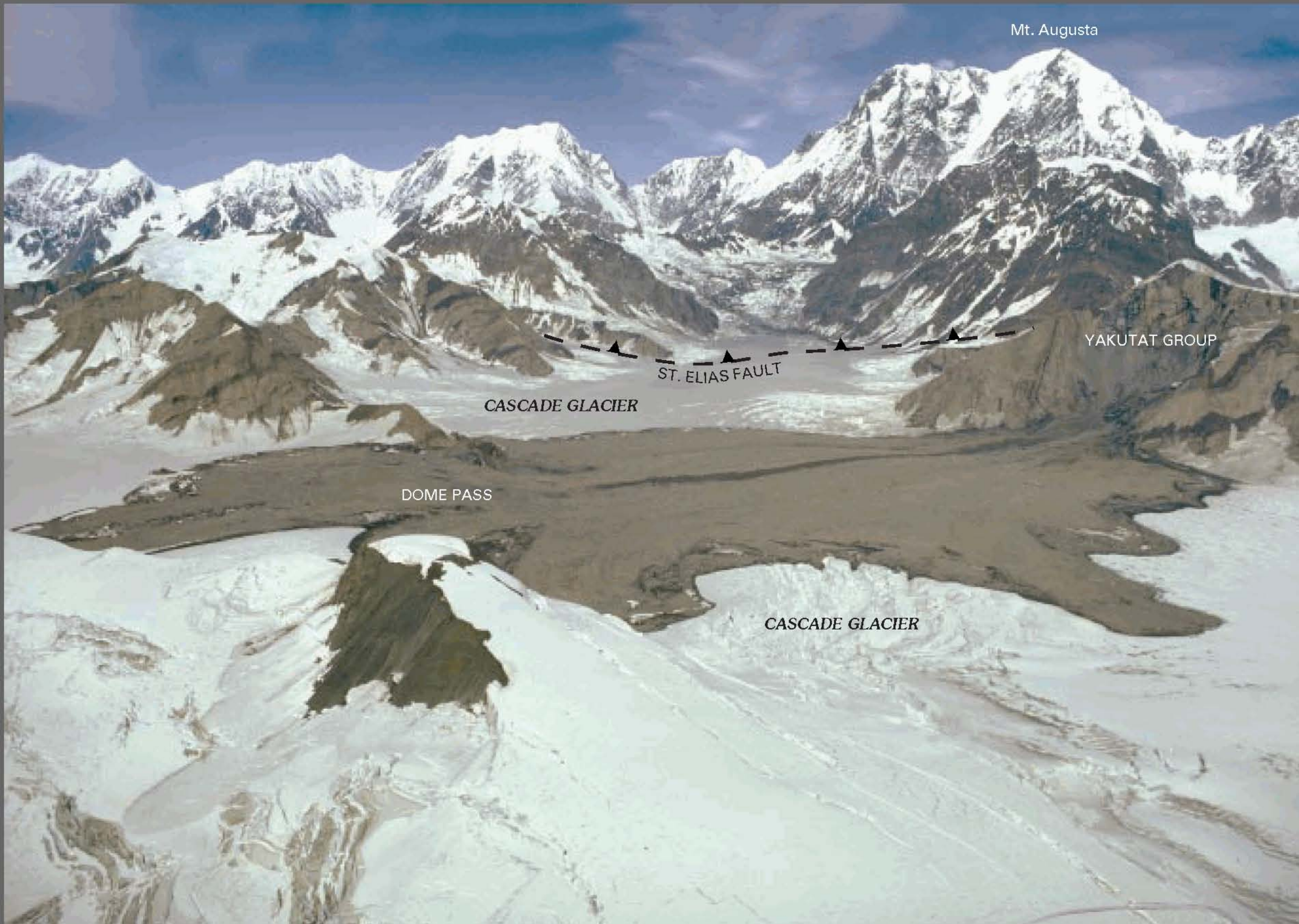
Finally, two large earthquakes in November 1987 and March 1988 (magnitude 7.9 for both) occurred in the Pacific plate seaward of the Pamplona zone. These shocks are interpreted to indicate fragmentation of the south edge of the Yakutat terrane by thrust faulting along the eastern extension of the Aleutian megathrust.

Ongoing deformation within the coastal zone is indicated by seismic activity, young folds and faults, and local shoreline uplift at rates as great as 0.4 in./yr. Clearly, large, potentially catastrophic earthquakes and the generation of tsunamis can be expected in this part of Alaska, but there is very little data on how often.

Volcanoes

On a clear day, the view to the east from the Glenn, Richardson, and Edgerton Highways between Slana and Chitina is awesome (fig. 38): four immense, glacier-clad summits rise thousands of feet above somber-hued foothills. Mt. Sanford (16,237 ft), Mt. Drum (12,010 ft), Mt. Wrangell (14,163 ft), and Mt. Blackburn (16,390 ft) in the western Wrangell Mountains dominate the west end of a Miocene to Holocene volcanic field that covers nearly 4,000 mi^2 in southern Alaska and continues into the northwest Yukon Territory as well. Discontinuous outcrops of similar volcanic rocks (fig. 39) extend southeastward to the vicinity of Icy Strait in Glacier Bay National Park and Preserve, and also are present on the south end of Admiralty Island in the Alaskan Panhandle. Correlation of the Admiralty Island Volcanics with the rocks near Icy Strait, if correct, documents about 75 mi of post-Oligocene dextral slip along the Chatham Strait fault.

The loftiest summits in the Wrangell Mountains and at least two of the high summits in the Saint Elias Mountains—Mt. Bona (16,421 ft), and Mt. Churchill (15,638 ft)—are composed primarily of voluminous piles of volcanic rocks or shallow intrusive rocks that formed beneath the volcanic edifices. At least 12 major eruptive centers occur in the Alaskan part of the volcanic field; activity began about 26 m.y. ago and has progressed generally northwesterly to reach Mt. Wrangell, the broad shield-shaped volcano rising above the southwestern Copper River Basin, which is still mildly active. Although no lava-producing eruptions have been documented in the last 200 years, Mt. Wrangell's summit *caldera* still has active *fumaroles* and occasionally emits minor bursts of *ash*, which darken the ice-covered summit. No other volcanoes in the field have been active in recent times. However, in the Copper River Basin west of Mt. Drum, three springs that produce warm, CO_2-enriched, saline mud are thought to be the result of degassing from a deep-seated magma body still present at depth. These so-called mud volcanoes (see fig. 63) have built up mounds of mud as much as 300 ft high and 8,000 ft in diameter, resembling small *shield volcanoes*. A small caldera near the summit of Mt. Churchill apparently was the source of two major eruptions of the White River Ash about 1,890 and 1,250 years ago. The two lobes of the White River Ash blanket an aggregate area of more than 130,000 mi^2 northward along the International Boundary and northeastward in the Yukon Territory.


Mt. Augusta
YAKUTAT GROUP
ST. ELIAS FAULT
CASCADE GLACIER
DOME PASS
CASCADE GLACIER

Cascade Glacier

Figure 37 (facing page). The St. Elias earthquake of July 1979 (magnitude 7.5) triggered a debris avalanche nearly 2 mi long that reached completely across Cascade Glacier, as well as numerous snowslides from the *nunatak* in the foreground. This photograph was taken in August 1979, soon after the event. The debris was derived from strongly deformed siltstone and shale of the Yakutat Group in the lower plate of the St. Elias fault (on the right) and mixed with snow and ice. The fluidized debris avalanche had sufficient momentum to climb at least 330 ft through Dome Pass, extending into a tributary glacier of Agassiz Glacier (on the left). Similar debris avalanches were triggered at many locations in the Chugach Mountains in 1964 by the great Alaskan earthquake (magnitude 9.2). Over the ensuing 30+ years, many debris fans have moved downglacier sufficiently to be detached from their source areas; their offset provides a means to measure aggregate surface glacier movement during the interval. The ridge in the background is formed by rocks in the upper plate of the St. Elias fault and consists of schistose flysch and basalt of the Chugach terrane. Dashed line shows the approximate position of the fault; sawteeth are on the upper plate. The highest peak is Mt. Augusta (14,070 ft). *(George Plafker)*

Figure 38 (page 74). A view to the north from the Chugach Mountains across the southeastern part of the Copper River Basin to Mt. Drum (12,010 ft), Mt. Sanford (16,237 ft), and Mt. Wrangell (14,136 ft). These three high peaks near the west end of the Wrangell Mountains display the varying morphology of young volcanic mountains. Mt. Drum (left) is a composite *stratovolcano*, consisting of tabular dacite to andesite lava flows and breccias, girdled by younger rhyolite and dacite domes. Its steeper profile is, in part, related to climactic explosive events that destroyed much of the summit and southern flank of the volcano. Mt. Sanford (center) displays an intermediate profile and consists of coalesced lava flows from at least three major centers. Mt. Wrangell (right) is a broad shield volcano built chiefly by the accumulation of hundreds of voluminous andesite flows. As suggested by its virtually unmodified morphology, it is the youngest volcano in the western Wrangell Mountains. Mt. Wrangell still is active, as evidenced by the presence of fumaroles and craters near its summit that occasionally emit small bursts of ash. *(G.R. Winkler)*

Figure 39 (page 75). A close-up of the longest tongue of Hole in the Wall Glacier, which spills into the valley of Skolai Creek from an ice field high to the south. The highest cliffs are composed primarily of nearly flat lying andesitic flows of the Miocene and younger Wrangell Lava. The location of their *vent* is not known. They unconformably overlie volcanic and sedimentary units of the Pennsylvanian and Permian Skolai Group, which form the multi-hued outcrops in the middle ground. Hole in the Wall Glacier has receded 0.5 to 1 mi and thinned 300 to 600 ft recently, no longer extending to the margins of its crescentic *terminal moraine*. It remains active, however, and its ice falls are severely crevassed. *(E.M. MacKevett, Jr.)*


Mt. Drum
Mt. Sanford
Mt. Wrangell

The Wrangell volcanic field consists principally of voluminous andesitic flows (some of which are subglacial), which issued from multiple centers and overlapped in places. Thin tephra deposits interbedded with the flows are widespread, and *dacite* and *rhyolite* domes are present locally. *Pyroclastic flow* deposits, such as formed at Katmai or Mount Saint Helens, however, are uncommon. The major constructional features apparently were broad shield volcanoes, similar in form to the present Mt. Wrangell, showing summit calderas that generally had nonexplosive origins. These volcanoes are immense, having volumes as great as 250 mi^3, and formed rapidly. Mt. Wrangell has the highest eruptive rate yet reported for a subduction-related volcano. Mt. Drum, however, presents a steeper morphology than the other large Wrangell volcanoes and apparently is a stratovolcano, more like typical subduction-related volcanoes around the Pacific Rim, such as volcanoes in the Cascade Mountains of Washington and Oregon.

Volcanism in the Wrangell volcanic field began in late Oligocene or early Miocene time about 26 m.y. ago, following the subduction beneath the continental margin of about 140 mi of the Yakutat terrane piggybacked on the Pacific plate. Between about 26 and 15 m.y. ago, the rate of Pacific plate movement relative to North America was about 1.8 in./yr, and the angle of convergence, relative to the Yakutat terrane boundary, was about 50°. About 5 m.y. ago, the rate of plate convergence increased to about 2.5 in./yr, and the angle of convergence, relative to the Yakutat terrane boundary, increased to about 68°. This initiation of more direct convergence and increased down-dip velocity coincides with greatly increased magma production in the Wrangell volcanic field, particularly near its west end. All of the very large andesitic shield volcanoes in the western Wrangell Mountains were constructed between 5 and 0.2 m.y. ago. Although underthrusting of the Pacific plate continues today, only a weakly seismic Benioff zone parallels the general trend of the volcanic field, and volcanism is virtually dormant. The cause of the marked reduction in volcanism is not understood. It may be related to progressive jamming of the Yakutat terrane at the continental margin and the taking up of most Pacific plate motion in dextral slip on the Queen Charlotte–Fairweather and Totschunda fault systems and in folding and thrust faulting in the belt between the Kayak and Pamplona structural zones (fig. 9).

Glaciers

Earthquakes and volcanism produce high mountains and at northerly latitudes high mountains foster glaciation. In Alaska this is particularly true where the high mountains stand close to moisture-laden storm systems moving inland from the North Pacific Ocean and the Gulf of Alaska. It is estimated that the Chugach, Saint Elias, and Wrangell Mountains are covered by at least 17,000 mi^2 of glacial ice at the present time—about 60 percent of the total surface area of glaciers in Alaska. Most of this total is included within the boundaries of Wrangell–Saint Elias National Park and Preserve.

Glaciation around the Gulf of Alaska beginning in late Tertiary time is recorded in glacial-marine deposits in the Yakataga Formation (figs. 40, 41) and in samples recovered from the continental shelf and floor of the North Pacific Ocean seaward of the continental slope. Episodic glacial-marine deposition started in mid-Miocene time (about 15 m.y. ago) in response to a global climatic cooling as well as tectonic uplift of the continental margin related to impingement of the northward-moving Yakutat terrane. At least three Miocene episodes are recorded by intervals rich in glaciogenic materials in lower parts of the Yakataga Formation in the Robinson Mountains. Normal cool-water marine sedimentation prevailed during parts of the Pliocene, but glacial diamictites became abundant again in onshore exposures of the Yakataga Formation that are of late Pliocene age (about 2.5 million years old). Diamictites also are present in seafloor samples of about the same age collected offshore, indicating that glaciers probably reached tidewater in many places. Well-exposed sections of the Yakataga Formation in the Malaspina Glacier area contain diamictites and pebbly mudstones nearly throughout. Glacial-marine deposits continued to dominate the sediment record in the Pleistocene and Holocene parts of both the Yakataga Formation, such as at Middleton Island, and offshore sediment samples. In fact, *ice-rafting* has been nearly continuous throughout the Quaternary (about the last 1.6 million years); dated samples indicate that the most intense Quaternary ice-rafting was about 400,000 years ago, when tidewater glaciers must have occupied much of the open waters of the Gulf of Alaska.

Figure 40. Outcrop view of pebbly sandstone (marine tillite) of the Yakataga Formation; the scale is in tenths of meters. Such "floating" clasts are not typical of a normal water-laid conglomerate, but instead suggest deposition as unsorted and poorly stratified material directly beneath a glacier or floating ice. The clasts appear to have been literally dumped into the deposit and show little subsequent reworking. They range widely in size; many are angular, and some are faceted—characteristics of glacial *till*. *(George Plafker)*

Figure 41. Fossiliferous marine tillite of the Yakataga Formation. Note that the pebbly siltstone is replete with clam fossils, yet also has numerous pebble and cobble clasts. If the clasts had been deposited by running water, the environment would have been too disturbed for clam growth; the clasts must have been carried to the site on rafts of ice, which melted—dropping the stones into the marine bottom sediment where the clams were living. *(George Plafker)*

During the Quaternary, the Cordilleran ice sheet expanded and contracted repeatedly. At its maximum extent, the ice sheet covered almost all of southern Alaska from the crest of the Alaska Range to the edge of the continental shelf, including the entire Wrangell–Saint Elias region. Subsequent retreats and advances to intermediate positions likely were numerous, but detailed local studies are few and commonly reveal that much of the record within the parklands has been disrupted or erased during the Wisconsin glaciation, the last major glaciation of North America, which lasted from about 120,000 to 10,000 years ago. During the late Wisconsin, the Cordilleran ice sheet covered much of the Wrangell–Saint Elias region onshore, but its distribution on the continental shelf was limited to major lobes seaward of the Bering and Malaspina Glaciers.

On the inland side of the Wrangell–Saint Elias region, glaciers have repeatedly flowed into the Copper River Basin from sources in the surrounding mountains. Some older, more extensive ice advances undoubtedly filled the entire basin, covering it with more than 1,000 ft of ice. During times of lesser ice advance, and even during the early and late stages of the most extensive advances, the basin was the site of a large lake dammed by glaciers in the Copper River canyons within the Chugach Mountains (fig. 42). The lake that formed during the Wisconsin glaciation is called glacial Lake Atna.[7]

For more details on the formation, history, and fate of glacial Lake Atna, see page 81.

The Copper River drains the basin by cutting through the Chugach Mountains to reach the Gulf of Alaska, and each time glaciers in the Chugach Mountains advanced sufficiently, the river was dammed by ice. This almost happens at the present time in the lower canyon, outside the parklands, where Miles and Childs Glaciers nearly join at the famous "Million Dollar Bridge." Overlapping positions of their terminal moraines indicate that these glaciers coalesced within the last few centuries. The fact that Miles Lake, immediately upriver from the bridge, has not yet drained completely suggests that the glacial dam may have been breached only recently, and sediments ponded upriver have not had time yet to be flushed downriver to the Copper River Delta. Farther upriver, Allen Glacier also might have dammed the Copper River in the relatively recent past. As each major glaciation began, these glaciers were probably the first to dam the Copper River, and a lake (or lakes) formed within the Copper River canyons. As glaciers advanced farther, the dams expanded in height, and the lake(s) migrated up the canyons and into the Copper River Basin and the Chitina Valley.

Figure 42 (facing page). The bluffs near the confluence of the Gakona and Copper Rivers expose nearly 300 ft of the Quaternary *lacustrine*, alluvial, and glacial deposits that fill the Copper River Basin. Most of the section seen in this view consists of finely laminated to indistinctly bedded sand, silt, and clay, with or without coarser material, that was deposited in glacial Lake Atna. A few beds contain organic material that has been dated by radiocarbon-age techniques. Outcrops in the lower left foreground (glove for scale) consist of alternating thin beds of coarser and finer grained material. The fractured, lighter colored beds above them are *varved* silt and clay. Beyond the scattered trees, the middle part of the section includes interbedded *diamicton*, silt, and sand. Some of the poorly sorted diamicton beds were probably deposited by slumping of deposits on the bottom of the lake, but other diamicton beds could represent the advance of glaciers into the lake. The upper 30 ft of the bluff consists of windblown sand and silt, some of which still is accumulating today. The entire section below the windblown material was deposited during the last major glaciation in Alaska between about 58,000 and 9,400 years ago, as dated here, and indicates rapid erosion of the mountains that surround the Copper River Basin. *(H.R. Schmoll)*

[7]"Atna" is the Indian name for the Copper River and means Big River, whereas "Chitina," the name of the major tributary that heads in copper country, means Copper River; apparently the English translation of Chitina was applied to the wrong (main) river.

The last major episode of glacial retreat in the Wrangell, Chugach, and Saint Elias Mountains began about 15 thousand years ago. Glacial ice had retreated from the continental shelf by at least 10 thousand years ago, and glaciers draining the coastal mountains had reached positions roughly comparable to those of the present time by about 9,600 to 9,300 years ago. Many Alaskan glaciers continue to retreat today. For example, the formerly three-lobed Malaspina piedmont glacier—a body of ice the size of Rhode Island—extends more than 45 mi from Yakutat Bay to Icy Bay and reaches within 300 ft of the Gulf of Alaska at the Sitkagi Bluffs. This body of ice is enormous, but its central lobe is stagnant or very slowly retreating, and its western (Icy Bay) and eastern (Yakutat Bay) lobes have retreated dramatically in historic time. Other large glaciers in the parklands have lost some of their former bulk. The Bagley Ice Field, which feeds the south-flowing piedmont lobe of Bering Glacier and the north-flowing Tana Glacier, and its eastward extension, the Seward Glacier, which feeds the Malaspina Glacier, together form the largest subpolar ice field in North America. However, they have thinned and the glaciers at their margins have retreated.

The positions of many glaciers along the Gulf of Alaska coastline were recorded during the 18th and 19th century explorations of Cook, La Pérouse, Malaspina, Vancouver, and others; and detailed studies of glaciers in the Glacier Bay, Prince William Sound, and Yakutat Bay regions began near the close of the 19th century. Follow-up investigations in the second half of the 20th century have provided a wealth of information on Gulf of Alaska historic glacier fluctuations and *proglacial* processes. Emerging from beneath the glaciers is a remarkably changeable Gulf of Alaska coastline. During more than 200 years of recorded observations, bays have been completely filled with sediment, new bays have appeared, glaciers have advanced or retreated as much as 25 mi, streams have been captured, and *spits* have grown as much as 6 mi in length. However, most of the shoreline has undergone erosion and retreat, and maximum retreat exceeding 2.5 mi is shown at Icy Bay.

On the Bering Glacier foreland, immediately west of parklands, the changes have been rapid and dramatic: in the last 50 years, the mouths of the Duktoth and Kaliakh Rivers have been forced westward 5.6 and 6.2 mi, respectively, by an annual cycle of spit growth, spring flooding, longshore sediment transport, and winter storm washover. Between 1914 and 1957, a 10 mi^2 bay at the mouth of the Tsivat River was completely filled and the river was diverted more than 7 mi westward to join the Tsiu River. In addition, melting and stagnation of the Bering Glacier terminus in this century have produced Lake Vitus, an ice-proximal lake of 4 mi^2, and have greatly expanded the Berg Lakes along the northwest margin of the Bering Glacier.

In the vicinity of Icy Bay, coastline evolution has been even more dramatic: the present bay has been created since the first decade of the 20th century (fig. 43). Before 1904, a large lobe of Guyot Glacier projected 3 or 4 mi seaward of a line between Icy Cape and Point Riou. Rapid retreat of Guyot, Yahtse, and Tyndall Glaciers began by 1909. As recently as 1957, the three glaciers ended at a deeply embayed, but common, ice front. Today, further retreat has exposed a series of rocky ridges that divide the inner bay into four fiords, completely separating the three glaciers. Total retreat since 1909 now exceeds 31 mi—an average recession of more than 0.35 mi/yr. Tyndall Glacier continues to retreat rapidly, but the terminuses of Guyot and Yahtse Glaciers may be stabilized. The coastline on both sides of the outer bay has undergone rapid erosion. The western shoreline has retreated more than 3 mi, and the eastern shoreline has retreated more than 1.2 mi, and has developed a large hooked spit, Pt. Riou, which has grown sporadically westward more than 4.3 mi. In 1794, when Vancouver explored the vicinity, he mapped a semicircular embayment east of Mt. St. Elias, which he also named Icy Bay, and it had a corresponding spit, which he named Pt. Riou. However, careful planimetry verifies that his bay was not the same as today's Icy Bay, but was located more than 3 mi to the east! Soundings by Tebenkov in 1807 show depths of as much as 15 fathoms. However, by the time of a new survey by Belcher in 1837, the bay had been filled with sediment derived from Malaspina Glacier, and no embayment appeared in the coastline anywhere between Yakutat Bay and Controller Bay.

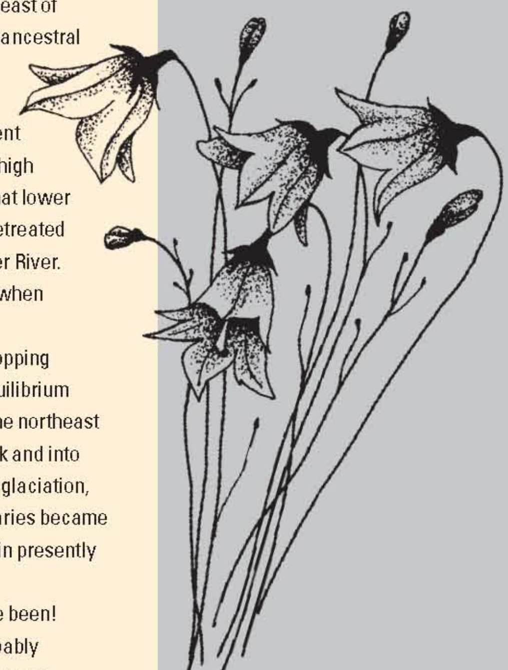
Geologic evidence for a glacial lake prior to the Wisconsin glaciation is found in only a few bluffs along the Copper and Chitina Rivers; most *lacustrine* deposits present today were formed in glacial Lake Atna. Typically, the ascending stratigraphic sequence is as follows [environment of deposition given in brackets]: (1) *gravel* [river]; (2) sand [first evidence of river ponding or lake margin]; (3) silt [lake]; (4) well-laminated clay and silt containing widely scattered pebbles, cobbles, and angular rocky debris [typical glacial lake deposits containing some ice-rafted debris]; and (5) stony silt and (or) diamicton [glacier ice nearby, advancing into the lake, and (or) displacing the lake at this site, forcing it to migrate farther up the basin]. In places, only the first four units of the sequence are present, followed by a repetition of the sequence, indicating that a lake formed but then drained or at least lowered (migrated downstream from the site) in response to ice retreat, only to reoccupy the site as the ice readvanced. Good exposures of these deposits can be seen just outside the park boundary on the west side of the Copper River, notably in bluffs near Gakona (fig. 42) and in nearby road cuts, and along the Tazlina River just upstream from the Richardson Highway (see fig. 68). In other bluffs along the Copper River and its tributaries, volcanic debris flows and other deposits that probably originated from Mt. Wrangell and Mt. Drum are interstratified with the alluvial, lacustrine, and glacial deposits. Taken together, the bluffs provide excellent cross-sectional views of these complexly intertonguing Quaternary deposits.

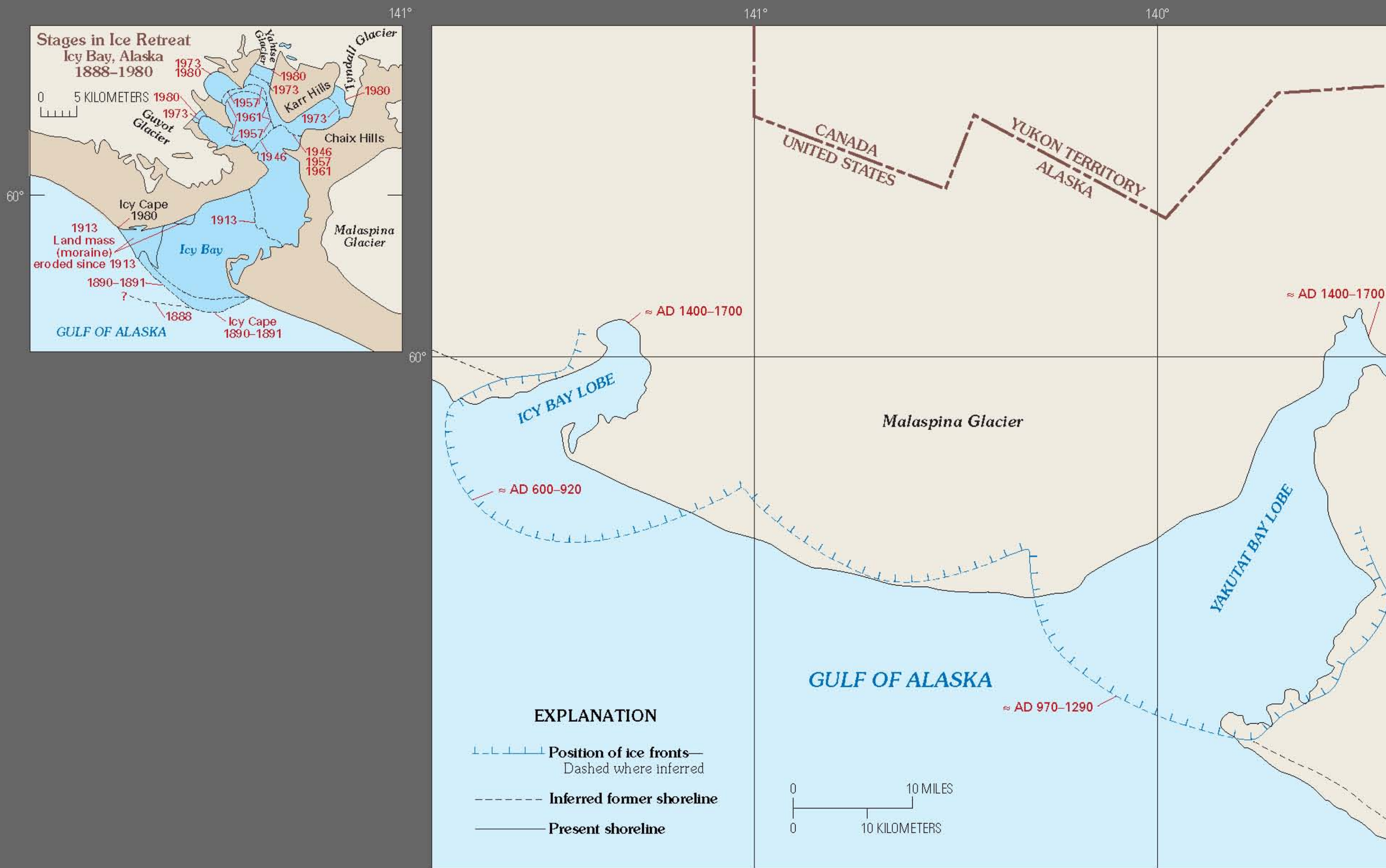
There also is substantial *geomorphic* evidence for the existence of glacial Lake Atna. The floor of the central Copper River Basin is generally a smooth, very gently sloping surface underlain by fine-grained deposits, commonly a stony silt and locally well laminated silt and clay. Strandlines marking former shores of the lake are present, although commonly rather subtle, at several altitudes. In the western part of the basin, a major strandline occurs at about 2,450 ft, and at this level the lake occupied about 3,500 mi^2; another major strandline, well formed around the base of Mt. Drum, is at about 2,300 ft. Lower strandlines are less prominent, but have been identified on aerial photographs at about 1,900 ft, 1,800 ft, and 1,600 ft. Many of these strandlines lie within parklands east of the Copper River. At other places, commonly flanking present-day tributaries of the Copper River, deltas formed at the margins of Lake Atna where ancestral streams entered the lake. Some of these deltas preserve locally prominent gravel deposits.

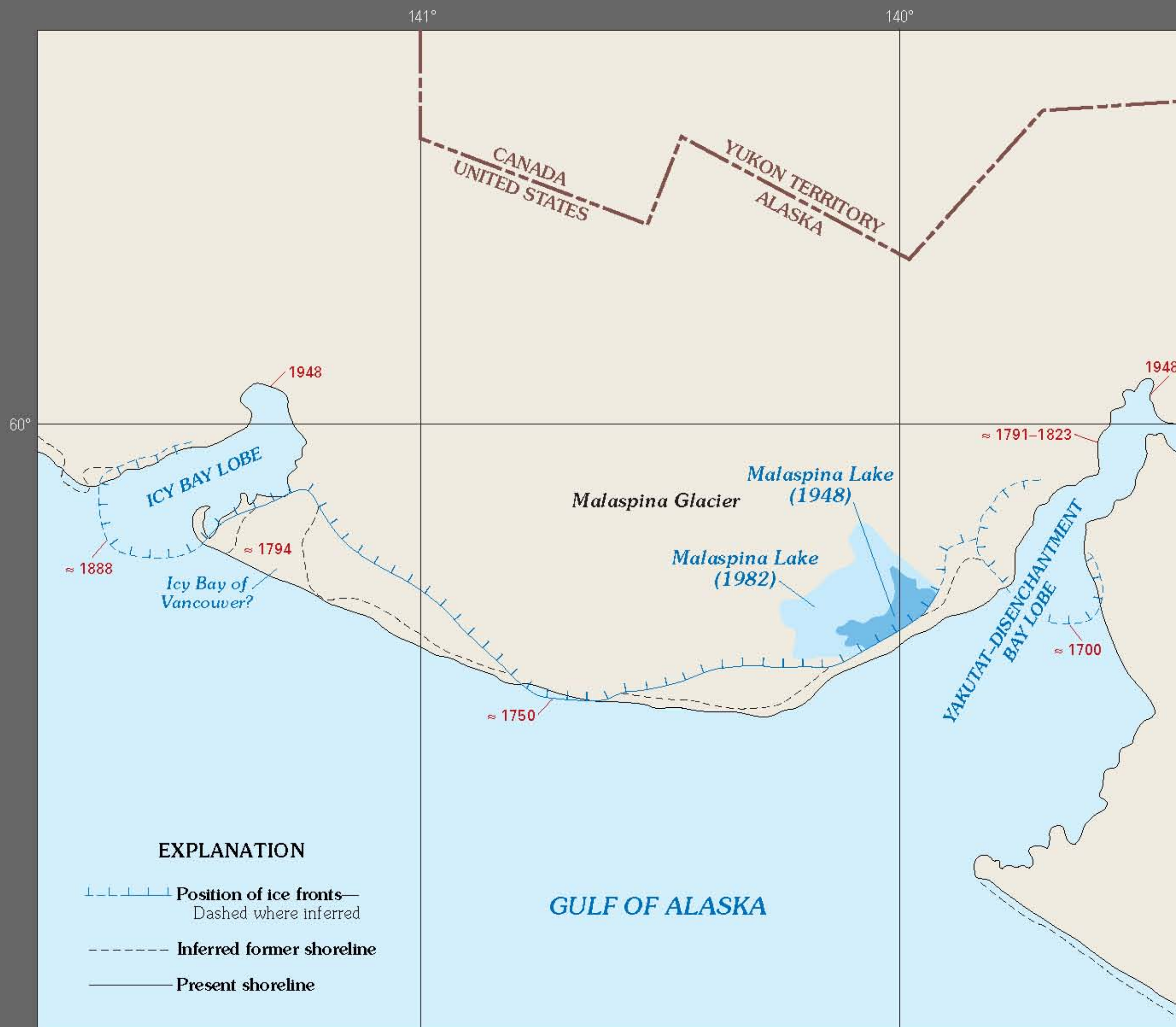
In a few places around the margins of the Copper River Basin are evidences of higher level lakes, and it is not clear whether some of these were part of the main Lake Atna or separate lakes that never were connected to the main lake. In the western part of the basin, a shoreline is present at about 2,650 ft in elevation. In the uppermost part of the basin within parklands along the Nabesna Road and the Copper River, a lake at a level as high as about 2,950 ft is evidenced mainly by the smoothed, subdued nature of the topography and channels that lead to small deltas at this and somewhat lower levels. This lake has been called glacial Lake Boomerang, and it is thought to have formed separately from Lake Atna as the Copper River glacier retreated while another glacier from the Wrangell Mountains still extended across part of the upper basin in the vicinity of Cobb Lakes just north of the Copper River. As this glacier subsequently retreated, the level of Lake Boomerang lowered until it merged with the separately existing 2,450-ft level of Lake Atna when the Boomerang dam gave way.

When Lake Atna first formed, it probably had no outlet, although it may have drained repeatedly during this time when it succeeded in overtopping the glacial dam in the Copper River canyon. In due course, however, the damming glaciers were high enough and the lake large enough that an equilibrium probably was reached whereby the lake maintained itself without any outlet. At times of highest lake levels, however, outlets probably existed to the northeast through Mentasta Pass (along the Slana River but flowing in a direction opposite to that of the present river) and in the northwest along Tyone Creek and into the Susitna River. The best developed strandlines probably formed at these times of stable thresholds. During the waning stages of the Wisconsin glaciation, however, glaciers retreated, lake level lowered, and the lake migrated to the lower basin. As the lake level lowered, the Copper River and its tributaries became entrenched below the level of the former floor of the lake as streams graded to successively lower base levels. Thus, all the major rivers in the basin presently occupy narrow valleys cut about 100 to 450 ft below the general level of the basin that formerly was the bottom of Lake Atna.

Eventually the lake drained completely down the canyons of the Copper River to the Gulf of Alaska. What a flood that final drainage must have been! Virtually no unconsolidated deposits remain in the canyons above the mouth of the Bremner River, the canyon having been scoured to bedrock, probably by the flushing action of the draining lake. A lower lake level may have reformed at times, however, as glaciers readvanced in the canyons, and lakes may form intermittently in the canyons until the beginning of the next major glaciation at some unknown future time, when a glacial lake may form again in the Copper River Basin.




Stages in Ice Retreat
Icy Bay, Alaska
1888–1980
0 5 KILOMETERS
Yahtse Glacier
Tyndall Glacier
Karr Hills
Guyot Glacier
Chaix Hills
1973
1980
1957
1961
1946
Icy Cape 1980
1913
1913 Land mass (moraine) eroded since 1913
Icy Bay
Malaspina Glacier
1890–1891
1888
Icy Cape 1890–1891
GULF OF ALASKA
141°
60°
141°
140°
CANADA
UNITED STATES
YUKON TERRITORY
ALASKA
≈ AD 1400–1700
ICY BAY LOBE
Malaspina Glacier
≈ AD 600–920
YAKUTAT BAY LOBE
GULF OF ALASKA
≈ AD 970–1290
EXPLANATION
Position of ice fronts—Dashed where inferred
Inferred former shoreline
Present shoreline
0 10 MILES
0 10 KILOMETERS
A



B

Figure 43. Positions of ice fronts and shorelines at various times in Icy, Yakutat, and Disenchantment Bays. *A*, Position of ice fronts and shorelines at culmination of older ÒprehistoricÓ advance. *B*, Position of ice fronts and shorelines at culmination of younger ÒhistoricÓ advance. *Inset*, stages in ice retreat at Icy Bay, 1888 through 1980.


Gilbert Point
RUSSELL FIORD
DISENCHANTMENT BAY
HUBBARD GLACIER
TURNER GLACIER

The Malaspina Glacier foreland extends about 47 mi east from today's Icy Bay and consists of roughly triangular *outwash* plains on both sides of the bulbous piedmont lobe of Malaspina Glacier (see fig. 75). Short but high-discharge streams drain the stagnant glacier. At the time of I.C. Russell's second expedition to Mt. St. Elias in 1891, ice was toppling from the glacier front at Sitkagi Bluffs directly onto a narrow shingle beach. There has been little subsequent retreat, and a mature spruce forest has grown on morainal material that covers the stagnant ice. On the east side of Malaspina Glacier, a large proglacial lake is expanding. The date of formation of Malaspina Lake (figs. 43, 75) is unknown, but maps published in 1914 show no evidence of it. Aerial photographs taken in 1941 show the lake at less than 50 percent of its current size.

Like many other large valley and piedmont glaciers in Alaska, the Malaspina Glacier contains numerous large surface moraines that are strikingly folded into zigzag patterns—particularly south of the Hitchcock Hills. These folds result from surge cycles in the Seward, Marvine, and other tributary glaciers, where periods of instability are marked by large-scale, but short-lived forward movement. Numerous surging glaciers have been noted in the eastern Wrangell Mountains, the eastern Chugach Mountains, and the Saint Elias Mountains near Yakutat Bay. Curiously, glaciers immediately adjacent to one another can behave very differently, such that one glacier is surging forward while its neighbor is stable or even slowly retreating. Where such glaciers join, their surface moraines can be deformed into very complex patterns. Like Malaspina, Bering Glacier also shows deformed moraines attributable to multiple surges.

Extending nearly across the mouth of Yakutat Bay is a submerged moraine complex deposited during the maximum advance of Hubbard Glacier (or, more properly, the Yakutat–Disenchantment Bay lobe of the combined Malaspina and Hubbard Glaciers) sometime between about 1,000 and 700 years ago (fig. 43). Thus, Hubbard Glacier has retreated nearly 40 mi northeastward in the last several hundred years to expose Yakutat and Disenchantment Bays. Even so, Hubbard is North America's largest tidewater glacier, and has a face nearly 6 mi wide that reaches heights of close to 300 ft (fig. 5). Ice retreat began sometime before 1400 and proceeded slowly but steadily for several centuries. A submerged moraine at the west end of Disenchantment Bay resulted from a temporary readvance that culminated between 1700 and 1791. At the time of explorer Malaspina's search for the fabled Northwest Passage in 1792, he navigated Yakutat Bay without difficulty, but was turned back in the vicinity of Haenke Island by floating ice that was impenetrable to his vessels. The name he gave to the fiord at the head of Yakutat Bay, Desengaña, indicates his disenchantment that no passage existed. Between 1792 and 1894, the terminus of Hubbard Glacier resumed its retreat to a position about 2 mi east of its current location near Osier Island. Since 1894, when systematic mapping of its terminus began, Hubbard Glacier has slowly readvanced, threatening to seal the mouth of Russell Fiord (fig. 44). In early 1986, the threat came true: Hubbard Glacier advanced sufficiently to block the connection between Disenchantment Bay and Russell Fiord. The water behind the glacial dam began to rise, creating a temporary "Lake" Russell. In the 5 months that the dam held, the lake rose about 80 ft above sea level, but in early October 1986 the dam failed and the lake emptied completely within the course of 28–30 hours. A new closure will likely take place in the near future unless Hubbard Glacier's slow advance is stabilized or reversed.

Hubbard Glacier

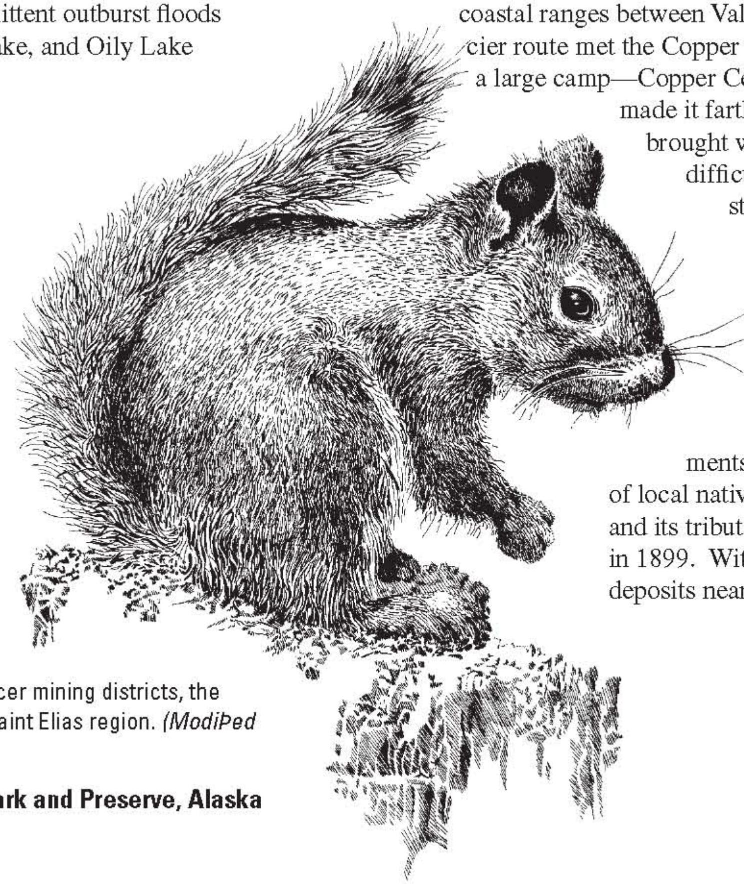
Figure 44 (facing page). View to the southeast of part of the terminus of Hubbard Glacier. The moraine-covered terminus of Turner Glacier is in the foreground, Disenchantment Bay is on the right, and Gilbert Point is on the mainland in the right background. Arrows show direction of glacier ßow. Russell Fiord is the body of water in the center background. Even a short advance of Hubbard Glacier is sufÞcient to dam Russell Fiord, creating a saltwater lake. Out of view behind Gilbert Point is a former outlet to the Yakutat foreland. Once a ÒLakeÓ Russell is formed, if it rises more than about 130 ft, it will reinstitute drainage down Old Situk Creek across the Yakutat foreland to the open Gulf of Alaska. *(George Plafker)*

Numerous other ice-dammed lakes are present in the Chugach, Saint Elias, and Wrangell Mountains; most of these occur where major glaciers dam tributary valleys that no longer are filled by ice. Named lakes within the Wrangell–Saint Elias region include the former Barkley Lake, dammed by the Tana Glacier (recession of the glacier removed the dam in the 1960's, and Barkley Lake has been almost completely drained); Agassiz Lakes and Oily Lake, dammed by the Libbey and Malaspina Glaciers, respectively; Upper and Lower Skolai Lakes, dammed by the Russell Glacier; and Hidden Creek Lake, west of McCarthy, dammed by the Kennicott Glacier (see fig. 71). Immediately southwest of parklands, Berg and Khitrov Lakes are dammed by Steller and Bering Glaciers, and Van Cleve Lake is dammed by the Miles Glacier. Several of these lakes are, or have been, sources for *glacier outburst floods*. Every summer, after enlarging for several months, Hidden Creek Lake drains through a subglacial channel about 10 mi long into the Kennicott River. In some years, sufficient hydraulic head is present that the outburst at the toe of the glacier generates very turbulent boils and even minor fountaining. In August 1974, the western span of the vehicle bridge that formerly crossed the Kennicott River to reach McCarthy was washed out by an especially vigorous outburst. Intermittent outburst floods also have been reported from Berg Lakes and Van Cleve Lake, and Oily Lake periodically drains subglacially, as well.

Figure 45 (facing page). Map showing locations of lode and placer mining districts, the Katalla oil Þeld, and the Bering River coal Þeld in the WrangellDSaint Elias region. *(ModiÞed from National Park Service)*

Gold and Copper—Or Was It Copper and Gold?

It was rumors of gold that first brought prospectors to the Wrangell Mountains, but it was copper that kept them there (fig. 45). With the discovery of large quantities of *placer* gold in the Klondike River area of the Yukon Territory late in the summer of 1896, a concerted stampede of would-be miners started north as soon as they were able to secure passage. Most gold-seekers in 1896 and 1897 landed at Dyea (or Skagway) and took the most direct routes over Chilkoot or White Passes to the headwaters of the Yukon River. However, information was scant, and—on paper—the head of Port Valdez, in northeastern Prince William Sound, looked nearly as close. Between autumn 1897 and March 1898, vessels landed several thousand stampeders to try this apparent alternative. None of the early arrivers seemed to realize that a formidable mountain barrier as much as 60 mi wide intervened between the coast and the Copper River Basin. Despite extreme hardships, argonauts soon pioneered a route over the Valdez Glacier, and over time, a few tried to find easier routes through virtually every low spot in the coastal ranges between Valdez and Yakutat. Where the Valdez Glacier route met the Copper River at the mouth of the Klutina River, a large camp—Copper Center—soon sprang up. Few stampeders made it farther up river because returning Klondikers brought word that not only was the way ahead very difficult, but the auriferous ground already was staked completely. Furthermore, rumors of local riches began to circulate. By 1899, modest discoveries of placer gold were made at Quartz Creek southwest of today's parklands in the Tonsina River drainage and along the Chistochina River northwest of the parklands. Learning of Chief Nicolai and his implements of pure copper, prospectors, with the help of local natives, moved eastward up the Chitina River and its tributaries, locating the Nikolai copper prospect in 1899. Within another year, the bonanza copper deposits near Kennicott Glacier had been located in



146°
144°
142°
140°
62°
60°
MENTASTA MOUNTAINS
TETLIN LOWLANDS
TETLIN NATIONAL WILDLIFE REFUGE
DAWSON RANGE
NISLING RANGE
NUTZOTIN MOUNTAINS
WRANGELL MOUNTAINS
SAINT ELIAS MOUNTAINS
CHUGACH MOUNTAINS
NATIONAL PRESERVE
NATIONAL PARK
KLUANE NATIONAL PARK
KLUANE GAME SANCTUARY
CHUGACH NATIONAL FOREST
Slana
Chistochina
Gakona
Gulkana
Glennallen
To Anchorage
Copper Center
Tonsina
Chitina
Taral
Nabesna
Chisana
Kennicott
McCarthy
Valdez
Cordova
Katalla
Beaver Creek
Burwash Landing
Destruction Bay
Nabesna district
Chisana district
Kotsina-Kuskulana district
Tonsina district
McCarthy-Nizina district
Bremner district
Bering River coal field
Katalla oil field
Nabesna Road
Alaska Highway
Richardson Highway
Atna Peaks
Castle Mountain
Skolai Pass
Chitistone Peak
Cooper Pass
Spirit Mountain
Strelna
Chokosna
Dan Creek
May Creek
WAXELL RIDGE
ROBINSON MOUNTAINS
GRANITE RANGE
MACCOLL RIDGE
ICEFIELD RANGES
BAGLEY ICEFIELD
Juniper Island
JEFFERIES GLACIER
COLUMBUS GLACIER
SEWARD GLACIER
MALASPINA GLACIER
HUBBARD GLACIER
MILES GLACIER
BERING GLACIER
ALLEN GLACIER
WERNICKE GLACIER
CHITINA GLACIER
NABESNA GLACIER
KASKAWULSH GLACIER
LOWELL GLACIER
GUYOT HILLS
KARR HILLS
CHAIX HILLS
SUCKLING HILLS
Cape Suckling
Cape Yakataga
ICY BAY
YAKUTAT BAY
Point Manby
Haenke Island
HAWKINS ISLAND
KAYAK ISLAND
COPPER RIVER DELTA
GULF OF ALASKA
YUKON TERRITORY
ALASKA
UNITED STATES
CANADA
BRITISH COLUMBIA
EXPLANATION
Wrangell–St. Elias National Park
Wrangell–St. Elias National Preserve
Native corporation lands
Unpaved road
Extent of mining districts
0 10 20 KILOMETERS
0 10 20 MILES

the lower part of the Chitistone Limestone near its contact with the underlying Nikolai Greenstone. Within another 2 or 3 years, most of the Nikolai-Chitistone contact, where it was accessible, had been prospected along the southern flank of the Wrangell Mountains, resulting in numerous copper discoveries both west and east of the Kennicott Glacier area. In 1901, placer and *lode* gold strikes were made on Golconda Creek, a tributary of the Bremner River; placer production ultimately reached 2,000 to 3,000 ounces of gold and minor silver from the Bremner district. The lode mines intermittently produced modest quantities of gold from quartz veins at the Yellow Band and Lucky Girl mines until the 1930's, finally totaling about 750 ounces. In 1901, placer gold in paying quantities also was discovered on Dan Creek, a tributary of the Nizina River (fig. 46); concerted prospecting nearby in 1902 located strikes on Chititu, Rex, and Young Creeks. By 1959, these placers of the Nizina district had produced about 143,000 ounces of gold. The Dan and Chititu Creek placers occasionally are worked seasonally on a small scale; all equipment and facilities are privately owned.

Dan Creek

Figure 46. Looking eastward up Dan Creek, from near its mouth, toward Nikolai and Lime Buttes. The hummocky terrain in the foreground results from hydraulic placer mining of the gold-bearing alluvial terraces and benches exposed in the middle ground. A section of pipe used to direct water for the hydraulicking remains in the left foreground. The ridges in the background are eroded from the Triassic Chitistone and Nizina Limestones, which overlie the slope-forming Nikolai Greenstone. Numerous small copper prospects are located near the greenstone-limestone contact in this area, but none contained sufÞcient ore-grade material to be mined. *(G.R. Winkler)*

It was the use of hydraulic techniques that led to successful placer mining at both Dan and Chititu Creeks. The first hydraulic plant was completed on Dan Creek in 1908 and another was completed at about the same time on Chititu and Rex Creeks. Both plants were subsequently expanded at least twice, pipelines and flumes were constructed, extensive ground was mined, and modest returns were achieved in good years. Piles of boulders left over from the hydraulicking still form only slightly weathered and lightly vegetated hummocks for up to a mile east of the Chititu Camp on Rex Creek, and extensive hydraulicked areas are present east of Dan Creek as well. The old camps are well preserved, some water and flume lines are still in position, and stretches of mostly disintegrated old sluice boxes remain today. Curiously, piles of native copper nuggets can be found next to the old sluice boxes in a few places. Apparently, after cessation of copper shipments from the Kennecott mines and closure of the Copper River and Northwestern Railway, the relatively low value copper nuggets were a nuisance: being heavy, they settled along with the gold, and periodic cleaning of the sluices was necessary to remove the nearly valueless copper from the paying gold. The copper nuggets were merely discarded at the bases of the old sluice lines. One exceptionally large copper nugget (weighing about 5,495 pounds) from Dan Creek, however, was salvaged for public display—moving first to Chitina, then Anchorage, and finally Fairbanks, where it currently occupies a conspicuous place in the Natural History Museum at the University of Alaska.

Optimistic prospectors reasoned that the north flank of the Wrangell Mountains would be just as rich as the south side, and as early as 1899, were examining copper, molybdenum, and gold prospects on tributaries of the Nabesna and Chisana Rivers at Jacksina, Monte Cristo, Bond, California, and Beaver Creeks, and at Orange Hill. The discoveries, however, generally were small, low grade, and difficult to reach; none rivaled in grade the rich discoveries at the Kennecott mines, and a year-round road connection from Nabesna to the Alaska highway system was not made until late 1933. Prior to that time, the cost of shipping out even pure metallic copper would have greatly exceeded its market value. Gold, given its higher unit value, was another matter. In 1913, Chisana was the scene of an old-style gold rush, a strike of 200 ounces of placer gold dug in 2 days by two men being rich enough to lure even miners from the Klondike, as well as from Puget Sound in the "Lower 48." Gold camps in the Nizina district on the south side of the Wrangell Mountains nearly emptied of miners immediately and even the operation of the Kennecott mines was impacted significantly. Several thousand stampeders reached Chisana during 1913, and between 500 and 600 residents stayed through the winter in anticipation of the 1914 mining season. Between 1913 and 1917, about $530,000 in gold (at $20.67/oz) was produced from drainages east of Chisana, principally Bonanza Creek (fig. 47), but a steady decline already had set in. Due to the persistence of a few miners, the camp has continued to produce some gold each year until the present time.

Persistence also paid off at Nabesna. High on the slopes of White Mountain, prospectors located pockets of coarse-grained sulfide minerals with associated gold where Triassic limestone had been intruded by a Cretaceous pluton. By the late 1920's, enough lode gold ore had been located in *contact-metamorphic (skarn)* deposits on the property that a mill was installed to treat the *refractory* ore. Between 1931 and 1940, gold ore valued at more than $1.8 million was shipped to smelters outside Alaska. However, the valuable pockets of ore were virtually exhausted by then, no new pockets were discovered, and the mine closed permanently in 1947.

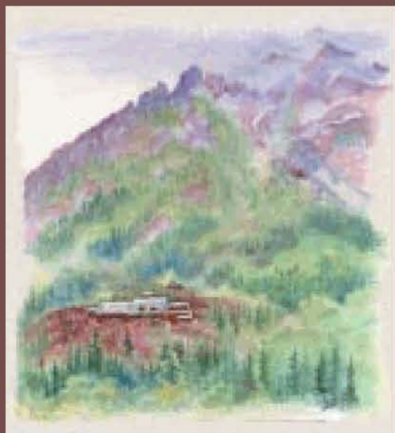
Only the copper discoveries east of the Kennicott Glacier on the south flank of the Wrangell Mountains proved to be rich enough to justify development of extensive transportation infrastructure. Near the crest of Bonanza Ridge (fig. 2), outcroppings of nearly pure copper sulfide ore 2-7 ft across and 15 or more ft in length assayed nearly 70 percent copper. They eroded to form a conspicuously green talus pile, the so-called "talus or slide ore," that was noted first (legend has it) from the edge of Kennicott Glacier, more than 2.5 mi distant and 2,600 ft below. The ridge-top discovery lode, the Bonanza vein, was staked in August 1900. Other lodes that show rich surface outcroppings, the Jumbo, Mother Lode, and Erie, were discovered in quick succession. A scramble of litigation, consolidation of claims, reorganization, and the input of major capital from the banking firms of the Guggenheim brothers and J.P. Morgan ensued, ultimately leading to construction of a 196-mi railroad from Cordova to the rich deposits—the Copper River and Northwestern Railway—and creation of a new major mining company, the Kennecott Copper Corporation—taking its name (albeit misspelled) from the nearby glacier. Rex Beach's 1912 novel, "The Iron Trail," provides a fictionalized, but generally accurate and entertaining account of the development of the railroad under the direction of M.J. Heney, General Contractor (Murray O'Neil of the novel), and E.C. Hawkins, Chief Engineer (Mr. Parker of the novel). A few years before, Heney and Hawkins had collaborated to build the White Pass and Yukon Railway from Skagway to Whitehorse, an engineering feat that greatly aided development of the Yukon Territory.

Copper ore from the Kennecott mines ranks among the richest ever produced from a large mining operation. During the period of major mining between 1911 (when the railroad was completed) and 1938 (when the mines closed), the mines yielded in excess of 536,000 t (metric tons) of copper and an estimated 100 t of silver from ore that averaged nearly 13 percent copper. The massive ore body near the base of the Jumbo vein was among the largest and richest ever discovered; it consisted of a single body of nearly pure chalcocite (Cu_2S) 325 ft long, 65 ft wide, and 50 ft high.

During the early period of mining between 1911 and 1915, principally high grade material was mined, and most ore was crushed and then milled (fig. 48) by gravity separation, using banks of vibrating tables. However, a significant portion of ore from the Kennecott mines, perhaps as much as 20 percent of the total, consisted of lower grade carbonate ore, composed principally of copper carbonate minerals such as malachite and azurite. Beginning in 1915, the innovative process of ammonia leaching, first used on a commercial scale at Kennicott, enabled successful milling of these oxidized ores. As mining grades continued to decrease, flotation recovery processes already in use elsewhere in the western United States were introduced in the mill by the end of 1923, enabling the recovery of copper from much lower grade ore bodies. By the mid-1920's, combined use of gravity separation, ammonia leaching, and flotation enabled overall recovery of about 96 percent of the copper from material processed in the mill.

The type of copper deposits represented by the Bonanza, Jumbo, Mother Lode, and other nearby mines and prospects presently are known to occur only along the southern flank of the Wrangell Mountains. Although a few small Kennecott-type deposits have been found elsewhere in the parklands, only the mines in the area of Bonanza Ridge constituted world-class orebodies. Most production was from lodes in the lower part of the Chitistone Limestone that have the following features: (1) they are localized on the southern limb of a northwest-trending syncline and form northeast-plunging masses that, in cross section, approximate the shape of upward-tapering isosceles triangles; (2) they bottom on impervious layers about 100–130 ft above the base of the Chitistone; (3) they are associated with hydrothermal dolomite and with breccias of diverse origins; and (4) they are exceptionally high grade, containing an intimate mixture of about 75 percent unoxidized sulfide ore (dominantly chalcocite and other minerals in the Cu_2S-CuS system) and about 25 percent oxidized carbonate ore. Discrete silver-bearing minerals are rare; most recovered silver probably was incorporated in crystal lattices of the copper sulfide minerals.

Figure 47 (facing page). Gold placer mining camp at the junction of Bonanza Creek with Little Eldorado Creek east of Chisana, established during the winter of 1913. As many as 100 men and women worked out of this tent camp during 1914, only one of many placer-mining camps in the Chisana area. *(S.R. Capps)*



Special geological conditions were necessary to create copper deposits of such exceptional size and richness as those at the Kennecott mines. The proximity of the Nikolai GreenstoneÑthe somber maroon-colored rocks forming the bulk of Bonanza RidgeÑis imperative: the basalt is the likely source of the copper. The Nikolai is intrinsically elevated in copper, containing on the average 155 parts per million (many basalts contain less than 100 ppm). In scattered locations, the Nikolai contains native copper as clots or Þllings in vesicular cavities or open spaces in ßows. In the Late Triassic, after basaltic eruptions ceased, carbonate sediments formed in a very shallow marine embayment upon the ßat volcanic platform in an arid, near-equatorial environment, forming the lower part of the Chitistone LimestoneÑthe light-gray cliff-forming outcrops that make up the top of Bonanza Ridge at the mines. Local intertidal areas in the embayment accumulated sabkha-facies sediment rich in sulfates, like gypsum ($CaSO_4(2H_2O)$, which became concentrated in evaporative brines, and organic-rich microbial mats. These carbonate rocks are thickest and contain the critical sabkha facies only in the vicinity of the Kennecott mines. Northeast-trending Þssures and solution cavities probably formed in Late Triassic time shortly after deposition of the Chitistone and are surrounded by zones of breccia and hydrothermal dolomite. These are favorable structural sites for later deposition of the Kennecott ore bodies. In the Late Triassic, Chitistone brines circulated downward into the underlying basalt, scavenging copper and forming small early veins and disseminations in the basalt. Although these Nikolai-hosted copper deposits are numerous and widespread, they are too small for exploitation. The main stage of ore deposition took place much later, probably about 110 m.y. ago near the close of the major regional *orogeny*, which caused large-scale movement and mixing of ßuids. Oxidized copper-rich brines, which moved out of the Nikolai Greenstone, reacted with sulfur-rich ßuids derived from reduction of gypsum in the presence of organic matter in the lower Chitistone Limestone. The regional orogeny increased the temperature sufÞciently to degrade the organic matter, producing H_2S, and provided the hydrologic head to move the thermal brines to the lowermost and stratigraphically thickest part of the sedimentary basin. When the circulating copper-rich brines encountered H_2S-rich ßuids, ore deposition ensued. Within the structurally prepared ground, the previously formed northeast-trending solution Þssures and breccias in the lower parts of the overlying carbonate rocks, particularly large and rich lodes formed. The upward-tapering wedge of the slightly sinuous main Bonanza vein, for example, was 1,900 ft long, 165-195 ft high, and 1.5-50 ft wide. It produced 653,000 t of ore grading 13.44 percent copper, and also contained more than 14 t of silver. At least 15 other smaller subparallel ore bodies were spaced about 200 ft apart in the workings of the Bonanza and Mother Lode mines, plunging northeastward nearly parallel to dips of the host Chitistone Limestone.

Kennicott Mill

Figure 48 (facing page). View of milling facilities at Kennicott as they appeared in 1964. Copper-silver ore from the Bonanza, Jumbo, Mother Lode, Erie, and Glacier mines reached the building on the skyline by tramlines from high on Bonanza Ridge. In the mill, the ore was concentrated by crushing, ßotation, and leaching, then was loaded on ore cars at approximately the left edge of the photograph area for the 196-mile journey via the Copper River and Northwestern Railway to Cordova for transport via steamship to Þnal smelting in Tacoma, Wash. More than ½ million t (metric tons) of copper and 100 t of silver passed through these buildings in 27 years! Beyond the buildings is the hummocky moraine-covered surface of the Kennicott Glacier, above which rises (about 25 mi distant) the summit of Mt. Blackburn. *(G.R. Winkler)*

Several other smaller copper deposits are hosted in the Chitistone Limestone in the Wrangell Mountains. Between 1922 and 1925, the Green Butte mine, east of McCarthy Creek, produced about 1,400 t of high-grade copper ore—a production that is dwarfed by the more than 1 million metric tons produced by each of the three main Kennecott mines. The Nelson prospect on lower Glacier Creek has extensive underground workings, but never produced copper ore. Other named prospects east of McCarthy include the Westover on Boulder Creek, the Peavine on the south side of the lower Chitistone River (which made a small test shipment of copper ore in 1973), the Schulze (named for long-time McCarthy resident and prospector Henry Schulze) on the high ridge north of Nikolai Pass, and the Binocular prospect on nearly inaccessible cliffs at the head of Radovan Gulch (named for Martin Radovan, the long-time prospector who discovered the copper-stained outcrops in the 1920's). West of McCarthy, named prospects in the Chitistone Limestone include the Regal, near Donoho Peak on the ridge between Root and Kennicott Glaciers, and the Mullen, Ammann, and Bunker Hill prospects on Copper Creek, a short tributary of the Kotsina River in the Kotsina-Kuskulana district. Several of these prospects were explored episodically in the 1950's, 1960's, or 1970's, but were never developed.

Small contact-metamorphic (skarn) deposits are present near contacts between the Chitistone Limestone and Late Jurassic intrusions at the Midas mine on Berg Creek, an eastern tributary of the Kuskulana River. Small quantities of copper ore were shipped from the Midas—probably because the ore contained slightly elevated gold values, which resulted in "credits" at the smelters.

In many places in the southern Wrangell Mountains, small copper prospects are hosted in the Nikolai Greenstone. The Nikolai mine on upper Nikolai Creek in the Nizina district is well known because of its role in stimulating early exploration leading to the Kennecott discoveries. It is dwarfed by deposits in the Chitistone Limestone, however, and very little, if any, copper ore actually was mined. East of McCarthy, the Erickson and Radovan greenstone prospects on Glacier Creek contain small lodes in complexly faulted and sheared zones in the Nikolai Greenstone; the Erickson is noted for its irregular masses and small stringers of native copper. Neither prospect, however, yielded ore.

West of McCarthy, numerous small greenstone-hosted deposits are present in the Hidden Creek area and in tributary drainages of the Lakina, Kuskulana, Kotsina, and Kluvesna Rivers. Dilapidated camps mark many of these locations, and exploration was particularly vigorous in the Elliott Creek area. For several decades after initial discoveries in the late 1890's and early 1900's, this so-called Kotsina-Kuskulana district was believed to hold promise for rich deposits of the Kennecott-type. However, almost none of the small copper lodes hosted in the Nikolai Greenstone extended upward into the overlying Chitistone Limestone, and none expanded outward above the contact, as prospectors hoped, into major ore bodies of the Kennecott-type. All proved to be much too small for exploitation, even with an operating railroad nearby. Nugget Creek, however, became noted for the discovery in 1900 of a native copper nugget in the creek bed that was 7 ft 3 in. long, 3 ft 8 in. wide, 10 in. thick, and was estimated to weigh 2–3 short tons. Small contact-metamorphic (skarn) deposits also are present in at least two places in the Nikolai Greenstone near Late Jurassic intrusions. Small copper veins at the Valdez mine on Nugget Creek were slightly enriched in silver; the mine actually had small shipments of ore. The Silver Star prospect, located near Granite Peak almost 2,500 ft above the north bank of the Kotsina River, contains veins that are particularly rich in silver; the prospect has been repeatedly evaluated. It originally was discovered by long-time Chitina prospectors Neil and Thomas Finnesand, who kept the claims current for nearly 70 years. Although the veins are hosted in the Nikolai Greenstone, the elevated silver values may be attributable to the hydrothermal influence of the nearby intrusion.

Small copper lodes hosted by the Nikolai Greenstone also are known south of the Chitina River. The Taral Indians had reported copper deposits between their village and the Hanagita River to the earliest prospectors in the region. By the early 1900's, several prospects had been located on the uplands east of the Copper River and one, the Blakney prospect, had been *patented*. None, however, proved to be large, and no ore was shipped.

Nickel-bearing copper deposits in the Spirit Mountain area, which were discovered about this same time, are hosted by mafic and ultramafic *sills* in metamorphic rocks of the southern Wrangellia terrane margin. During World War II, the Spirit Mountain deposits were reevaluated as a possible source of nickel—a metal of strategic importance in the military and industrial expansion at that time—and a resource of 6,500 t grading 0.7 percent Ni and 0.5 percent Cu was estimated. The resource was very small by worldwide standards, and with the end of the war, interest waned. Subsequent activity in the area of the deposits has been sparse, and few traces remain of early exploratory work.

Although only one lode mine—the Nabesna gold mine (fig. 49)—ever produced ore from the north side of the Wrangell Mountains, the area remained a favorable target for mineral exploration until the late 1970's. Much of this activity, especially in the later years, was driven by the search for *porphyry* copper-molybdenum deposits—large, low-grade concentrations of the minerals pyrite (FeS_2), chalcopyrite ($CuFeS_2$), and molybdenite (MoS_2) disseminated through a granitic intrusion. Typically, porphyry deposits also contain gold and silver as byproducts. The first porphyry copper-molybdenum deposit was discovered as early as 1899 at Orange Hill near the terminus of the Nabesna Glacier; by the 1940's, it had been explored by tunnels and drilling. The deposit occurs in the border zone of a large mid-Cretaceous granitic pluton—the Nabesna pluton—that intrudes the Pennsylvanian and Permian Tetelna Volcanics, Permian Mankomen Group, and the Triassic Nikolai Greenstone and younger Triassic limestones. The sulfide minerals locally have been oxidized, forming brightly colored outcrops, as the name of the deposit implies. Subsequent geologic studies and mineral exploration indicated that similar plutons and host rocks occurred in a belt that extended about 60 mi east of the Orange Hill deposit nearly to the Canadian border. Metal values in the porphyry deposits are quite variable: some bodies contain mostly molybdenum, some contain both molybdenum and copper, and some contain mostly copper. By the late 1960's four additional porphyry copper-molybdenum deposits had been discovered and explored. These deposits are Bond Creek (in the Nabesna pluton) and Carl Creek, Baultoff and Horsfeld (in the Klein Creek pluton). Together, Orange Hill and these four deposits contain about 1 billion t of ore running about 0.2–0.3 percent Cu and 0.02 percent Mo, grades too low to encourage development. In the Chisana pluton, a smaller porphyry system also underlies Gold Hill; the pluton lies in about the center of the productive placer deposits of the Chisana district, and erosion of the porphyry system or peripheral veins may have provided much of the gold for the surrounding placers.

Geological Sketches of a Few Notable Spots

The Nabesna Road

The present Nabesna Road branches off from the Glenn Highway at the small community of Slana and ends at the Nabesna mine about 46 mi to the southeast (fig. 50). A National Park Service Visitor Center is located in Slana; all visitors should check in prior to driving the road for information on current road conditions, land status, and facilities. The Nabesna Road originally was built in the 1920's to carry supplies in to the mine and haul gold ore out. At that time, it extended all the way to the Richardson Highway near Gakona, a distance of about 105 mi. The western part of the original road was later incorporated into the Slana-Tok Cutoff portion of the Glenn Highway that was constructed during World War II to provide a direct link to Anchorage from the newly built Alaska Highway. At the present time, the Nabesna Road is maintained for year-round travel as far as Devils Mountain Lodge near mile 43.

The first 25 mi of the Nabesna Road traverses the northeasternmost extension of the Copper River Basin separating the Mentasta Mountains to the north from the Wrangell Mountains to the south. Leaving Slana, the road is built mostly on extensive, flat-lying *alluvial* deposits of the Slana and Copper Rivers until about Rufus Creek (mile 7), where it climbs up on a bench underlain by lake deposits of glacial Lake Atna. In this area, shorelines of the glacial lake record two prominent lake levels at about 2,450 ft elevation and at about 2,300 ft. On the south side of the road just before mile 9 is the turnoff to Batzulnetas; the vestiges of this 19th century Native village are on private property on the north bank of the Copper River about 2 mi from the Nabesna Road. The road continues over relatively flat terrain underlain by various deposits of glacial Lake Boomerang, including lake-modified glacial moraine and related alluvial deposits.

The occasional cleared areas along this first 12 mi of the road afford exceptional views to the south of the ice-capped western Wrangell volcanoes (fig. 50). Lofty Mt. Sanford volcano (16,237 ft, 300,000–900,000 years old) and its older diminutive neighbor, Capital Mountain volcano (7,731 ft, 1 million years old) are best visible near Slana. Farther to the east, the bare jagged summit of Tanada Peak (9,358 ft) is a remnant of Tanada volcano (1–1.5 million years old). The dark massif or "island" conspicuous on the lower flanks of the Wrangell Mountains west of Tanada Peak lies near the headwaters of the Copper River and is made up of older lavas (about 2 million years old) whose source is unknown.

At about mile 17, the road climbs a short steep hill onto unmodified moraine. The top of the hill just past mile 18 affords good views of the west end of the Mentasta Mountains, here underlain by ancient lava flows and volcaniclastic rocks of the Pennsylvanian and Permian Tetelna Volcanics of the Skolai magmatic arc. In places along this west end of the Mentasta Mountains, uplift and erosion have exposed diorite intrusions and metamorphic rocks that formed deep in the core of the Skolai arc. The small area of conspicuous bright color that lies part way up the Mentasta's mountainside is an area of pyrite (FeS_2) rich rock that has been altered by oxidation.

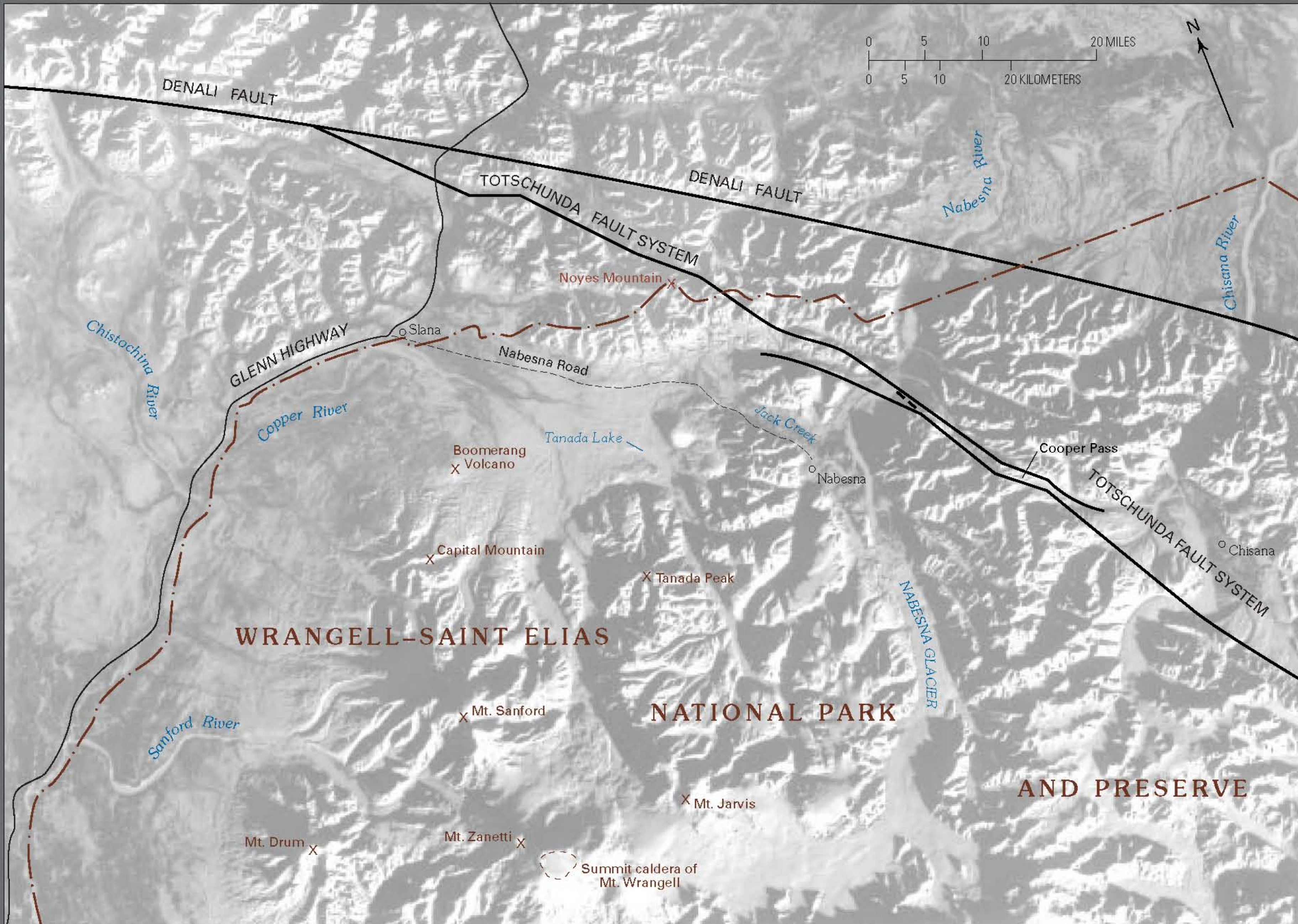
The road continues southeast mostly on hilly morainal deposits, occasionally crossing areas of alluvial deposits from streams flowing off the Mentasta Mountains. At Rock Lake (mile 22), an old unmaintained trail leads about 3 mi up into the headwaters of Rock Creek where the only known Alaskan deposit of corundum (Al_2O_3) occurs. The corundum is present as gray crystals as much as 2 in. long in thin alkali *pegmatite* dikes cutting metamorphic rocks of the Skolai arc.

Just past Long Lake, the road ascends a fairly steep morainal hill, the top of which (mile 23) marks a major drainage divide between the Copper River, which flows south into the Pacific Ocean, and tributaries of the Yukon River, which ultimately flows west into the Bering Sea. From the divide area, there are excellent views to the south of the ice-clad summit of Mt. Jarvis (13,421 ft, 1–1.7 million years old), the jagged volcano of Tanada Peak, and—farther to the east—the broad shield of the Skookum Creek volcanic center (2–3 million years old). After leaving the divide, the road descends to the *alluvial fan* of Little Jack Creek, winds around the Twin Lakes, and then crosses the extensive alluvial fans of Trail Creek (mile 29) and Lost Creek (mile 31). **(If these streams are running high, which they occasionally do in the summer after heavy rains, caution is advised.)** The absence of vegetation on the Trail and Lost Creek fans affords good views of the Mentasta Mountains to the north; they are underlain by the dark lavas of the Triassic Nikolai Greenstone and capped by contrasting light-colored Triassic limestones (fig. 51). Beyond, the higher peaks expose shale and sandstone of the younger Jurassic and Cretaceous Nutzotin Mountains sequence.

After crossing the fan at Chalk Creek (mile 33), the road begins a slight descent into the relatively narrow and fault-controlled Jack Creek valley that separates the Boyden Hills to the north from the Skookum Creek volcanic center of the Wrangell Mountains to the south. The Boyden Hills are composed of ancient lava flows and volcaniclastic rocks of the Pennsylvanian and Permian Tetelna Volcanics that have been intruded by a large Cretaceous granodiorite pluton. Locally, a few lava flows and pyroclastic rocks from the Skookum Creek center overlie the older rocks of the Boyden Hills. East of mile 33, glacial terraces form prominent hillside benches just above brushline on both sides of the road; they are particularly conspicuous in the Boyden Hills on the north side of the valley. The road crosses Jack Creek near mile 36 and continues high on the south side of the valley, crossing a number of steep alluvial fans from streams that drain the rugged Wrangell Lava terrain, before reaching Devils Mountain Lodge near mile 43.

Nabesna Mine

Figure 49 (facing page). The Nabesna mine at the end of the Nabesna road. View is to the northeast from one of the mine adits high above the mill (left) and the camp (center). Waste rock (tailings) from the mill covers the nearly barren area downhill to its left. The Nabesna mine produced about $1.8 million in gold between 1930 and 1940 from small, high-grade pockets of polymetallic ore in Triassic carbonate rocks near contacts with a mid-Cretaceous intrusion. *(D.H. Richter)*



0 5 10 20 MILES
0 5 10 20 KILOMETERS
N
DENALI FAULT
DENALI FAULT
TOTSCHUNDA FAULT SYSTEM
TOTSCHUNDA FAULT SYSTEM
Nabesna River
Chisana River
Noyes Mountain
Slana
Chistochina River
GLENN HIGHWAY
Nabesna Road
Copper River
Jack Creek
Tanada Lake
Boomerang Volcano
Nabesna
Cooper Pass
Chisana
Capital Mountain
Tanada Peak
NABESNA GLACIER
WRANGELL–SAINT ELIAS
NATIONAL PARK
AND PRESERVE
Mt. Sanford
Sanford River
Mt. Jarvis
Mt. Drum
Mt. Zanetti
Summit caldera of Mt. Wrangell

Figure 51 (page 100). The Mentasta Mountains after a summer snow shower. View is up Lost Creek valley. Peaks in foreground are composed chießy of Triassic Nikolai Greenstone and light-colored Triassic limestone. Higher peaks in distance are composed of sandstone and shale of the Jurassic and Cretaceous Nutzotin Mountains sequence. Triassic limestone here is only about 650 ft thick, much thinner than its correlative rocks (Chitistone Limestone, Nizina Limestone, and McCarthy Formation) along the south side of the Wrangell Mountains. *(D.H. Richter)*

Figure 52 (page 101). Volcanic vent in the 2Ð3 million-year-old Skookum Creek volcanic center near the end of the Nabesna Road; the valley of Jack Creek is in the background. Actual vent is Þlled with bedded, dacitic pyroclastic debris. Dark-colored rocks on ridge to right of vent are younger andesitic lava ßows that lap onto the vent. Note person standing on the ridge crest. *(D.H. Richter)*

Figure 50 (above and facing page). Satellite image of a northwest part of WrangellÐSaint Elias National Park and Preserve taken February 11, 1979. The approximate locations of some settlements, rivers, creeks, glaciers, and peaks discussed in the text are shown. The Nabesna Road runs southeastward from Slana near its junction with the Glenn Highway to the Nabesna mine, following the valleys of the Copper River and Jack Creek. Several of the major volcanic centers in the western Wrangell Mountains can be seen in this image. The pronounced linearity of topographic depressions formed along the Denali and Totschunda faults are conspicuous in the upper half of the view. *(U.S. Geological Survey Landsat 2 image)*

On the south side of the road at mile 36.3, near the base of a large yellowish rhyolite dome of the Skookum Creek volcanic center, a trail provides access into the bowels of this 2–3 million-year-old volcano (fig. 52). Excellent exposures of dome lavas, pyroclastic deposits, dikes, and other volcanic features can be viewed from the trail. The trail begins at an elevation of about 2,900 ft and extends approximately 2.5 mi to an elevation of about 5,000 ft.

Devils Mountain Lodge at the end of the maintained Nabesna Road is the home of the Ellis family who homesteaded here in the late 1950's. The lodge, which has its own airstrip, offers visitors a variety of services, including flightseeing, guided hunting and fishing trips, and overnight accommodations.

An unmaintained road extends about 2-3 mi beyond the lodge and crosses some wet boggy areas. The road may be impassable to some vehicles, but it provides a decent walkway for access to some interesting geologic features and viewpoints of the Nabesna River valley. Less than a mile from Devils Mountain Lodge, a trail takes off on the right and climbs through spruce forest to the abandoned Rambler mine located at the base of nearly vertical cliffs of massive Triassic limestone. The mine attempted to exploit a mass of gold-bearing pyrrhotite (iron sulfide) that formed in the limestone as a result of the intrusion of a small Cretaceous quartz diorite pluton. The main road continues on to the Nabesna mine camp (fig. 49), which was a flourishing community between 1930 and 1940. The mine is privately owned. Some camp buildings still are used; however, the mill is in disrepair and the tram system that transported ore from the mine adits hundreds of feet above in the limestone cliffs is mostly down. The ore body, similar in origin to the Rambler mine deposit, but much larger and more complex, consisted chiefly of gold-bearing pyrite associated with numerous metamorphic minerals including garnet, diopside, and magnetite.

The Nabesna mine overlooks the broad valley of the Nabesna River that separates the Boyden Hills and the Mentasta Mountains on the west from the more extensive and higher Nutzotin Mountains on the east. The prominent triangular peak at the east end of the Boyden Hills is Devils Mountain, part of the Cretaceous pluton that underlies much of the Boyden Hills. Beyond the Boyden Hills are shale and sandstone of the Jurassic and Cretaceous Nutzotin Mountains sequence that locally exhibit the bright-yellow colors characteristic of oxidized iron sulfide minerals. The peaks in the Nutzotin Mountains directly across the river are capped by light-colored Triassic limestone; the darker rocks below are mostly basaltic lava flows of the Triassic Nikolai Greenstone. The Totschunda fault system, an active structural feature, cuts through the mountains behind the limestone-capped peaks and separates these older rocks from the younger Nutzotin Mountains sequence that forms the higher mountains in the distance. On the skyline farther south is a sharp, unnamed 11,000-ft peak that is the erosional remnant of a 7-million-year old volcano.

Cooper Pass and the Totschunda Fault System

Cooper Pass (fig. 53), a few miles southeast of the end of the Nabesna Road, is a low divide that separates the Nutzotin and Wrangell Mountains. Trails of gold-seekers enroute to Chisana from the west still are visible in the pass. Cooper Pass and the valley of Totschunda Creek, immediately to the west in the Mentasta Mountains, are occupied by a major crustal break—the Totschunda fault system. Indeed, it is the weakening and rupturing of the crust along the fault that have aided erosion in producing the topographically low passes and valleys, which have allowed both ancient and modern peoples to travel with relative ease through the mountains.

The Totschunda fault system (fig. 9), made up of a number of discrete dextral strike-slip faults, branches off the Denali fault in the mountains northwest of Wrangell–Saint Elias National Park and Preserve and extends southeasterly on a straight course through the Mentasta Mountains and between the Nutzotin and Wrangell Mountains for more than 100 mi (fig. 50). It appears to end in the higher elevations of the Saint Elias Mountains, where it may evolve into the Duke River thrust fault extending east into the Yukon Territory of Canada (see fig. 36). On the south side of the Saint Elias Mountains, however, the young Fairweather fault—also a young strike-slip fault—is almost directly on trend with the Totschunda, suggesting that these two major structures may actually connect.

Glacial deposits offset by the Totschunda fault system (fig. 54) indicate rates of movement of about 0.8 in./yr for the past 10,000 years. If this rate prevailed back in time, then the apparent total movement of 6 mi along the Totschunda fault system could have been accomplished in 500,000 years. Hence, the available evidence suggests that, like the Fairweather fault to the south, the Totschunda also is a geologically young structure. Faster rates, which certainly are possible, would of course make the fault system even younger.

Movement along the Totschunda fault system may have begun in response to the continued push of the Pacific plate at a time when subduction was impeded because of jamming by the Yakutat terrane. This reduction in rate of subduction not only was responsible for the onset of faulting, but it also terminated voluminous magma production that was feeding the volcanoes of the Wrangell Mountains. At the present time, subduction of the Pacific plate still is slow, volcanism remains quiet, and parts of the Wrangellia composite terrane southwest of the Totschunda fault system that once were part of the North American plate are partially coupled to the Pacific plate.

Chitistone Gorge–The Goat Trail–Skolai Pass

The 5,000-ft-high canyon walls of the Chitistone River display in nearly continuous exposures much of the classic upper Paleozoic and lower Mesozoic stratigraphy of Wrangellia. The lower volcanic and upper sedimentary sequences of the Pennsylvanian and Permian Skolai Group (the Station Creek and Hasen Creek Formations, respectively) are spectacularly exposed in the Chitistone Gorge at the east end of the canyon (fig. 55), near where the river headwaters tumble over thick andesitic flows to form Chitistone Falls. These sequences were deposited in an intraoceanic island arc between about 310 and 265 m.y. ago. On the north side of the lower canyon, the overlying Triassic trinity of the Nikolai Greenstone, the Chitistone and Nizina Limestones, and the McCarthy Formation crop out from river level to the top of Chitistone Mountain, as well as on the south side of the canyon above Peavine Bar. The Nikolai Greenstone was extruded onto a subaerial volcanic plateau, beginning about 230 m.y. ago. The platform subsequently was inundated and covered by marine carbonate sediments, deposited first on intertidal mudbanks, but progressively in deeper water environments until about 200 m.y. ago. Immediately west of Grotto Creek, an anticlinal arch cored by the Nikolai Greenstone is overturned on its eastern limb and broken by a west-dipping thrust fault (fig. 21). This structure is typical of the folds and faults produced by the Late Jurassic and earliest Cretaceous orogeny that affected all of Wrangellia. Overlying the deformed upper Paleozoic and lower Mesozoic units of Wrangellia above a markedly angular contact are Cretaceous sedimentary rocks of the Kennicott and Moonshine Creek Formations (fig. 56). These marine conglomeratic sandstones and mudstones indicate deposition in high-energy conditions near the shoreline of a transgressing sea, beginning about 125 m.y. ago. Many strata in the Moonshine Creek Formation near the head of Contact Gulch are abundantly fossiliferous, containing pelecypods, gastropods, and ammonites of several varieties. Overlying the Cretaceous rocks above a slightly angular contact are Miocene *lignitic* sedimentary rocks of the Frederika Formation and Miocene to Holocene andesitic to dacitic flows and tephra of the Wrangell Lava. The erosional surface beneath these sequences dips shallowly northeastward truncating successively older pre-Tertiary units. From about 0.5 mi east of Chitistone Falls to Skolai Pass and lower Russell Glacier, all outcrops are Wrangell Lava, including the rugged ramparts and pinnacles of aptly named Castle Mountain. For more than 90 mi west of Skolai Pass, from Nizina Glacier (fig. 57) to the Copper River Basin, the entire crest of the Wrangell Mountains consists of volcanic or intrusive rocks produced in the vast Neogene volcanic field.

The path over the Goat Trail and Skolai Pass has existed since the gold rushes of the late 19th century, forming a rugged segment of one route from Valdez to the White River followed by the ebb-and-flow of argonauts to and from the Klondike or the Fortymile mining districts on the Yukon River. Early in the 20th century, the route also was used by some stampeders to the Chisana gold rush on the north flank of the Wrangell Mountains.

Totschunda Fault System

Figure 53 (page 104). Vertical to overturned thin-bedded Triassic limestone strata in Cooper Pass. Beds have been deformed by movement along the Totschunda fault system. Note person standing in creek bed. *(D.H. Richter)*

Figure 54 (page 105). View northwest from Totschunda Creek in the foreground along the topographic depression that marks the course of the Totschunda fault system through the Mentasta Mountains. Young fault movement is marked by the offset glacial deposits in the low area immediately beyond the bend of Totschunda Creek. *(D.H. Richter)*


TOTSCHUNDA FAULT

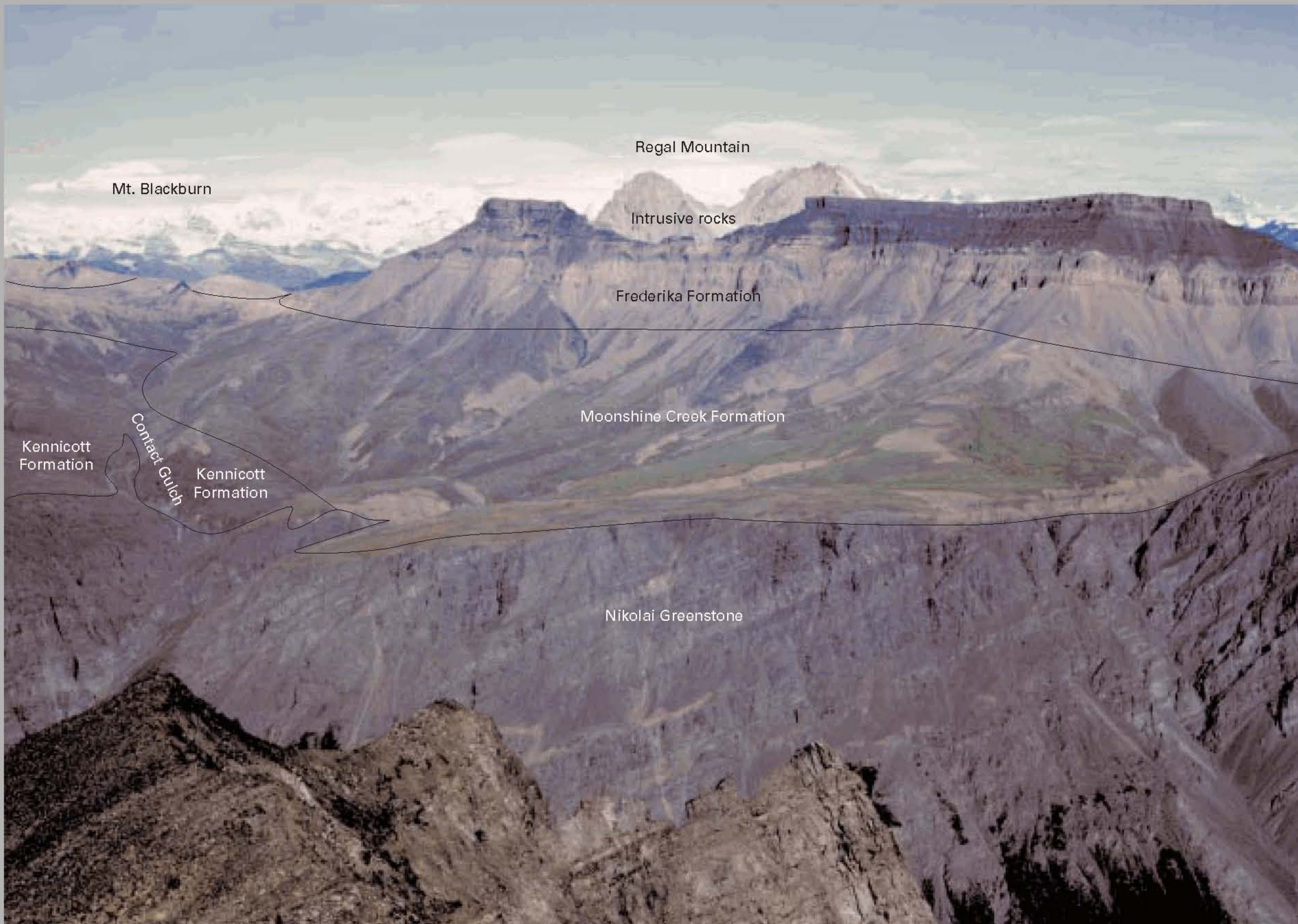
Chitistone River Canyon

Figure 55 (facing page). The south side of the upper Chitistone River canyon, where Permian marine mudstone, sandstone, and marble of the Hasen Creek Formation (Skolai Group) in the foreground are strongly folded and faulted and are intruded by Triassic gabbroic plutons in the upper right and middle left. These plutons probably crystallized from magma chambers that fed the overlying extrusive basalt of the Nikolai Greenstone, which makes up the ridge on the skyline. *(E.M. MacKevett, Jr.)*

Figure 56 (page 108). View, to northwest, of the upper walls of the Chitistone River canyon; Contact Gulch on the left. The trail to Skolai Pass is out of view at the base of the canyon walls. The canyon is cut in west-dipping basalt flows of the Triassic Nikolai Greenstone, which are overlain above an angular unconformity by shallowly east dipping Cretaceous marine sedimentary rocks of the Kennicott and Moonshine Creek Formations. The Cretaceous rocks form the subdued slopes in the middle ground and are overlain with slight angularity by the flat-lying nonmarine sedimentary rocks of the Tertiary Frederika Formation, which form the conspicuous mesas. Subvolcanic intrusive rocks form the two rugged peaks rising behind the mesas, and the snow-covered summits of Mt. Blackburn (left) and Regal Mountain (center) form the distant skyline. *(G.R. Winkler)*

Figure 57 (page 109). View, to north, of Nizina Glacier in the eastern Wrangell Mountains. Chimney Mountain, eroded from flat-lying flows of the Wrangell Lava, is the conspicuous peak just to the left of center. The Regal and Rohn Glaciers, principal tributaries of the Nizina, enter the main glacier on the left and right sides of Chimney Mountain, respectively, creating *medial moraines* of differing colors below their merger. In the 1913 gold rush to Chisana, the shortest route from the Chitina River Valley ascended 20 mi directly up Nizina and Rohn Glaciers, then descended 20 mi down Chisana Glacier on the north side of the mountains to emerge in the vicinity of the diggings. The trail was named after George C. Hazelet, its founder and principal booster, who also established a roadhouse at the head of Whiskey Hill Glacier near the summit (out of view behind Chimney Mountain) for the aid of the stampeding argonauts. *(G.R. Winkler)*


Gabbro
Nikolai Greenstone
Gabbro
HASEN CREEK FORMATION


Regal Mountain
Mt. Blackburn
Intrusive rocks
Frederika Formation
Moonshine Creek Formation
Contact Gulch
Kennicott Formation
Kennicott Formation
Nikolai Greenstone


Chimney Mountain
ROHN GLACIER
REGAL GLACIER
NIZINA GLACIER

Volcanoes of the Wrangell and Saint Elias Mountains

On a fair-weather day, the view to the east from the Glenn, Richardson, and Edgerton Highways in the Copper River Basin between Slana and Chitina is dominated by four glacier-clad volcanoes: Mt. Sanford (16,237 ft, fig. 58), Mt. Drum (12,010 ft, fig. 59), Mt. Wrangell (14,163 ft, fig. 60), and Mt. Blackburn (16,390 ft, fig. 61). Although these mountains rise from a welter of ridges that themselves reach elevations of more than 6,500 ft, their volcanic edifices are so large that they dwarf the landscape at their bases. The volcanoes in the western Wrangell Mountains all are less than 5 million years old and have retained much of their volcanic shape.[8] They compose the west end of the Wrangell volcanic field that began to form about 26 m.y. ago and now covers much of the higher elevations of the Wrangell and Saint Elias Mountains in southern Alaska and northwest Yukon Territory, an area of about 4,000 mi^2.

At least 12 eruptive centers, mostly large shield volcanoes, have been recognized in the Alaskan part of the field. In general, the oldest eruptions began in the Sonya Creek area near the Alaska-Yukon border, and migrated northwestward until about 200,000 years ago, when vigorous activity ceased in the Mt. Drum and Mt. Wrangell areas. Although Mt. Wrangell still is considered to be active, it has produced no documented lava flows in the past 10,000 years. It does, however, discharge hot gases at the summit and locally exhibits occasional *phreatic* explosive activity from a number of small summit craters that temporarily blanket the ice-covered summit area with ash (fig. 60). Only one other volcano, Mt. Churchill near the Alaska-Yukon border, has been active in the past few thousand years. A small caldera near the summit of Mt. Churchill was the source of two large *plinian* eruptions of the White River Ash about 1,890 and 1,250 years ago (fig. 62). The smaller and older ash lobe spread mainly northward and the larger, younger lobe spread eastward, reaching as far as the Northwest Territories in Canada. In aggregate, the two lobes of White River Ash blanketed an area of more than 130,000 mi^2 with about 12 mi^3 of ash. Other evidence of relatively recent magmatic activity may be a group of warm springs or mud volcanoes centered about 18 mi west of Mt. Drum in the Copper River Basin (fig. 63). These springs discharge warm (14°–50° C), saline mud highly charged with carbon dioxide and have built large mounds rising 150–350 ft above the surrounding terrain. Intermittently, the discharges can be quite vigorous, spurting mud as much as 30 ft above the vents. The thermal activity suggests the presence of a cooling magma body in the underlying crust, but is not considered to be precursory to a volcanic eruption. However, the CO_2 in the discharged gases kills animals, birds, and trees in the vicinity of active springs and poses a life-threatening hazard to human visitors, too.

Mt. Sanford

Figure 58 (facing page). Mt. Sanford (16,237 ft), viewed from the southwest. The mountain's massif is more than 12 mi across and consists of coalescing flows from at least three earlier eruptive centers beginning about 900,000 years ago, upon which were extruded voluminous flows from a central vent. Some of these overlying flows, which are undated, may have been extruded as recently as 100,000 years ago. The earlier West Center forms a slight notch in the left-hand skyline and the spectacular gash of the south face of the volcano, more than 8,000 ft high, displays the flows from the central vent, which may have filled a summit crater. The ridge in the foreground consists of undated andesite flows that emanated from fissures on the flanks of Mt. Wrangell, out of view to the right. *(G.R. Winkler)*

[8] For more extensive discussion, readers are encouraged to consult: Richter, D.H., Rosenkrans, D.S., and Steigerwald, M.J., 1995, Guide to the volcanoes of the western Wrangell Mountains, Alaska—Wrangell-St. Elias National Park and Preserve: U.S. Geological Survey Bulletin 2072.


Snider Peak

Like its neighboring volcanoes, Mt. Drum is built mostly of andesite flows, but unlike its neighbors, it also erupted a number of dacite and rhyolite domes (fig. 59). Thus, it has more the form of a stratovolcano than a shield volcano. It was constructed in two major eruptive cycles between 700,000 and 250,000 years ago. Subsequently, the top and south face of Mt. Drum were destroyed in a cataclysmic explosive eruption, probably about 150,000 years ago. Higher Mt. Sanford (fig. 58) is largely ice covered, which hides details of its eruptive history. It was constructed between about 870,000 and 320,000 years ago, largely of coalesced andesite flows from a number of centers. Mt. Blackburn (figs. 4, 61), the oldest of the western group and considerably dissected, consists of a thick sequence of andesitic flows that were intruded between 3 and 4 m.y. ago by large plutons that may represent part of the subvolcanic magma chambers.

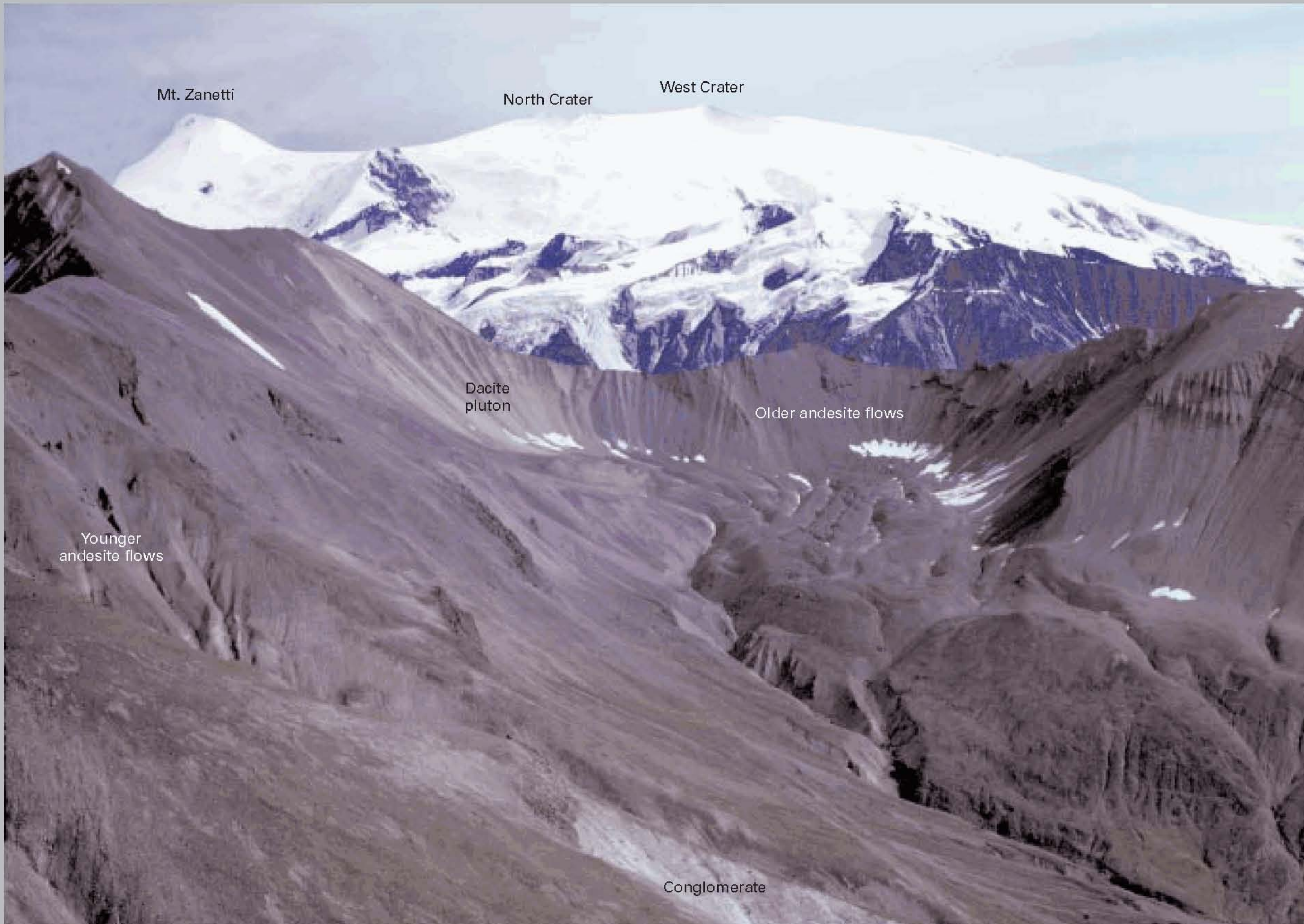
Other large and high volcanoes are present in the Wrangell volcanic field, but are not visible from the main highway system. Mt. Jarvis (13,421 ft), largely hidden from view behind Mt. Sanford and Mt. Wrangell, can be seen best from the Nabesna Road between miles 13 and 20. It developed between about 1.7 and 1.0 m.y. ago. The pyramidal summit of Regal Mountain (13,845 ft), which rises in a remote location in the easternmost Wrangell Mountains, is the source for a radiating series of major valley glaciers. It can be glimpsed at the head of Root Glacier from near McCarthy. The age of this volcano has not been determined. In the western Saint Elias Mountains, rising above the heads of the Russell, Klutlan, and Hawkins Glaciers, are Mt. Bona (16,421 ft), Mt. Churchill (15,638 ft), and University Peak (14, 470 ft). They cannot be seen from any park roads. Other than the caldera on Mt. Churchill, which erupted the young White River Ash, the Bona-Churchill massif is apparently constructed of older andesitic lava flows of unknown age. University Peak is eroded mainly from a subvolcanic granodioritic intrusion that is about 8.4 million years old. The Miocene intrusion is so homogeneous and so little jointed that it has weathered into nearly sheer faces on all sides. Finally climbed in 1955, it was the last major peak within the parklands to be summitted.

Mt. Drum

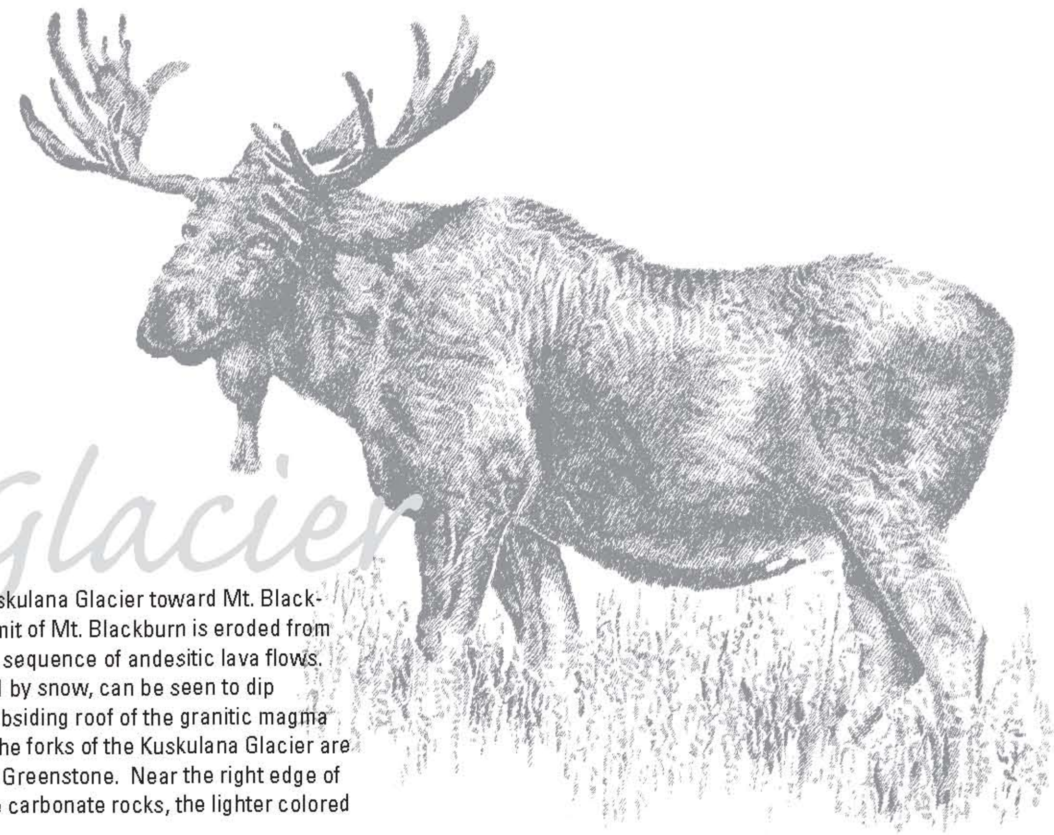
Figure 59 (facing page). Mt. Drum (12,010 ft), westernmost volcano in the Wrangell volcanic field, is a stratovolcano built in at least two eruptive cycles between about 700,000 and 240,000 years ago. Seen here from the southeast, its composite internal structure, consisting of lava flows and numerous separate domes, is conspicuous. Snider Peak, the conspicuous gray craggy summit on the left, apparently was the last dome to be formed. Its formation may be associated with the cataclysmic eruptions that destroyed much of the south face of Mt. Drum, producing pyroclastic flows and debris avalanches. The large Chetaslina volcanic debris and mud flow that is exposed along the Copper River from the Chetaslina River to the Chitina River also may be a result of these eruptions. This series of events was much like the catastrophic eruptions of Mt. St. Helens in 1980, but apparently removed a much larger volume of volcanic material. The hillside in the foreground consists of undated andesitic flows that emanated from fissures on the flanks of Mt. Wrangell; these flows, which fill paleovalleys on the flanks of the volcano, probably were erupted prior to 600,000 years ago, when the main shield of Mt. Wrangell began to form. *(G.R. Winkler)*

Mt. Wrangell

Figure 60 (facing page). Mt. Wrangell (14,163 ft), the youngest and still mildly active volcano in the western Wrangell Mountains, is a broad, ice-covered shield of enormous bulk. The view here, from the southwest, shows more than 9 mi of the volcanic edifice in the background, and only includes the highest part of the mountain. Snow-covered Mt. Zanetti (13,009 ft), on the left skyline, is a large satellite cinder cone. Three small craters, containing active fumaroles, are situated on the rim of a summit caldera. North and West Craters can be seen here as dark mounds near the apparent summit; West Crater is dark because of fresh ash erupted between snowstorms in August 1969, when this view was taken, and North Crater also emits episodic small bursts of ash. Mt. Wrangell was built principally between about 600,000 and 400,000 years ago, but voluminous flows emanated from the southwest flank of the mountain as recently as 80,000–50,000 years ago. One of these flows extends at least 40 mi from the mountain, extending nearly to the mouth of the Kotsina River near Chitina. In this view, the ridges in the left foreground consist of conglomerate of Pleistocene age (light-gray color) overlain by andesite flows (shades of purplish dark gray) that probably were erupted prior to 600,000 years ago. Unconformably beneath these flows and conglomerate, in the middle and right foreground, is a still older volcanic complex, consisting of andesite flows and volcaniclastic rocks that have been intruded by dacite dikes and small plutons. The intrusions have been dated at about 1.35 million years old. This Pleistocene and Pliocene? complex may be related to the Chetaslina vent on the southwest flank of Mt. Wrangell, which was active from about 1.5 to 1.0 m.y. ago. *(G.R. Winkler)*


Mt. Zanetti
North Crater
West Crater
Dacite
pluton
Older andesite flows
Younger
andesite flows
Conglomerate


Andesitic lava flows
McCarthy Formation
Chitistone, Nizina
Limestones
3.4 Ma pluton
Nikolai Greenstone
KUSKULANA GLACIER



Kuskulana Glacier

Figure 61 (facing page). View to northeast up moraine-covered terminus of the Kuskulana Glacier toward Mt. Blackburn (16,390 ft), the highest peak in the Wrangell Mountains. The broad, domal summit of Mt. Blackburn is eroded from a subvolcanic granite pluton approximately 3.4 million years old that intrudes a thick sequence of andesitic lava flows. In this view, flows on the west flank of the mountain, the ledges of which are defined by snow, can be seen to dip inward beneath the domal summit, suggesting collapse of a filled caldera into the subsiding roof of the granitic magma reservoir. The basal ridges of Mt. Blackburn (without snow cover) that lie between the forks of the Kuskulana Glacier are composed of east-dipping, maroon-weathering basaltic flows of the Triassic Nikolai Greenstone. Near the right edge of the view, the Nikolai Greenstone is overlain by scattered outcrops of Triassic marine carbonate rocks, the lighter colored Chitistone and Nizina Limestones and the McCarthy Formation. *(G.R. Winkler)*

White River Valley

Figure 62 (facing page). The Holocene White River Ash in the White River valley. View is to the northeast looking across the White River in Yukon Territory, Canda. All the light-colored patches in this view are volcanic ash, not snowbanks. The blanket of ash here is about 3 ft thick and is chiefly from the older, north lobe of the White River Ash, erupted about 1,890 years ago from Mt. Churchill, 25 mi to the southwest. Sunlight-dappled slopes in middle ground are about 6 mi across. *(D.H. Richter)*

Smaller or lower volcanic centers are present along the north flank of the Wrangell Mountains and are most readily viewed to the south from various points along the Nabesna Road. These include the dissected volcanoes of Tanada Peak, Boomerang Volcano, and Capital Mountain that were constructed between 1.5 and 1.0 m.y. ago. Skookum Creek Volcano (fig. 52), near the east end of the road, is the only volcano accessible by road. A geological trail, beginning at mile 36.3, offers opportunities to examine flows, domes, vents, dikes, and other features formed by diverse volcanic processes. These remnants of the Skookum Creek Volcano were formed originally between 3.2 million and about 2.0 m.y. ago.

Volcanism in the Wrangell volcanic field is linked to subduction of the Pacific oceanic plate along with the piggybacking Yakutat terrane. The volcanism began in the late Oligocene or early Miocene, about 26 m.y. ago. For the first 10–12 million years, the angle of subduction was oblique, and volcanic activity may have been sporadic and restricted to a few large centers. The 20-million-year-old Sonya Creek volcanic center north of the White River, however, contains the largest caldera known in the Wrangell volcanic field, and the volume of material erupted from the center was huge. About 5 m.y. ago, the rate of plate convergence increased, and the angle of subduction became less oblique. This change coincided with greatly increased magma production in the west end of the Wrangell volcanic field, where all of the immense andesitic shield volcanoes were constructed between 5 million and 0.2 m.y. ago. Although some underthrusting of the Pacific plate continues today, much of the stress imposed by northward motion of the Pacific plate is presently relieved by movement along the strike-slip Fairweather and Denali-Totschunda fault systems, effectively stopping the generation of magma in the crust. Evidence further suggests that movement on the Fairweather and Totschunda faults may have been initiated 100,000–200,000 years ago or about the time voluminous magma production ceased. Reasons for this change are not well understood. It may be a consequence of the progressive jamming of the Yakutat terrane, forcing the stress of the Pacific plate convergence to be relieved by faulting rather than by subduction.

Copper River Canyon–Copper River Basin

The course of the Copper River is a real anomaly: Alaska's third largest river reaches the Gulf of Alaska by cutting a deep canyon directly across one of the State's ruggedest ranges, the youthful Chugach Mountains (fig. 64; see also fig. 67). It seems likely that the river is antecedent—that is, the position of its canyon was established before uplift of the coastal ranges. As the mountains began to rise in the Miocene Epoch about 15 m.y. ago, the ancestral Copper River was able to erode at an equal pace. As the rate of uplift increased in the last 5 million years or so, the already incised river still maintained its course—until a complicated Quaternary history of damming by glaciers in its middle and lower canyons interrupted its flow episodically, impounding Lake Atna in the Copper River Basin. The presence of the glacial lake is indicated not only by the accumulated lacustrine sediments, now exposed in many places in river bluffs within the Copper River Basin, but also by the ancient shorelines formed at several levels around the margins of the basin. The shorelines indicate positions at which the lake was stable for extended periods.

The bedrock and unconsolidated fill of the Copper River Basin is permanently frozen in most places, a condition called permafrost, or permanently frozen ground. It may extend to depths of 165–245 ft in the central Copper River Basin. Seasonal thawing of the upper 1–2 ft of the unconsolidated fill creates widespread quagmires, bogs, ponds, and landslides, because the water remains near the surface above the permanently frozen materials beneath. Permafrost presents obstacles to standard engineering procedures: once thawing is initiated, it is difficult to arrest or reverse, and differing properties of the diverse unconsolidated materials lead to unpredictable foundation conditions (fig. 65). Most engineering solutions attempt to shield or insulate the ground from thawing or to artificially freeze or refreeze it. In areas of permafrost, the Alaska pipeline has been elevated on insulated piers, not buried, as is the normal pipeline construction practice. Modern buildings and highways have been placed on thick gravel pads. Where engineering solutions were inadequate, however, differential settlement, sloughing, or catastrophic slope failures have resulted. A drive on the highways of the Copper River Basin may be the best indicator of the difficulties posed by differential melting of ice-rich permafrost: bulges, depressions, and cracks require perpetual repair of damage induced by disruption of the permafrost conditions beneath.

Figure 63 (facing page). Aerial view of the lower Klawasi mud volcano in the Copper River Basin about 11 mi east of Glennallen. The summit pond, which is about 100 ft in diameter, is filled with warm saline mud that is agitated continually by exsolving carbon dioxide. *(D.H. Richter)*

The Copper River canyon was a major obstacle to overcome in building the Copper River and Northwestern Railway to transport the ore from the McCarthy area mines (fig. 66). Many sagas have developed around the construction achievements between 1906 and 1911, when the railroad was completed. The successful completion of the 1,500-ft "Million Dollar Bridge" less than 2 days before spring breakup brought the seasonal onslaught of broken river ice and pent-up icebergs from Miles Lake is well documented and also well dramatized in Rex Beach's 1912 novel, "The Iron Trail." Perhaps equally dramatic from a geological perspective was the successful placement of track across the ice-cored terminal moraines left from recent advances of the Childs, Grinnel, Miles, Heney, and Allen Glaciers (fig. 67). To go around these features directly upriver from the Million Dollar Bridge would have involved very expensive rock work and two additional bridges across the Copper River, so track was laid directly across the moraines. In most places, little excavation was needed and the morainal debris served as insulating material. For a stretch of 5 mi on Allen Glacier, however, the track was laid directly on the stagnating tongue of the glacier, which supported dense alders and other brush. At first, the builders stripped the moraine—a mistake. It became necessary to place tons of gravel on top of the ice to replace the insulating cushion of moraine. This stretch of track, however, also was subject to constant advance of the glacier, so it had to be reset and replaced frequently. Trackwalkers preceded each train, and trains crept across. There was a minor surge of Allen Glacier in 1912, which necessitated extra repairs, but, thanks to constant railbed maintenance, the trains kept moving through the lower canyon. In the upper canyon, from the mouth of the Tasnuna River to Chitina, practically the entire line required excavation in bedrock. The heaviest rock work was in Woods Canyon just downriver and opposite the Indian village of Taral, where many thousands of cubic feet of bedrock had to be dynamited to form cuts and tunnels. The railroad grade has been heavily invaded by alders and other brush, and all bridges have collapsed partially or been washed out entirely. The grade provides a possible footpath down the Copper River, although it is difficult and river and stream crossings are dangerous.

Copper River Canyon

Figure 64 (facing page). View of the upper end of the Copper River canyon, looking northeast. The Wrangell Mountains form the skyline, dominated by Mt. Blackburn (16,390 ft), the highest point. The Chitina River Valley, an easterly extension of the Copper River Basin, separates the Wrangell Mountains from the Chugach Mountains in the foreground. Spirit Mountain (7,287 ft) is the sharp peak at the right edge of the view (foreground). The summit of Spirit Mountain is eroded from north-dipping higher grade metamorphic rocks of the Wrangellia terrane, which were emplaced above a thrust fault (the Border Ranges fault) upon lower-grade argillite and metasandstone of the Chugach terrane, exposed lower on the mountain. The Chitina and Copper Rivers join just off the left edge of the view and flow southward toward the viewer to cross the axis of the Chugach Mountains in a canyon that reaches depths in excess of 7,700 ft. *(G.R. Winkler)*

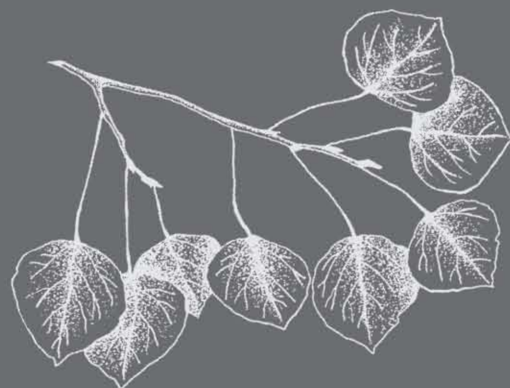
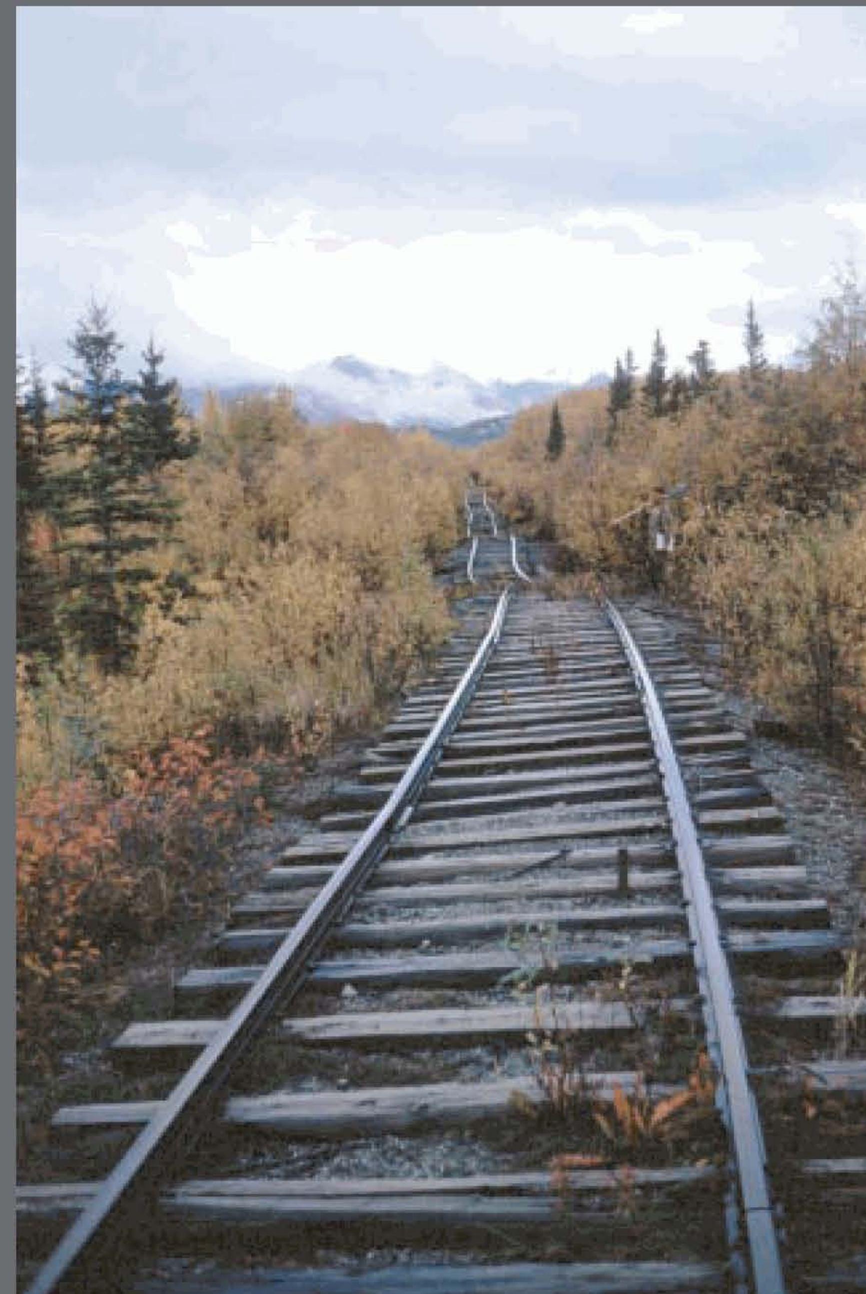


Figure 65. Differential subsidence of the roadbed along the Copper River and Northwestern Railway about 9.5 mi east of Chitina and 3 mi west of Strelna. Fine-grained sediments underlying the roadbed were disturbed during construction, and ice-rich permafrost began to thaw, causing subsidence and lateral displacement; this section of the roadbed required frequent maintenance. The photograph was taken in 1960, decades after the 1938 abandonment of the railroad. *(L.A. Yehle)*

Figure 66 (facing page). Looking west down the Bremner River to its confluence with the Copper River. The Copper River flows from right to left directly across the axis of the Chugach Mountains, an indication that the drainage is antecedent, or predates the major uplift of the mountain range. During Pleistocene (and possibly Pliocene) time, the Copper River repeatedly was blocked by glacial dams in its lower canyon (out of view to the left). Only within the past few hundred years have the Miles, Allen, and Childs Glaciers retreated sufficiently that the dams have been breached, and the sediment deposited immediately behind the glacial dams (the light-gray unvegetated areas in this view) has been exposed. Upriver, the Copper River canyon (out of view to the right) becomes increasingly narrow and little sediment remains on the floor of the canyon. The Copper River and Northwestern Railway (CRNWR) followed the west (far) bank of the river in this area, crossing the ice-cored moraine of the Heney Glacier at its terminus (just left of center). The instability of the roadbed caused by seasonal melting of the ice necessitated frequent maintenance and resetting of the tracks. The roadbed was abandoned in 1938 and the rails removed later. *(G.R. Winkler)*




Heney
Glacier
CRNWR
COPPER RIVER
BREMNER RIVER

The McCarthy Road

The McCarthy Road (fig. 67) extends 62 mi eastward from Chitina to the west bank of the Kennicott River near McCarthy. Prior to traveling the road, visitors can acquire information at the Wrangell–Saint Elias National Park headquarters in Copper Center or the Ranger Station in Chitina. Much of the land along the McCarthy Road is privately owned. For the most part, the road follows the grade of the Copper River and Northwestern Railway, which was completed in 1911 to ship ore from the Kennicott area to tidewater at Cordova on Prince William Sound. The railroad was abandoned in late 1938, and part of the track was removed and recycled during World War II.

After crossing the Copper River just upriver from its confluence with the Chitina River, the McCarthy Road first passes through some sandy dune fields. These *eolian* deposits probably were formed over many hundreds of years from material derived from the Copper and Kotsina River floodplains by sustained, high-velocity winds that blow up or down the Copper River, depending upon atmospheric pressure gradients between the coast and the interior. Intertonguing glacial, alluvial, and lacustrine deposits fill the Copper River Basin to thicknesses exceeding 1,000 ft. The Copper River and its tributaries have deeply eroded these deposits to form steep bluffs extending many miles (fig. 68). The bluff ascended by the road exposes a thick section of glacial-*fluvial* and glacial-lacustrine deposits, which are topped by eolian deposits thousands of years older than those on the floodplain below. Locally, these sequences contain thin ash beds and a thick volcanic debris flow derived from nearby volcanoes. The debris flow, which is well exposed in roadcuts going up the bluff and also in the bluffs along the north side of the Kotsina River upstream from the Copper River bridge, contains a chaotic mix of angular clasts, some as large as houses, of variously colored volcanic rocks. The flow probably resulted from the cataclysmic eruption that destroyed the top and south face of Mt. Drum volcano some 150,000 years ago.

After ascending the steep bluffs, the McCarthy Road meanders eastward through the broad Chitina River Valley (fig. 69), alternately passing over complex arrays of unconsolidated glacial, lacustrine, *paludal*, eolian, or alluvial deposits that fill this extension of the Copper River Basin. Although from a distance this land surface looks deceptively flat, it actually is quite irregular, due to elevated morainal remnants, *kames*, *kettles*, *eskers*, possible wave-cut shorelines of glacial Lake Atna, lake- and swamp-filled depressions, dune ridges and deflation hollows, and gravelly terraces and channels of former glacial meltwater streams. Bedrock forms knobs and ridges in many places, indicating that the surface underlying the unconsolidated deposits also is very irregular. A pullout at mile 3.9 has a sweeping view to the south of the Chugach Mountains and the well-entrenched Chitina River at the foot of a steep, east-sloping bluff eroded from the Triassic Chitistone Limestone. Continuing east, the road passes through cuts that successively expose bedrock of the Triassic Nikolai Greenstone and Chitistone Limestone, metamorphosed volcanic rocks of the late Paleozoic Skolai arc, and granodiorite of the Late Jurassic Chitina arc.

At mile 16.5, southeast of Strelna, the road crosses the Kuskulana Bridge, spanning the 240-ft-deep gorge of the Kuskulana River. The gorge is eroded through glacial deposits into metamorphosed volcanic rocks of the Skolai arc. At one location, downriver from the bridge crossing, pillowed forms are preserved in the metavolcanic rocks, indicating that they were deposited under water—presumably on the submarine apron of the Skolai arc. In fair weather, the ice-clad summit of Mt. Blackburn is visible from the south end of the bridge. Between mile 19 and mile 23, several road cuts expose interlayered alkalic gabbro and orthogneiss, unusual rock types that also underlie all of Gilahina Butte directly south of the road. These rocks are believed to be the metamorphosed intrusive equivalents of the metavolcanic rocks exposed in the Kuskulana River gorge.

At mile 28.5, the road crosses the Gilahina River, passing on the left the remains of an old wooden railroad trestle, originally 880 ft long and 80–90 ft high. The trestle required a half million board feet of lumber, but was constructed in only 8 days in January 1911. As the road turns southward, an excellent view of Nelson Mountain, south of the Chitina River, opens up. Nelson Mountain is composed of north-dipping strata of metamorphosed upper Paleozoic volcanic rocks and limestone. In early January 1993, a huge landslide, 2.8 mi long, 0.7 mi wide at its toe, and covering about 1.5 mi^2, broke loose from near the top of the mountain and coursed 4,300 ft down the northeast flank. The slide apparently was not triggered by an earthquake. It slid about one-third of the way across the Chitina River before coming to rest. The outermost part of the slide is currently being eroded and channeled by the river and the landslide scar is gradually being degraded and vegetated also. However, it will remain a conspicuous feature for many years, and landslides may recur because large fractures remain in the headwall breakaway zone of the slide; adjacent bedrock is favorably oriented for additional slope failures.

At approximately mile 35, on the slopes of the Crystalline Hills north of Moose Lake, is a large light-gray fault-bounded mass of metamorphosed Permian limestone that contrasts with the somber dark gabbro and orthogneiss that make up most of the rest of the Crystalline Hills. Where the road crosses Crystal Creek at about mile 42, a small outcrop of the gabbro is present on the north side of the road, and at mile 48 the Permian limestone is well exposed near an historic wooden railroad trestle site. At mile 50, the broad opening of the Lakina River valley provides an excellent view to the north of Mt. Blackburn in the background, as well as the conspicuously layered andesitic flows of the Wrangell Lava that make up Castle Peak.

For the easternmost 15 mi of its route to McCarthy, the road passes almost exclusively through diverse unconsolidated deposits. Fireweed Mountain forms the conspicuous ridge to the north of the road between milepost 52 and 60. It is eroded from dark-gray Cretaceous marine mudstone of the Chititu Formation, the same formation that makes up Sourdough Hill southeast of McCarthy, as well as most of the ridges farther southeast between Dan and Young Creeks. On Fireweed Mountain and throughout its extent, the Chititu Formation is thoroughly intruded by light-gray porphyritic sills, dikes, and small plutons of granitic rocks. These granitic rocks are believed to be shallow-seated intrusive phases of the Wrangell Lava. Much larger related plutons underlie Porphyry Mountain and Sourdough Peak east of McCarthy and much of Mt. Blackburn, where they range in age from at least 8.6 to 3.4 million years old; some bodies may be even younger, inasmuch as they intrude as high as the upper part of the Wrangell Lava on Mt. Blackburn. A small outcrop of Chititu Formation occurs along the McCarthy Road where it dips into Swift Creek at approximately mile 58.5.

At mile 62, the road ends on the west bank of the Kennicott River, which tumbles through bouldery outwash of the Kennicott Glacier, the source of the river a short distance to the north. Footbridges cross two channels of the Kennicott River at the east end of the road, providing access to McCarthy about 0.5 mi east of the footbridges, and Kennicott, which is located about 5 mi north of McCarthy. Camping, parking, meals, guided river trips, shuttle service, and lodging are available in the McCarthy or Kennicott areas. Air charters are available from McCarthy; reservations are recommended.

Wrangell–Saint Elias

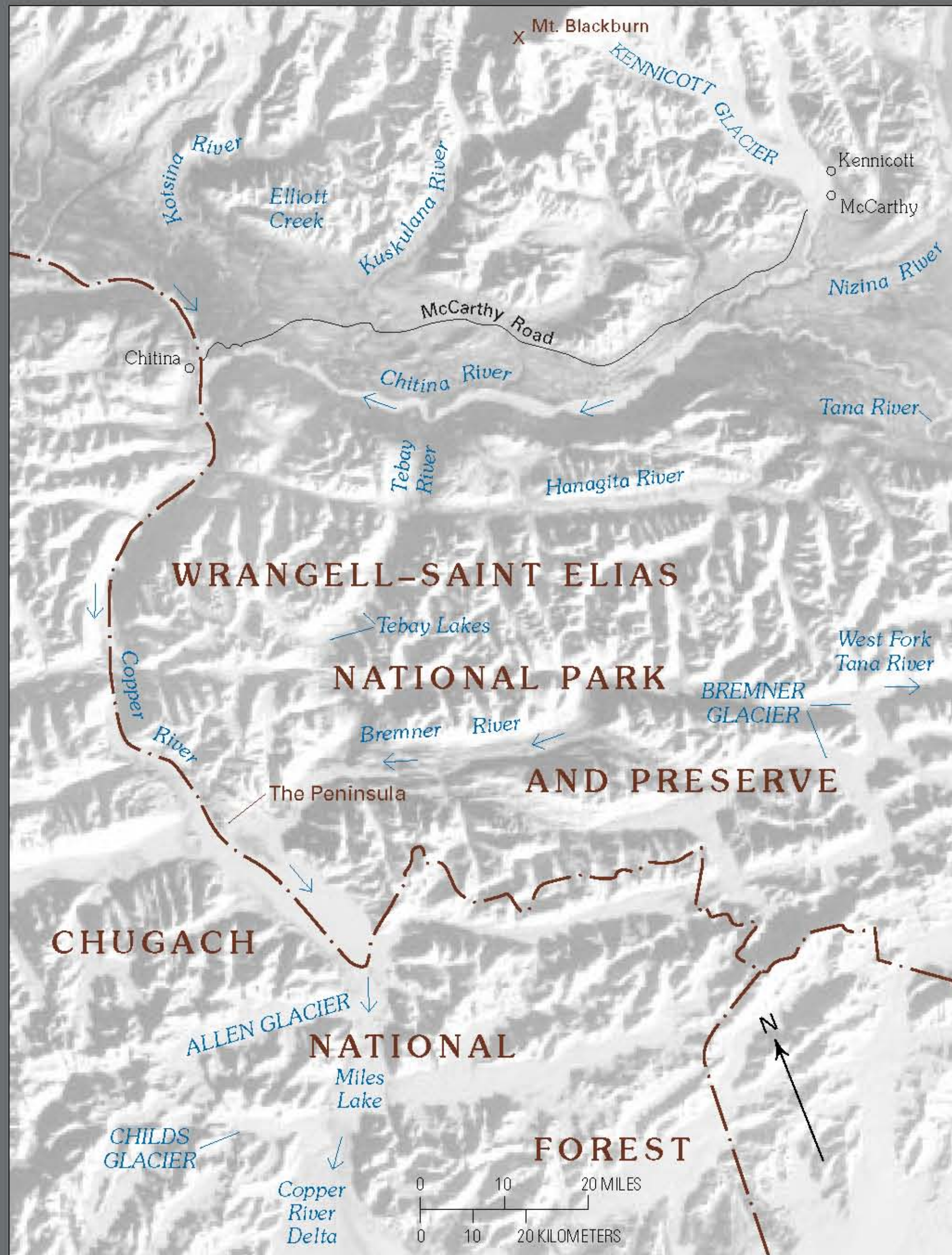
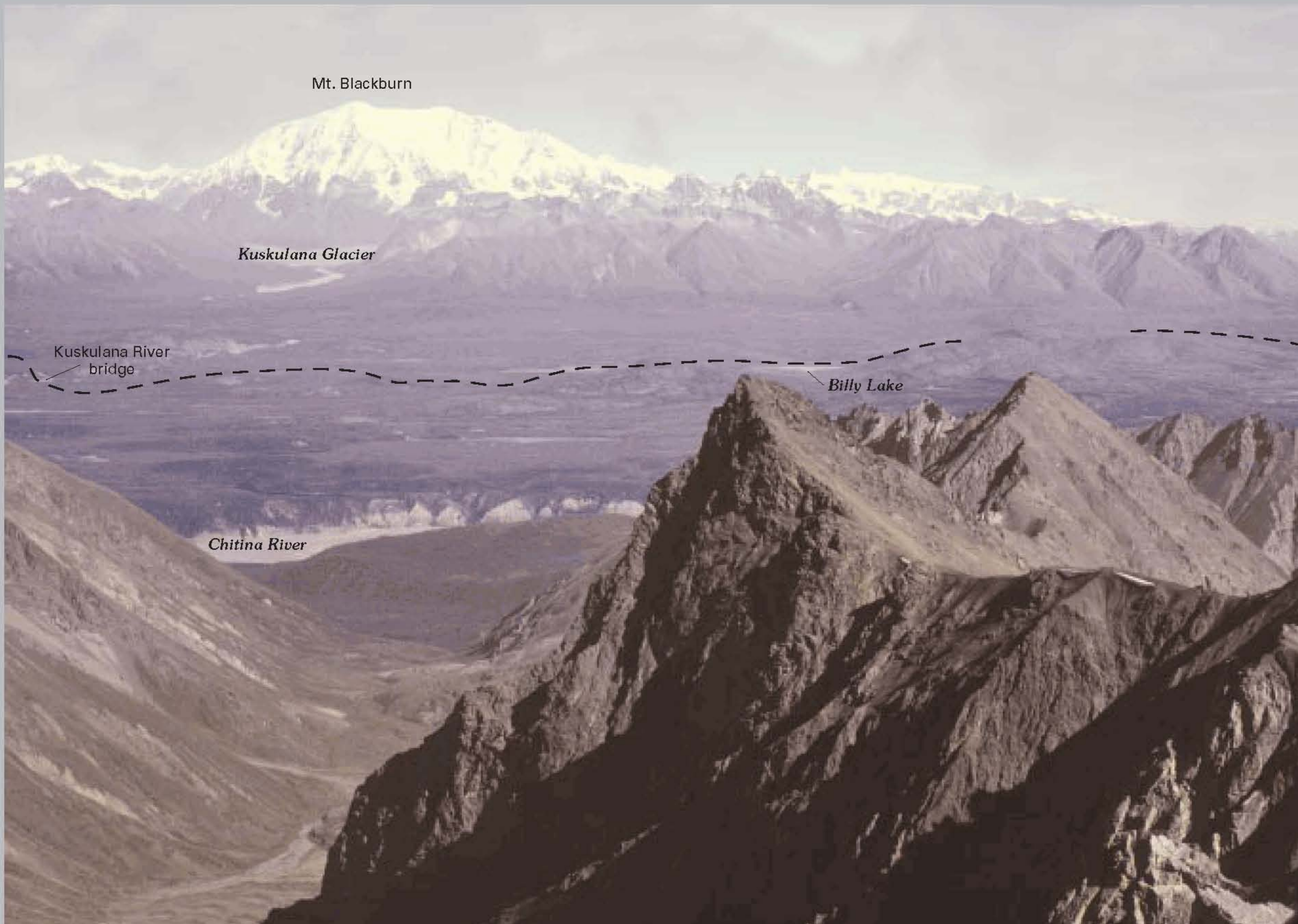


Figure 67. Satellite image of a southwest part of Wrangell–Saint Elias National Park and Preserve taken February 20, 1979. The approximate locations of some settlements, rivers, creeks, lakes, glaciers, and peaks discussed in the text are shown. The McCarthy Road follows the lowlands of the Chitina River Valley in the upper third of the view. Arrows indicate direction of flow of rivers. *(U.S. Geological Survey Landsat 2 image)*

Figure 68 (page 130). Bluffs along the Tazlina River just upstream from the Richardson Highway north of Copper Center expose about 200 ft of mainly alluvial and lacustrine deposits of Quaternary age. The alluvial deposits, consisting of well-sorted gravel interlayered with minor sand beds, are the darker colored beds above river level and in the middle of the section. Each section of gravel and sand represents a time when no lake was present in this part of the basin. The gravel along the river in the foreground is a present-day equivalent of those deposits. The lower alluvial beds in the section include the thin distal edge of the Sanford volcanic debris flow (v), the lighter colored lens less than 3 ft thick near the base of the bluff in the center. The debris flow, containing numerous clasts of andesite, originated from a collapsed dome on the eastern flank of Mt. Drum and invaded a river valley that was much like the present one, but which existed about 200,000 to 300,000 years ago. Overlying each major alluvial unit are conspicuous lighter colored beds of fine sand, silt, and clay which indicate that a lake first encroached upon and then completely inundated the area. The younger of these lakes was glacial Lake Atna. Coarser grained lake deposits, including diamicton perhaps deposited when a glacier invaded this part of the lake, occupy most of the upper part of the section. *(H.R. Schmoll)*

Figure 69 (page 131). The Chitina River Valley from the northern slopes of the Chugach Mountains. The McCarthy Road follows the lowlands directly behind Billy Lake just to the right of center. (Dashed line indicates approximate alignment of the road.) The lake-filled depressions, bedrock knobs, and complexly intertonguing lenticular surficial deposits of the valley floor (exposed locally in the Chitina River bluffs) indicate the former presence of glaciers that filled the entire valley. In the background, ice- and snow-clad Mt. Blackburn (16,390 ft), the highest peak in the western Wrangell Mountains, is a broad volcanic dome and caldera constructed of lava flows intruded by subvolcanic plutons between about 4.2 and 3.4 m.y. ago. The moraine-covered terminus of the Kuskulana Glacier can be seen at the foot of Mt. Blackburn. The peak rises above rugged ridges eroded from Paleozoic and Mesozoic units of the Wrangellia terrane. The sharp ridges in the foreground are eroded into metamorphosed Paleozoic rocks of the southern margin of the Wrangellia terrane as well as Jurassic plutons of the Chitina magmatic arc. *(G.R. Winkler)*

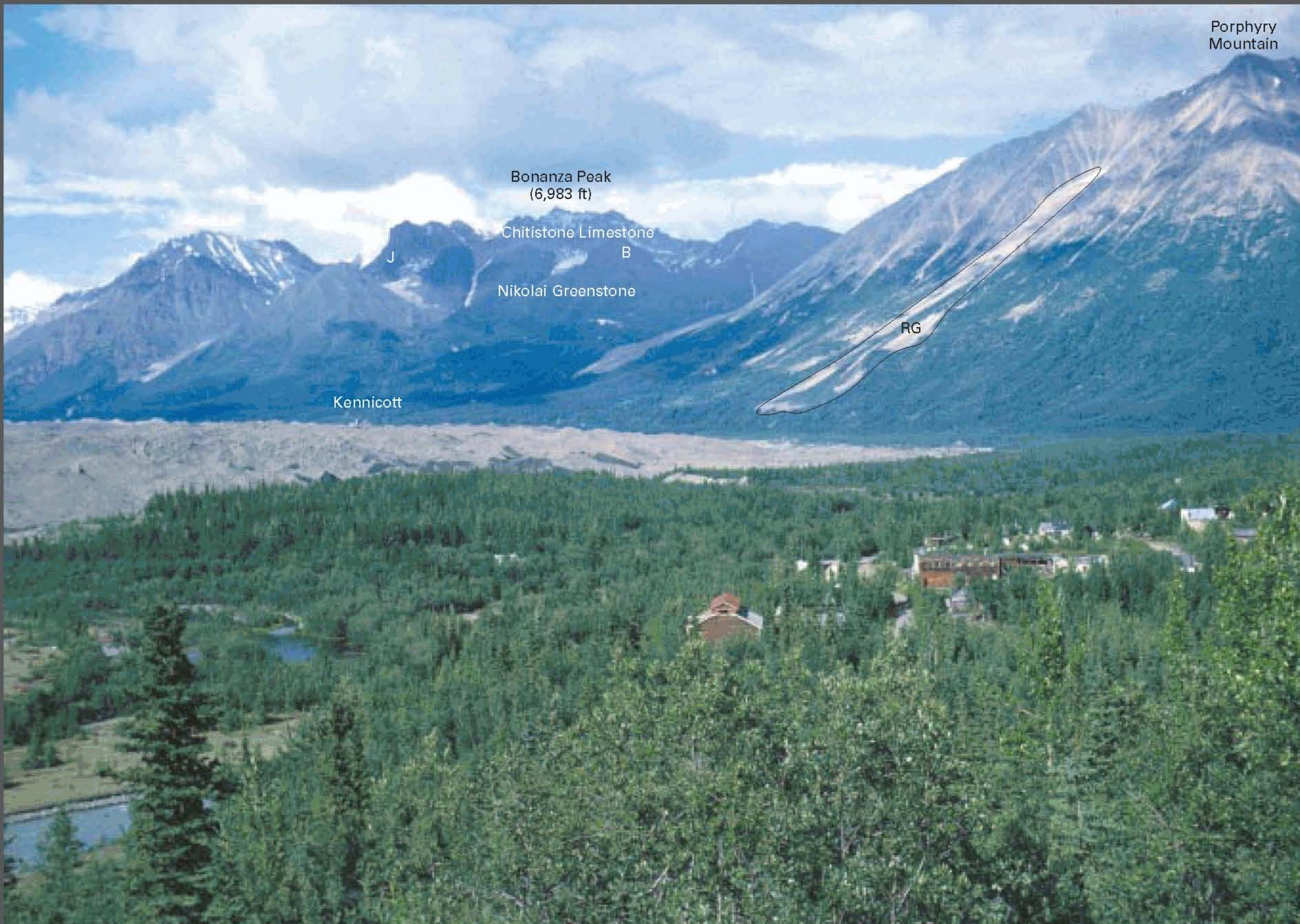

V


Mt. Blackburn
Kuskulana Glacier
Kuskulana River
bridge
Billy Lake
Chitina River

Kennicott Glacier and Kennicott River

The terminus of Kennicott Glacier is just a short walk northwest from the historic town of McCarthy (fig. 70). The short, turbid Kennicott River emerges in two principal channels from beneath the glacier carrying a heavy load of "rock flour," or suspended sediment, derived from the glacier's erosive action. The lower part of the glacier, too, is "dirty," being completely covered by morainal material for more than 4 mi above its terminus. The Kennicott Glacier has thinned and receded since its maximum modern advance about 1860. Since 1909, the time of surveys for the Copper River and Northwestern Railway grade, the glacier has retreated more than 2,000 ft, an average annual rate of about 20 ft. It also has thinned near its terminus, perhaps by as much as 175 ft. Photographs taken in the early 1900's during active mining show a significantly higher ice surface for areas near the Kennicott mill. The mill site, where copper ore from the Bonanza, Jumbo, Mother Lode, Erie, and Glacier mines was processed, is located just above the east edge of the moraine-covered glacier at the mouth of National Creek, about 4 mi above the glacier's terminus. On the west edge of the glacier, about 9 mi from its terminus, the ice-free tributary valley of Hidden Creek is dammed by the Kennicott Glacier, creating a lake that expands every summer. Five other smaller glacier-dammed lakes also form annually along the margins of Kennicott and Root Glaciers. The Kennicott River has annual late-summer floods caused by the sudden drainage of Hidden Creek Lake beneath the glacier. The other lakes also discharge abruptly, but their contribution to floods on the river is small. In recent years, the maximum discharge of the Kennicott

Figure 70 (facing page). The west edge of McCarthy and its surroundings, 1964, viewed to the north. McCarthy, in the right foreground, is the "wide-open" town that sprang into being in summer 1905 as company-run facilities were being developed at Kennicott 5 mi to the north. The moraine-covered lower end of Kennicott Glacier occupies the middle ground, and the Kennicott mill-site can be seen on its far edge. Bonanza Ridge makes up the central skyline, and Porphyry Mountain is on the right. The Triassic Nikolai Greenstone makes up the shoulders of Bonanza Ridge, overlain near the crest by the Chitistone Limestone. Porphyry Mountain is eroded from a porphyritic pluton about 9 million years old. The plutonic rock is thoroughly jointed and weathers into small fragments that move downhill slowly, forming concentrically furrowed piles of barren rubble, called rock glaciers (RG). The process is similar to glacial flowage: ice in the interstices of the rubble freezes and thaws, lubricating seasonal downslope movement. The episodic movement generally produces furrows paralleling the outline of the rock glacier's margin. The Jumbo mine (J) is located just above the greenstone-limestone contact beneath the prominent cliff to the left of center, and the Bonanza mine (B) is located just below the highest point on the ridge. Separate tramlines, each more than 3 mi long, connected the Bonanza and Jumbo mines with the mill nearly 4,000 ft below. To reach the mines from the mill, workers either hiked a 4-mi trail or rode the tramline buckets—a ride that could be dangerous but was much preferred to walking. During the peak years of production in the late 1910's and early 1920's, more than 300 miners were employed year-round, most of them living in facilities high on Bonanza Ridge near the mines. Winter conditions were particularly rigorous, of course, frequently keeping the miners indoors or underground. On occasions, destructive snowslides cut off communications with the mill for days, threatened bunkhouses, and destroyed tramline supports. The tramlines were rebuilt as soon as possible, so that the mill could return to operations around the clock. *(G.R. Winkler)*


Porphyry
Mountain
Bonanza Peak
(6,983 ft)
Chitistone Limestone
J
B
Nikolai Greenstone
RG
Kennicott


Mt. Blackburn
Donoho Peak
Chitistone and
Nizina Limestones
Overturned syncline
Valley of
Hidden Creek
KENNICOTT GLACIER
Nikolai Greenstone
ROOT GLACIER
Jumbo
tram station
Bonanza tramline
angle station

River during these outburst floods has ranged between about 18,000 and 32,000 cubic feet per second (cfs), compared to a normal mid-summer discharge of about 1,300 cfs. These outburst floods cause channel erosion, aggradation, and migration of the Kennicott River, interrupting transportation links and destroying property. Flood water discharges from numerous sites along the margin of the glacier, but over time, the net effect of the outburst floods has been to shift river drainage increasingly into the western channel. Bridges spanning the Kennicott River were frequently damaged or destroyed between 1911 and 1938 during operations on the Copper River and Northwestern Railway—repair costs were a significant part of the annual maintenance budget. In August 1974, an unusually abrupt and large flood destroyed a vehicle bridge across the western channel of the river, limiting subsequent access to McCarthy in the summer months to hand-propelled cable cars across the turbulent river. Replacement bridges, for foot traffic only, were completed across both channels in 1996. The increasing concentration of discharge into the west channel poses a potential hazard to facilities on the west side of the river; channel migration and discharge volumes are being closely monitored.

The 27-mi-long Kennicott Glacier (fig. 71) heads on the east face of Mt. Blackburn (at 16,390 ft, the highest peak in the Wrangell Mountains) and the south faces of Rime Peak (12,741 ft), Atna Peaks (13,860 ft), and Parka Peak (13,280 ft). The south summit of Mt. Blackburn was first ascended in 1912 by Dora Keen and George Handy, assisted by John Barrett and several other McCarthy residents, including a team of dogs. The climbing party used Kennicott Glacier as their route of approach to the mountain. In its lower reaches, the Kennicott Glacier is joined from the north by two tributary glaciers, Gates and Root Glaciers. Unlike Kennicott Glacier, each tributary glacier has little surface moraine, and the ice is almost totally exposed. Each also has a steep, crevassed icefall; on Root Glacier, Stairway Icefall forms a striking scene from near Kennicott—particularly on a sunny day when the remarkably blue tint of the depths of its crevasses contrasts with the more normal white of the surrounding glacier.

Donoho Peak and the ridge extending to the north separate Gates and Root Glaciers. The north-dipping section exposes most of the definitive Triassic and Jurassic units of the Wrangellia terrane, overlain unconformably at the north end of the ridge by the Miocene Frederika Formation and the Miocene to Holocene Wrangell Lava. Donoho Peak is underlain by a conspicuous overturned syncline, which is cored by the Nizina Limestone, and forms a gray-colored zigzag on the east face of the peak (fig. 71).

The Kennicott Glacier was named in 1899 by Oscar Rohn, USGS, for Robert Kennicott, a pioneer Alaskan explorer and director of the Western Union Telegraph Expedition to the Bering Straits region in 1865. The Kennecott Copper Corporation, formed in 1915, took its name from the glacier, but inexplicably replaced the "i" with an "e."

Mt. Blackburn

Figure 71 (facing page). Mt. Blackburn (16,390 ft) looking west from Bonanza Ridge in the early autumn. Kennicott Glacier (at the base of Mt. Blackburn) and Root Glacier (in the middle distance) are separated by Donoho Peak. Beyond Kennicott Glacier near the left edge of the view is a valley formed by Hidden Creek. The lower end of Hidden Creek valley is ice free but is dammed by Kennicott Glacier to form Hidden Creek Lake. The 2-mi-long lake drains annually beneath Kennicott Glacier, usually between late July and early September, sometimes forming damaging outburst floods on the Kennicott River. Forming the south shoulder of Donoho Peak is the darker weathering Triassic Nikolai Greenstone, which is overlain by the lighter gray Chitistone and Nizina Limestones. An overturned syncline on the north flank of Donoho Peak forms a conspicuous zigzag in the limestone. This fold formed during Jurassic and Cretaceous mountain-building that affected much of coastal Alaska from the present Wrangell Mountains to southeastern Alaska. The richest copper lodes of the type found at the Kennecott mines occur in the lower part of the Chitistone, which has been intensively prospected throughout its extent in the Wrangell Mountains. This view is taken from above the angle station in the foreground where a tramline from the Bonanza mine on the ridge above changed directions around a massive flywheel for the rest of its 16,000-ft journey down to the mill on the edge of Kennicott Glacier. *(G.R. Winkler)*

Tebay Lakes

Tebay Lakes occupy a glacially sculpted drainage divide in the northern Chugach Mountains between tributaries of the Chitina and Bremner Rivers (fig. 72). The chain of lakes drains northward via the Tebay River to a confluence with the Chitina River. Curiously, Upper Tebay Lake is separated by an alluvium-filled flat only about 0.4 mi across from the vigorous southward-flowing Falls Creek, a tributary of the Little Bremner River. Upper Tebay Lake, and ultimately Middle and Lower Tebay Lakes, too, are threatened with stream piracy by headward erosion of the shorter, steeper drainage of Falls Creek. Such disorderly drainage patterns are widespread in the Chugach and Wrangell Mountains, where recent glaciation has remodeled earlier drainage patterns. The disordered patterns are called deranged drainage and are characterized by streams that drain both into and out of lakes, streams that follow circuitous indirect routes rather than short direct routes, swampy interstream areas, and poorly defined drainage divides. During times of deglaciation, nearby glaciers may recede at markedly different rates, such that one valley empties of ice while an adjacent valley remains plugged. Meltwater seeking to flow downhill is abundant, of course, but when its way is blocked by either glaciers or glacial moraines that fill preexisting channels, it finds an alternate path that may ignore valley morphology. A few miles northeast of the Tebay Lakes, the Hanagita River and its tributaries provide many examples of deranged drainages. The upper end of the Hanagita River is separated from the Klu River by only a narrow swampy muskeg, but instead of following its probable former path via the Klu and Chakina Rivers to the Chitina River, the Hanagita instead flows westward at a low gradient in and out of several lakes before joining the steep lower canyon of the Tebay River. Furthermore, Grant Creek, a short tributary which one might expect to drain directly northward into the Chitina River, instead flows southward into the Hanagita—definitely the long way around. A contemporary example of how this can happen is provided by the Bremner Glacier, which at its terminus divides into a western lobe, giving rise to the North Fork of the Bremner River, and an eastern or Tana lobe, giving rise to the West Fork of the Tana River. The two lobes of the glacier block, at its midpoint, a valley that undoubtedly in pre- or inter-glacial times held a single drainage that drained eastward into the Tana River. Now the head of the North Fork of the Bremner flows westward with a lazy gradient for 12 mi, suddenly plunging through Twelvemile Canyon to join the main Bremner River. Such two-way glaciers abound in the northern Chugach Mountains. Their complete melting would expose many additional deranged drainages.

On a clear sunny day in mid-July 1997, fishermen on Lower Tebay Lake reported their wilderness quietude interrupted by a loud rumbling noise. The glacier-fed tributary entering Tebay River just downstream from the lake's outlet abruptly flooded. Floodwaters were transporting and depositing mature spruce trees and boulders as large as 2 ft across on the alluvial fan at the confluence. A second flood occurred later in the same summer. These floods were triggered by sudden drainage from beneath the glacier at the head of the tributary and triggered debris flows that reached as far as the foot of the fan at the Tebay River. Lower Tebay Lake drains along the contact between this alluvial fan and bedrock. Aggradation on the fan during the two major glacial outburst floods in the summer of 1997 choked the outlet, causing the lake level to rise approximately 7 ft. Shoreline areas were inundated, and the lake volume increased by more than 1 billion gallons. According to residents, temporary fluctuations of lake level had occurred in the past, probably the result of similar but smaller floods and alluvial fan aggradation. Although the level of Lower Tebay Lake has dropped slightly since the 1997 events, the gradient of Tebay River below its outlet is very low and the river has little erosive capability. Apparently many years will pass before the river entrenches sufficiently to return the lake to its pre-1997 level.

Tebay Lakes

Figure 72 (facing page). Tebay Lakes occupy a glacially sculpted drainage divide in the Chugach Mountains; view is to the southwest. The foreground ridge consists of fault-bounded slices of metamorphosed sedimentary, volcanic, and plutonic rocks of the southern margin of the Wrangellia terrane. The glacier-clad crest of the Chugach Mountains in the background is carved from accretionary assemblages of the Chugach terrane. Tebay Lakes drain northward (from left to right in this view) past the viewer into the Chitina River, the "long way around," instead of directly southward into the adjacent valley of Falls Creek, a short, steep tributary of the Bremner River—a prime example of glacially deranged drainage. *(G.R. Winkler)*


Chugach terrane
Falls Creek
To the
Bremner River
To the
Chitina River
Wrangellia
terrane

Bagley Ice Field

The Bagley Ice Field (fig. 73) and its eastward extensions, the Columbus and Seward Glaciers, fill a remarkably linear trough in the interior of the Chugach and Saint Elias Mountains that stretches more than 125 mi from near Mt. Hawkins (10,291 ft) on the west to Mt. Vancouver (15,700 ft) on the east. For most of its length, the ice-filled feature is more than 4 mi wide; in places, it reaches widths of more than 15 mi; its thickness is not known, but probably exceeds 3,000 ft for much, if not all, of its length. Thus, its total volume of glacial ice is immense. The Bagley Ice Field spills seaward in piedmont lobes at its west end, the Bering Glacier, and its east end, the Malaspina Glacier, each of which is roughly the size of Rhode Island.

The Bagley trough is structurally controlled. For most of its length, it is underlain by the Contact fault system, a major accretionary boundary between the Mesozoic Chugach and Paleogene Prince William terranes (fig. 9). At its east end, the Contact fault is inferred to follow an arcuate bend southeastward under the Valerie Glacier to merge with the active Fairweather fault system. Within the parklands, there are no places where the Contact fault is exposed. Its linear trace suggests a steep, if not vertical attitude, and the trough-like morphology suggests a broad zone of sheared bedrock, more easily quarried by glacial ice. West of the parklands, the Contact fault system extends linearly under Martin River and Miles Glaciers to the Copper River canyon. Farther west beyond Childs Glacier, however, its trace is more sinuous, and where it is well exposed near Cordova Peak, the fault occupies a narrow zone and dips northward at only 30°. In the vicinity of Mt. Tom White, the Contact fault system is intruded by the 50-million-year-old Van Cleve pluton, which shows little, if any, offset across the projected trace of the Contact fault. Thus, we are confronted by the seeming inconsistency that, although the east end of the fault system merges with an active plate boundary (the Queen Charlotte–Fairweather transform fault system), the west end of the Contact fault system has been locked since Eocene time. Apparently, in the vicinity of Mt. St. Elias, post-Eocene motion of the Fairweather fault system has been transferred to a braided network of faults, including the Chugach–St. Elias, Coal Glacier, and Chaix Hills faults, and broken folds that are seaward of the Contact fault system. This complex fold-and-thrust belt connects, under the outer continental shelf, with the plate boundary in the Aleutian megathrust.

Icy Bay

Icy Bay (fig. 74) has been formed by rapid, post-1904 retreat of Guyot, Yahtse, and Tyndall Glaciers. At the beginning of the 20th century, the coast was nearly straight and coastal charts showed an “Icy Cape,” the nearly vertical front of a tidewater glacier that calved icebergs into the open Gulf of Alaska. A 95-year retreat, averaging about 0.3 mi/yr, has opened a multi-armed bay more than 31 mi long (fig. 43). If recession of Tyndall Glacier continues at that rate for another 30 years, sea-kayakers in Taan Fiord (fig. 1) will be able to step out almost at the base of Haydon Peak, less than 4 mi (20,000 ft horizontally) from its 11,945-ft summit. And the massif of Mt. St. Elias will be just a stone’s throw beyond that.

Longer term glacier recession in the vicinity of Icy Bay has exposed the nearly barren, but rapidly revegetating ridges of the Guyot, Karr, and Chaix Hills. The hills consist of virtually continuous exposures of Yakataga Formation. The presence of coarse ice-rafted detritus of local provenance in Miocene sections of Yakataga Formation indicates initial uplift of the coastal mountains and the presence of tidewater glaciers as long as 15 m.y. ago. Multiple local unconformities (sometimes called “megachannels”) and deformation in Pliocene and Pleistocene sections of Yakataga Formation in the hills indicate continuing episodic Neogene uplift, and the abundance of glacially derived detritus increases upsection. Uplifted marine (wave-cut) terraces at elevations of about 170, 80, and 50 ft in the vicinity of Icy Cape are dated at roughly 5,000, 2,500, and 1,300 years old, indicating continuing youthful uplift of the Icy Bay area at an average rate of about 0.4 in./yr for the last 5,000 years. Although some of this uplift may be due to non-tectonic rebound from unloading of glacial ice, most is tectonic and is attributable to stepwise uplift during major earthquakes. The 0.4 in./yr rate lags calculated long-term regional tectonic uplift rates. The Icy Bay area may be overdue for a major plate boundary earthquake that will elevate the land again, perhaps many meters at once, bringing the recalculated rate of uplift closer to the long-term rate.

Bagley Ice Field

Figure 73 (facing page). Evening view to the west from a camp near Juniper Island at the junction of the Tana and Jefferies Glaciers with the Bagley Ice Field. The Jefferies Glacier here is about 2.5 mi wide. It flows around the shoulder of Needle Mountain on the right to feed the Tana Glacier, source of the Tana River, the major southern tributary of the Chitina River. *(D.J. Miller)*


Mt. McPherson
Pt. Riou
GULF OF ALASKA
Malaspina foreland
Kichyatt Point
Karr Hills
Guyot
Hills
YAHTSE GLACIER

Malaspina Glacier

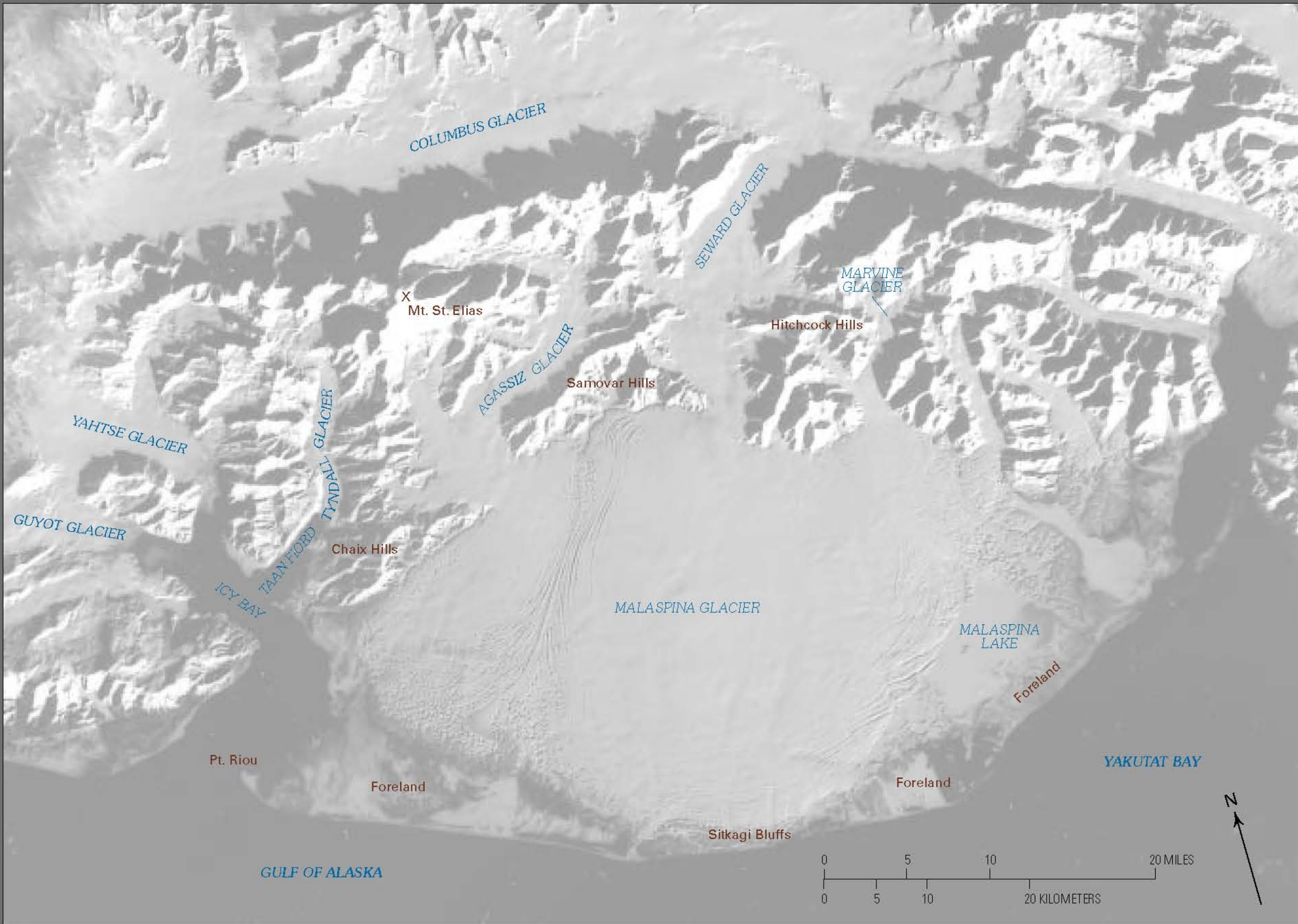
A broad coastal lowland extends about 50 mi between Icy Bay and Yakutat Bay. It consists of roughly triangular outwash plains on both sides of the bilobate Malaspina Glacier. The Rhode Island-sized piedmont glacier (fig. 75) is formed from the merger of the larger Seward Glacier lobe, which gathers most of its ice from the Mt. Logan area in Canada, and the much smaller Agassiz Glacier lobe, which gathers most of its ice from the Mt. St. Elias massif. Short, but high-discharge streams drain the entire perimeter of the stagnant glacier, and their high sediment load is rapidly expanding a foreland area seaward of the glacier.

Several climbing and exploratory expeditions to Mt. St. Elias in the late 1800's used the glacier foreland as routes of approach. Photographs taken during the expeditions showed stunning glacial features, features that have stimulated periodic studies throughout the 20th century and designation of Malaspina Glacier as a national natural landmark, principally because of the unusual patterns of its surface moraines. The recent glacial history of the Malaspina area includes a complicated chronology of advances and retreats (fig. 43). There has been little net change in the position of the central bulb of the Malaspina Glacier for more than 1,000 years. A mature spruce forest has grown on moraine that covers the stagnant ice. However, advances between A.D. 600 and 900 of Yahtse, Guyot, and Tyndall Glaciers filled Icy Bay, forming a northwestern lobe that merged with the Agassiz lobe. Advances between A.D. 970 and 1290 of Hubbard Glacier formed a southeastern Yakutat Bay lobe that merged with the Seward lobe. During these advances, Malaspina Glacier would have presented a continuous tidal front from west of Icy Bay to Yakutat, a village constructed on the terminal moraine from this advance. Mature spruce trees in the Yakutat area are about 600 years old, indicating that the Yakutat lobe of the Malaspina Glacier had begun to recede before A.D. 1400. The ice lobes in both Icy Bay and Yakutat Bay may have receded to near or upvalley from their present positions by about A.D. 1700, as shown by buried dated trees near Pt. Manby, and near Guyot, Lucia, and Hidden Glaciers. The legend of the Yakutat Natives that a large bay formerly extended nearly to the foot of Mt. St. Elias may originate from the deep recession in Icy Bay during this interval.

About A.D.1700, the glaciers began to advance rapidly again, reaching beyond the mouth of Icy Bay and to approximately Blizhni Point in Yakutat Bay. By Malaspina's visit in 1792, however, Hubbard Glacier had retreated again at least as far eastward as Haenke Island in Disenchantment Bay. In contrast, at the time of Vancouver's visit in 1794, today's Icy Bay was ice filled. In the 20th century, Icy Bay began to empty rapidly, but the position of Malaspina Glacier's central bulge has remained relatively stable. It must be a dynamic balance achieved by voluminous input of multiple ice streams heading in the St. Elias and Logan massifs, however, because many of Malaspina's tributary glaciers, as well as most glaciers in the Yakutat Bay area, show periodic short surges and retreats.

Surge cycles in such tributaries as Seward and Marvine Glaciers are responsible for the striking zigzag patterns exhibited by folded moraines on the Malaspina Glacier in such places as south of the Hitchcock Hills. Periods of instability in the tributary glaciers are marked by large-scale, but short-lived forward movement. Curiously, immediately adjacent glaciers can behave very differently: one glacier may surge forward while its neighbor is stable or even slowly retreats. Where such glaciers join, they can be strongly deformed below their point of merger, which is reflected in very complex patterns in the moraines on their surfaces.

Figure 74 (facing page). View of Icy Bay, looking south, taken in 1980 from above the terminus of the Yahtse Glacier. Karr Hills are on the left edge of the view, and Guyot Hills are on the lower right. The iceberg-choked inner bay indicates active calving of the tidewater glaciers surrounding the head of the bay. Open waters of the Gulf of Alaska are in the distance, separated from Icy Bay by the flat Malaspina foreland on the left. The compound recurved spit of Pt. Riou extends from the right end of the foreland—just barely visible behind the ridge on the skyline (in the upper center of the view), which descends from Mt. McPherson. Kichyatt Point, at the east end of the ridge, separates the inner and outer parts of Icy Bay. All bedrock in this view consists of the Yakataga Formation, fossiliferous glacial-marine siltstone, sandstone, and diamictite, that was deposited rapidly just seaward of an icebound and tectonically active coastline during the last 6 million years. *(George Plafker)*


COLUMBUS GLACIER
SEWARD GLACIER
MARVINE GLACIER
X
Mt. St. Elias
Hitchcock Hills
AGASSIZ GLACIER
Samovar Hills
TYNDALL GLACIER
YAHTSE GLACIER
GUYOT GLACIER
TAAN FIORD
Chaix Hills
ICY BAY
MALASPINA GLACIER
MALASPINA LAKE
Foreland
YAKUTAT BAY
Pt. Riou
Foreland
Foreland
Sitkagi Bluffs
GULF OF ALASKA
N
0
5
10
20 MILES
0
5
10
20 KILOMETERS

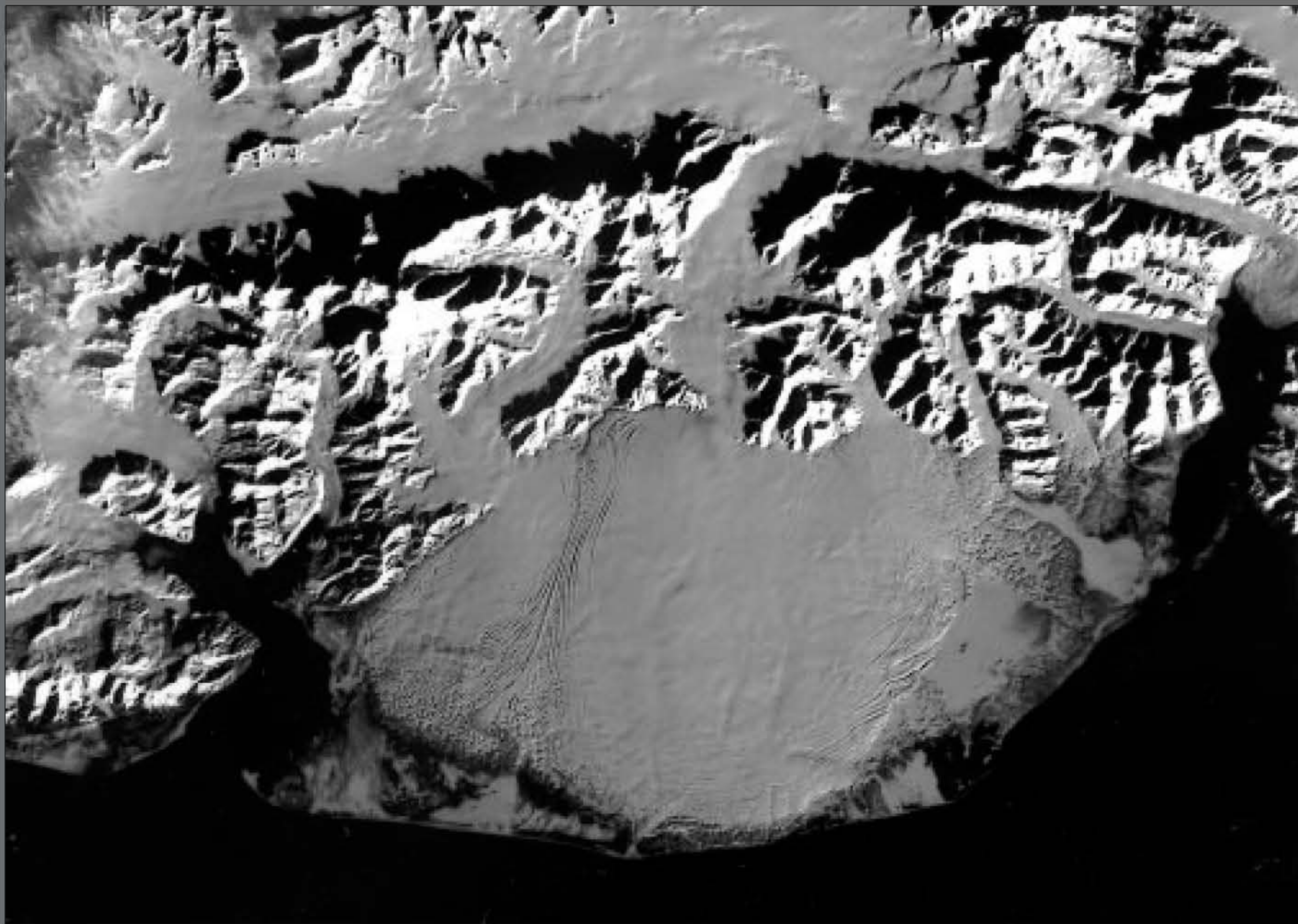


Figure 75. Satellite image of the Malaspina Glacier area taken February 17, 1979; north is at the top of the image and the Gulf of Alaska at the bottom. The multi-armed indentation of Icy Bay is conspicuous near the left edge of the photograph. It has formed by glacial recession since 1904. The lobes of the Agassiz and Seward Glaciers combine to form the enormous bulb of the Malaspina Glacier; the two major tributaries are separated by curving moraines derived from the Samovar Hills. The east edge of the Malaspina Glacier (on the right of this view) is covered by strikingly zigzagged moraines derived from the Hitchcock Hills area. The pattern of the deformed moraines indicates uneven motion between the Malaspina and Marvine Glaciers along their merger zone. Forelands formed by unconsolidated sediment are expanding seaward on both sides of the Malaspina Glacier. The western foreland now covers the area of a former coastal indentation called "Icy Bay" by Vancouver in 1794 (see p. 80 and fig. 43). *(U.S. Geological Survey Landsat 2 image)*

Disenchantment Bay–Hubbard Glacier–Russell Fiord

Hubbard Glacier (fig. 76; also see fig. 5) is North America's largest tidewater glacier; it has a face more than 6 mi wide that reaches heights of more than 300 ft. Like Malaspina Glacier, it has a complex recent chronology of advances and retreats (fig. 43). Extending nearly across the mouth of Yakutat Bay is a mostly submerged moraine complex deposited during the maximum advance of Hubbard Glacier sometime between about 1,000 and 700 years ago, at which time it merged with the Seward lobe of the Malaspina Glacier. Phipps Peninsula and the ridges along the southern shore of Yakutat Bay (on one of which Yakutat is sited) are formed by an emergent part of this terminal moraine. Beginning sometime before 1400, Hubbard Glacier retreated slowly for several centuries, ultimately retreating more than 37 mi northeastward to expose Yakutat and Disenchantment Bays. A submerged moraine near the west end of Disenchantment Bay is expressed by uneven seafloor topography; it was formed during a temporary readvance that culminated between 1700 and 1791. At the time of Malaspina's search for the fabled Northwest Passage in 1792, he navigated Yakutat Bay without difficulty but was turned back in the vicinity of Haenke Island by floating ice that was impenetrable to his vessels. Apparently, a rapid retreat of Hubbard Glacier was in progress, choking upper Disenchantment Bay with icebergs. Between 1792 and 1894, the terminus of Hubbard Glacier continued to retreat to a position about 2 mi east of its current location near Osier Island. Since 1894, when systematic mapping of its terminus began, Hubbard Glacier has slowly but persistently readvanced, threatening to seal the mouth of Russell Fiord. During 1973 and 1974, a short-lived surge brought the face of the glacier to within about 0.6 mi of Osier Island (fig. 43). In early 1986, what had been predicted came true: the advancing ice and subglacial moraine of Hubbard Glacier blocked Sand Dab Passage, the connection between Disenchantment Bay and Russell Fiord. Between May and October, the water behind the glacial dam rose about 80 ft above sea level, creating an increasingly fresh "Lake" Russell. On October 7, the ice dam burst and the lake emptied completely within the course of 28–30 hours. The southeastern front of Hubbard Glacier now rests on a shoal, which minimizes calving losses. A new closure will likely take place in the near future unless Hubbard Glacier's current slow advance is stabilized or reversed. If the closure lasts an estimated 7 to 14 months (the time required for the water to rise about 130 ft), "Lake" Russell will discharge into the former overflow channel at the south end of the fiord, connecting with the Situk River and increasing its average discharge by approximately tenfold. Such a large increase in discharge may scour salmon spawning habitat on the river, negatively impacting the local fishery.

Hubbard Glacier

Figure 76 (facing page). The southeastern part of the terminus of Hubbard Glacier, North America's largest tidewater glacier; view is to the southeast. Osier Island, in the foreground, separates the waters of Russell Fiord, on the right, from the head of Disenchantment Bay, on the left. Osier Island rises above a shoal that nearly closes Sand Dab Passage between the two bodies of water. Gilbert Point on the mainland rises directly behind the camera station. In early 1986, Hubbard Glacier advanced to contact Gilbert Point and close Russell Fiord, temporarily raising the water level in the fiord. In October 1986, an outburst flood swept away the ice dam, as well as the subglacial moraine and sediments that had accumulated on the shoal connecting Osier Island with the mainland, thus returning Russell Fiord to its former water level and deepening—at least temporarily—Sand Dab Passage. *(George Plafker)*

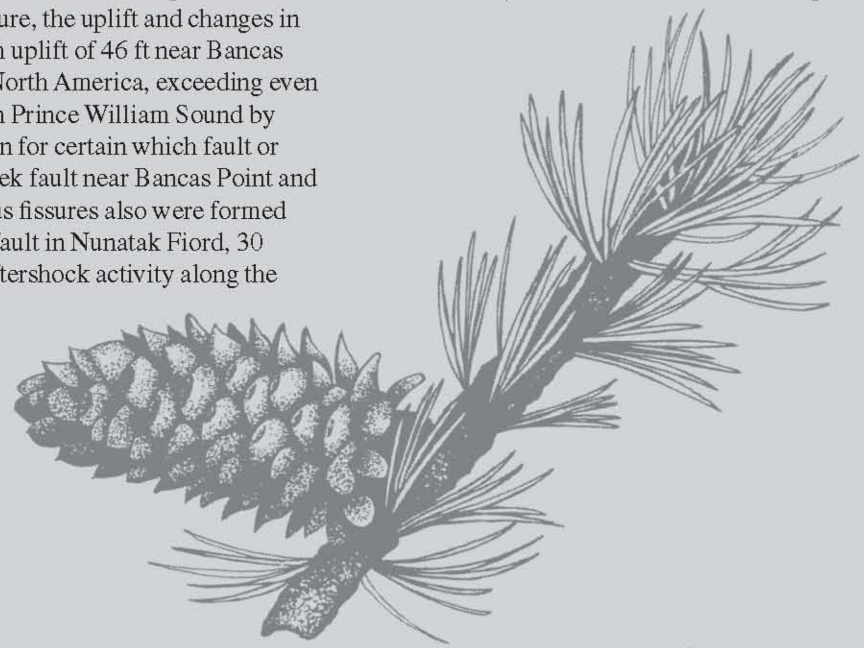

VALERIE GLACIER
HUBBARD GLACIER
SAND DAB PASSAGE
DISENCHANTMENT BAY
Osier Island
RUSSELL FIORD
Gilbert Point


Pre-earthquake cliff
Pre-earthquake beach
46 ft
Modern cliff
Modern beach
(submerged at high tide)
Hubbard
Glacier

On September 10, 1899, two major earthquakes and dozens of aftershocks jolted a large region near Yakutat Bay, elevating shorelines from 18 to 46 ft and triggering widespread slides and avalanches, ground breakage, glacier crevassing and calving, and at least one tsunami (tidal wave). Dramatic eyewitness accounts of several prospectors, who happened to be camped near Hubbard Glacier at the head of Disenchantment Bay at the time of the shocks, as well as detailed follow-up investigations by USGS geologists in the early 1900's, indicated clearly the magnitude of the widespread shoreline changes in the Yakutat Bay region. Elevated wave-cut bedrock platforms are conspicuous still in many places in upper Disenchantment Bay (fig. 77), although they have been heavily overgrown with brush and small trees. The barren wave-cut bench at Bancas Point, encrusted by dead barnacles and mussels, raised well above the reach of tides, provided a graphic image of, and the means to accurately measure, the uplift and changes in shoreline caused by the earthquakes. The maximum uplift of 46 ft near Bancas Point is the greatest noted to the present writing in North America, exceeding even the 37-ft maximum produced on Montague Island in Prince William Sound by the Great Alaska earthquake of 1964. It is not known for certain which fault or faults ruptured in the 1899 events, but the Esker Creek fault near Bancas Point and faults on the Yakutat foreland are suspect. Numerous fissures also were formed on The Nunatak above the trace of the Fairweather fault in Nunatak Fiord, 30 mi northeast of Yakutat, possibly indicating some aftershock activity along the Fairweather fault as well.

Glaciers in the Yakutat Bay region also were strongly affected by shaking from the 1899 earthquakes. Many glaciers, including parts of the Malaspina, became severely crevassed, and calving rates at tidewater glaciers increased markedly. Minor advances of several glaciers in the Yakutat Bay region followed several years after the earthquakes.

People felt the 1899 earthquakes at least as far northwest as Valdez, Copper Center, and Mentasta Pass in the Nutzotin Mountains, and at least as far east as Whitehorse and Atlin in the Yukon Territory. Light shocks were also felt at scattered locations at much greater distances from Yakutat where conditions were particularly favorable. These eyewitness accounts clearly indicate that the impact of a series of major temblors of the type associated typically with a plate boundary seismic event can be widespread.



Disenchantment Bay

Figure 77 (facing page). View to the northeast across Bancas Point on the north side of Disenchantment Bay near Yakutat, showing a wave-cut bench that was elevated 46 ft in the 1899 Yakutat earthquakes. The current wave-cut bedrock cliff is subject to the wash of storm waves and thus is unvegetated. Immediately above it is a bench, the pre-earthquake beach, and a higher wave-cut bedrock cliff, which have been partially revegetated in the century since the earthquakes. This former shoreline was uplifted abruptly during the earthquakes, the maximum uplift recorded in any North American earthquake. *(George Plafker)*


EXPLANATION
Wrangell–St. Elias National Park
Wrangell–St. Elias National Preserve
Native corporation lands
Unpaved road
0 10 20 KILOMETERS
0 10 20 MILES
GULF OF ALASKA
WRANGELL MOUNTAINS
CHUGACH MOUNTAINS
SAINT ELIAS MOUNTAINS
NUTZOTIN MOUNTAINS
MENTASTA MOUNTAINS
KLUANE NATIONAL PARK
NATIONAL PRESERVE
NATIONAL PARK
Slana
Chistochina
Gakona
Gulkana
Glennallen
Copper Center
Tonsina
Chitina
Valdez
Cordova
Katalla
Nabesna
Chisana
McCarthy
Beaver Creek
Destruction Bay
Burwash Landing
UNITED STATES
CANADA
146°
144°
142°
140°
62°
60°

Acknowledgments

Our current geologic knowledge about the region of Wrangell–Saint Elias National Park and Preserve was achieved largely through the leadership and decades-long scientific persistence of a trio of distinguished USGS geologists. **Edward M. MacKevett, Jr.**, **George Plafker**, and **Donald H. Richter** took the solid, but reconnaissance information provided by the geologic pioneers of the early 20th century, and extended it topically and regionally throughout eastern southern Alaska. Through their personal studies and wholehearted support of, and collaboration with, academic, industrial, and governmental colleagues, the trio led an explosive increase in the amount, breadth, and quality of earth-science information available for the region. Pursuing detailed studies in the McCarthy area that probed the geologic setting and genetic controls for the Kennecott copper deposits, **Ed MacKevett** established a framework for the southern Wrangell Mountains that has guided an entire generation of follow-up inquiries. Pursuing tectonic and stratigraphic studies throughout the Gulf of Alaska continental margin, **George Plafker** has led multifaceted investigations that have revolutionized our understanding of the dynamics of continuing continental growth of southern Alaska. This work provided the detailed substance upon which many fundamental concepts of accretionary tectonics have come to be based. Beginning with detailed geologic mapping in the Nabesna area, **Don Richter** established a geologic framework for the northern Wrangell Mountains and eastern Alaska Range that prompted corroborating studies throughout the region. His special expertise in volcanology soon led him and numerous colleagues to undertake companion studies in the Wrangell volcanic field that have established, for the first time, the stratigraphy, eruptive history, and geologic setting for most volcanic centers in the field.

Ed MacKevett, August 1967, above the Chitistone River canyon.

George Plafker, July 1985, Chugach Mountains.

Don Richter, August 1982, near the headwaters of the Copper River.

Figure 78 (facing page). Index map of the Wrangell–Saint Elias region showing localities of photographs included in this report. Arrows indicate direction of view. *(Modified from National Park Service)*

This guidebook also summarizes the history of remarkably changeable coastlines and glaciers of the Gulf of Alaska region. The reports of **Bruce Molnia**, USGS, are insightful sources for much of this information, as are long-term glaciological studies of **Robert Krimmel**, **Larry Mayo**, **Mark Meier**, **Austin Post**, and numerous others. The brief synopses of the Copper River Basin area depend on the expertise of USGS geologists **Oscar Ferrians**, **Don Nichols**, **Hank Schmoll**, **John Williams**, and **Lynn Yehle**. **Hank Schmoll** and **Lynn Yehle** generously provided unpublished materials for use in this guidebook. **Mike Wilson**, Exxon Research, graciously provided unpublished photographs from surveys in the northeastern Gulf of Alaska, and **Joe McGregor**, USGS, guided searches through the historical photographic collections of the U.S. Geological Survey library in Denver, Colorado. Contributors of the photographs used in this guide are indicated in parentheses at the end of each caption.

Danny Rosenkrans, Geologist, National Park Service, suggested the underlying tectonic theme for this guidebook, and provided unpublished materials from NPS files. From his long tenure in Wrangell–Saint Elias National Park and Preserve, he also contributed a unique perspective on the continuity and dynamism of geologic processes in the parklands.

Geoffrey Bleakley, Historian, NPS, reviewed the brief historical sections of the guidebook, improving their emphasis and content. **Marti Miller** and **Ric Wilson**, USGS geologists, reviewed the entire manuscript, markedly improving the overall style and substance of this guidebook. **Tom Judkins** carefully reviewed stratigraphic nomenclature and usage.

The manuscript was edited by **Lorna Carter** and graphics were prepared by **Carol A. Quesenberry**, who also provided the photocomposition and design. **Susan Bartsch-Winkler** prepared the original color artwork from sketches made in the McCarthy and Nabesna area, and **Carol A. Quesenberry** prepared the original pen-and-ink drawings.

Glossary of Geologic Terms[9]

Accretion. The attachment, or welding, of geologic materials to a continental margin or to an exotic *terrane*. An *accretionary terrane*, thus, is a fault-bounded body of rock of regional extent that differs in its geologic history from contiguous terranes and was added to a continent or another terrane at its margin. Also see: *terrane*.

Alkalic. An *igneous* rock that contains more alkali metals (particularly sodium and potassium) than are considered average for the group of rocks to which it belongs.

Alluvial. Pertaining to, or deposited by, a stream or running water.

Alluvial fan. An outspread fan-shaped mass of sediment deposited by a stream or river where its gradient abruptly decreases—typically where it issues from a narrow mountain valley onto a plain or broad valley.

Alluvium. A general term for unconsolidated sediment deposited by running water.

Ammonite. Type of extinct coiled cephalopod, characterized by a thick, strongly ornamented and sutured shell. Age range, Jurassic to Cretaceous.

Amphibolite. Foliated *metamorphic rock* consisting mainly of amphibole and plagioclase.

Anatexis. Melting of preexisting crustal rocks to form a *magma*, which retains isotopic characteristics of the melted rocks. Magmas formed at greater depths in the mantle have different ratios of chemical elements and lack a characteristic crustal signature.

Andesite. Dark, fine-grained *volcanic rock* containing an intermediate percentage of silica (SiO_2), the extrusive equivalent of *diorite*; a common rock type from volcanoes formed above *subduction* zones.

Anticline. A fold, generally convex upward, the core of which contains the stratigraphically lower and older rocks. Ant: *syncline*.

Arc. A generally curved and roughly aligned belt of volcanoes above a *subduction* zone; also used to describe the *volcanic* and *plutonic* rocks formed there. Syn: *island arc, magmatic arc; volcanic arc.*

Argillite. A dense, dark rock derived from metamorphism of *mudstone*.

Ash. Unconsolidated fine-grained clastic material ejected by volcanic eruption.

[9]From *The Glossary of Geology*, 4th ed., published by The American Geological Institute and reprinted with their expressed permission.

Basalt. Dark, fine-grained volcanic rock containing less than 52 weight percent silica (SiO_2), the extrusive equivalent of *gabbro*; a common rock type formed in ocean basins, as well as continental interiors.

Basement. A lowest mass of rock, possibly having complicated structure, that underlies the major rock sequences of interest; the substrate.

Batholith. A large mass of *intrusive igneous* rock that has more than 100 km^2 of surface exposure.

Bed. The smallest formal stratigraphic unit of sedimentary rocks, limited to certain distinctive strata whose recognition is particularly useful.

Benioff zone. A landward-dipping plane beneath *trenches* of the circum-Pacific belt, along which earthquake foci cluster. According to the theory of *plate tectonics* and *sea-floor spreading*, subducting *lithospheric plates* sink into the upper *mantle*, causing earthquakes along their upper boundaries, defining this *seismic* zone.

Bioclastic. Consisting primarily of fragments broken from material of biologic origin, but not necessarily organic; may consist largely of broken pieces of shells.

Blueschist. Strongly *foliated metamorphic* rock that has a blue color owing to the presence of sodic amphibole minerals; indicates relatively high pressure, intermediate-temperature conditions of formation.

Brachiopod. A type of solitary bivalve that is bilaterally symmetrical. Age range, Cambrian-present, but most typically found as fossils in Paleozoic rocks.

Breccia. Coarse-grained *clastic* rock consisting of angular fragments held together by a mineral cement; may form by *sedimentary, igneous*, or *tectonic* processes.

Brittle. Said of a rock that fractures rather than bends. Ant: *ductile*.

Bryozoan. Colonial invertebrate that has an external skeleton. Age range, Ordovician-present, but most typically found as fossils in Paleozoic rocks.

Caldera. Large, roughly circular volcanic depression, whose diameter is many times larger than that of an included *vent*; generally formed by collapse of volcanic edifice.

Carbonate. Sediment or rocks that are formed principally by organic or inorganic precipitation of calcium, magnesium, or iron carbonate minerals—for example, *limestone* or *dolomite*.

Cataclastic. Fabric produced in a rock by severe mechanical deformation—thorough breakage or granulation.

Clast. An individual constituent, grain, or fragment of a sediment or rock, produced by mechanical weathering.

Claystone. A very fine grained *sedimentary rock* in which grains of clay size ($<$0.01 mm in diameter) predominate.

Conglomerate. A coarse-grained *sedimentary* rock composed predominantly of rounded *clasts* larger than 2 mm in diameter; consolidated equivalent of *gravel*.

Contact-metamorphic. A type of mineral deposit that is formed near contacts between host rocks and invading *plutons*; compositional changes and crystallization of new minerals are induced by heat and the combining of constituents from both host rock and *magma*; where the invaded rocks are *limestone, skarns*—consisting of coarse-grained lime-bearing silicate minerals—form and are intergrown with the metallic minerals.

Continental plate. A rigid segment of the Earth's *lithosphere* made up of relatively less dense materials (2.7 g/cm^3), called *continental crust*, that are typical of continental interiors; separated from adjacent lithospheric plates by zones of *seismic* activity. Ant: *oceanic plate, oceanic crust*.

Continental shelf. That part of the continental margin that is between the shoreline and the *continental slope*—typically nearly flat and at depths between 0 and 200 m.

Continental slope. That part of the continental margin that slopes between 3° and 6° into the deeper parts of the ocean.

Convergence. The relative motion between two plates that are moving toward each other; convergence generally is taken up in *subduction* zones by displacement directly across the zone (along *dip*-slip faults, which slip down the dip), but may have components parallel to the zone (along *strike-slip* faults, which slip horizontally) or obliquely to it (along oblique-slip faults).

Coquina. A *limestone* composed predominantly of mechanically worked fossil debris.

Coral. Bottom-dwelling sessile marine invertebrate organism (polyp) that may be colonial or solitary. Age range, Ordovician-present.

Craton. A part of the Earth's *continental crust* that has attained stability and has been little deformed for a prolonged time.

Crinoid. A type of echinoderm with a disk-shaped or globular body and branched appendages. Age range, Ordovician-present; stems or segments of stems (columnals) are more likely to be preserved as fossils, and are especially common in Paleozoic rocks.

Crust. The outermost layer of the Earth, that part above the *mantle*; it represents less than 0.1 percent of the Earth's volume, and consists of *continental crust* and *oceanic crust*.

Dacite. A fine-grained volcanic rock that has an intermediate percentage of silica, the extrusive equivalent of *granodiorite*.

Detritus. Fragmental material, such as gravel, sand, silt, or clay, that is derived from older rocks and moved away from its place of origin.

Dextral. Displacement along a fault such that, when viewed along the fault, the side to the viewer's right apparently has moved toward him/her and the side on the viewer's left has moved away from him/her. Syn: *right-lateral.* Ants: *sinistral, left-lateral.*

Diamictite. Nonsorted or poorly sorted *terrigenous sedimentary* rock that contains a wide range of particle sizes, such as a rock containing sand or gravel in a muddy *matrix.*

Diamicton. An unconsolidated equivalent of a *diamictite*, that is, a sediment that contains sand and (or) larger particles in a muddy matrix.

Dike. A tabular *igneous* intrusion that cuts across the layering of the enclosing rocks.

Dip. The inclination of a surface, or the angle that a surface, such as a fault or a bed, makes with the horizontal.

Disconformity. An *unconformity* in which the bedding planes above and below the break are essentially parallel, indicating a significant interruption in sedimentation—either an interval of erosion or nondeposition.

Dolomite. A *carbonate sedimentary* rock of which more than 50 percent consists of the mineral *dolomite* ($CaMg(CO_3)_2$)—thus, a variety of *limestone* rich in magnesium *carbonate.*

Dropstone. An oversized clast in much finer grained sediment; most *dropstones* originate through *ice-rafting.*

Drumlin. A smoothly rounded, elongate hill, mound, or ridge, consisting of glacial sediment, built under the ice or shaped by its flow.

Ductile. Said of a rock that bends and shows little fracturing. Ant: *brittle.*

Eolian. Pertaining to the wind—in particular, wind-blown sediments, such as form dunes, or *sedimentary rocks*, consolidated from such sediments.

Epicenter. The point on the Earth's surface that is directly above the *focus* of an earthquake.

Epidote-amphibolite grade. Conditions of metamorphism that create mineral assemblages characterized by epidote and amphibole; believed to result from regional conditions of high pressure and temperature.

Esker. A narrow, sinuous ridge composed of irregularly stratified sand and gravel, which was deposited by a glacial stream confined by ice and was left behind when the ice melted.

Evaporite. A nonclastic *sedimentary* rock formed primarily of minerals produced from a saline solution that was extensively or totally evaporated. Examples include bedded rock salt or gypsum.

Extrusive rocks. *Igneous* rocks that have been erupted onto the surface of the Earth, such as lava *flows* or volcanic *ash.* Ant: *intrusive rocks.*

Fault. A fracture or zone of fractures along which displacement of the sides relative to one another has taken place. Two or more intersecting faults formed in a particular deformational episode form a *fault system.*

Felsic. An *igneous* rock having abundant light-colored minerals (such as feldspar and quartz [silica]).

Flow. A lava *flow* or a *pyroclastic flow*, a discrete body of *extrusive* volcanic rock.

Fluvial. Of or pertaining to a river or rivers.

Flysch. A marine *sedimentary* rock sequence that is characterized by thick, poorly *fossiliferous*, repetitively bedded clastic rocks—generally rapidly deposited and derived by erosion of adjacent deforming mountain belts.

Focus. The initial rupture point of an earthquake, which may be shallow or deep.

Foliation. A planar arrangement of textural or structural features in any type of rock—especially the planar fabric of *metamorphic rocks* that results from alignment and flattening of constituent grains; such rocks are said to be *foliated.*

Fossiliferous. Containing fossils—the remains, traces, or imprints of animals or plants.

Fumarole. A *vent* that discharges hot volcanic gases and steam.

Fusulinid. A small protozoan characterized by a multichambered external shell (or test); resembles the shape of a grain of wheat. Age range, Ordovician to Triassic.

Gabbro. A dark-colored intrusive *igneous* rock composed principally of calcic plagioclase and pyroxene, with or without olivine; has approximately the same chemical composition as the *extrusive* rock *basalt.*

Gastropod. Any *mollusk* characterized by a single, generally asymmetrical nonchambered shell that is closed at the apex—for example, a snail. Age range, Cambrian to present.

Geomorphic. Pertaining to the surface features (landforms) of the Earth; *geomorphology* is the science that classifies, describes, and interprets the nature, origin, and development of present landforms and the geologic changes that they record.

Glacial-fluvial. Of or pertaining to the combined effects of glaciers and rivers; glacial-fluvial sediment is glacially eroded but deposited by rivers.

Glacial-lacustrine. Of or pertaining to the combined effects of glaciers and lakes; glacial-lacustrine sediment is glacially eroded but deposited in lakes.

Glacial-marine. Of or pertaining to the combined effects of glaciers and oceans; glacial-marine sediments are eroded by glaciers but deposited in a marine environment.

Glacier-outburst flood. A sudden release of meltwater from a glacier or a glacier-dammed lake; often annual. Syn: *jökulhlaup*, a term for such floods in Iceland, where they are common.

Glauconite. A green iron-rich earthy or flaky mineral, occurring abundantly in some *sandstone*; an indicator of very slow sedimentation.

Gneiss. A foliated rock formed by regional metamorphism, in which bands of granular minerals alternate with bands of prismatic, flaky, or elongate minerals; the bands usually differ in color, as well as texture. The fabric, which is said to be *gneissose*, is a product of regional metamorphism involving widespread elevated temperature or pressure conditions.

Granite. A coarsely crystalline quartz-bearing *intrusive igneous* rock that results from solidification of a *magma* at depth in the Earth's crust; its chemical composition is nearly equivalent to *rhyolite*, a volcanic rock.

Granitic. Said of all igneous intrusive rocks that consist of coarse-grained mineral crystals of approximately equal size; typical of *granites*.

Granodiorite. An *intrusive igneous* rock that contains less alkali feldspar than *granite*; has approximately the same chemical composition as *rhyodacite*, a volcanic rock.

Gravel. An unconsolidated accumulation of rounded rock fragments consisting predominantly of particles larger than sand (diameter greater than 2 mm); the unconsolidated equivalent of *conglomerate*.

Graywacke. Dark-colored sandstone containing poorly sorted and poorly rounded clasts and abundant fine-grained *matrix*; generally reflects an environment in which erosion, transportation, deposition, and burial were rapid—such as adjacent to a rising mountain belt.

Greenschist. A strongly foliated *metamorphic rock*, consisting of well-aligned platy minerals, whose green color is due to the presence of the minerals chlorite, epidote, and (or) actinolite; believed to form at temperatures in the range 300°-500° C.

Greenstone. Any dark-colored, fine-grained altered or metamorphosed *mafic igneous* rock; generally *basaltic* in composition exhibiting a dark-greenish color.

Grooved pavement. A bare consolidated or semiconsolidated smooth rock surface showing linear, elongated depressions produced by the drag of objects propelled by a current over it; the surfaces beneath glaciers often are scoured nearly smooth, but are grooved by boulders entrained in the moving ice.

Groundmass. Material between the coarser crystals in a *porphyritic igneous* rock; it may be either finely crystalline or glassy material.

Hydrothermal. Pertaining to hot water, to its action, or to the products of its action, such as a mineral deposit precipitated from a hot aqueous solution.

Icefall. The part of a glacier that is highly crevassed because of a very steep slope over which the glacier passes.

Ice-rafting. The transporting of rock fragments of all sizes on or within icebergs, ice floes, or other forms of floating ice. When the ice melts, such rock fragments become *dropstones*, plunging to the bottom to be incorporated in generally finer grained sediment.

Igneous. A rock or mineral that solidified from molten material, or *magma*.

Intrusive rocks. *Igneous* rocks emplaced in preexisting rocks beneath the Earth's surface. Ant: *extrusive rocks*.

Island arc. A chain of islands, generally arcuate in map view, that are formed by *magmatic* processes above a zone of *subduction*. Island arcs generally are underlain by *extrusive* volcanic rocks, which are intruded by *intrusive* rocks formed from the same *magma*. Thus, approximate synonyms are *magmatic arc* and *volcanic arc*. The Aleutian island arc consists of a chain of volcanic islands rising above a *subduction zone*, the Aleutian (Trench) *megathrust*.

Isotope. One of two or more species of the same chemical element, having the same atomic number but a different atomic weight. Radiometric measurements of geologic time are obtained by comparing abundances of parent and daughter isotopes produced in geologic materials by radioactive decay having known decay rates.

Kame. A low hummock or irregular ridge deposited at the margin of a melting glacier as a delta or fan and composed of stratified sand and *gravel*.

Kettle. A bowl-shaped depression, commonly without surface drainage and occupied by a lake or swamp, that formed by the melting of a block of stagnant ice (left behind by a retreating glacier) that had been enclosed within glacial detritus.

Lacustrine. Pertaining to, or formed in, a lake; in particular, *glacial-lacustrine* sediments often are finely banded, or *varved*, where bands are formed by coarser sediment accumulated annually during the ice-free season topped with thinner, finer (and often organic) sediment deposited during the winter.

Lentil. A minor stratigraphic unit of limited geographic extent that is a subdivision of a rock formation; it forms a lens that terminates on all sides within a formation.

Lignite. A brownish-black coal that is intermediate in coalification between peat and subbituminous coal.

Limestone. A *carbonate sedimentary* rock, consisting predominantly of calcite ($CaCO_3$).

Lithology. The nature of a rock based on such characteristics as its mineralogic composition, color, and grain size.

Lithosphere. The solid part of the Earth (as opposed to the atmosphere and hydrosphere) that includes the *crust* and upper *mantle*; it generally is about 60 mi thick.

Lithotectonic terrane. A fault-bounded assemblage of rocks that is characterized by a unique geologic history. Thus, terranes generally differ in their lithologies (the characteristics of the rocks from which they are constituted) and they differ in subsequent structural modifications which those rocks have undergone (their tectonic histories).

Lode. A mineral deposit in solid rock, as opposed to *placer* deposits.

Mafic. An *igneous* rock composed chiefly one or more iron- and magnesium-bearing dark-colored minerals. Ant: *felsic.*

Magma. Molten rock generated below the Earth's crust and upper *mantle*; the parent of nearly all volcanic and plutonic rocks. *Magmatism* denotes the processes by which magma is produced. Thus, a *magmatic arc* is another name for *island arc* or volcanic *arc*, and emphasizes that, if island arcs are eroded below the level of their volcanic carapace (which is the case for most ancient arcs), deep-seated plutonic rocks are exposed.

Mantle. The zone of the Earth below the crust and above the core.

Marble. A metamorphic rock consisting of recyrstallized *limestone* or *dolomite*—many marble bodies have a coarse-grained sugary texture.

Marine. Of the sea or ocean; thus, marine *sedimentary rocks* were deposited in the ocean, and frequently contain fossils of marine organisms. Ant: nonmarine.

Megathrust. The contact along which one plate is overriding another in a *subduction* zone—depicted as a single fault trace, a megathrust represents the front of a broad zone across which plate boundary interaction occurs. Thus, a megathrust is the surface trace of a *subduction zone.*

Melange. A body of rock that lacks internal stratal continuity and includes fragments and blocks of varying sizes, both exotic and native, embedded in a finer grained fragmental *matrix*; the fabric disruption may be either tectonic or gravity induced.

Metamorphic rocks. Any rock derived from preexisting rocks by mineralogic, chemical, or structural changes, induced by marked changes in pressure, temperature, or shearing stress at depth in the Earth's crust; the rocks are said to be *metamorphosed.*

Mid-ocean ridge. A continuous medial mountain range extending through the Atlantic, Indian, and South Pacific Oceans, generally with a central volcanic *rift* valley that, according to the hypothesis of *sea-floor spreading*, is the source of new *oceanic crust.*

Migmatite. A composite rock consisting of layers or streaks of *igneous* or igneous-appearing and *metamorphic* materials; the layers or streaks are generally distinguishable by contrasts in color or grain size.

Mollusk. A solitary invertebrate characterized by a nonsegmented body that is bilaterally symmetrical and covered by a shell; examples include clams, snails, and *ammonites.*

Moment magnitude. A measure of the strength of an earthquake, or the energy released by it, as calculated from seismographic observations, but also including a factor relating to actual fault displacements; for very large earthquakes, moment magnitudes generally exceed those computed from seismograms only.

Monzonite. A compositional class of *igneous intrusive* rocks containing very little quartz.

Moraine. A mound, ridge, or other distinct accumulation of unsorted, unstratified materials that is being carried by a glacier or has been deposited by direct action of glacial ice. They may be *lateral*, if they are carried on, or deposited near the side of a glacier; *medial*, if they are carrried near the middle of a glacier, usually formed by merging of *lateral moraines* below the junction of two coalescing glaciers; and *terminal*, if they are carried on, or deposited at the end of a glacier.

Mudstone. An indurated fine-grained *sedimentary* rock consisting of approximately equal amounts of clay- and silt-sized material; it lacks the fine lamination of *shale.*

Neotectonic. The study of the post-Miocene (that is, younger than about 5 million years) structures and structural history of the Earth's crust.

Nunatak. An isolated knob, hill, or ridge of bedrock that projects prominently above the surface of a glacier and is completely surrounded by it.

Oceanic plate. A rigid segment of the Earth's *lithosphere* made up of relatively more dense materials ($\approx$3.0 g/cm^3), called *oceanic crust*, that are typical of ocean basins; separated from adjacent lithospheric plates by zones of *seismic* activity. Ant: *continental plate.*

Oceanic plateau. A broad, more or less flat-topped region bordered by escarpments and rising above the sea floor; many oceanic plateaus have been covered by regionally extensive *basalt flows.*

Offset. The horizontal component of displacement along a *fault*, measured perpendicular to the disrupted horizon.

Ogive. An arcuate surface feature on a glacier repeated at intervals down a glacier, generally formed at the base of an *icefall*. Surface bulges (*wave ogives*) are produced by acceleration of the ice through the steep icefall, which fractures it and, in the summer, subjects it to increased melting. In the winter, the ice surface is protected by a mantle of snow. The net result is annual flucutation in the thickness of ice emerging at the bottom of the icefall, which may be accentuated by compression of the decelerated ice below the icefall. Dark bands (*band ogives*) are produced during the summer season when the glacier surface is exposed and airborne sediment accumulates on the surface; lighter bands form during the winter when the ice is mantled by snow. In many places, both types of ogives occur together.

Orogeny. The processes by which structures within mountainous areas are formed, including folds and faults in the shallower levels of the crust and metamorphic and plutonic rock bodies in the deeper crustal levels.

Orthogneiss. A *gneiss* formed by metamorphism of an intrusive *igneous* rock.

Outwash. Stratified detritus (chiefly sand or gravel) washed out from a glacier by meltwater streams and deposited in front of or beyond the margin of a glacier.

Paleomagnetism. The study of natural remanent magnetism in rocks in order to determine the direction and intensity of the Earth's magnetic field in the past.

Paleontology. The study of life in past geologic times, based on fossil plants and animals. Thus, a *paleontologic age* is a relative age determined by examination of fossils, and generally is expressed by reference to a named interval of the geologic time scale, based on world-wide correlation of fossil groups.

Paludal. Pertaining to, or formed in, a marsh or swamp; many *paludal* sediments are highly organic.

Patent. An exclusive title to mineral-bearing land previously on the public domain, conveyed by the Federal government to any citizen of the United States who demonstrates that mineral resources exist on or beneath the land, that improvements have been made on the land, and an official survey has been obtained, and who pays $5/acre for lode claims and $2.50/acre for placer claims. After the patent is issued, the claimant may make any use of the land that he/she sees fit.

Pegmatite. An exceptionally coarse grained *igneous* rock, usually occurring as *dikes* or veins near the margins of *plutons*.

Pelecypod. An aquatic *mollusk*, such as a clam, having a bilaterally symmetrical bivalve shell. Age range, Ordovician to present.

Permafrost. Unconsolidated deposits or bedrock in which a temperature below freezing has existed continuously for a long time. The thickness of permafrost reaches more than 3,000 ft at high latitudes and underlies about one-fifth of the world's land area. Pore spaces in perennially frozen unconsolidated materials generally are occupied by ice, a condition known as ice-rich permafrost.

Phreatic. Said of a non-incandescent volcanic eruption that produces principally steam; it is produced by the heating and expansion of ground water by an underlying heat source—a *pluton*.

Phyllite. A metamorphosed *shale* rock, in which minute crystals of micaceous minerals impart a silky sheen to the rock's surfaces.

Piedmont glacier. A thick, continuous sheet of ice at the base of a mountain range, formed by the spreading out and coalescing of valley glaciers from higher elevations of the mountains.

Pillow basalt. A *basaltic* lava, displaying pillow structure—that is, discontinuous pillow-shaped masses formed by underwater extrusion. Generally, the pillows fit closely, such that the concavities of one match the convexities of another.

Placer. A surficial mineral deposit formed by mechanical concentration of mineral particles in unconsolidated materials. Ant: *lode*.

Plate tectonics. A theory of global scale, in which the *lithosphere* is divided into a number of rigid plates that interact with one another at their boundaries, causing earthquakes and deformation.

Plinian. An explosive volcanic eruption that produces large and persistent eruption clouds consisting of fragmental volcanic rock and gases; large volumes of *tephra* are characteristic.

Pluton. An *igneous* intrusion, implying no connotation as to shape, size, or depth of emplacement.

Porphyry. (1) An *igneous* rock of any composition that contains conspicuous large crystals (or phenocrysts) in a fine-grained *groundmass*; such a texture is said to be *porphyritic*. (2) Certain types of *porphyritic igneous* rocks contain disseminated deposits of gold, copper, or molybdenum and thus are called (for example) *porphyry* copper deposits.

Proglacial. Immediately in front of, or just beyond, the outer limits of a glacier or ice sheet and generally in direct contact with the ice.

Protolith. The unmetamorphosed rock from which a given *metamorphic rock* was formed by metamorphism.

Provenance. A place of origin—in particular, the area from which the constituent minerals of a *sedimentary* rock are derived, as well as the rock types of which the area is composed.

Pyroclastic. A general term that refers to all volcanic material that is produced by explosive eruptive activity, such as *ash*, bombs, and other *tephra*.

Quartz diorite. A dark-colored *igneous intrusive* rock, having approximately the same chemical composition as *andesite* —its volcanic equivalent.

Radiolarian chert. A well-bedded microcrystalline marine *sedimentary* rock consisting largely of opaline-silica tests of *radiolaria*—pelagic microfossils ranging in age from Cambrian to present.

Radiometric age. An absolute age expressed in years before the present determined by calculating the time required to produce the measured abundances of parent and (or) daughter *isotopes* of radioactive elements of known decay rates.

Red beds. *Sedimentary* strata that are predominantly reddish in color due to the presence of ferric oxide (hematite) coatings on many grains; indicative of well-oxidized conditions, such as are present in many tropical, semiarid climates.

Refractory. An ore from which it is difficult or expensive to recover its valuable constituents; most refractory ores require chemical processing, which produces chemically reactive waste material.

Rhyolite. Common, light-colored, fine-grained or glassy extrusive *igneous* rock with more than 70 weight percent silica (SiO_2), the extrusive equivalent of *granite*; a common rock type in continental volcanic provinces, often produced in explosive eruptions. *Rhyodacite* contains less silica and is the extrusive equivalent of *granodiorite* or *quartz monzonite*.

Rift. An elongate trough that is bounded by normal faults marking a zone along which the entire thickness of the *lithosphere* has ruptured under extension. Rifts generally focus volcanism and may be located either on *continental plates*, as in the East African rift valleys, or *oceanic plates*, as in *mid-ocean ridges*.

Sabkha. A supratidal environment of sedimentation, occurring under arid to semiarid conditions on restricted coastal plains just above normal high-tide level, where salts crystallize at or near the surface. Many sabkhas occur in the Persian Gulf region.

Sandstone. A clastic *sedimentary* rock composed principally of grains of sand (0.08–2.0 mm in diameter).

Schist. A strongly foliated metamorphic rock, in which the majority of the constituent minerals are closely aligned; such rocks are said to be *schistose*, and they readily break into flakes or slabs parallel to the schistosity (the direction of alignment).

Sea-floor spreading. A hypothesis that *oceanic crust* is created by upwelling of *magma* along *mid-ocean ridges* and spreads laterally and symmetrically away from the ridges; this movement provides the impetus for plate motion in the hypothesis of *plate tectonics*.

Seamount. An elevated area of the sea floor, 1,000 m or higher, that generally consists of oceanic volcanic rocks; seamounts may be single, but more typically form aligned chains rising above the ocean floor.

Sedimentary rock. A rock resulting from the consolidation of loose sediment that has been accumulated in layers.

Seiche. An oscillation of the surface of water in an enclosed or semi-enclosed basin (such as a lake or bay) that continues, pendulum-like, for a time after cessation of the originating force. Many seiches were generated by the 1964 Great Alaskan earthquake.

Seismicity. Seismic activity, produced by earthquakes or other Earth vibrations, such as those induced by explosions.

Seismologic. Of, or pertaining to, the study of earthquakes and the structure of the Earth.

Shale. A fine-grained and finely laminated detrital *sedimentary* rock, which breaks readily into thin layers approximately parallel to the bedding. (This characteristic of fissility, imparted by the fine lamination, distinguishes *shale* from *mudstone*.)

Shield volcano. A volcano in the shape of a broad flattened dome, built by *flows* of very fluid *basalt* or *andesite*. Mt. Wrangell is an excellent example.

Sill. A tabular *igneous* intrusion that parallels planar structures in the surrounding rocks.

Siltstone. A fine-grained detrital *sedimentary* rock consisting predominantly of silt-size grains ((0.04–0.08 mm in diameter).

Spiculite. A *sedimentary* rock consisting principally of the siliceous spicules of invertebrates—particularly sponge spicules.

Spit. A small point of land, commonly consisting of sand or gravel deposited by longshore currents, that is attached to land at one end and extends into open water at the other.

Stratigraphy. The science of rock strata, including their original succession, age relations, form, distribution, physical, chemical, and biological properties, and mode of origin.

Stratovolcano. A large, steep-sided conical volcano that is constructed of alternating layers of lava flows and *pyroclastic* deposits that are intruded by abundant *dikes* and *sills*. Mt. Drum is an excellent example. Syn: *stratocone*.

Strike-slip. A nearly vertical fault on which movement is parallel to the fault's strike. With *dextral* strike slip, rocks to the right of the fault surface, when viewed along the fault, move toward the viewer; with *sinistral* strike slip, rocks to the left of the fault move toward the viewer.

Stromatolite. An organic *sedimentary* structure produced by trapping and binding of sediment during growth and metabolic activity of microorganisms, principally blue-green algae; structures typically are bulbous or columnal, but also may be flat.

Subduction. The process of one lithospheric plate descending beneath another, generally along linear zones that are marked by topographic *trenches* on the ocean floor. These *subduction zones* generally dip downward in the direction of plate convergence and are paralleled, in the down-dip direction, by *magmatic arcs* generated during subduction by the melting of the *lithosphere* at about 100 km depth in the subduction zone.

Surging glacier. A glacier that periodically flows very rapidly. During a *surge*, a large volume of ice may move down-glacier at velocities of as much as several meters per hour and the surface of the glacier may become severely crevassed. Surges cannot be sustained for more than brief periods (typically, 1–4 years) and generally are separated by much longer periods of normal accumulation and ice flowage.

Syenite. An *igneous intrusive* rock that contains mostly alkali feldspar.

Syncline. A fold, generally concave upward, the core of which contains the stratigraphically higher and younger rocks. Ant: *anticline*.

Synorogenic. Occurring at the same time as, or forming as a result of, orogenic activity.

Tectonic. Said of, or pertaining to, the forces involved in creating the structures and deformational features of the outer part of the Earth, including their mutual relations, origin, and evolution.

Tephra. A general term for all *pyroclastic* materials of a volcano, categorized, according to size (from smallest to largest), as *ash, lapilli, blocks*, and *bombs*.

Terrane. A fault-bounded body of rock of regional extent, characterized by a geologic history different from that of contiguous terranes.

Terrigenous. Derived from the land or continent.

Thrust. An overriding movement of one crustal unit over another, as in *thrust* faulting.

Till. Unsorted and unstratified materials that originally were deposited directly by a glacier; when lithified, they become the *sedimentary* rock called *tillite*.

Tonalite. An *igneous intrusive* rock consisting principally of quartz and plagioclase feldspar.

Transcurrent fault. A large-scale *strike-slip* fault.

Transform fault. A particular type of *strike-slip* fault along which the displacement abruptly stops or changes form.

Trench. An elongate depression of the deep-sea floor, generally formed at convergent plate boundaries where an *oceanic plate* is subducted beneath a *continental plate*.

Tsunami. A sea wave produced by any large-scale, short-duration disturbance of the ocean floor, principally by earthquakes, but also by slides, or volcanic eruptions.

Tuff. A general term for all consolidated *pyroclastic* rocks.

Ultramafic rocks. A general name for very dark *igneous* rocks that consist mostly of minerals rich in iron and magnesium.

Unconformity. A break in the geologic record where a rock unit is overlain by another that is not next in the direct stratigraphic succession—the contact between the two units is said to be unconformable. A considerable interruption in deposition may be present at unconformities, often representing uplift and erosion indicated by loss of previously formed sequences. Thus, many—but not all—unconformities are marked by an absence of parallelism between strata below and above the unconformable contact.

Underplating. Said of a process that incrementally emplaces tabular fault-bounded masses of rocks beneath like masses formed earlier, resulting in fault-bounded stacks (plates) of rock that enlarge from their underside. Underplating is a common process on the inner sides of many *subduction zones*, where materials derived from the converging tectonic plates are structurally stacked against and beneath the lip of the upper or overriding plate.

Underthrust. A type of *thrust* fault in which the lower rock mass has been actively moved under the upper, passive rock mass.

Varve. A *sedimentary* bed or sequence of layers deposited in 1 year's time—usually in still water adjacent to glaciers. A glacial varve normally includes a thicker summer layer consisting of coarser, lighter colored sediment produced during the season of rapid melting, and a thinner winter layer consisting of finer, often organic and darker colored sediment slowly deposited from suspension in quiet, icebound water.

Vent. The opening at the Earth's surface through which volcanic materials are emitted.

Volcanic rocks. Finely crystalline or glassy *igneous* rocks resulting from volcanic action near the Earth's surface, either ejected explosively or extruded as lava. Ant: *plutonic rocks*.

Volcaniclastic rocks. Pertaining to clastic rocks that contain volcanic material.

Window. An eroded area of a *thrust* sheet that displays the rocks underlying the thrust sheet.

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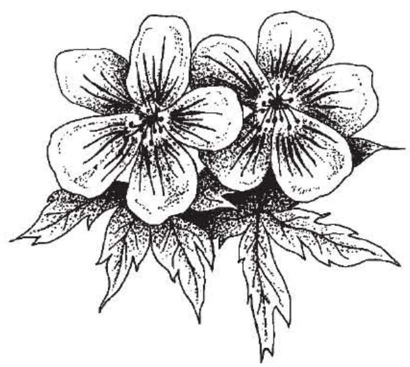

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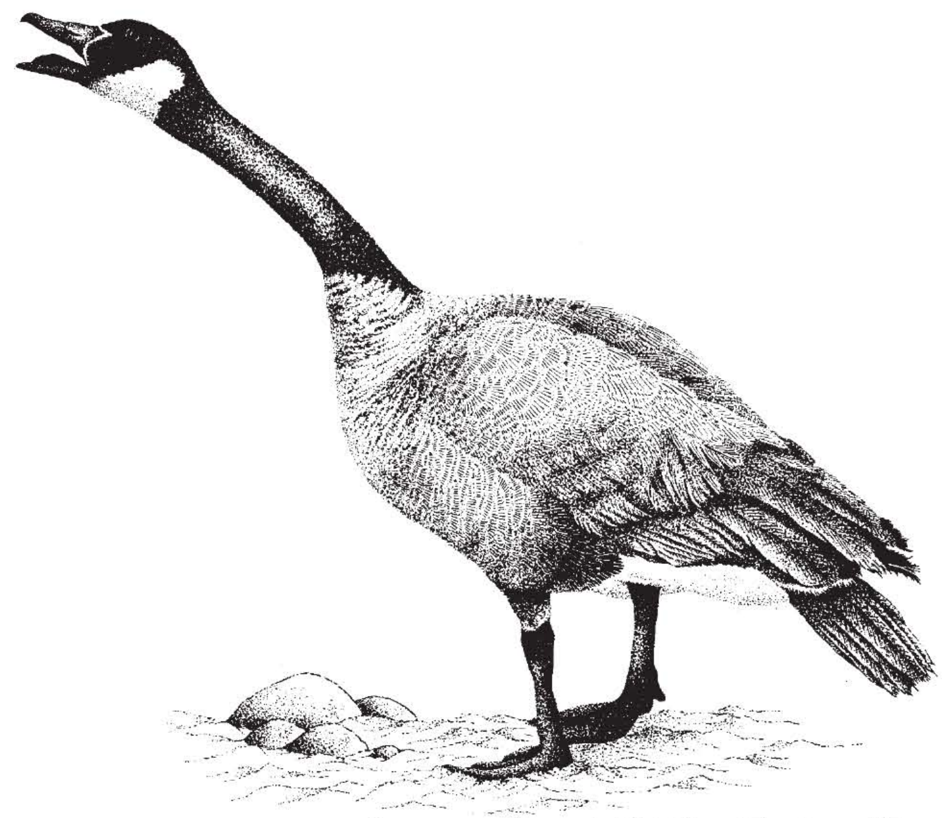

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