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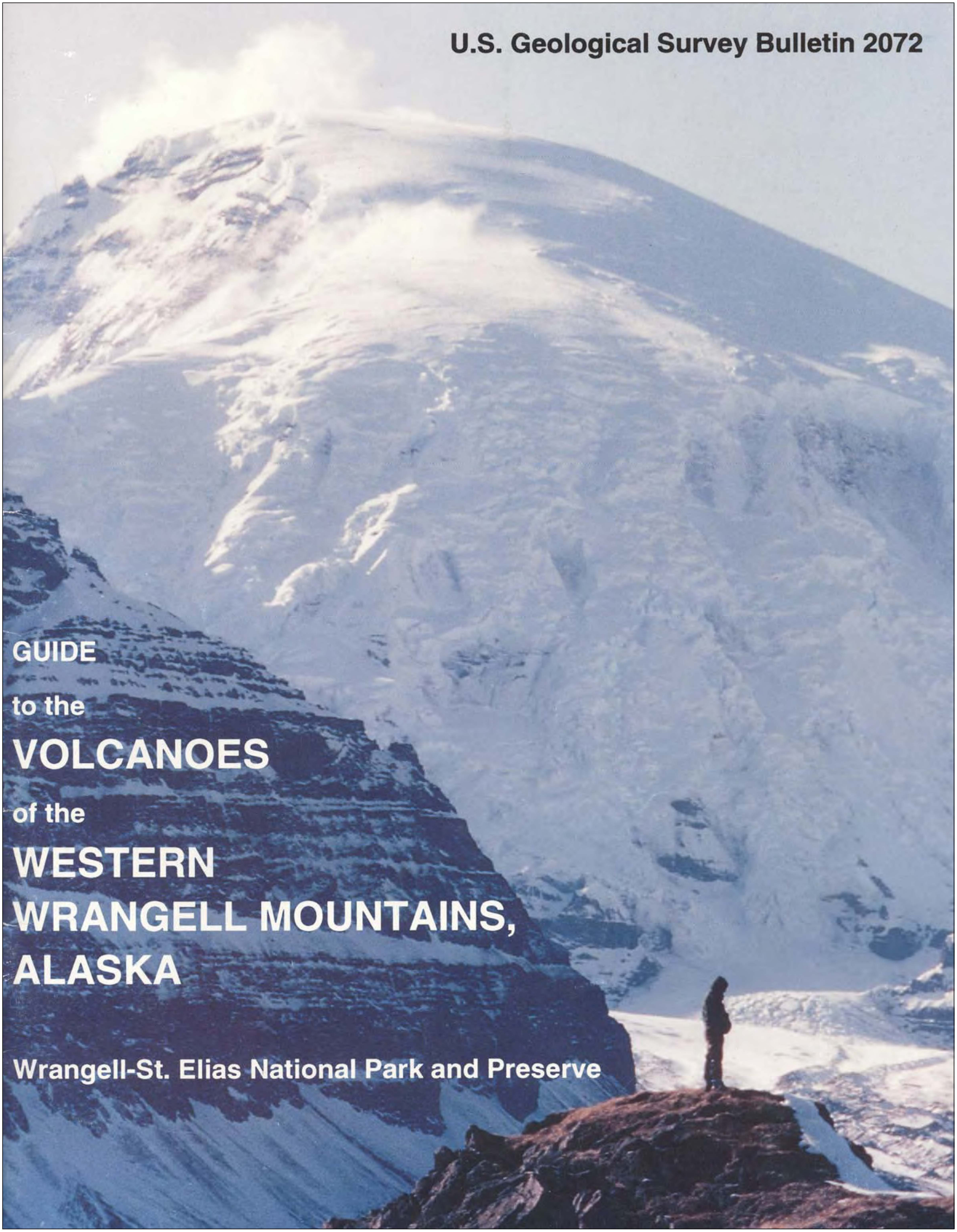

GUIDE to the VOLCANOES of the WESTERN WRANGELL MOUNTAINS, ALASKA

Wrangell-St. Elias National Park and Preserve

Frontispiece. Mount Wrangell from near Tonsina (about 20 mi south of Copper Center), probably during summer 1902. Dark ash, apparently from phreatic eruptions, blankets the ice- and snow-covered surface of the volcano, and a prominent steam plume rises from one of the summit craters. Mount Zanetti, a large cinder cone on the north flank of Mount Wrangell, is at left. Photograph by W.C. Mendenhall, U.S. Geological Survey.

Guide to the Volcanoes of the Western Wrangell Mountains, Alaska—Wrangell-St. Elias National Park and Preserve

By Donald H. Richter, Danny S. Rosenkrans, *and* Margaret J. Steigerwald

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Cover. The massive, ice-covered face of Mount Sanford. View westward across West Glacier. Photograph by D. Rosenkrans, 1984.

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GLOSSARY OF GEOLOGIC TERMS

This glossary defines some geologic words and terms that are used frequently throughout this guide and that may be unfamiliar to the reader. Definitions are mostly modified from the third edition (1987) of the *Glossary of Geology*, published by the American Geological Institute, Alexandria, Va.

Accreted—The attachment, or welding, of an exotic terrane to another terrane.

Agglutinate—A lava flow consisting chiefly of remobilized, generally welded cinder, spatter, and volcanic bombs.

Andesite—See basalt.

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

Basalt—Basalt and the other rock names—andesite, dacite, and rhyolite—used frequently in this guide refer to a series of common volcanic rocks that are distinguished primarily by their silica (SiO_2) content. Basalt contains the least silica (less than about 52 weight percent) and rhyolite the most silica (more than about 70 weight percent); andesite and dacite contain intermediate amounts. The silica content of a volcanic rock is determined by that of its parent magma, which, in turn, affects a magma's physical properties and allows insight into its mode of eruption. For example, low-silica rocks (basalts) tend to crystallize from hot (>1,000°C [2,040°F]), fluid, nonexplosive magmas, whereas high-silica rocks (rhyolites) tend to crystallize from "cool" (<900°C [1,675°F]), viscous, sometimes-explosive magmas.

Caldera—A large, generally circular volcanic depression whose diameter is many times larger than that of the included central vent.

Chalcocite—A heavy, blackish-gray mineral containing approximately 80 weight percent copper and 20 weight percent sulfur.

Cinder cone—Small, steep-sided conical hill built mainly of cinder, spatter, and volcanic bombs

Cirque—A crescentic or horseshoe-shaped basin at the head of a glacial valley, formed by the plucking action of ice when the valley was filled by a glacier.

Dacite—See basalt.

Dike swarm—A group of dikes (tabular injections of magma along crustal fractures), either radial outward from a single source or in parallel arrangement.

Exotic terrane—A sequence of rocks that formed at some distance from where it is now found that was transported to its present position by crustal-plate motion.

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

Granite—A coarsely crystalline igneous rock that results from solidification of a magma at depth in the Earth's crust. Its chemical composition is nearly equivalent to that of rhyolite.

Intracaldera—Referring to lava flows and other volcanic features that are confined to a caldera.

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

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

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

Metamorphic rock—A rock derived from preexisting rocks by chemical, mineralogic, or structural changes at depth in the Earth's crust.

Meteoric—Referring to water of recent atmospheric origin, such as rain or snow.

Pacific "rim of fire"—Part of the continental margin of the Pacific Ocean, so named because of the active volcanoes that occur along much of it.

Phreatic activity—An explosive steam and rock-fragment eruption caused by the sudden heating of ground water as it comes in contact with hot volcanic rock or magma.

Pluton—A body of igneous rock that solidified in the Earth's crust.

Pyroclastic—A general term referring to all volcanic material that is produced by explosive eruptive activity, such as ash, cinder, spatter, and bombs.

Radiocarbon dating—Calculating the age of organic material by measuring the relative amount of the radioactive isotope of carbon (^{14}C) remaining in the sample.

Radiometric K-Ar dating—Calculating the geologic age of a rock by measuring the relative amounts of the radioactive isotope of potassium (K) and its decay product argon (Ar) within the rock.

Rhyolite—See basalt.

Rift zone—A system of fractures on the flank of a volcano that generally originate in the summit area and along which eruptions may occur.

Ring fracture—A circular fault pattern generally associated with caldera subsidence.

Shield volcano—A broad dome built mainly of fluid lava flows.

Spreading ridge—A suboceanic zone where magma rises between two crustal plates and forces them apart.

Stratovolcano—A large, steep-sided conical mountain built mainly of pasty lava flows, cinder, and pyroclastic deposits.

Strike-slip fault—A major vertical crustal break along which movement has been generally horizontal and parallel to the trace of the fault.

Subduction—A zone were one crustal plate overrides another along a convergent margin.

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

Guide to the Volcanoes of the Western Wrangell Mountains, Alaska—Wrangell-St. Elias National Park and Preserve

By Donald H. Richter, Danny S. Rosenkrans,[1] *and* Margaret J. Steigerwald[1]

INTRODUCTION

Magnificent, breathtaking views of the snow-covered Wrangell Mountains in Wrangell-St. Elias National Park and Preserve (see back cover) await every visitor to this part of Alaska on a clear day. Mount Wrangell itself, a massive shield-shaped volcano and namesake of the range, still occasionally signals its active presence with steam plumes, while nearby, Mounts Sanford, Drum, and Blackburn lie dormant, the eroded peaks of older, once larger volcanoes. Knowing that these spectacular mountains are volcanic remnants provokes many intriguing questions: When did they last erupt? How tall were they? How do they compare with other volcanoes of the world? Will they erupt again? These are some of the questions addressed in this guidebook.

Designed for both the geologist and the lay reader, this guide describes the geologic history of various landscapes viewed from major roadways in and around Wrangell-St. Elias National Park and Preserve. It identifies places where visitors can touch a mudflow, view the chronologic development of a Wrangell volcano, and even hike into the core of an ancient volcano. In addition, it summarizes current studies on the eruptive history of the Wrangell volcanoes and interprets their significance and origin in light of modern geologic theory.

A "Glossary" is included at the front of this guide, and a listing of "Selected References" are included at the end. The glossary briefly defines many of the geologic terms that are used throughout the guide and that may be unfamiliar to the general reader; a term defined in the glossary is *italicized* the first time it appears in the text. The references enable the reader to pursue in more detail such areas of interest as early exploration, general geology, volcanology, and geologic maps.

[1]Wrangell-St. Elias National Park and Preserve, U.S. National Park Service, Glennallen, Alaska.

Manuscript approved for publication September 27, 1993.

EARLY HISTORY AND GEOLOGIC EXPLORATION

Ahtna Athabaskan natives traveled the river corridors, foothills, and passes of the Wrangell Mountains for several hundred years prior to European arrival in the area. They lived in semipermanent camps, leaving for weeks at a time to hunt and to gather berries, birch wood, and other resources. Trade routes with other native peoples were well established. Copper, found near the present-day town of McCarthy, was used for tools and for trade with other native groups. Rumors of the copper deposits, as well as the lure of fur animals, attracted Russians into the Copper River Basin from the 1760's to 1867. Many encountered considerable hostility from the Ahtna, who resisted the Russian domination of their villages.

The first recorded geographic observations of the western Wrangell Mountains were made by Lt. Henry T. Allen of the U.S. Army in 1885. In March of that year, Allen and three companions landed at the mouth of the Copper River and began one of the most remarkable journeys in the history of Alaskan exploration (fig. 1). Mapping as they went, the party ascended the Copper River around the west end of the Wrangell Mountains, crossed the Alaska Range through Suslota Pass, and then proceeded down the Tok, Tanana, Koyukuk, and Yukon Rivers to the Bering Sea just in time to catch the last boat to leave the Alaska coast before freezeup in early September. Allen's party was the first scientific expedition to cross the Alaska Range from the Gulf of Alaska to the Yukon River.

Before going north over the Alaska Range divide into the Tanana River Valley, Allen explored the upper Copper River Basin, the Chitina River Valley, and the western Wrangell Mountains. He named the Chitina and the Chitistone Rivers (both names incorporating the Athabaskan word "chiti," meaning "copper") and established friendly relations with Chief Nicolai and his Copper River group of Ahtna Indians. He measured the heights and named many of the high Wrangell peaks, including Mount Blackburn, Mount Drum, and Mount Sanford, during his long summer sojourn in the area.

After Allen's exploration, several scientific parties explored the Wrangell Mountains area. The team of Lt. Frederick Schwatka of the U.S. Army and geologist C.W. Hayes of the U.S. Geological Survey reached the Chitina River Valley by way of the White River and Skolai Pass (fig. 1) in 1891.

Spurred by these early explorations and the influx of prospectors during the Klondike gold discoveries in Canada, the U.S. Geological Survey and the War Department notably increased their efforts to make topographic and geologic maps of the country. U.S. Geological Survey geologist F.C. Schrader accompanied the 1898 U.S. Army survey led by Capt. William Abercrombie up the Copper River and into the Wrangell Mountains. That same year, U.S. Geological Survey geologist W.C. Mendenhall joined U.S. Army Capt. Edwin Glenn's expedition from Cook Inlet up the Matanuska River into the Copper River Basin. Alfred Brooks and William Peters of the U.S. Geological Survey and Oscar Rohn and A.H. McNeer of the War Department conducted separate expeditions to the Nabesna and Chisana areas on the north side of the Wrangell Mountains in 1899.

These journeys eventually led to mineral development of the Wrangell Mountains. The first gold discovery in the northern Wrangell Mountains was on Jacksina Creek near the headwaters of the Nabesna River in 1899. In that same year,

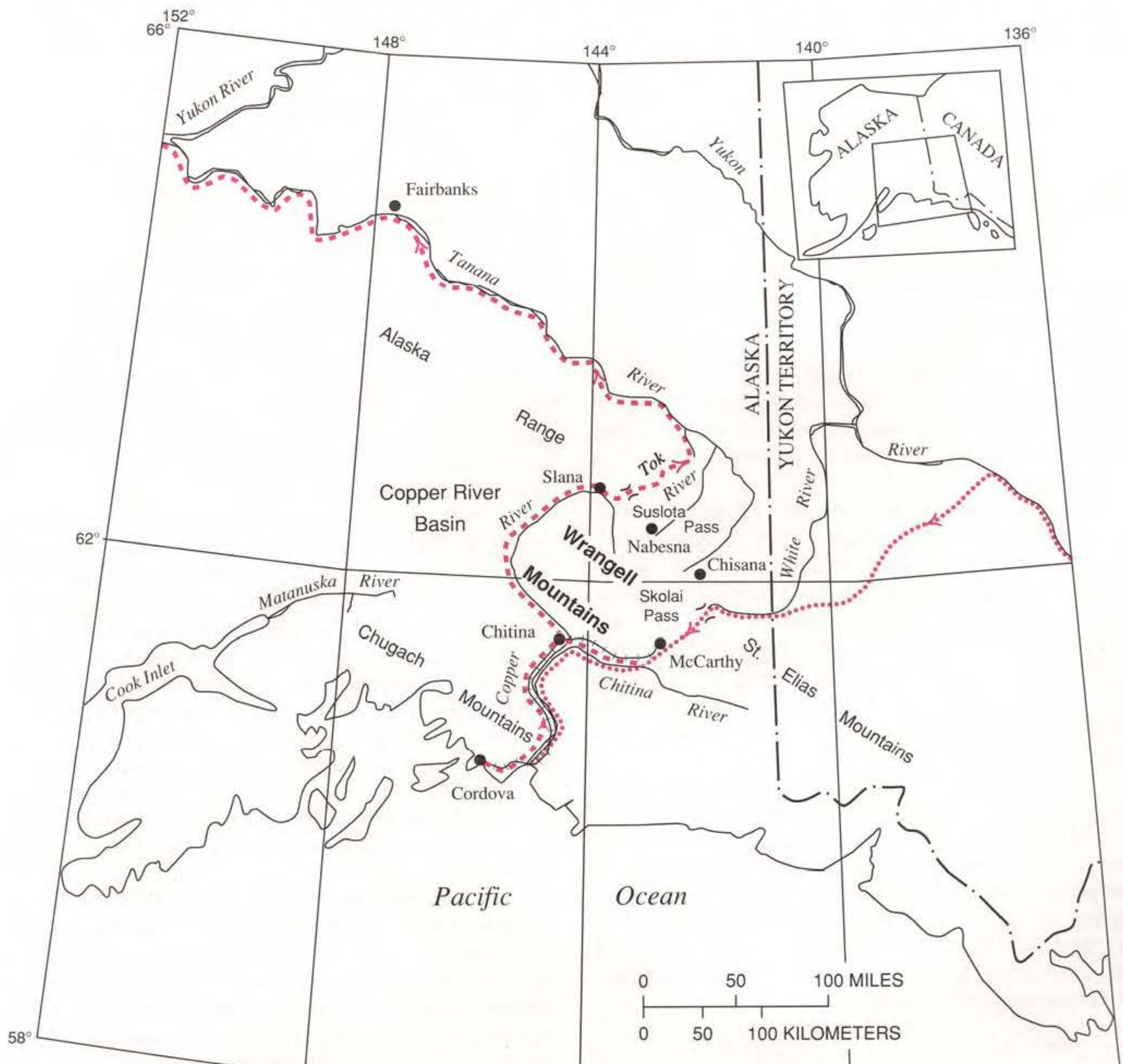


Figure 1. South-central Alaska and part of the Yukon Territory, Canada, showing early exploration routes of Allen in 1885 (red dashed line) and Schwatka and Hayes in 1891 (red dotted line) and route of the Cordova-Kennicott Railroad (barred line) that was used from 1911 to 1938.

Oscar Rohn, on his exploration of the upper Chitina Valley, found rich pieces of *chalcocite* ore in the glacial moraine of Kennicott Glacier[1] and pointed out similarities to the rich copper deposits of Michigan's Lake Superior District. Rohn also named the Chitistone Limestone and the Nikolai Greenstone, geologic formations that proved to be important hosts for mineral deposits. A year later, prospectors traced the chalcocite to deposits on Bonanza Ridge, which eventually became the incredibly rich Bonanza Mine, one of five mines that supplied copper and silver ore to the now-historic Kennecott Mill.

The Kennecott mines did not go into full production until 1911, when the completion of a 196-mi-long railroad from Cordova, near the mouth of the Copper River, to the Kennicott mining town allowed transport of the rich copper concentrate (fig. 1). In 27 years of operation, over a billion pounds of ore valued at $100 to 300 million was hauled on the railroad.

The mine and the railroad were abandoned in 1938, when the rich ore was exhausted. The railroad bed now provides the base for most of the Chitina-McCarthy Road along the south flank of the Wrangell Mountains in the heart of Wrangell-St. Elias National Park and Preserve.

Gold discoveries in the Nabesna area led to construction of the Nabesna Road, which was built in the early 1930's and used to haul gold ore from the now-closed Nabesna Mine. Today, the Nabesna Road provides vehicle access along the north side of the Wrangell Mountains into Wrangell-St. Elias National Park and Preserve.

A NATIONAL PARK IN THE WRANGELLS

After the Kennecott mines closed, several efforts were made to revive interest in the area. Ernest Gruening, Director of U.S. Territories and later Alaska's governor and a U.S. Senator, was the first to recommend the area as a national park or monument. After a flight over the area in 1938, he wrote a memorandum to the Secretary of the Interior:

> * * *the region is superlative in its scenic beauty and * * * measures up fully and beyond the requirements for its establishment as a National Monument and later as a National Park. It is my personal view that from the standpoint of scenic beauty, it is the finest region in Alaska * * *. I have travelled through Switzerland extensively, have flown over the Andes, and am familiar with the Valley of Mexico and with other parts of Alaska. It is my unqualified view that this is the finest scenery that I have ever been privileged to see.

Passage of the Alaska Native Claims Settlement Act in 1971 authorized the Federal government to withdraw and study Federal lands in Alaska for future uses. In 1978, President Jimmy Carter declared the area a National Monument because of its scientific and cultural significance. When Congress passed the Alaska National Interest Lands Conservation Act in 1980, the Wrangell Mountains became part of the 13.2 million acre Wrangell-St. Elias National Park and Preserve, the largest unit in the U.S. National Park system.

Wrangell-St. Elias is one of four contiguous conservation units spanning some 24 million acres that have been recognized by the United Nations as an international World Heritage Site. The original 1978 designation included Wrangell-St. Elias and Kluane National Park in the Yukon Territory of Canada. In 1993, both Glacier Bay National Park and Preserve and a new park, the Alsek-Tatshenshini Provincial Park in British Columbia were added to that designation. Altogether, it is the largest internationally protected area in the world.

GEOLOGIC BACKGROUND

The Wrangell Mountains, which form much of Wrangell-St. Elias National Park and Preserve, are made up largely of thousands of lava flows that have been erupted mostly from large broad volcanoes during the past 26 million years. This extensive volcanic terrain, which is called the Wrangell volcanic field (fig. 2), covers about 4,000 mi^2 (10,400 km^2)—an area a little smaller than the State of Connecticut—and extends eastward from the Copper River Basin through the Wrangell Mountains, into the St. Elias Mountains of Alaska and the Yukon Territory of Canada.

The principal basement rocks on which the Wrangell volcanoes erupted their great outpourings of lava are much older rocks and have had a complex geologic history. These rocks belong to what is referred to in the geologic literature as the Wrangellia terrane, which is part of an even larger group of *exotic terranes*—the Wrangellia composite terrane—that have been *accreted* to Alaska and the North American Continent during the past few hundred million years. On the basis of geophysical and fossil evidence, rocks of the Wrangellia terrane were formed in a tropical environment thousands of miles south of its present position. The Wrangellia terrane began as a *volcanic arc* about 300 million years ago, probably along the margin of an ancient North American Continent. As arc-related volcanic activity waned, a rift developed between the arc and continent, allowing the eruption of thousands of cubic miles of *basalt* lava flows that flooded and filled the rift-formed basin. Subsequently, shallow warm seas inundated the land, depositing layers of marine limestone and other sediment on the volcanic rocks.

[1]Kennicott Glacier was named by Oscar Rohn of the U.S. War Department in 1899 for Robert Kennicott, a pioneer Alaska explorer and director of the scientific corps of the Western Union Telegraph Expedition in 1865. The Kennecott Mines Co., which developed and mined the rich copper deposits, took its name from the glacier but misspelled it with an "e" instead of an "i".

During the next 200 million years, the Wrangellia terrane was gradually transported northward, where it was welded to other terranes and eventually docked against western North America about 100 million years ago (fig. 3). It now forms a belt extending from southern Alaska to southern British Columbia. Subsequently, other terranes, such as those composing the Southern Margin composite terrane, have been carried northward and accreted to continental Alaska. The last terrane to arrive—the Yakutat terrane—docked about 26 million years ago, concurrent with and partly responsible for the development of the Wrangell volcanic field.

VOLCANOES AND PLATE TECTONICS

The preceding section briefly discussed how the rocks on which the Wrangell volcanoes are built were not formed where they are found today but were transported a great distance from their place of origin. The tremendous forces capable of moving terranes and even entire continents are principally the result of the motion and interaction of the many semirigid plates that compose the crust of the Earth (fig. 4). This concept of a dynamic Earth's crust, called plate tectonics, has developed since the 1950's and revolutionized

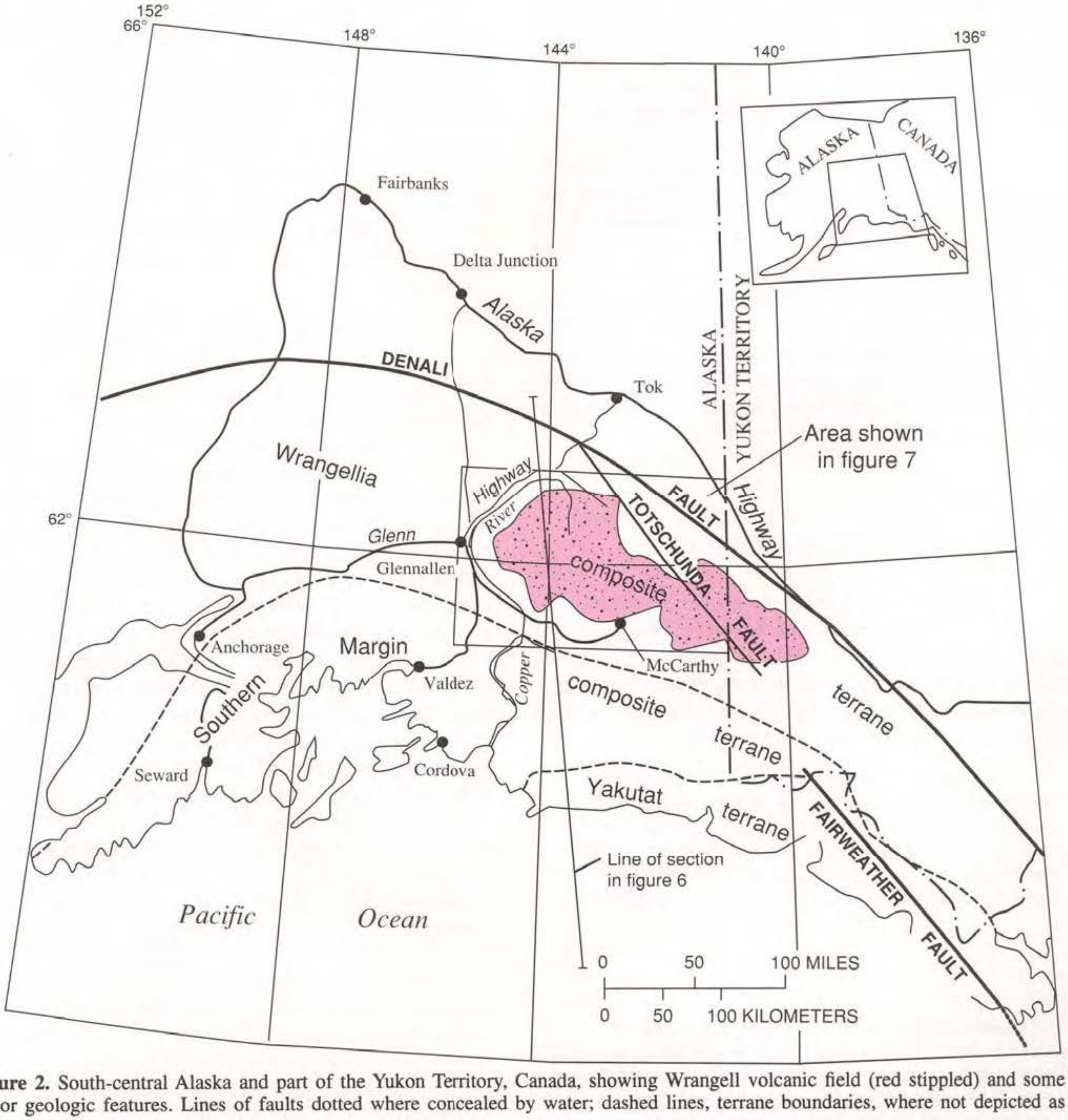


Figure 2. South-central Alaska and part of the Yukon Territory, Canada, showing Wrangell volcanic field (red stippled) and some major geologic features. Lines of faults dotted where concealed by water; dashed lines, terrane boundaries, where not depicted as faults.

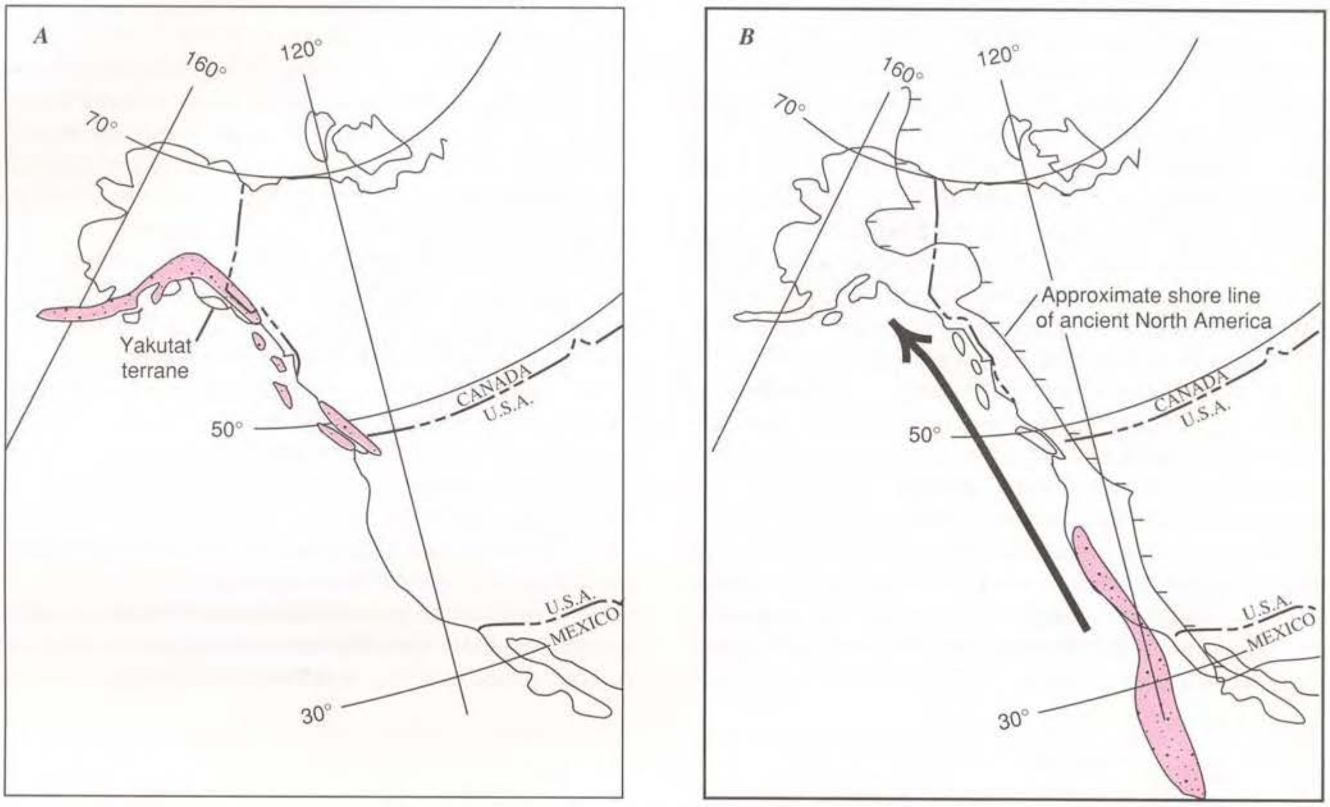


Figure 3. Western North America, showing (*A*) present position of Wrangellia composite terrane (red stippled area) and (*B*) its probable position 250 million years ago, before it moved northward as part of an ancient Pacific plate.

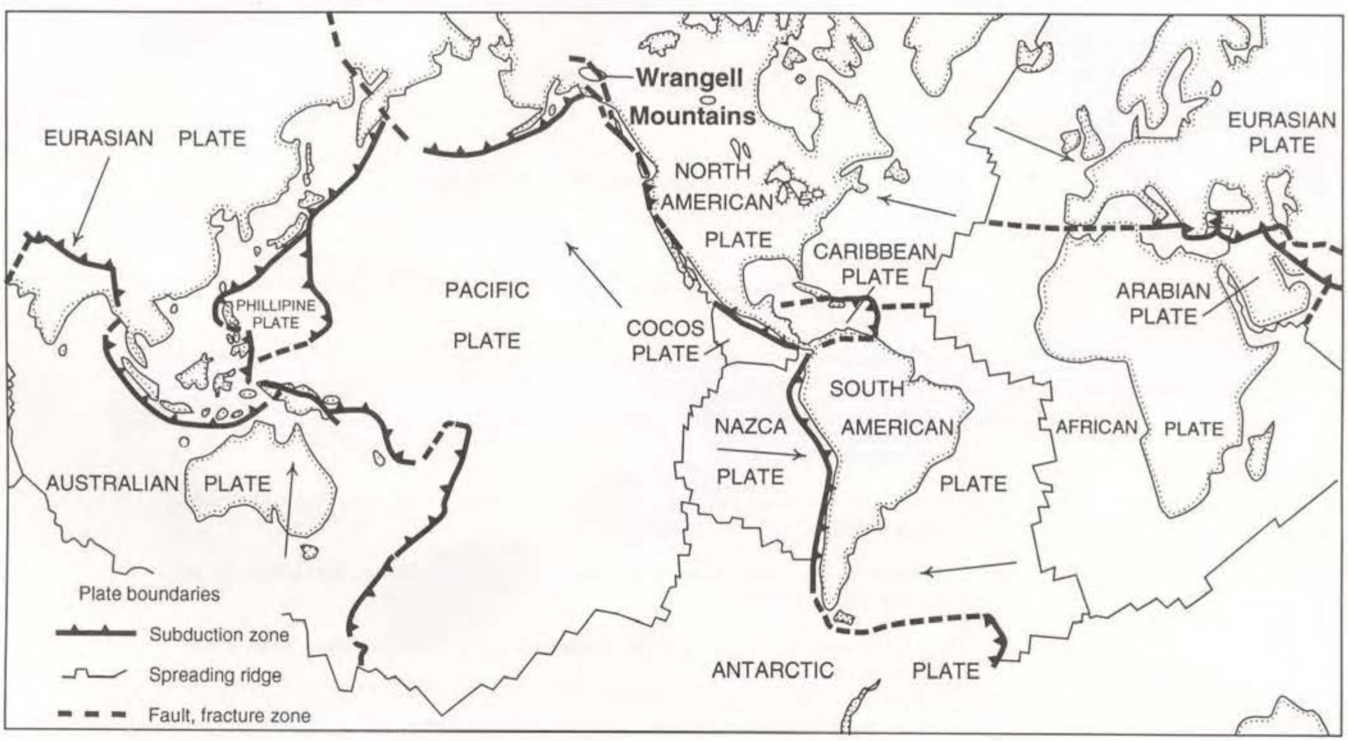


Figure 4. Major crustal plates of the world. Arrows indicate directions of relative plate motion.

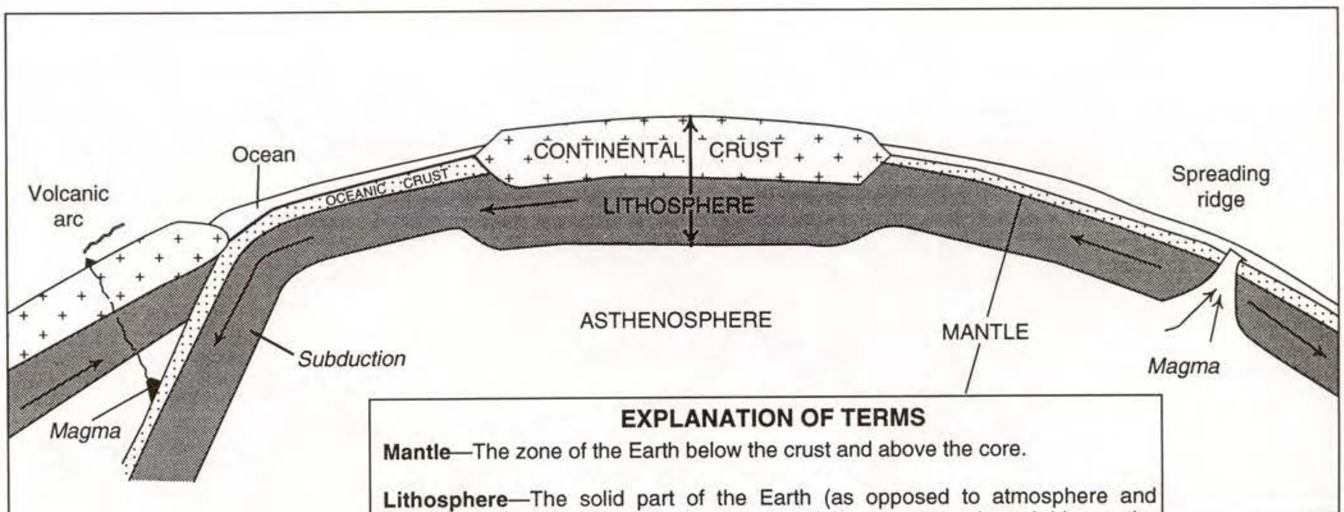
our understanding of the processes that build mountains and cause earthquakes and volcanic eruptions.

The speeds at which these crustal plates move across the surface of the Earth range from less than 1 to as much as 5 in/yr (2–12 cm/yr). Seemingly slow, these rates, over the course of millions of years, however, can move crustal plates hundreds, even thousands, of miles.

Although the ultimate cause of the motion of the plates is not well understood, geologists surmise that the immediate driving force is *magma* welling up from the *asthenosphere* along zones referred to as *spreading ridges* or rift zones (fig. 5). Most of these spreading ridges occur in the Earth's mid-oceanic areas, where they mark the boundaries between oceanic crustal plates. As new magma is periodically or continuously erupted along an oceanic spreading ridge, it forces older crust outward. The new magma cools, welding itself to the older crust, and then is followed by another batch of new magma, repeating the process. In contrast to new crust being added to a plate along a oceanic spreading ridge, old crust can also be consumed along crustal plate boundaries through a process called *subduction*. Here, one plate, generally a heavier oceanic plate, plunges under a lighter continental plate, where it eventually is assimilated back into the asthenosphere.

More importantly, however, in terms of the hazard to life and property, these subduction zones underlie most of the world's destructive volcanoes and are the ultimate cause of their volcanic activity. At depths of about 65 mi (100 km), heating of the subducting slab of light oceanic plate produces a magma (different chemically from the magma produced at a spreading ridge) by processes that are not well understood. This magma may form by partial melting of the crustal slab, by partial melting of the overlying *mantle* wedge as hot fluids stream up from the slab, or by combinations of these and other processes. Whatever its origin, the newly generated, light magma rises through the dense *lithosphere*, where it may undergo further chemical changes. It may eventually be erupted at the surface as a lava flow, dome, or as volcanic ash in a volcano. If the magma fails to reach the surface, it cools and crystallizes underground to form a body of igneous rock, generally referred to as a *pluton*.

In addition to plate subduction and ridge spreading, another important type of plate boundary occurs where two adjacent plates, traveling in different (but parallel) directions



EXPLANATION OF TERMS

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.

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.

Figure 5. Diagrammatic cross section through the Earth's crust and upper mantle, showing plate-tectonic features discussed in text. Arrows indicate directions of relative plate motion.

and at different speeds, slip past each other, forming a *strike-slip fault* zone. These plate boundaries, like subduction zones, are the sites of some of the world's largest earthquakes. The San Andreas fault system in California is an example of a plate-contact strike-slip fault. In Alaska, the Denali-Totschunda fault system, north of the Wrangell Mountains, and the Fairweather fault, south of the Wrangell Mountains, are strike-slip faults that presently form a principal boundary between the Pacific and North American crustal plates (fig. 2).

THE WRANGELL VOLCANOES

HOW DID THEY FORM?

The first Wrangell volcanoes formed about 26 million years ago, when the northwestward-moving Pacific plate, with its piggyback load of the Yakutat terrane, began to be subducted beneath the continental North American plate (fig. 6). Strong subduction and voluminous magma production, which have continued until relatively recently, have been responsible for the growth of the volcanoes and the development of the Wrangell volcanic field.

Since about 200,000 years ago, strike-slip movement along the Fairweather and Denali-Totschunda faults has accommodated some of the stress imposed by the northwestward motion of the Pacific plate. Thus, both the rate of subduction of the Pacific plate under the North American plate and the production of magma under the western Wrangell volcanoes have decreased. Although some eruptive activity will undoubtedly continue here in the future, voluminous outpourings of lava, like those that built the large shields of Mount Sanford and Mount Wrangell, seem unlikely.

The volcanoes of the western Wrangell mountains (fig. 7) are unlike most other volcanoes erupted above subduction zones and, indeed, may be unique around the entire Pacific rim. Rather than erupting explosive lavas forming steep-sided cones, they have been built by the accumulation of hundreds of relatively fluid lava flows to form broad mountains with gentle slopes, typical of shield volcanoes (fig. 8). Now, however, only youthful Mount Wrangell still displays a shieldlike form; the other, generally older volcanoes have

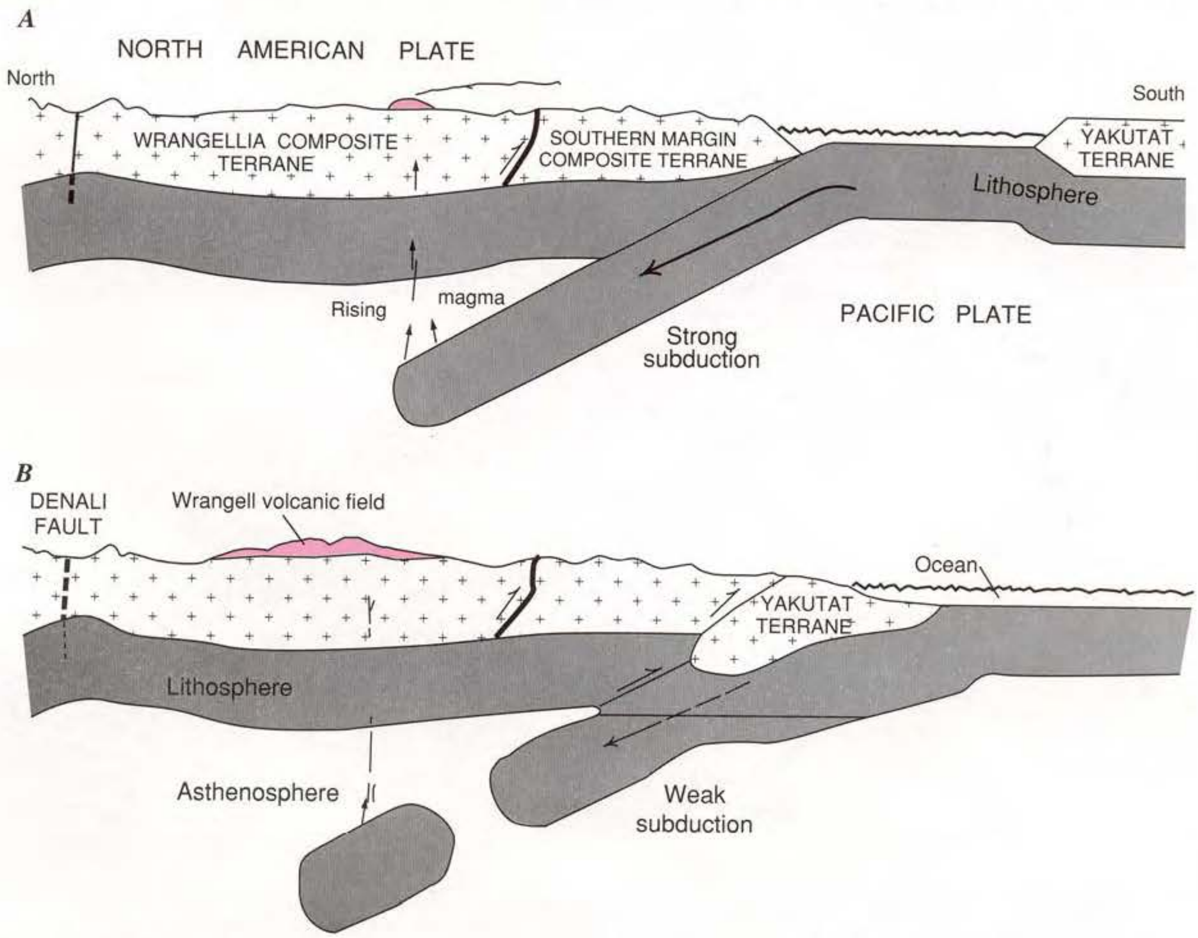


Figure 6. Diagrammatic north-south cross sections through south-central Alaska and the northern Pacific Ocean (see fig. 2), showing development of Wrangell volcanic field through subduction of the Pacific plate beneath the North American plate 25 million years ago (*A*) and at present (*B*).

had much of their superstructure removed by glacial and other erosional processes.

Moreover, all of the known Wrangell shield volcanoes, except Boomerang, are characterized by large summit collapse areas or *calderas*, 1 to more than 6 mi (1–10 km) in diameter, that have been filled with great thicknesses of flat-lying lava flows (fig. 8). Unlike most volcanoes along convergent plate margins, however, these calderas have formed relatively passively, possibly like the volcanoes of Hawaii. There, caldera collapse has occurred in response to the subvolcanic withdrawal of magma from beneath the summit, which, in effect, removes support for the summit area and causes it to subside or collapse. There is no known field evidence in the Wrangell Mountains to suggest that any of the calderas formed as a result of explosive volcanic activity, like what occurred at Mount Pinatubo in the Philippines in 1991. In the St. Elias Mountains, however, a small caldera on Mount Churchill probably formed as a result of large explosive eruptions that produced the White River Ash Bed (described later in this guide).

In addition to the large shield volcanoes, many smaller *cinder cones* are scattered, apparently randomly, throughout the Wrangell volcanic field. These cones, typically of basaltic or *andesitic* composition, represent eruption from a single, small volcanic vent and generally were formed after the growth of their host shield volcano. The largest of these cones, Mount Gordon, is described later in this guide.

HOW OLD ARE THEY?

All the volcanoes of the western Wrangell Mountains are less than 5 million years old. Their ages record a progression in volcanic activity from Mount Blackburn (3–4.5 million years old) in the southeast to Mount Drum (0.2–0.5 million years old) in the northwest (fig. 9). Mount Wrangell,

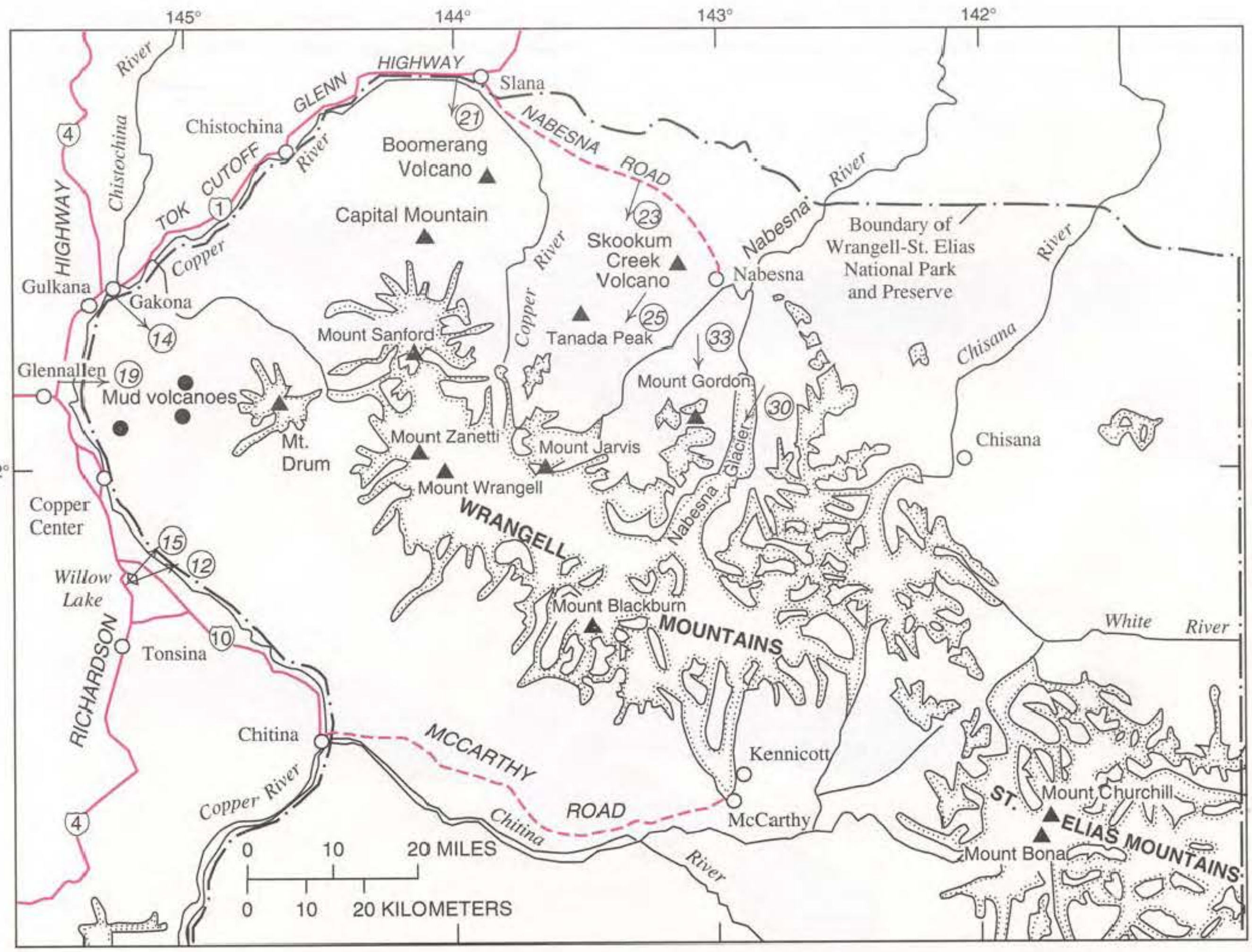


Figure 7. Wrangell Mountains and part of the St. Elias Mountains (see fig. 2), showing locations of volcanoes and other geologic features discussed in text. Stippled lines, areas of icefields and glaciers. Arrows indicate accessible viewing areas discussed in text; circled numbers refer to figures showing photographs of volcanoes.

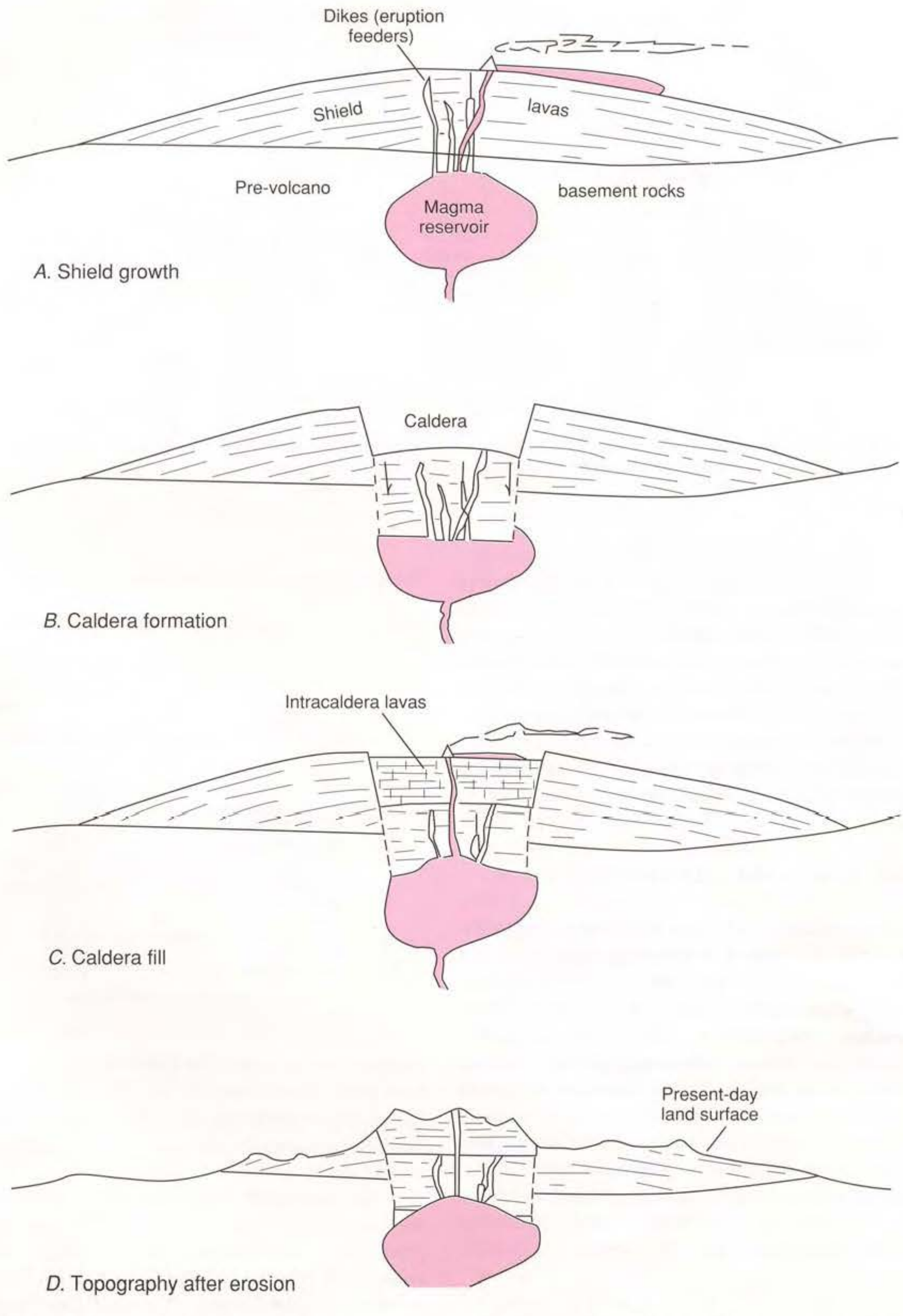


Figure 8. Diagrammatic cross section model illustrating development of a Wrangell volcano. *A*, Growth of shield by outpourings of voluminous lava flows from summit and rift vents. *B*, Collapse of summit caldera due to withdrawal of magma from a high-level magma reservoir. *C*, Filling of caldera by lava flows erupted from intracaldera vents. *D*, Present topography after erosion. Profile is that of Tanada volcano from mile 26 on the Nabesna Road. Growth of shield and collapse and filling of caldera probably occur partly concurrently.

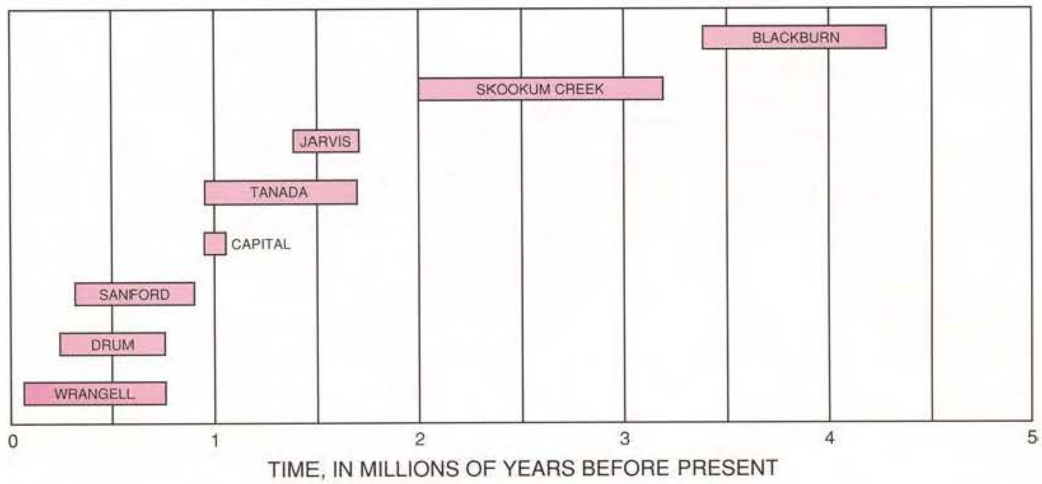


Figure 9. Known periods of eruptive activity for radiometrically dated western Wrangell volcanoes. Ends of bars correspond to known beginning and end of eruptive activity.

which has *fumaroles* on its summit and is considered an active volcano, may have erupted lava flows as recently as 50,000 years ago, but reliable data to fully verify this young age are unavailable. Farther to the southeast, in the eastern Wrangell Mountains and the St. Elias Mountains (beyond the general area of this guide), the volcanoes are progressively older. The earliest known volcanic activity in the Wrangell volcanic field occurred about 26 million years ago near the Alaska-Yukon Territory boundary.

HOW TALL ARE THEY?

The Wrangell volcanoes range in elevation from a few thousand feet above sea level (Boomerang, 3,949 ft [1,204 m]) to a maximum of 16,390 ft (4,996 m) at Mount Blackburn. Many have impressive summits, higher than 10,000 ft (3,050 m); others, especially some of the older volcanoes, are more subdued and generally have had large parts of their structures removed by erosion. The 10 highest named peaks in the Wrangell Mountains are listed in table 1. All of these peaks are volcanic in origin, and most mark the general area of central-vent eruptive activity. In addition to these peaks, a few unnamed peaks, all of volcanic origin and all higher than 13,000 ft (4,000 m) occur in the general vicinity of Mount Blackburn and Mount Jarvis.

HOW DO THEY COMPARE WITH OTHER MOUNTAINS?

The Wrangell volcanoes are among the highest mountains in North America and some of the largest (by volume) in the world. As listed in table 2, Mount Blackburn and Mount Sanford are the 12th and 13th tallest mountains, respectively, in North America; Mount Bona, a Wrangell volcano to the east in the St. Elias Mountains, ranks 11th.

Table 1. Highest peaks of the Wrangell Mountains.

[Peaks are listed in descending order by height; those in boldface are described in text]

Rank	Name	Height	
		(ft)	(m)
1	**Mount Blackburn**	16,390	4,996
2	**Mount Sanford**	16,237	4,949
3	**Mount Wrangell**	14,163	4,317
4	Atna Peaks	13,600–13,860	4,145–4,225
5	Regal Mountain	13,845	4,220
6	**Mount Jarvis**	13,421	4,091
7	Parka Peak	13,200	4,023
8	**Mount Zanetti**	13,009	3,965
9	Rime Peak	12,741	3,883
10	**Mount Drum**	12,010	3,661

In comparison with most *stratovolcanoes* associated with convergent plate margins, such as along the *Pacific "rim of fire,"* the Wrangell shield volcanoes are much more voluminous (fig. 10). Mount Wrangell and Mount Sanford, for example, each consist of about 250 mi^3 (1,000 km^3) of lava in comparison with about 8 mi^3 (32 km^3) for Mount St. Helens, Wash., which erupted in 1980, and about 45 mi^3 (190 km^3) for Mount Rainier, Wash. Fujiyama, in Japan, one of the world's largest stratovolcanoes, has a volume of about 185 mi^3 (740 km^3).

Table 2. Highest mountains of North America.

[Mountains are listed in descending order by height; those in boldface are in the Wrangell Mountains]

Rank	Name	Location	Height (ft)	Height (m)
1	Mount McKinley------	Alaska -----------	20,320	6,194
2	Mount Logan ----------	Canada------------	19,850	6,050
3	Pico de Orizaba -------	Mexico------------	18,700	5,700
4	Mount St. Elias--------	Alaska-Canada --	18,008	5,489
5	Popocatépetl -----------	Mexico------------	17,887	5,452
6	Mount Foraker --------	Alaska ------------	17,400	5,304
7	Iztaccíhuatl-------------	Mexico------------	17,343	5,286
8	Mount Lucania --------	Canada------------	17,147	5,226
9	King Peak--------------	Canada------------	16,971	5,172
10	Mount Steele ----------	Canada------------	16,440	5,011
11	Mount Bona -----------	Alaska ------------	16,421	5,005
12	**Mount Blackburn ---**	Alaska ------------	16,390	4,996
13	**Mount Sanford-------**	Alaska ------------	16,237	4,949
14	Mount Wood-----------	Canada------------	15,880	4,840
15	Mount Vancouver-----	Alaska-Canada --	15,700	4,785

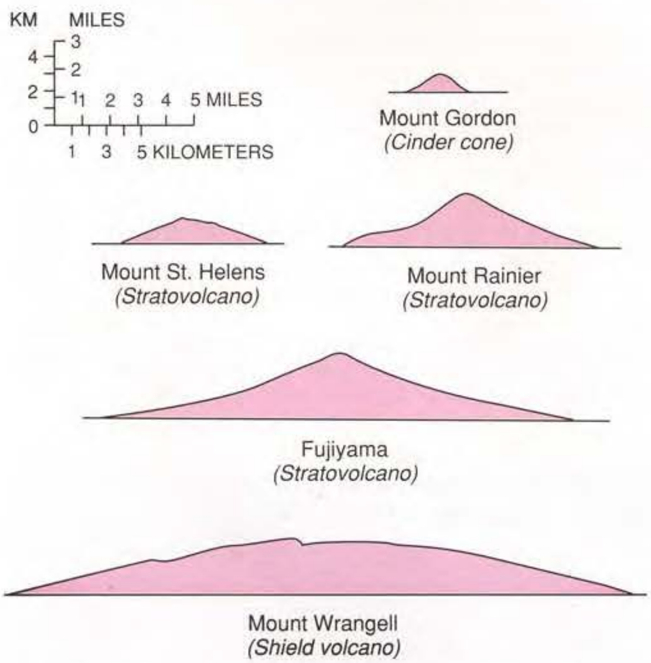


Figure 10. Comparative profiles of some Pacific-rim volcanoes. Mount Gordon, a cinder cone, and Mount Wrangell, a shield volcano, are described in text; Mount St. Helens, Mount Rainier, and Fujiyama are well-known stratovolcanoes.

DESCRIPTIONS OF INDIVIDUAL VOLCANOES

MOUNT WRANGELL

Mount Wrangell, the youngest volcano in the western Wrangell Mountains (figs. 11, 12), is a large, broad, ice-covered shield of tremendous bulk. Although no lava-producing eruptions have been documented in historical time, geologists consider the volcano to be active.

Name.—Reported in 1885 by Lt. Henry T. Allen of the U.S. Army as named by the Russians after Baron von Wrangell, Russian explorer, admiral of the Imperial Russian Navy, and Governor of Russian America from 1830 to 1836. Mount Zanetti, a large cinder cone on the Mount Wrangell shield, is a local name reported by W.C. Mendenhall, U.S. Geological Survey geologist, in 1903. Ahtna name: K'elt'ae-ni ("the one who controls the weather"); when erupting: Uk'eledi ("the one with smoke on it"). It is interesting to note that Allen named another mountain in the western Wrangell Mountains, Mount Tillman, after Samuel L. Tillman, a professor at the U.S. Military Academy. In a panoramic sketch of the volcanoes as seen from about the present Tonsina townsite, Mount Sanford was called Mount Tillman; and on a plan map of the volcanoes, Mount Wrangell was called Mount Tillman. Although we will probably never know what lay behind this "extra" volcano, the confusion possibly stemmed from observations at widely separated viewpoints during times of inclement weather. The name "Tillman" was dropped from all maps after about 1900.

Type and form.—Shield volcano containing an ice-filled summit caldera, 3.5 mi (6 km) long by 2.5 mi (4 km) wide, that is breached on its south side. Three small craters, containing active fumaroles, are situated along the rim of the summit caldera: North and West craters lie directly on the rim, and East Crater sits on top of a small cone on the rim. North Crater, the largest, consists of two overlapping craters, about 0.6 mi (1 km) in total diameter; West and East craters are somewhat smaller, less than 0.5 mi (0.8 km) in diameter. Mount Zanetti, a large cinder cone, occurs high on the northwest flank of the Mount Wrangell shield.

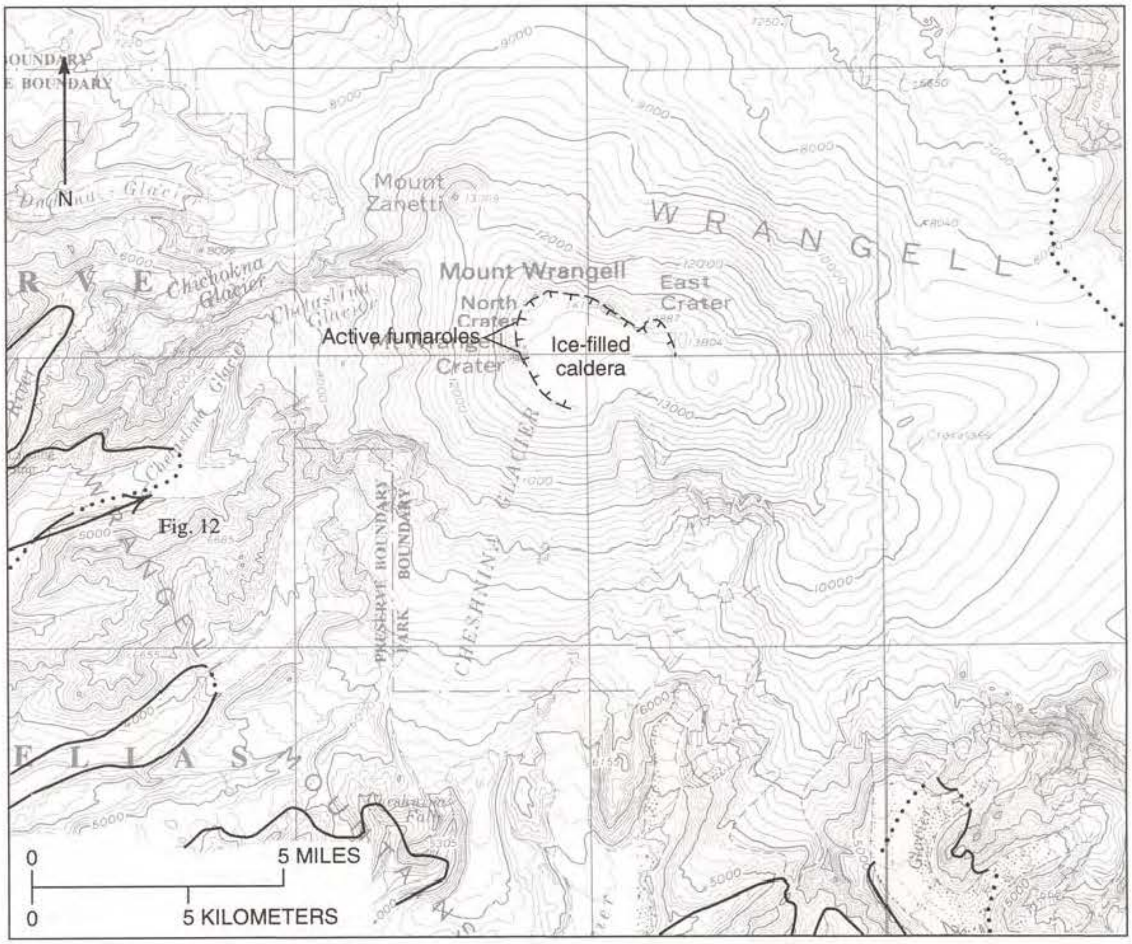
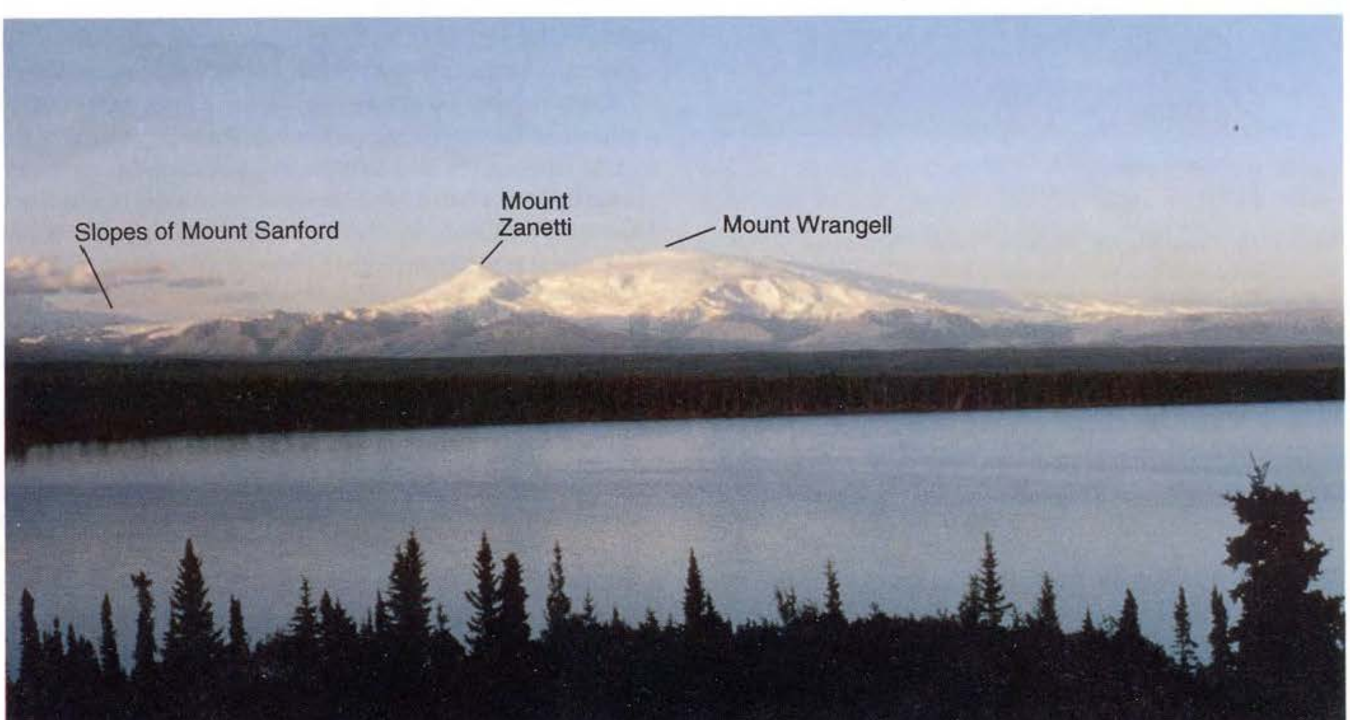


Figure 11. Topographic and generalized geologic map of Mount Wrangell. Heavy lines, approximate present limit of Mount Wrangell lavas, dotted where concealed by ice. Arrow indicates direction of view in figure 12. Base from U.S. Geological Survey Gulkana, Nabesna, Valdez, and McCarthy quadrangle maps.



Location.—50 mi (80 km) east of Glennallen, Alaska, at lat 62°00′ N., long 144°00′ W. Shown on U.S. Geological Survey Gulkana A–1, Nabesna A–6, Valdez D–1, and McCarthy D–8 quadrangle maps.

Height.—14,163 ft (4,317 m). First ascent, 1908. Mount Zanetti is 13,009 ft (3,965 m) high.

Latest eruptive activity.—Since the late 1700's, there have been at least three reports (1784, 1884–85, and 1900) of violent eruptive activity, including sightings of active lava flows, on Mount Wrangell. Although the reports of flowing lava have never been confirmed, Mount Wrangell is still considered an active volcano. The three summit postcaldera craters contain active fumaroles, and on calm days a steam plume can sometimes be seen rising from the summit. In addition, at least two craters (West and North Craters) have been the sites of sporadic *phreatic activity* throughout historical time, and occasionally the summit area is blanketed by a thin layer of dark ash (see frontispiece). On the basis of radiometric dating K-Ar dating, the lava flows most recently erupted from Mount Wrangell may be 50,000 to 100,000 years old. Some recent research indicates that summit fumarolic and phreatic activity may wax and wane in response to changes in the summit heat flux, which, in turn, may increase after major earthquakes in southern Alaska. For example, after the 1899 Yakataga, Alaska, earthquake, ash falls on the summit icefield were apparently common; and after the great 1964 Alaska earthquake, thermal activity increased markedly at the summit. Apparently, seismic activity can open clogged parts of water-convection channels beneath the craters to allow more efficient heat transfer. Before the 1964 earthquake, visible plumes at the summit of Mount Wrangell were from West Crater, whereas after the earthquake, fumarolic activity increased markedly in North Crater. Through the early 1980's, the heat flux increased again and melt rates were so high that lakes formed intermittently in North Crater for several years. Since 1986, however, after the melting of more than 130 million yd^3 (100 million m^3) of ice, the ice volume has been slowly building up again.

Volcanic history.—The main bulk of the Mount Wrangell shield was built chiefly by the accumulation of hundreds of voluminous andesitic lava flows from 600,000 to 200,000 years ago. The summit caldera probably collapsed within the past 200,000 years, possibly as recently as 50,000 years ago. The cone of Mount Zanetti and a few flows on the south flank of Mount Wrangell are probably the youngest products of the volcano. Mount Zanetti probably erupted during the waning stage of the latest major glaciation, possibly less than 25,000 years ago, and a large, young andesite flow that originated in the summit area and traveled more than 40 mi (64 km) south and west into the ancestral Copper River Basin may be only 50,000 years old.

Glaciers.—Perennial ice and snow cover more than 90 percent of the Mount Wrangell shield. This large icefield is the source of many alpine glaciers that feed into both the Copper River and Yukon River drainages. Nabesna Glacier, the largest and longest of these glaciers, has its origin high on the southeast slopes of Mount Wrangell and flows more than 50 mi (80 km) east and then north, where it forms the source of the Nabesna River, a major tributary of the Tanana River.

Best viewing.—Mount Wrangell is readily visible along the Richardson Highway from Tonsina north to Glennallen and along most of the Edgerton Highway to Chitina. North of Glennallen, views are mostly blocked by Mount Drum; however, it comes into view again between Gakona and Chistochina on the Tok Cutoff of the Glenn Highway. Two excellent viewpoints are at Willow Lake (mile 87) (fig. 12) on the Richardson Highway and at mile 20 on the Tok Cutoff of the Glenn Highway.

> Mount Wrangell, the first of the higher volcanoes of the Wrangell Mountains to be climbed, has also been the site of numerous scientific expeditions and investigations. The relative ease of access to the volcano and its high northern-latitude elevation combine to provide an ideal natural laboratory. In 1953, Terris Moore, then president of the University of Alaska, landed a ski-equipped small plane in the ice-filled summit caldera to begin a cosmic-ray-research program in cooperation with New York University. Since then, more than 100 ski-plane landings have been made on the summit in support of various scientific investigations. In 1961, Carl Benson of the University of Alaska's Geophysical Institute began glaciovolcanic studies on Mount Wrangell's summit, a program that continues to the present.

MOUNT DRUM

Mount Drum is the westernmost Wrangell volcano. Though more than 4,000 ft lower in elevation than its neighbor, Mount Sanford, this volcano dominates the local landscape as it rises above the adjacent Copper River Basin lowlands (figs. 13–15).

Name.—Named in 1885 by Lt. Henry T. Allen, of the U.S. Army after Adj. Gen. Richard C. Drum (1825–1909), who served in the Mexican and Civil Wars and later attained the rank of brigadier general. Ahtna name: Hwdaandi ("downriver")-K'elt'aeni ("the one who controls the weather").

Type and form.—Stratovolcano or shield volcano whose original morphology has been severely modified by

◀ **Figure 12.** Mount Wrangell from Willow Lake (in foreground) at mile 87 on the Richardson Highway. View northeastward; photograph by U.S. National Park Service.

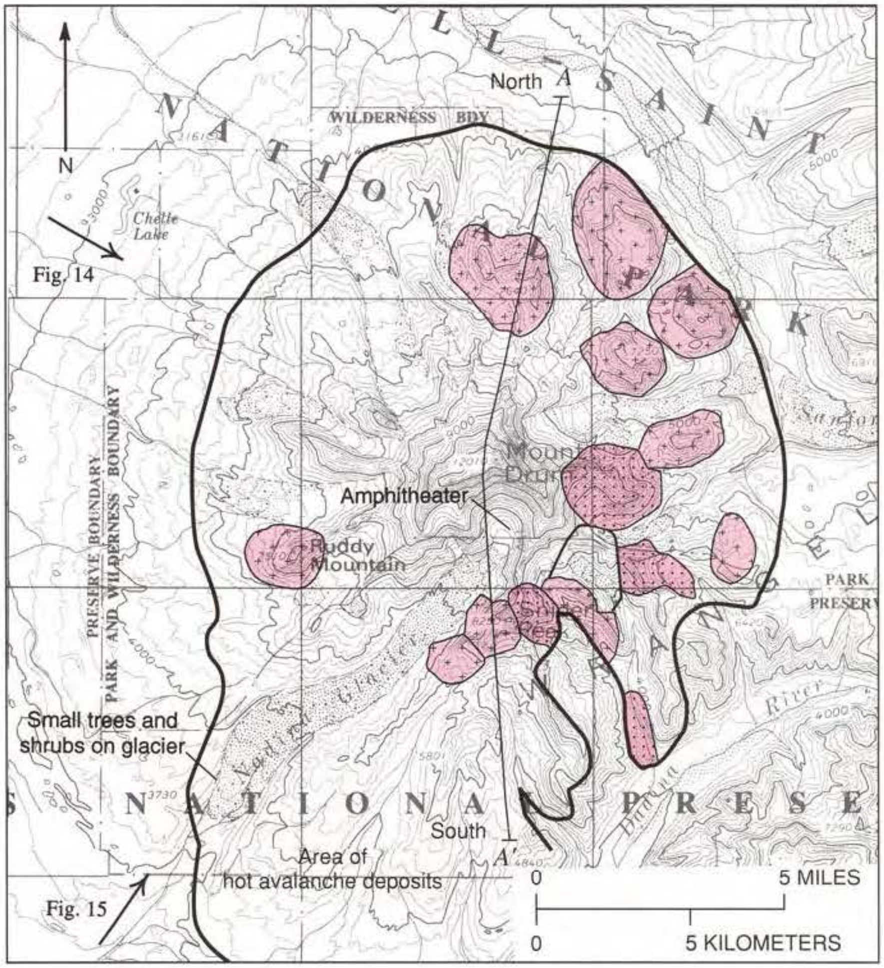


Figure 13. Topographic and generalized geologic map of Mount Drum. Heavy line, approximate present limit of Mount Drum lavas; stippled areas, cycle 1 domes; crossed areas, cycle 2 domes. Arrows indicate directions of view in figure 14 (from northwest) and figure 15 (from southwest). *A–A′*, line of cross section in figure 16. Base from U.S. Geological Survey Gulkana and Valdez quadrangle maps.

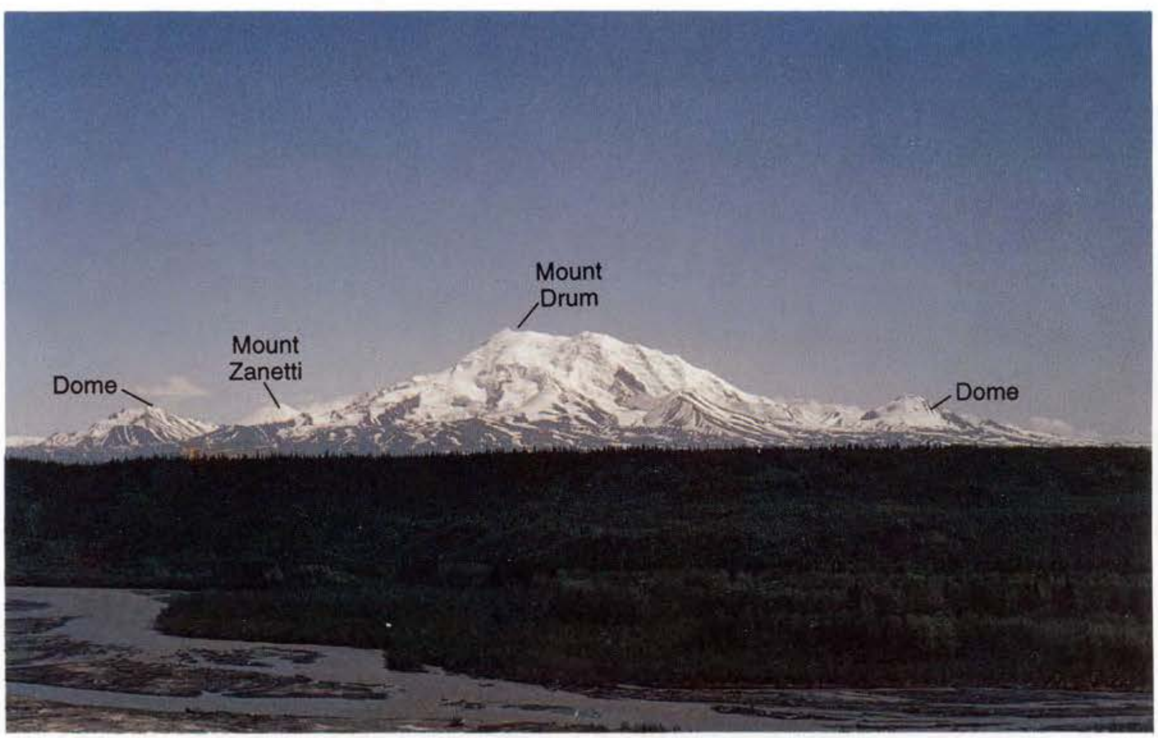


Figure 14. Mount Drum from mile 1 on the Tok Cutoff of the Glenn Highway. The Copper River is in foreground. View southeastward; photograph by U.S. Geological Survey. Copper River in foreground.

violently explosive eruptive activity and subsequent glacial erosion. Several small peaks, each formed by an individual late-stage volcanic dome, ring the main structure along about 270° of arc on the south and east sides of the volcano.

Location.—29 mi (47 km) due east of Glennallen, Alaska, at lat 62°07′ N., long 144°38′ W. Shown on U.S. Geological Survey Gulkana A–2 quadrangle map.

Height.—12,010 ft (3,661 m). First ascent, 1954; Heinrich Harrer, Keith Hart, and George Schaller.

Latest eruptive activity.—Violently explosive volcanic activity destroyed the top and much of the south face of Mount Drum, probably between 250,000 and 150,000 years ago. The last documented eruptive activity, based on *radiometric K-Ar dating* techniques, occurred at Snider Peak about 240,000 years ago (fig. 16).

Volcanic history.—Mount Drum was constructed between about 700,000 and 240,000 years ago during two major cycles of eruptive activity. The first cycle (700,000–500,000 years ago) included the development of an early stratovolcano or, possibly, shield volcano, consisting largely of andesitic lava flows and breccias. A series of early *rhyolite* domes formed toward the end of the first cycle of activity; their distribution suggests that they were erupted along a short arcuate fracture system on the new volcano's southeast flank. The second cycle of activity (500,000–240,000 years ago) apparently followed the emplacement of the rhyolite domes without a significant time break. Again, large volumes of mostly andesitic lava were erupted, building a volcanic pile that may have been as high as 14,000 to 16,000 ft (4,300–4,900 m). Toward the end of this period of constructional activity, as many as 10 *dacite* domes were erupted along at least two major arcuate fracture systems that almost completely encircled the volcano at distances as far as 5 mi (8 km) from the central vent. Snider Peak dome and its associated lava flows, which were erupted about 240,000 years ago, probably represent the last products of constructional volcanic activity on Mount Drum. After the eruptions at Snider Peak and, possibly, as recently as 100,000 years ago, cataclysmic eruptions destroyed much of the volcano. These explosive eruptions, which apparently originated on the south flank of the volcano, possibly near Snider Peak, produced a series of hot and cold volcanic avalanches and mudflows containing as much as 1.5 mi^3 (7 km^3) of material and covering an area of about 80 mi^2 (207 km^2). The mudflows (fig. 17) produced during the destruction of part of Mount Drum were extremely fluid because of the addition of large volumes of water from melted ice and snow at and near the eruption site. Cascading down the lower south flank of the volcano, these mudflows, carrying along house-size and larger masses of cohesive volcanic rocks,

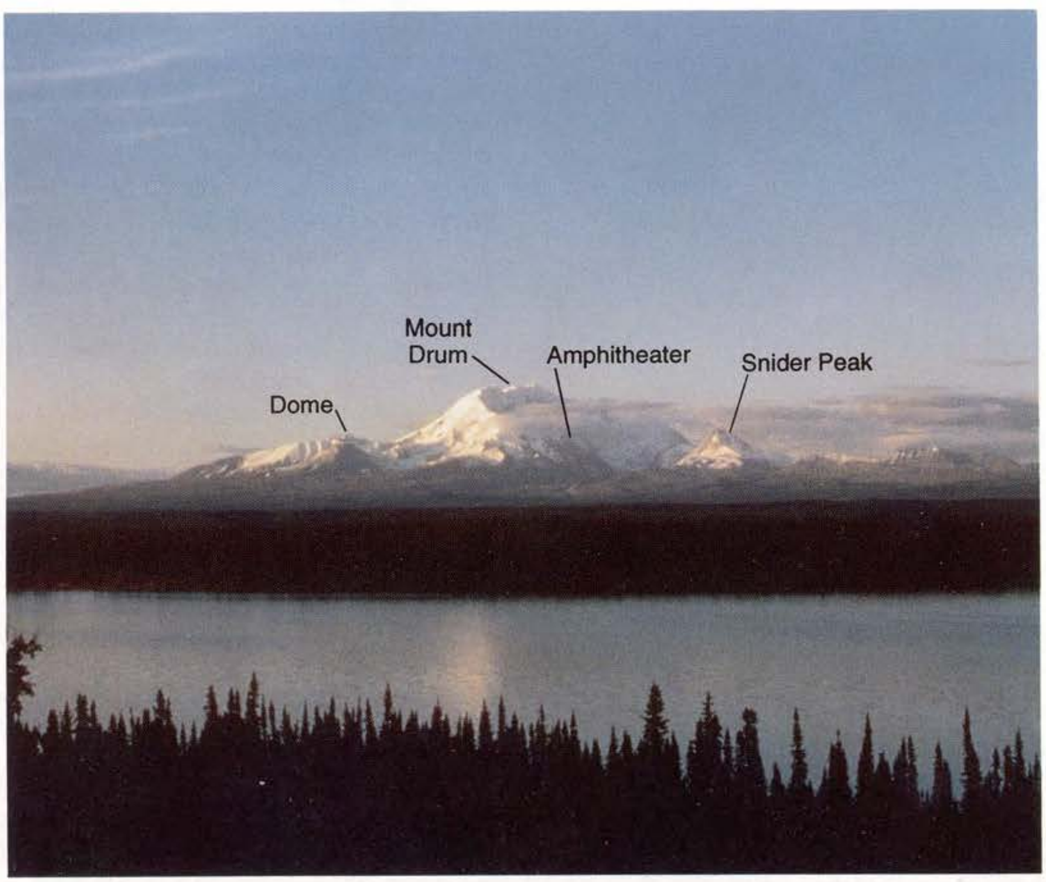


Figure 15. Mount Drum at sunset from Willow Lake (in foreground) at mile 87 on the Richardson Highway. Great amphitheater, resulting from late cataclysmic explosive activity, is partly hidden by clouds. View northeastward; photograph by U.S. National Park Service.

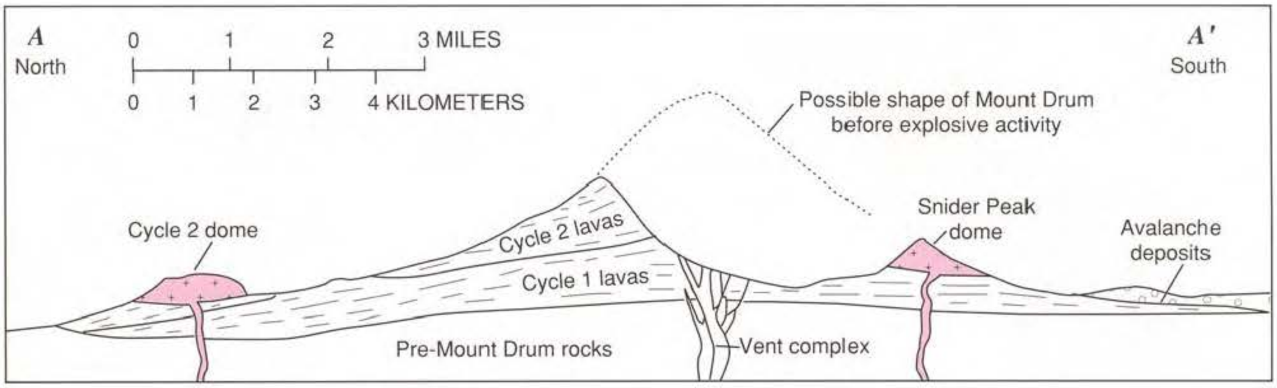


Figure 16. Generalized geologic cross section through Mount Drum (see fig. 13 for location).

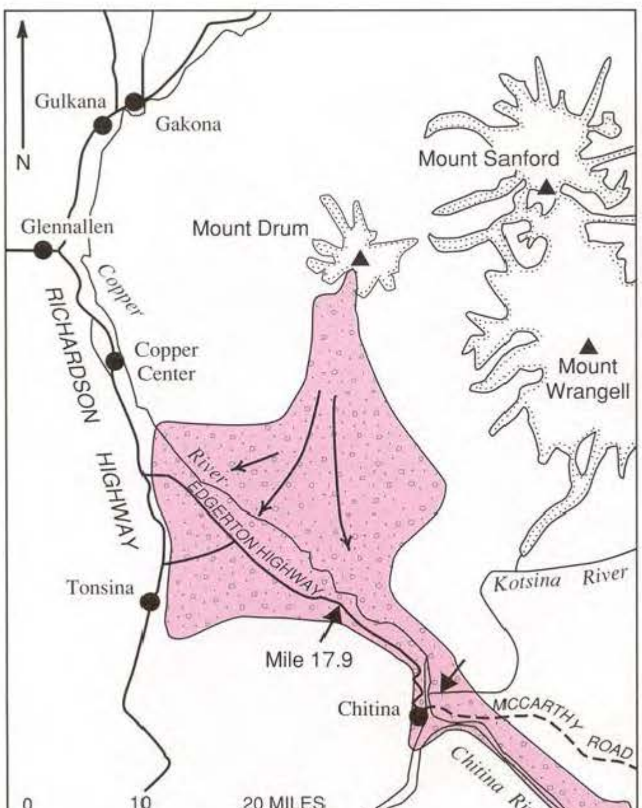


Figure 17. Approximate extent of volcanic avalanche and mudflow deposits (red stippled areas) probably generated by late cataclysmic eruptions of Mount Drum (flow direction shown by long arrows). Short arrows denote areas along the Edgerton Highway and the McCarthy Road where mudflows are well exposed. Stippled lines, extent of glaciers and icefields.

poured into the Copper River Basin and coursed down the Copper River Valley to at least the location of the present village of Chitina, a distance of more than 52 mi (84 km) from their source. The mudflow deposits are well exposed in the cliffs of the Kotsina River where it joins the Copper River near Chitina and in roadcuts along the McCarthy Road just east of the Copper River Bridge. The mudflows also crop out at mile 17.9 on the Edgerton Highway to Chitina at the top of the bluff where the highway drops down into the Tonsina River Valley.

Glaciers.—At least 11 alpine glaciers extend outward from the perennial icefield that mantles most of Mount Drum above elevations of about 8,000 ft (2,400 m). The largest, Nadina Glacier, flows southwest more than 9 mi (14 km) from the large amphitheater on the volcano's south flank. Scattered spruce trees and shrubs cover the lower, stagnant end of the glacier below about 3,500 ft (1,070 m) elevation.

Best viewing.—Mount Drum is the first of the Wrangell volcanoes to come into view when driving east from Anchorage toward Glennallen on the Glenn Highway. It is readily visible from the Glenn Highway as far east as Chistochina and all along the Richardson Highway from Tonsina north to Sourdough. Excellent viewpoints are at mile 1 on the Tok Cutoff of the Glenn Highway and at Willow Lake (mile 87) on the Richardson Highway (fig. 15).

MOUNT SANFORD

Mount Sanford is the highest and probably least understood of the three major volcanoes in the extreme western Wrangell Mountains (figs. 18, 19). Its imposing height makes it the first of the Wrangell volcanoes that visitors may see when driving to Anchorage from Tok and the Alaska Highway. The spectacular south face of the volcano, at the head of Sanford Glacier, rises 8,000 ft (2,400 m) in 1 mi (1.61 km)—one of the steepest gradients in North America.

Name.—Named in 1885 by Lt. Henry T. Allen of the U.S. Army after the Sanford family (Allen was a descendant of Reuben Sanford). Ahtna name: Hwniindi ("upriver") K'elt'aeni ("the one who controls the weather").

Type and form.—Complex shield(?) volcano whose present massive structure apparently was built on coalescing flows from at least three older volcanic centers referred to as the north, west, and south Sanford eruptive centers.

Location.—30 mi (48 km) southeast of Chistochina, Alaska, at lat 62°13′ N., long 144°08′ W. Shown on U.S. Geological Survey Gulkana A–1 and B–1 quadrangle maps.

Height.—16,237 ft (4,949 m). First ascent, 1938; Terris Moore and Bradford Washburn.

Latest eruptive activity.—The flows, domes, and subvolcanic intrusive rocks that constitute some of the main bulk of Mount Sanford may be as young as 100,000 years on the basis of morphology and the apparent absence of extensive glacial erosion. The latest radiometrically dated activity, however, was the eruption of a series of basaltic lava flows from a *rift zone* on the northeast flank of the mountain about 320,000 years ago.

Volcanic history.—The Mount Sanford volcanic complex began to form about 900,000 years ago, when eruptive activity was initiated from at least three centers, outboard of the present main structure. Andesitic eruptions from these centers probably continued for a few hundred thousand years and formed a group of low, coalescing shield(?) volcanoes. Volcanic activity then apparently shifted to a central vent, superimposing the large andesitic structure we see today on flows from the earlier outboard centers. Visual examination from aircraft of the south face of Mount Sanford, the principal window through the volcano's ice cover, suggests that the upper 2,000 ft (610 m) of the volcano is a broad, thick dome or lava flow filling a summit crater. A feature of the Mount Sanford complex that may be unique in the Wrangell volcanic field is a large rhyolite flow that probably was erupted from the north Sanford center about 600,000 to 500,000 years ago. This apparently single flow has a volume of about 5 mi^3 (20 km^3) and is locally more than 1,000 ft (305 m) thick; it flowed more than 11 mi (18 km) off the volcano's northeast flank (fig. 18).

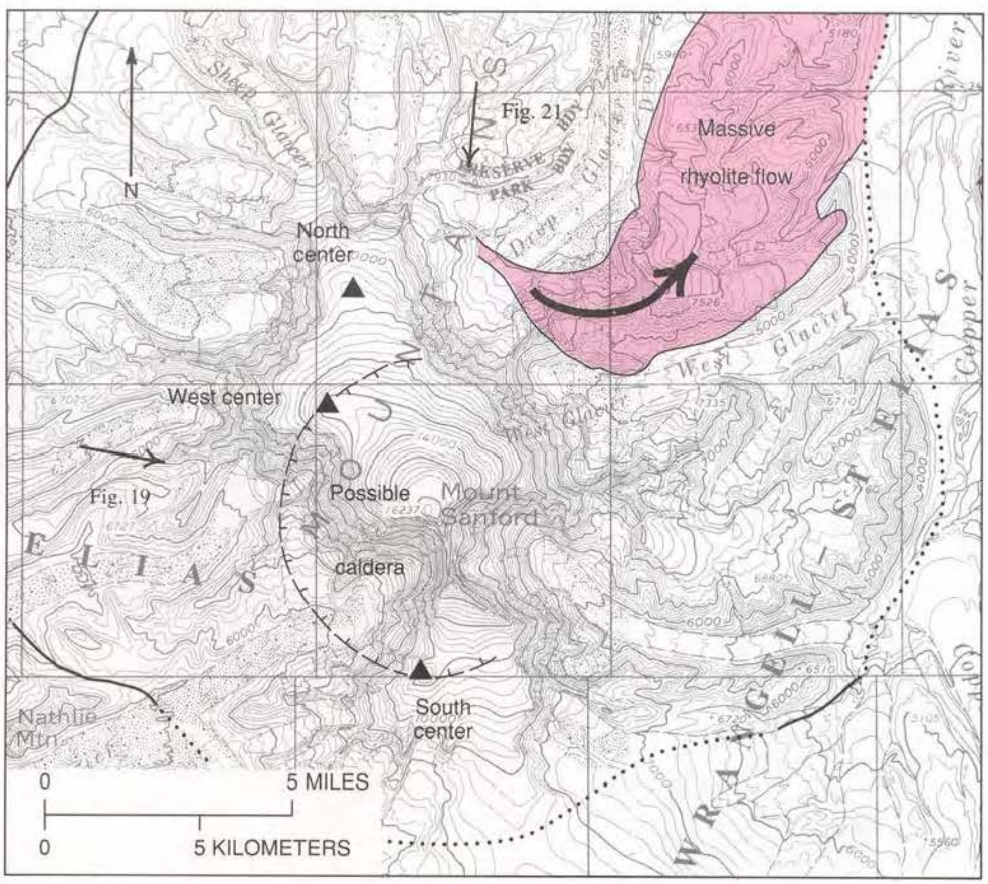


Figure 18. Topographic and generalized geologic map of Mount Sanford (flow direction shown by heavy arrow). Heavy lines, approximate present limit of Mount Sanford lavas, dotted where concealed by ice or young surficial deposits; triangles, approximate vent areas of subsidiary eruptive centers. Arrows indicate directions of view in figure 19 (from west) and figure 21 (from north). Base from U.S. Geological Survey Gulkana and Nabesna quadrangle maps.

Glaciers.—Above 8,000 ft (2,400 m), most of Mount Sanford is covered by a perennial icefield. On the south flank of the volcano, this icefield merges with the great expanse of ice that covers its neighbor, Mount Wrangell. Elsewhere, the icefield is the source of several large alpine glaciers. One of these glaciers, Sanford Glacier, which originates in the great *cirque* at the base of the spectacular south face of Mount Sanford, carries a tremendous load of debris from almost-continuous rockfall and avalanching off the 8,000-ft (2,400 m)-high face.

Best viewing.—As travelers drive south on the Tok Cutoff of the Glenn Highway, Mount Sanford is first visible at about mile 70, a few miles south of Mentasta Summit, and remains in view most of the way to Gakona and south to Glennallen on the Richardson Highway. Some of the best viewpoints are from the Gulkana Airport (fig. 19), a few miles north of Glennallen, and at miles 1, 20, and 58 along the Tok Cutoff.

CAPITAL MOUNTAIN

Capital Mountain is a relatively small, dissected volcano north of Mount Sanford (fig. 20). Though extremely rugged. with spectacular scenery, the mountain is dwarfed by its younger and loftier neighbors (fig. 21).

Name.—Reported as a local name in 1902 by Thomas G. Gerdine, U.S. Geological Survey topographer. Ahtna name: Tsedghaazi Dzel' ("rough-rock mountain")

Type and form.—Shield volcano containing a small summit caldera. A *dike swarm*, which may be unique in the Wrangell volcanic field, radiates outward from a plug within the caldera (fig. 20). Much of the original shield has been removed by erosion, leaving the *intracaldera* lava flows as present topographic high points.

Location.—20 mi (32 km) southeast of Chistochina, Alaska, at lat 62°25′ N., long 144°07′ W. Shown on U.S. Geological Survey Gulkana B–1 quadrangle map.

Height.—7,731 ft (2,356 m). High point is on an erosional rib of intracaldera lavas.

Latest eruptive activity.—The emplacement of a rhyolite dike, about 5 mi (8 km) long, across the summit of the volcano about 1 million years ago is the latest known activity on the volcano.

Volcanic history.—Capital volcano was probably constructed within a period of less than 100,000 years about 1 million years ago. It evidently began as a small andesitic volcano and rapidly built a shield about 10 mi (16 km) in diameter and probably no more than 8,000 ft (2,400 m) high. During the end phases of shield building, withdrawal of magma from beneath the central vent area allowed the summit to collapse and form a 2.5-mi (4 km)-diameter summit

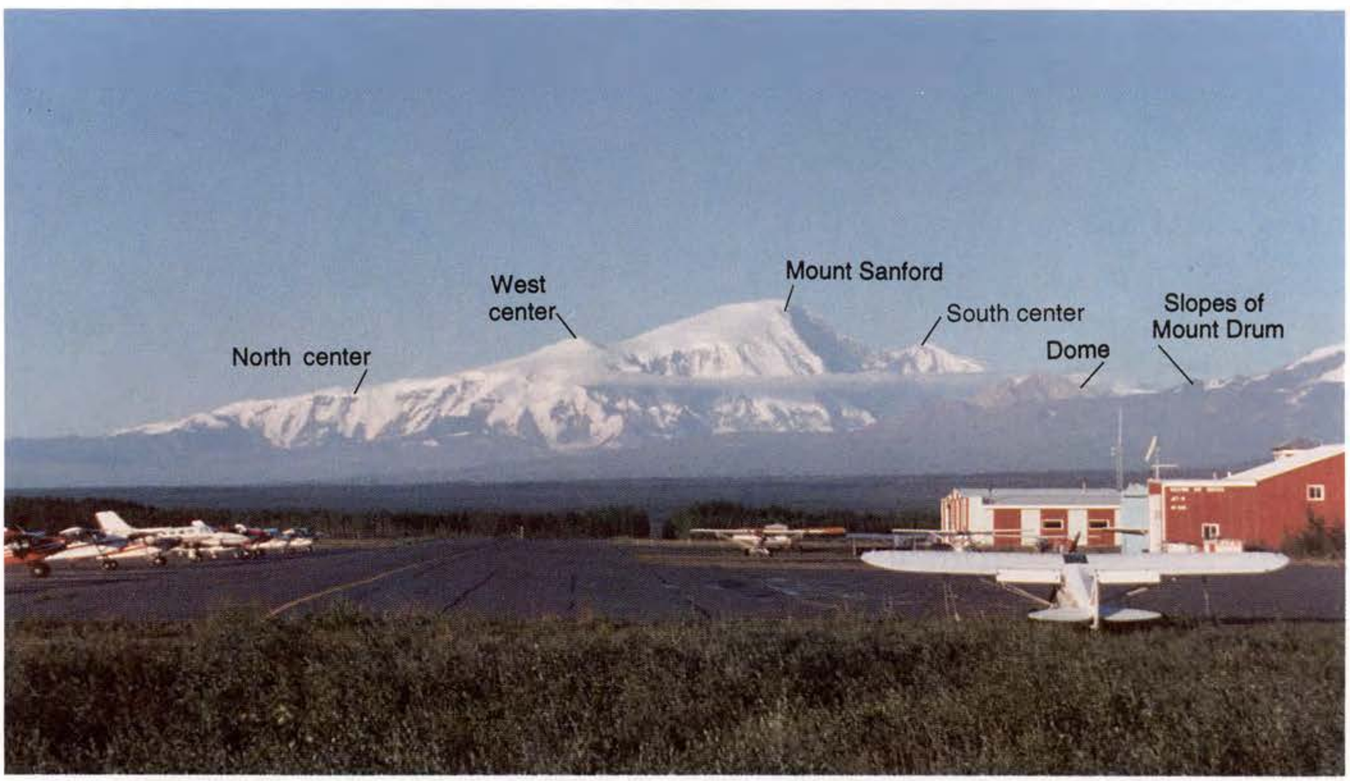


Figure 19. Mount Sanford from the Gulkana Airport on the Richardson Highway. View southeastward; photograph by U.S. Geological Survey.

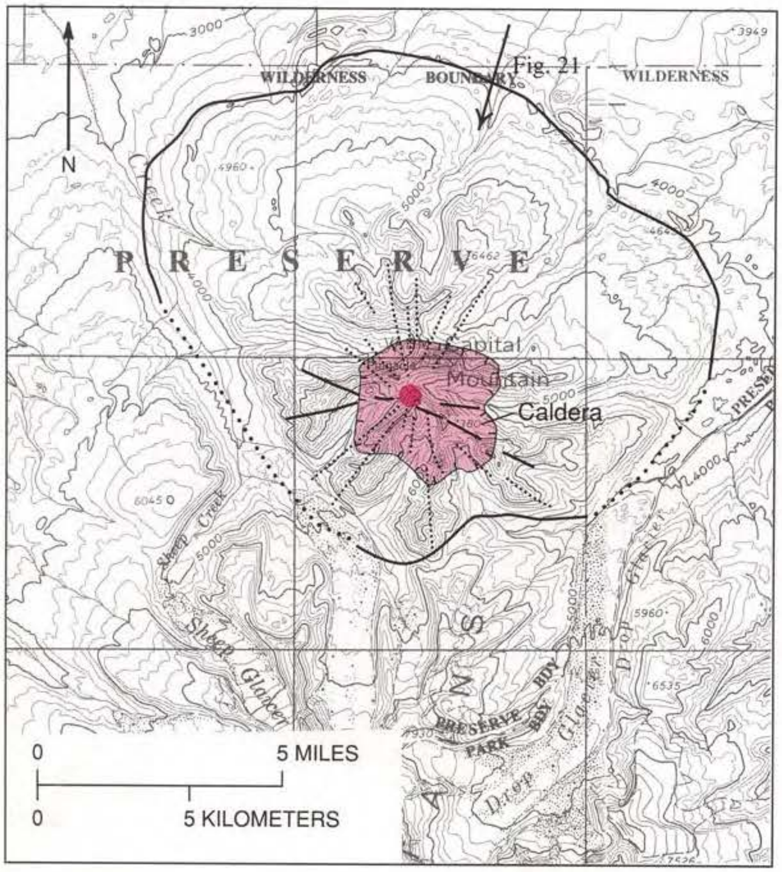


Figure 20. Topographic and generalized geologic map of Capital Mountain. Heavy line, approximate present limit of Capital Mountain lavas, dotted where concealed by young surficial deposits; dashed (rhyolite dike) and dotted (andesite dikes) lines, radial dike swarm; dot, intracaldera plug. Arrow indicates direction of view in figure 21. Base from U.S. Geological Survey Gulkana and Nabesna quadrangle maps.

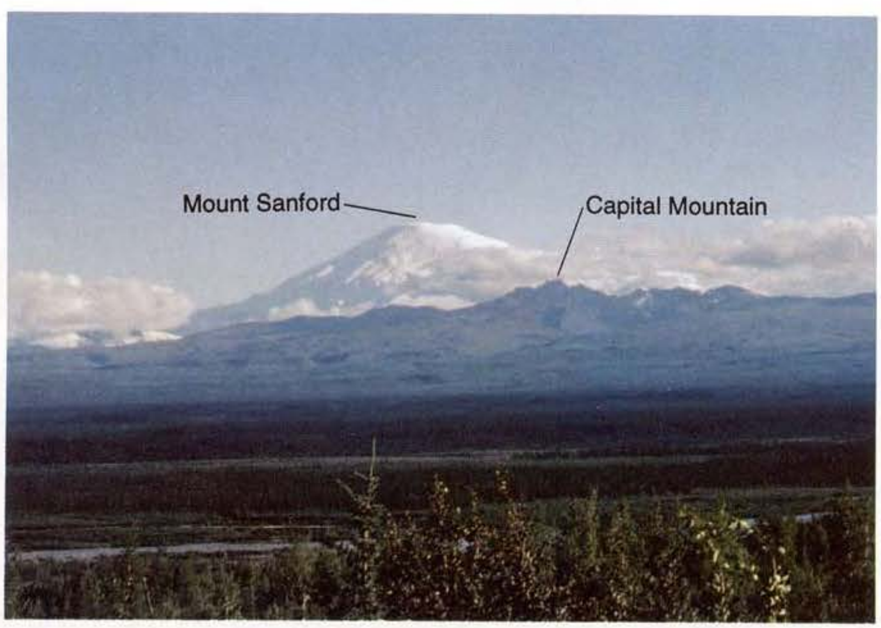


Figure 21. Capital Mountain (in midground) and Mount Sanford (in background) from mile 58 on the Tok Cutoff of the Glenn Highway. The Copper River is in foreground. View southward; photograph by U.S. Geological Survey.

caldera. During and after caldera collapse, eruptive activity resumed, filling the caldera with more than 1,500 ft (450 m) of thick, flat-lying andesite flows. Final activity was the intrusion of a spectacular radial dike swarm, consisting of hundreds of andesite dikes and a few dacite and rhyolite dikes, as much as 4 mi (6 km) long, whose locus is a prominent andesitic plug near the center of the caldera that probably marks the volcano's central vent.

Glaciers.—No glaciers exist on Capital Mountain today. However, young moraines in two deep valleys extending outward from the summit area were deposited by alpine glaciers that were present as recently as 10,000 years ago. Also, the extent of deep erosion exhibited by Capital Mountain and the presence of old glacial deposits high on the volcano's flanks are evidence that it was virtually covered by ice during a major period of glaciation which followed the end of eruptive activity about 900,000 years ago.

Best viewing.—Viewed from a distance along the highways around the western Wrangell Mountains, Capital Mountain is nearly lost in the foothills of its much taller neighbor, Mount Sanford (fig. 21). The best viewpoints are between miles 20 and 70 on the Tok Cutoff of the Glenn Highway and along the first 25 mi of the Nabesna Road.

TANADA PEAK

Tanada Peak is the erosional remnant of an andesitic volcano that is mostly older and considerably larger than its neighbor to the west, Capital volcano (fig. 20). The peak is the high point on a prominent, ice-free, serrated ridge that rises precipitously above a series of more gently sloping foothills (figs. 22, 23).

Name.—Named in 1902 by D.C. Witherspoon, U.S. Geological Survey topographer, after nearby Tanada Lake. Ahtna name: Tanaadi Dzel' ("moving-water lake")

Type and form.—Shield volcano containing a 4-mi (6 km)-wide by 5-mi (8 km)-long summit caldera. Most of the shield has been removed by erosion, leaving the intracaldera lava flows as present topographic high points.

Location.—17 mi (27 km) southwest of the old Nabesna Mine at the end of the Nabesna Road at lat 62°18′ N., long 143°31′ W. Shown on U.S. Geological Survey Nabesna B–6 quadrangle map.

Height.—9,358 ft (2,852 m).

Latest eruptive activity.—An elongate cluster of andesite cones on the north flank of the Tanada shield that erupted about 970,000 years ago probably represent the latest activity of the volcano (fig. 22).

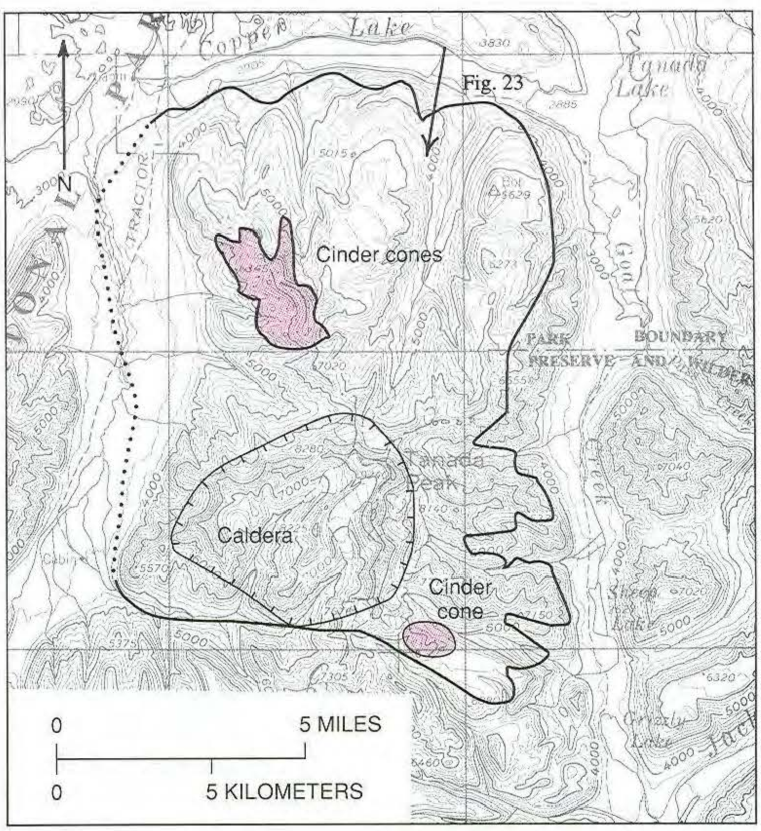


Figure 22. Topographic and generalized geologic map of Tanada Peak. Heavy line, approximate present limit of Tanada Peak lavas, dotted where concealed by young surficial deposits. Arrow indicates direction of view in figure 23. Base from U.S. Geological Survey Nabesna quadrangle map.

Volcanic history.—Tanada volcano is built on a series of lava flows, most of which are older than 1.8 million years, indicating that the volcano had its beginning sometime later, probably about 1.5 million years ago. During the next few hundred thousand years, thousands of eruptions built a large andesitic shield that may have reached an elevation of more than 10,000 ft (3,000 m). Before about 1 million years ago, the top of the shield collapsed, forming a large summit caldera. Subsequent intracaldera eruptions filled the caldera with more than 4,000 ft (1,200 m) of andesite lavas before central-vent activity ceased. A few dikes that cut both the shield and intracaldera lavas may be related to the eruptive activity responsible for the late cinder cones on the volcano's north flank.

Glaciers.—A few small glaciers that occupy some of the deep valleys in Tanada Peak's summit area are remnants of much larger alpine glaciers that 100,000 years ago covered most of the volcano and were responsible for carving away much of the volcano's shield.

Best viewing.—Tanada Peak can best be seen along the first 30 mi of the Nabesna Road, which extends eastward off the Tok Cutoff of the Glenn Highway at the village of Slana. An excellent viewpoint is at Long Lake (mile 23.5) on the Nabesna Road.

MOUNT JARVIS

Mount Jarvis is the high point of a 5-mi (8 km)-long, north-trending, ice-covered ridge largely hidden behind Mount Sanford and Tanada Peak (figs. 24, 25).

Name.—Named by F.C. Schrader, U.S. Geological Survey geologist, in 1903 after Lt. Daniel H. Jarvis of the U.S. Revenue Cutter Service, who led an overland relief expedition to aid a whaling fleet trapped in Arctic Ocean ice off Point Barrow in 1897–98. Ahtna name: Tsic' etggodi Dzel' ("rock is chipping mountain")

Type and form.—Shield volcano containing summit caldera. The summit caldera is poorly defined and may be a group of two or more nested calderas, as much as 6 mi (9.6 km) long.

Location.—31 mi (50 km) southwest of the community of Nabesna, at lat 62°01′ N., long 143°37′ W. Shown on U.S. Geological Survey Nabesna A–6 quadrangle map.

Height.—13,421 ft (4,091 m). High point at unnamed north end of ridge, 13,025 ft (3,970 m).

Latest eruptive activity.—A large dacite dome-flow complex at the extreme north end of Jarvis volcano, which has been dated at 1.0 million years old, may be the latest activity of the volcano (fig. 24).

Volcanic history.—Development of the Mount Jarvis volcano began about 1.7 million years ago with the eruption of extensive andesite flows. Andesite volcanism continued until about 1.0 million years ago, probably contemporaneously with the formation of a summit caldera or group of calderas. By 1.0 million years ago, the Jarvis magmas became more silicic in composition and produced the satellitic dacite domes and flows at the north end of the volcanic complex. An interesting product of a dacite cinder cone on the southeast flank of the volcano (fig. 24) is an extensive agglutinate flow that exhibits spectacular columnar joints. This flow resulted from

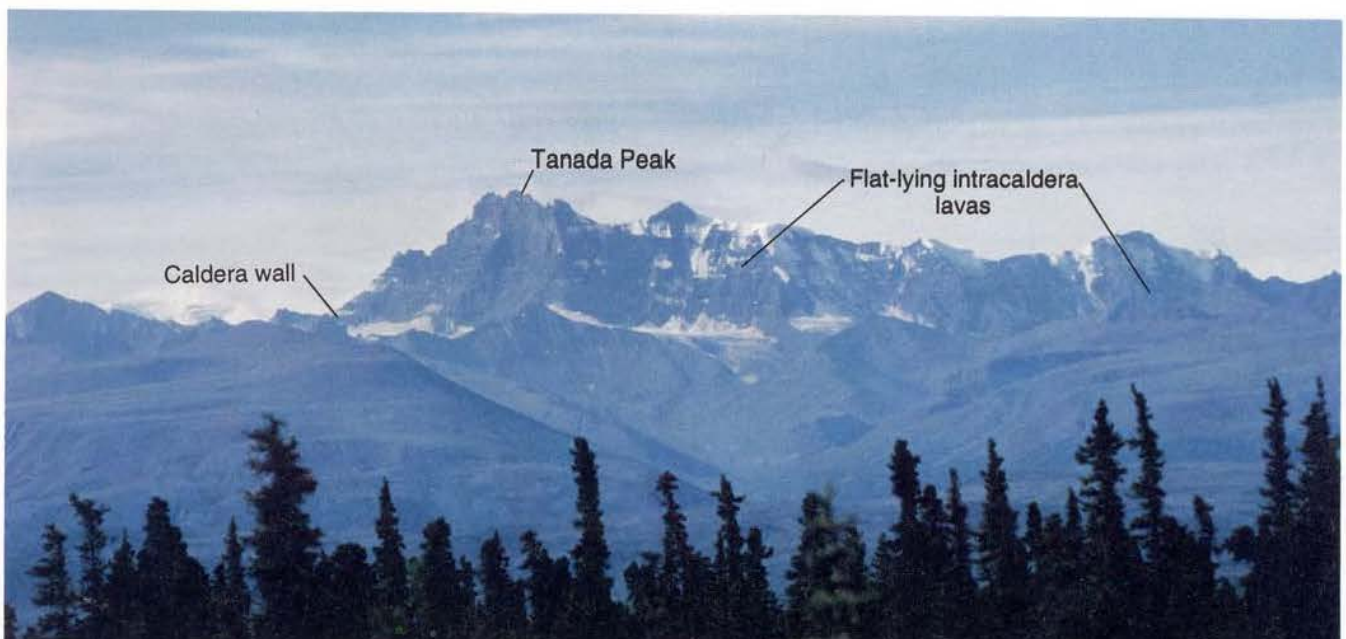


Figure 23. Tanada Peak from mile 26.5 on the Nabesna Road. View southward; photograph by U.S. Geological Survey.

collapse of the cone wall and mobilization of the wall materials (cinders, spatter, and bombs) while they were still hot and fluid enough to flow.

Glaciers.—Most of Mount Jarvis and the Jarvis ridge are covered by icefields and glaciers. Jacksina Glacier, the largest glacier associated with Mount Jarvis, has its origin low on the east flank of the massif, where ice tongues from the two high points of the Jarvis ridge coalesce.

Best viewing.—Mount Jarvis can best be seen along the Nabesna Road between miles 13 and 20.

SKOOKUM CREEK VOLCANO

Skookum Creek volcano is the only volcano in the western Wrangell Mountains that is accessible by road (fig. 26). It is one of the oldest volcanoes described in this guide, and because it has been intensely modified by erosion, it offers opportunities to examine subsurface volcanic processes through its spectacular exposures of domes, vents, dikes, and other geologic features.

Name.—Informal, after Skookum Creek, which has its source below the central high point of the volcano.

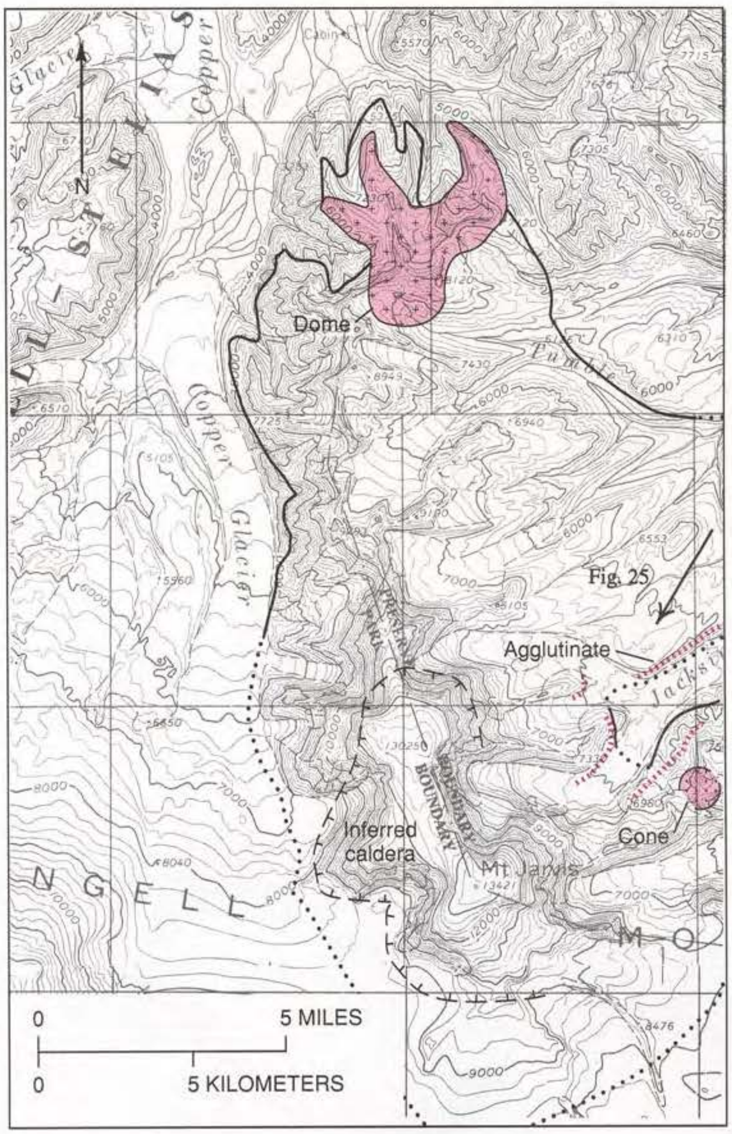


Figure 24. Topographic and generalized geologic map of Mount Jarvis. Heavy line, approximate limit of Mount Jarvis lavas, dotted where concealed by ice; red crossed area, young dacite dome and associated flows; red stippled area, young dacite cone. Arrow indicates direction of view in figure 25. From U.S. Geological Survey Nabesna and McCarthy quadrangle maps.

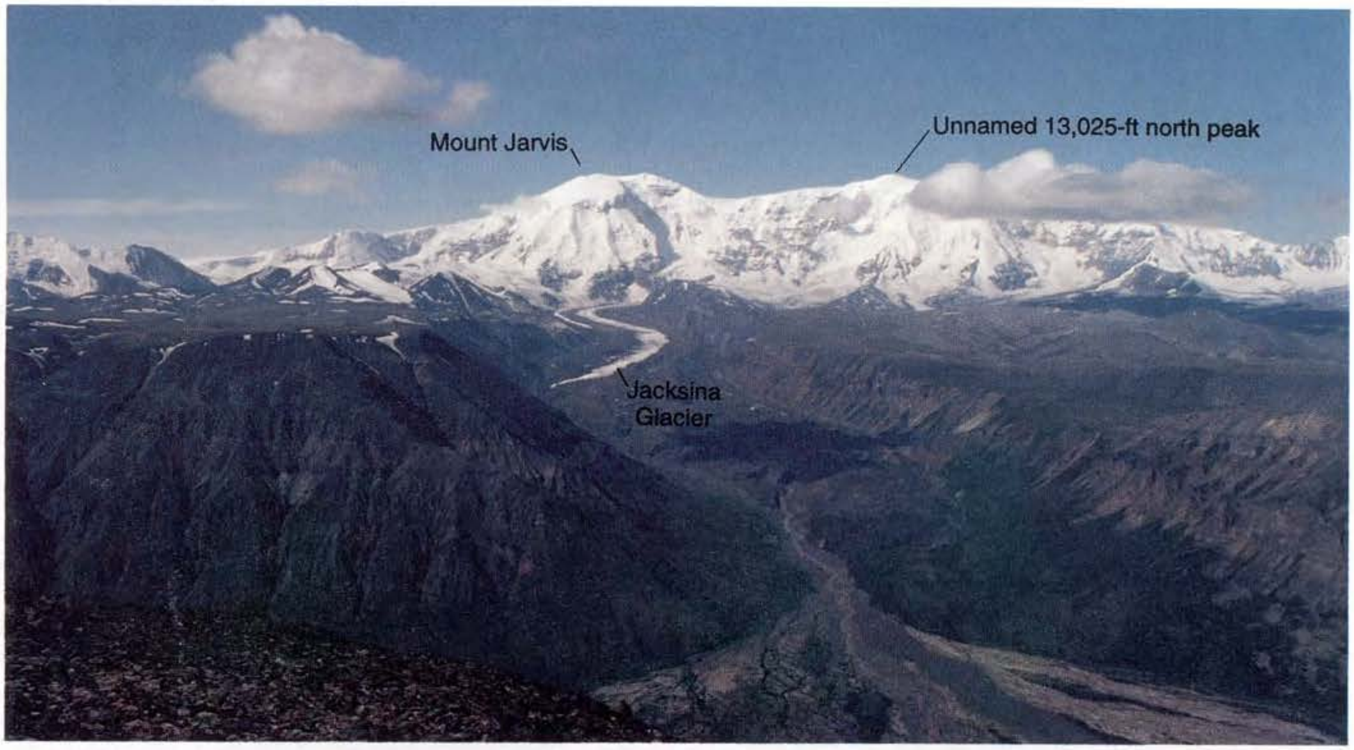


Figure 25. Mount Jarvis from southeast slopes of Skookum Creek volcano. View southwestward; photograph by U.S. Geological Survey.

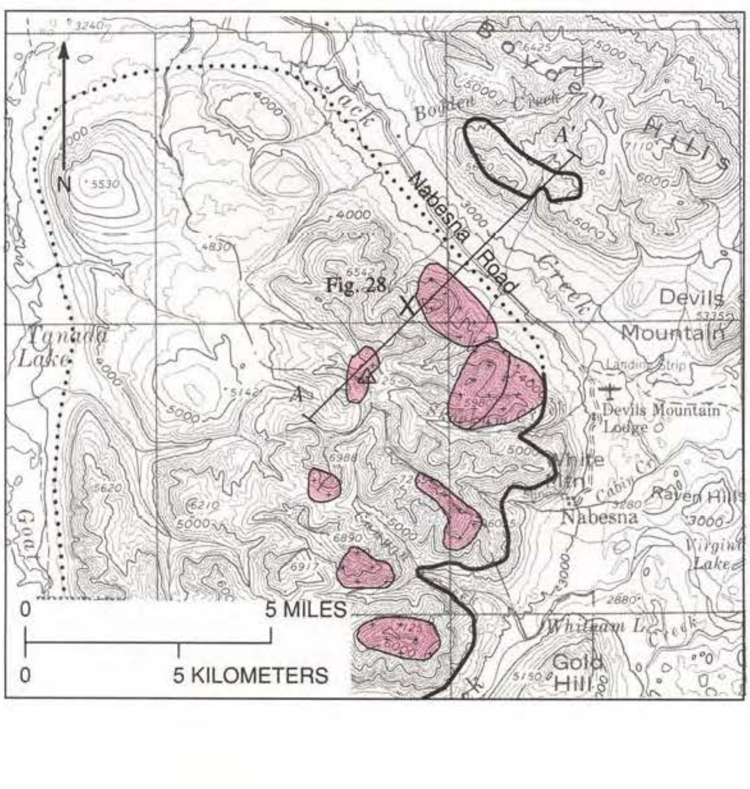


Figure 26. Topographic and generalized geologic map of Skookum Creek volcano. Heavy line, approximate limit of Skookum Creek lavas, dotted where concealed by young surficial deposits; red crossed areas, rhyolite and dacite domes. Peak at 7,125 ft, at head of Skookum and Canyon Creeks, was apparent center of principal eruptive activity. X, area of dikes shown in figure 28. Cross section through volcano along line *A–A′* is shown in figure 27. Base from U.S. Geological Survey Nabesna quadrangle map.

Type and form.—Possibly a shield volcano with a large caldera that is outlined by a ring of domes.

Location.—Central high point is 5 mi (8 km) northwest of the old gold-mining camp of Nabesna at lat 62°24′ N., long 143°08′ W. Shown on U.S. Geological Survey Nabesna B–5 quadrangle map.

Height.—Central high point, 7,125 ft (2,172 m). A 4-mi (6.5 km)-long, high ridge attains a height of 7,265 ft (2,214 m) 2.5 mi (4 km) southeast of this central high point.

Volcanic history.—The earliest known eruptive activity of Skookum Creek volcano was the production of a series of basalt flows about 3.2 million years ago, followed by voluminous andesite flows that continued until about 2 million years ago, when most eruptive activity ceased. During the early period (3 million years ago) of andesitic volcanism, several dacite and rhyolite domes were emplaced around the periphery of the volcano (figs. 26, 27). These domes, which form an approximate circle about 9 mi (14.5 km) in diameter, may reflect the leakage of magma along the walls of a subsiding caldera. If a caldera did form, then the younger (2–2.7 million years old) andesite flows, which form an extensive flat-lying sequence throughout most of the central part of the volcanic edifice, may represent intracaldera fill. A few small basalt cinder cones that still show original morphology lie scattered over the eroded volcanic surface. These relatively young cones, which postdate Skookum Creek eruptive activity by at least 1 million years, probably are not part of the volcanic system responsible for the formation of Skookum Creek volcano.

Best viewing.—The last 10 mi (16 km) of the Nabesna Road (about miles 32–42) follows a 2-mi (3 km)-wide valley that cuts through the northeastern part of the volcano. The road skirts two large domes on the volcano's flank and affords spectacular views of various volcanic rocks. Also, hikers can take short (less than 3 mi [5 km]) treks into side valleys, where the rocks and their structures can be observed in detail (fig. 28).

MOUNT BLACKBURN

Mount Blackburn, the highest peak in the Wrangell Mountains, is the erosional remnant of a large volcano (fig. 29). Although it is the oldest volcano described in this guide, its extreme height and ice cover largely preclude any detailed study of its internal structure (fig. 30).

Name.—Named by Lt. Henry T. Allen of the U.S. Army in 1885 after Joseph Clay Stiles Blackburn (1838–1918), State and U.S. Congressman and U.S. Senator from Kentucky. Ahtna name: K'als'i Tl'aadi ("the one at cold waters").

Type and form.—Probably a large shield volcano containing a large summit caldera. The original structure has been severely modified by erosion.

Location.—Main peak, 36.5 mi (58.5 km) northeast of the village of Chitina at lat 61°44′ N., long 143°26′ W. Shown on U.S. Geological Survey McCarthy C–7 quadrangle map.

Height.—Main peak, 16,390 ft (4,996 m); unnamed subsidiary peak 1.5 mi (2.5 km) to the southeast, 16,286 ft (4,964 m). First ascent, 1912; Dora Keen and G.W. Handy.

Volcanic history.—The oldest dated rock from Mount Blackburn (4.2 million years old) is a *granite* that intrudes Blackburn lavas along an arcuate *ring fracture* which is interpreted as a caldera margin (fig. 29). These older lavas, which probably represent the early products of a shield volcano, may be as old as 5 million years. Most of the Mount Blackburn massif, however, is composed of younger granite (3.4 million years old) that intrudes a thick sequence of fairly flat lying andesite flows, suggesting that a filled caldera collapsed into a large, shallow granitic magma reservoir between 4.2 and 3.4 million years ago. There is no evidence of any volcanic activity after the collapse and fill of this caldera.

Glaciers.—The Mount Blackburn massif is almost entirely covered by icefields and glaciers. It is a principal source of ice for Kennicott Glacier, which flows south and terminates near the small town of McCarthy. The mountain also con-

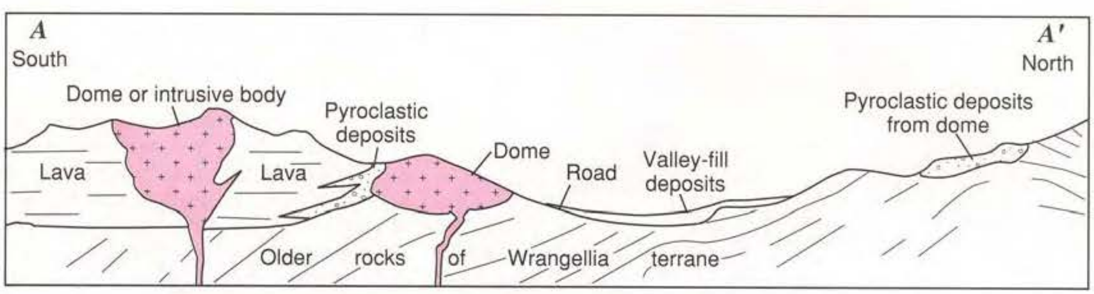


Figure 27. Cross section (see fig. 26) through Skookum Creek volcano, showing some hypothetical subsurface features.

tributes a considerable volume of ice to large, north-flowing Nabesna Glacier and the Kuskulana Glacier system.

Best viewing.—The best views of Mount Blackburn are from Glennallen south to beyond Willow Lake on the Richardson Highway. Additional excellent vantage points are at mile 24 (Chokosna Lake) and mile 49.2 along the Chitina-McCarthy Road, which skirts the south edge of the Wrangell Mountains, and from Kennicott, the historic millsite, 4 mi (6.5 km) north of McCarthy.

BOOMERANG VOLCANO

Boomerang volcano, which forms a low broad hill northeast of Capital volcano, is a conspicuous topographic feature, rising 1,000 ft (300 m) above the relative flatlands of the upper Copper River Basin (fig. 31).

Name.—Informal, after nearby Lake Boomerang.

Type and form.—Small shield volcano with summit crater.

Location.—13 mi (21 km) south of the village of Slana, Alaska, at lat 62°31′ N., long 143°55′ W. Shown on U.S. Geological Survey Nabesna C–6 quadrangle map.

Height.—3,949 ft (1,204 m).

Volcanic history.—Very little is known about the age and eruptive history of Boomerang volcano. It is a small shield volcano, composed principally of andesite flows, that was active before the construction of Capital volcano (1 million years old), because Capital lavas appear to overlie the southwest flank of Boomerang volcano.

Best viewing.—Boomerang volcano is visible from about mile 50 to Slana on the Tok Cutoff of the Glenn Highway and from Slana to about mile 20 on the Nabesna Road.

MOUNT GORDON

Mount Gordon is a largely ice covered cinder cone that was constructed on a broad volcanic plateau west of

Figure 28. A pair of 6-foot-thick andesite dikes intrude poorly consolidated rhyolite pyroclastic deposits of Skookum Creek volcano. Where dikes are closer than about 3 ft (1 m), the intervening rhyolite has been fused to a dense gray glass by heat from dikes. Photograph by U.S. Geological Survey.

Nabesna Glacier (figs. 32, 33). Though not visible from any road in the area, it is included in this guide because it is typical—and one of the largest—of the many young cinder cones scattered throughout the Wrangell volcanic field.

Name.—Named by F.C. Schrader, U.S. Geological Survey geologist, in 1903 after a prospector who was exploring in the area in 1899.

Type and form.—Basaltic cinder cone with summit crater and associated lava flows. The cinder cone still exhibits most of its original volcanic form but has a significant ice mantle.

Location.—16.8 mi (27 km) south of the community of Nabesna at lat 62°08′ N., long 143°05′ W. Shown on U.S. Geological Survey Nabesna A–5 quadrangle map.

Height.—9,040 ft (2,755 m)

Volcanic history.—The Mount Gordon cinder cone is probably less than 1 million years old, on the basis of freshness of form. A series of fluid basaltic lava flows that flowed mostly to the north preceded the construction of the cinder cone (fig. 32). Where not covered by ice, the cone consists largely of cinder, spatter, and spindle-shaped volcanic bombs. Coarse air-fall deposits that fell from ash plumes during Mount Gordon's eruptions blanket the area as far as 8 mi (13 km) from the cone.

Best viewing.—Though not visible from any road, Mount Gordon is viewable from short climbs into the easily accessible mountains northwest of the small community of Nabesna.

Figure 29. Topographic and generalized geologic map of Mount Blackburn. All remaining Mount Blackburn lavas are confined to an inferred caldera whose walls are mostly ice covered. Red stippled areas, granitic rocks of a postulated exhumed magma chamber in caldera; red crossed area, older syncaldera granites. Arrow indicates direction of view in figure 30. Base from U.S. Geological Survey McCarthy quadrangle map.

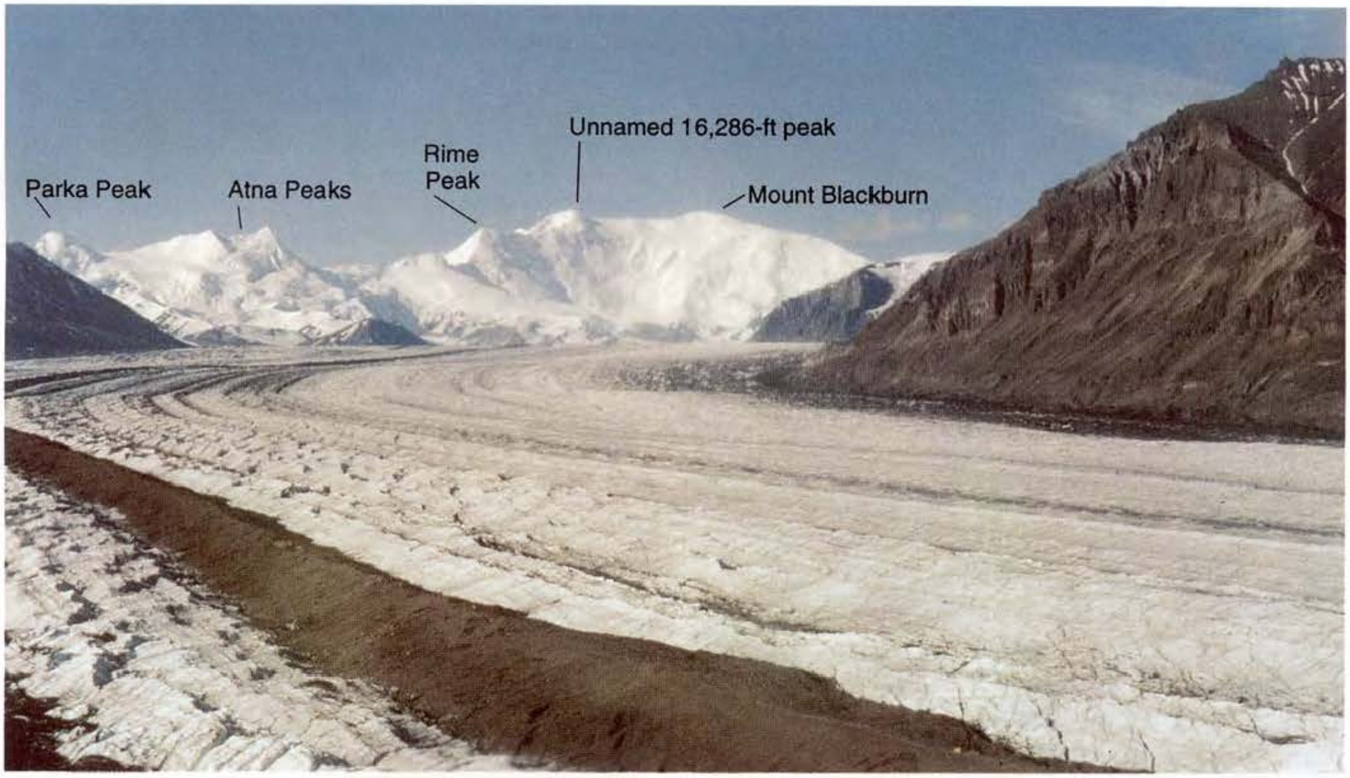


Figure 30. Mount Blackburn, highest of western Wrangell volcanoes, from east of Nabesna Glacier (in foreground). View southwestward; photograph by U.S. Geological Survey.

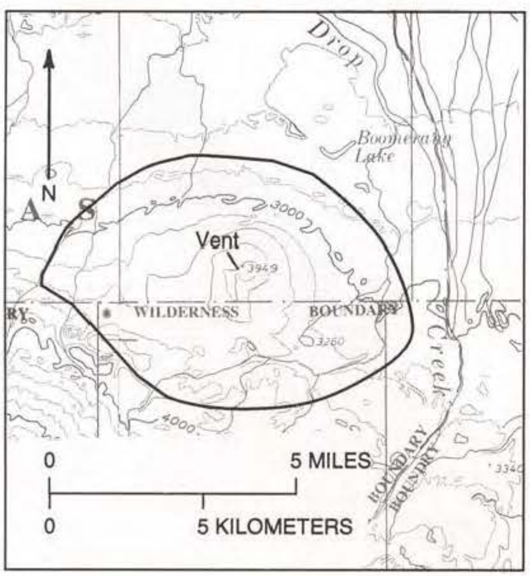


Figure 31. Topographic and generalized geologic map of Boomerang volcano. Heavy line, approximate present limit of Boomerang lavas. Peak at 3,949 ft is on small crater that was site of central-vent activity. Base from U.S. Geological Survey Nabesna quadrangle map.

WHITE RIVER ASH

Though not a product of any of the western Wrangell volcanoes, the White River Ash Bed is an important Wrangell volcanic deposit that is readily visible along the Alaska Highway near the Alaska-Yukon Territory boundary (fig. 34). The ash is briefly described here so that travelers along the highway may recognize it and understand its significance and origin.

The White River Ash Bed is exposed in many roadcuts along the Alaska Highway between the village of Tok, Alaska, and the city of Whitehorse, Yukon Territory, Canada. It is present as a conspicuous light-gray layer, as much as 2 ft (0.6 m) thick, within a few inches (centimeters) of the surface, just under the organic-soil layer. The ash occurs in two distinct lobes, each the product of one of the most voluminous *pyroclastic* eruptions in North America in the past 2,000 years. *Radiocarbon dating* of wood and other organic material buried by the ash indicates that the northern lobe was deposited from an eruption cloud about 1,900 years ago, and the eastern, larger lobe about 1,250 years ago. Together, these two lobes cover more than 130,000 mi^3 (335,000 km^3) in the Yukon and Northwest Territories of Canada and adjoining eastern Alaska and consist of a total of at least 12 mi^3 (50 km^3) of volcanic ash.

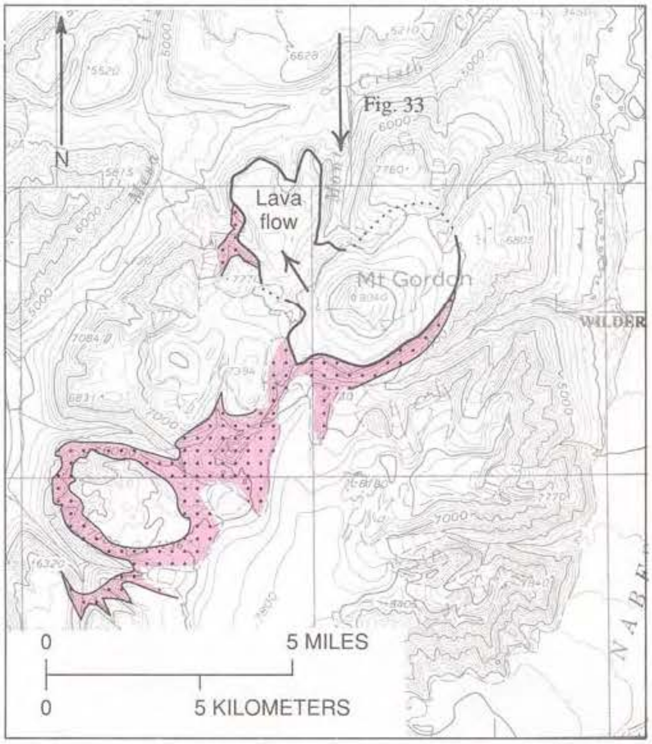


Figure 32. Topographic and generalized geologic map of Mount Gordon. Heavy line, approximate limit of Mount Gordon cinder and lavas, dotted where concealed by ice or young surficial deposits; red stippled areas, areas known to be underlain by lapilli tuff derived from Mount Gordon. Short arrow indicates direction of lava flow from Mount Gordon; long arrow indicates direction of view in figure 33. Base from U.S. Geological Survey Nabesna quadrangle map.

Figure 33. Mount Gordon from south of Skookum Creek volcano. View south; photograph by D.H. Richter, 1994.

The source of the White River Ash is Mount Churchill (15,638 ft [4,766 m]), a volcano in the eastern part of the Wrangell volcanic field in the St. Elias Mountains of Alaska (fig. 7). A small ice-filled caldera that formed as a result of the explosive eruptions occupies the summit area of Mount Churchill.

Mount Churchill is 40 mi (64 km) east of the town of McCarthy but is not visible from any road system. At the community of Koidern, Yukon Territory, Canada (fig. 34), where the ash deposit is thickest (2 ft [0.6 m]) along the Alaska Highway, Mount Churchill lies 55 mi (88 km) to the southwest.

MUD VOLCANOES

The mud volcanoes of the Copper River Basin are another geologic feature that is visible from the highway and commonly asked about by visitors. They are not volcanoes like those we have described in the preceding part of this guide but instead are mud-rich springs that have built up mounds of mud, as much as 300 ft (91 m) high and 8,000 ft (2,440 m) in diameter, resembling small shield volcanoes (fig. 35).

The largest of these mud volcanoes, referred to as Shrub, Upper Klawasi, and Lower Klawasi, occur within the boundary of Wrangell-St. Elias National Park and Preserve about 18 mi (29 km) west of Mount Drum (fig. 7). They are visible from the Richardson Highway between Glennallen and the Edgerton Highway, where they appear as low mounds rising above the forested floor of the Copper River Basin. The mud-rich waters are charged with carbon dioxide (CO_2) and contain anomalously high concentrations of sodium (Na^+), chloride (Cl^-), and bicarbonate (HCO_3^-). Water temperatures range from about 54°F (12°C) at Shrub to about 85°F (29°C) at the Upper Klawasi springs. The chemistry of the waters suggests that the springs are discharging a mixture of ancient seawater and *meteoric* water, containing CO_2 derived from both a magmatic source—possibly the cooling Mount Drum magma reservoir—and a *metamorphic-rock* source that might be deeply buried limestone in the underlying Wrangellia composite terrane which is being metamorphosed by the enormous pressures caused by deep burial and by the heat of the adjacent volcanic systems.

ACKNOWLEDGMENTS

We take this opportunity to acknowledge the work of the pioneer geologists of the U.S. Geological Survey, namely, C.W. Hayes, W.C. Mendenhall, F.C. Schrader, Alfred Brooks, Oscar Rohn, S.R. Capps, and F.H. Moffit, whose early studies in the Wrangell Mountains, have been invaluable to those of us who followed. We also express our heartfelt appreciation to Robert L. Smith of the U.S. Geological Survey, a more recent investigator, who many years ago not only started the first author thinking about

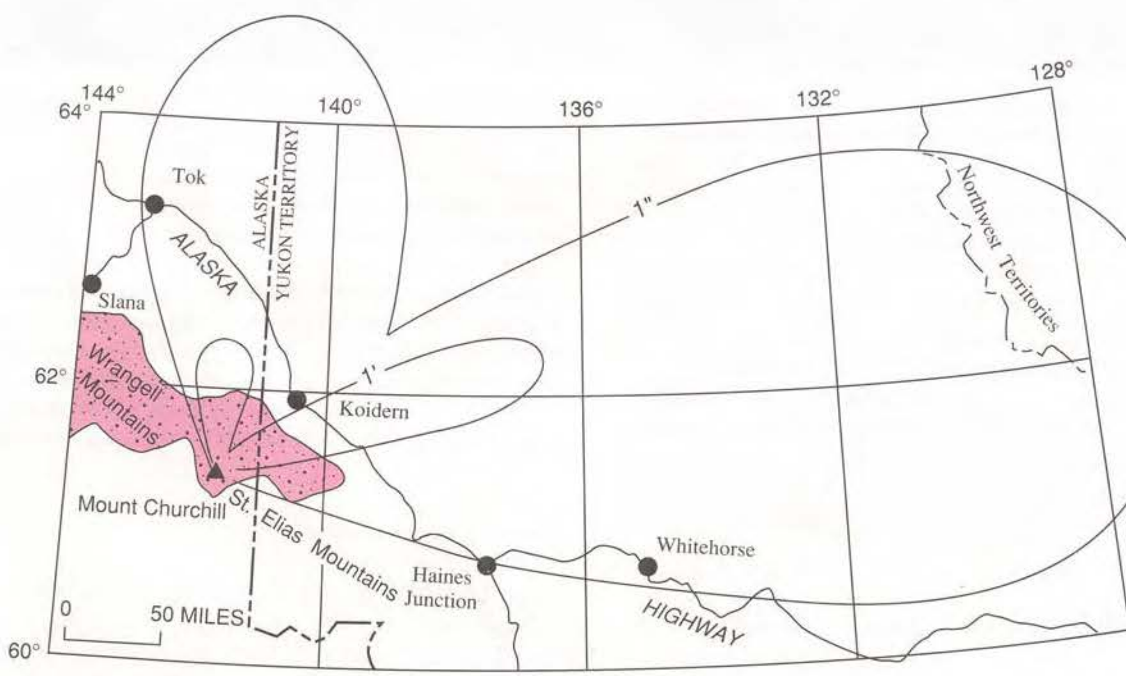


Figure 34. Distribution of the White River Ash Bed in Alaska and Canada. Lines denote outer limits of 1 in (2.5 cm) and 1 ft (0.3 m) accumulations of ash. Red stippled area, Wrangell volcanic field.

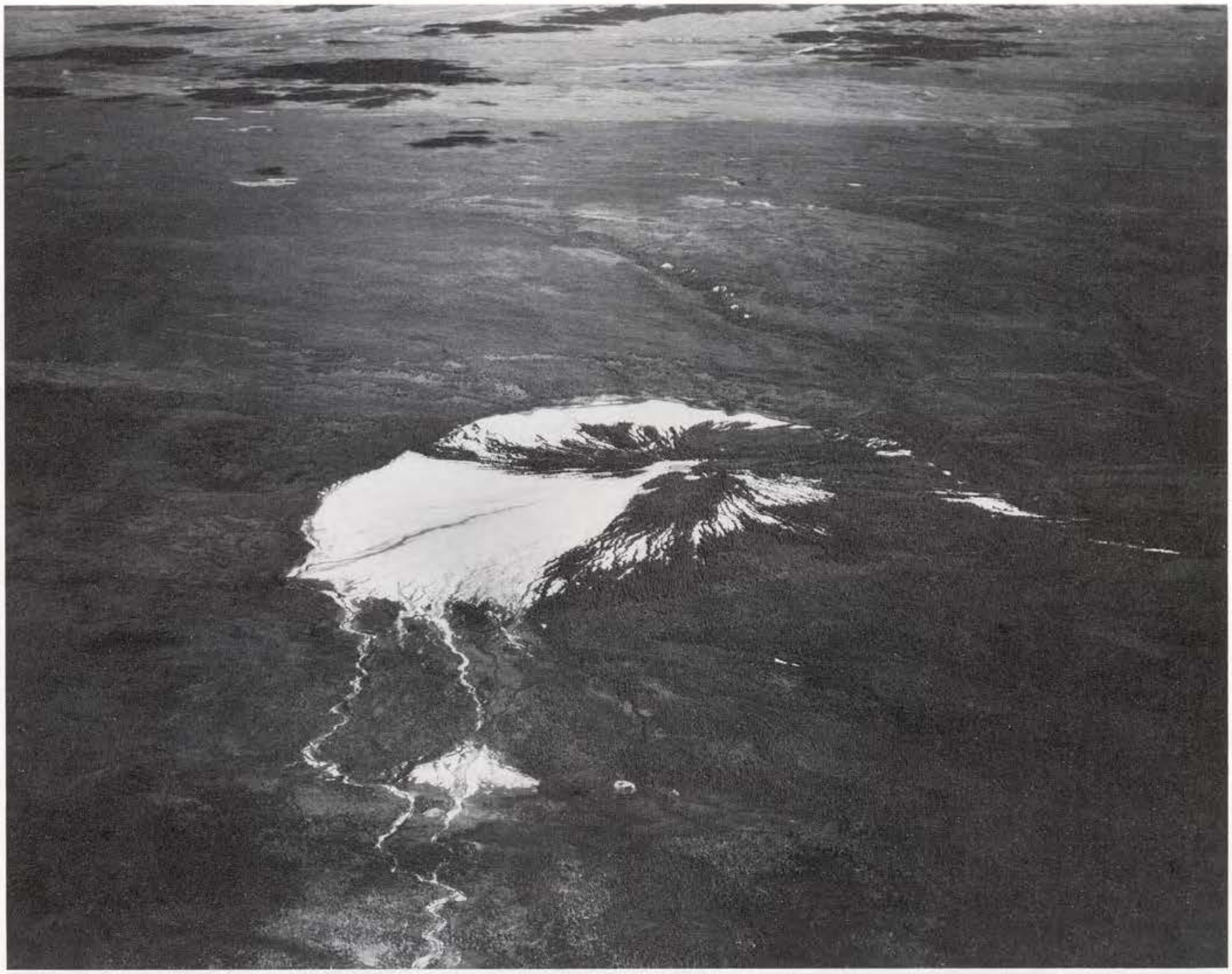


Figure 35. Lower Klawasi mud volcano. Light areas are mud covered and do not support any vegetation. Mud-rich springs discharge into a small mud-rich lake just visible at top of mound. Oblique aerial photograph by Bradford Washburn, taken in 1938.

Wrangell volcanism but also aided in the first field studies of the Wrangell volcanoes. Tina Neal of the U.S. Geological Survey, Kitty Reed of the Washington Department of Natural Resources, and Carl Benson of the University of Alaska, Fairbanks, reviewed the manuscript and made major improvements in its contents and readability.

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