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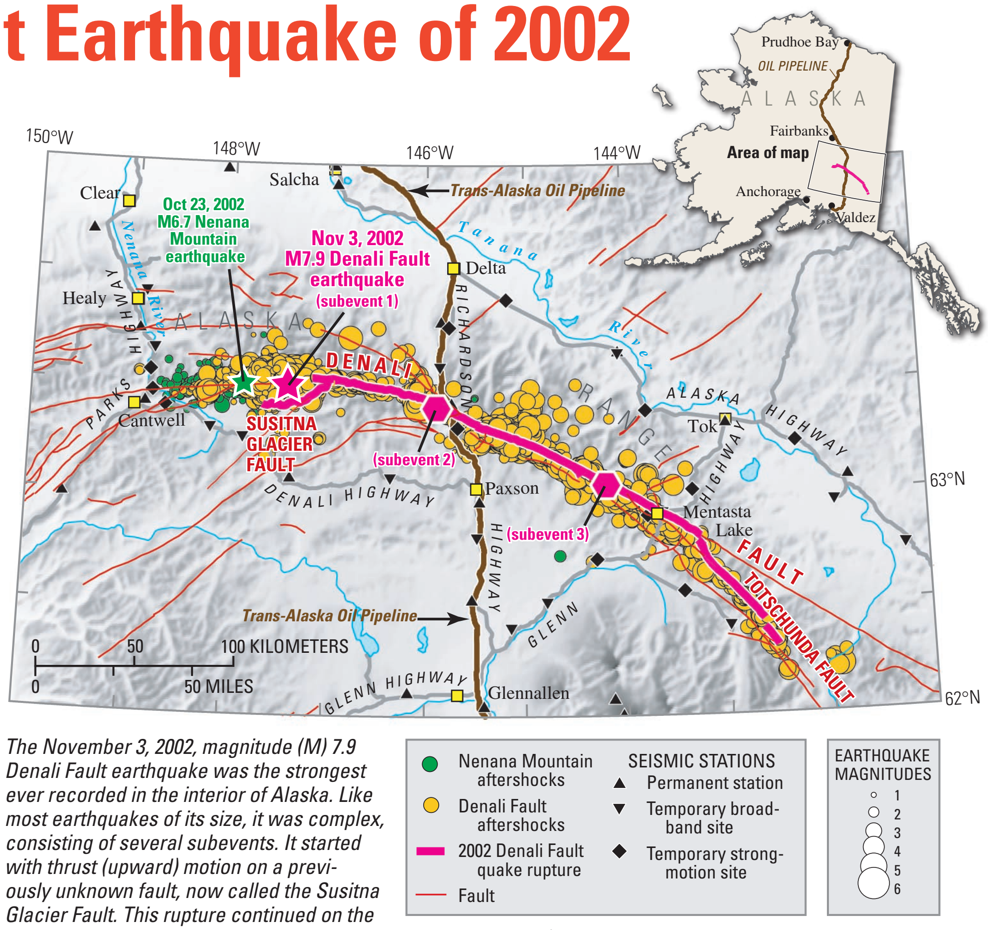
REDUCING EARTHQUAKE LOSSES THROUGHOUT THE UNITED STATES

Rupture in South-Central Alaska—The Denali Fault Earthquake of 2002

A powerful magnitude 7.9 earthquake struck Alaska on November 3, 2002, rupturing the Earth's surface for 209 miles along the Susitna Glacier, Denali, and Totschunda Faults. Striking a sparsely populated region, it caused thousands of landslides but little structural damage and no deaths. Although the Denali Fault shifted about 14 feet beneath the Trans-Alaska Oil Pipeline, the pipeline did not break, averting a major economic and environmental disaster. This was largely the result of stringent design specifications based on geologic studies done by the U.S. Geological Survey (USGS) and others 30 years earlier. Studies of the Denali Fault and the 2002 earthquake will provide information vital to reducing losses in future earthquakes in Alaska, California, and elsewhere.

Shortly after midday on November 3, 2002, a magnitude 7.9 earthquake ruptured the Denali Fault in the rugged Alaska Range, about 90 miles south of Fairbanks. Called the Denali Fault earthquake, this shock was the strongest ever recorded in the interior of Alaska. Although comparable in size and type to the quake that devastated San Francisco in 1906, the Denali Fault earthquake caused no deaths and little damage to structures because it struck a sparsely populated region of south-central Alaska.

This powerful shock may have been triggered by a magnitude 6.7 temblor, the Nenana Mountain earthquake, that occurred nearby on the same fault 10 days earlier. Like the Denali Fault quake, the Nenana Mountain shock caused only limited damage because of its remote location. In contrast, the 1994 Northridge, California, earthquake, which had the same magnitude, caused 67 deaths and $40 billion in damage when it struck the densely populated Los Angeles region.

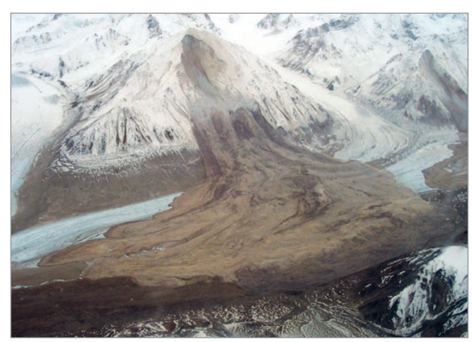


The November 3, 2002, magnitude (M) 7.9 Denali Fault earthquake was the strongest ever recorded in the interior of Alaska. Like most earthquakes of its size, it was complex, consisting of several subevents. It started with thrust (upward) motion on a previously unknown fault, now called the Susitna Glacier Fault. This rupture continued on the Denali Fault, where largely horizontal "right-lateral" movement (in which the opposite side moves to the right, when you look across the fault) propagated eastward at more than 7,000 miles per hour. As the rupture propagated, it offset streams, glacial ice, frozen soil, and rock, opening some cracks so wide that they could engulf a bus. The rupture crossed beneath the Trans-Alaska Oil Pipeline and terminated on the Totschunda Fault, 184 miles east of the epicenter, about 90 seconds after the quake began. The maximum horizontal movement (fault offset) of about 29 feet occurred in the eastern part of the rupture, near subevent 3.

Effects of the Denali Fault Quake

The Denali Fault earthquake ruptured the Earth's surface for 209 miles, crossing beneath the vital Trans-Alaska Oil Pipeline, which carries 17% of the U.S. domestic oil supply. Although slightly damaged by movement on the fault and by intense shaking, the pipeline did not break in the quake, averting a major economic and environmental disaster. This success is a major achievement in U.S. efforts to reduce earthquake losses.

Violent, prolonged shaking from the quake triggered thousands of landslides, especially on the steep slopes of the Alaska Range. Mountainsides gave way,



This huge landslide from an unnamed 7,000-foot-high peak in the Alaska Range, less than 10 miles west of the Trans-Alaska Oil Pipeline, was triggered by the 2002 Denali Fault earthquake. The fault rupture offset the ice of the mile-wide Black Rapids Glacier, in the foreground, which the landslide subsequently covered.

THE TRANS-ALASKA OIL PIPELINE SURVIVES THE QUAKE—A TRIUMPH OF SCIENCE AND ENGINEERING

One matter of great concern immediately following the magnitude 7.9 Denali Fault earthquake in November 2002 was the fate of the Trans-Alaska Oil Pipeline, built in the 1970's. This vital lifeline transports about 17% of the domestic oil supply for the United States. At current prices, the value of oil flowing daily through the pipeline is about $25 million.

To transport oil from Prudhoe Bay on the Arctic Ocean to the ice-free port of Valdez on the Gulf of Alaska, the pipeline had to cross the Denali Fault. During the 2002 Denali Fault quake, the ground was offset beneath the pipeline, and violent shaking damaged a few of the pipeline's supports near the fault, but the pipeline did not break.

The survival of the pipeline in the Denali Fault earthquake was the result of careful engineering to meet stringent earthquake design specifications based on geologic studies done in the early 1970's by the U.S. Geological Survey, Woodward-Lundgren and Associates, and others in conjunction with the Alyeska Pipeline Service Company. Those studies located the Denali Fault within a 1,900-foot corridor crossing the pipeline route and estimated that the pipeline could be subjected to a magnitude 8.0 earthquake in which the ground might slip 20 feet horizontally and 5 feet vertically. These estimates proved to be remarkably accurate for the 2002 magnitude 7.9 earthquake, in which the rupture crossed the pipeline within the 1,900-foot corridor, and the fault shifted about 14 feet horizontally and 2.5 feet vertically.

To accommodate the projected fault movement and intense earthquake shaking from a magnitude 8.0 quake, the zigzagging Trans-Alaska Oil Pipeline, where it crosses the Denali Fault, is supported on Teflon shoes that are free to slide on long horizontal steel beams. Such creative engineering solutions used in the pipeline design and the studies that led to them cost only about $3 million when they were done in the 1970's. Had the pipeline ruptured in the Denali Fault quake, the lost revenue and the cost of repair and environmental cleanup could have easily exceeded $100 million, perhaps many times.

burying the valleys and glaciers below in deposits of rock and ice as much as 15 feet thick. The majority of landslides clustered in a narrow band extending about 8 to 12 miles on either side of the rupture.

One facility that was badly damaged by the earthquake was the runway at Northway Airport, 40 miles from the eastern part of the November 3, 2002, fault rupture. The runway was rendered unusable by lateral spreading, accompanied by sand boils. These effects were the result of a phenomenon called "liquefaction," in which strong, prolonged earthquake shaking transforms loose, water-saturated sediments into a liquid slurry. Areas that experienced liquefaction during the earthquake include much of the Tanana River Valley north and east of the rupture and other locations near smaller rivers.

Like some other large earthquakes, the Denali Fault quake triggered small shocks as far as 2,000 miles away, mainly in volcanic areas. Yellowstone National Park had the most energetic swarm of triggered earthquakes. Following the Denali Fault earthquake, Lake Union in Seattle experienced an earthquake-induced seiche, or water sloshing, which knocked many houseboats off their moorings and caused minor damage. Seiches were seen as far away as Lake Pontchartrain in Louisiana.

Documenting the Quake

The locations of the Nenana Mountain and Denali Fault earthquakes and their aftershocks were determined by the Alaska Earthquake Information Center (AEIC) at the University of Alaska Fairbanks. AEIC receives data from more than 370 seismic stations, integrating all seismic networks in Alaska. A few of these stations are part of the new Advanced National Seismic System (ANSS) being deployed by the USGS and cooperators. After the Nenana Mountain earthquake, AEIC installed several temporary seismographs, including some ANSS instruments. When the Denali Fault earthquake struck a few days later, these stations helped to provide crucial data. Additional instruments were deployed after the Denali Fault quake, and as of December 2002, a total of 26 temporary seismic stations were gathering data on the quake's aftershocks.

During the 10 days following the Denali Fault earthquake, geologists from the USGS and Alaska Division of Geological and Geophysical Surveys, as well as several universities, mapped and measured the earthquake rupture on the ground and using aircraft. They identified the previously unknown Susitna Glacier Fault in the area where the quake began and showed that the rest of the rupture exactly followed a rupture, hundreds of years old, that geologists had documented in the 1970's. They also located major landslides caused by the quake. The pattern of landsliding may help to better estimate levels of shaking along the length of the fault, especially because of the sparsity of seismic instruments in this rugged mountainous region.

Implications for Future Quakes Elsewhere

Because the 2002 Denali Fault earthquake occurred on a "strike-slip" fault, like the San Andreas Fault, it offers a realistic example of effects likely to accompany the next major earthquake in California. The Denali Fault quake is similar to three earthquakes that ruptured the San Andreas Fault in the past few centuries. These include the magnitude 7.8 San Francisco earthquake in 1906, the magnitude 7.9 Fort Tejon earthquake in 1857 north of Los Angeles, and a quake that struck east of what is now Los Angeles in about 1685. Evidence of the 1685 earthquake (magnitude 7 to 8) was only discovered in the past 20 years.

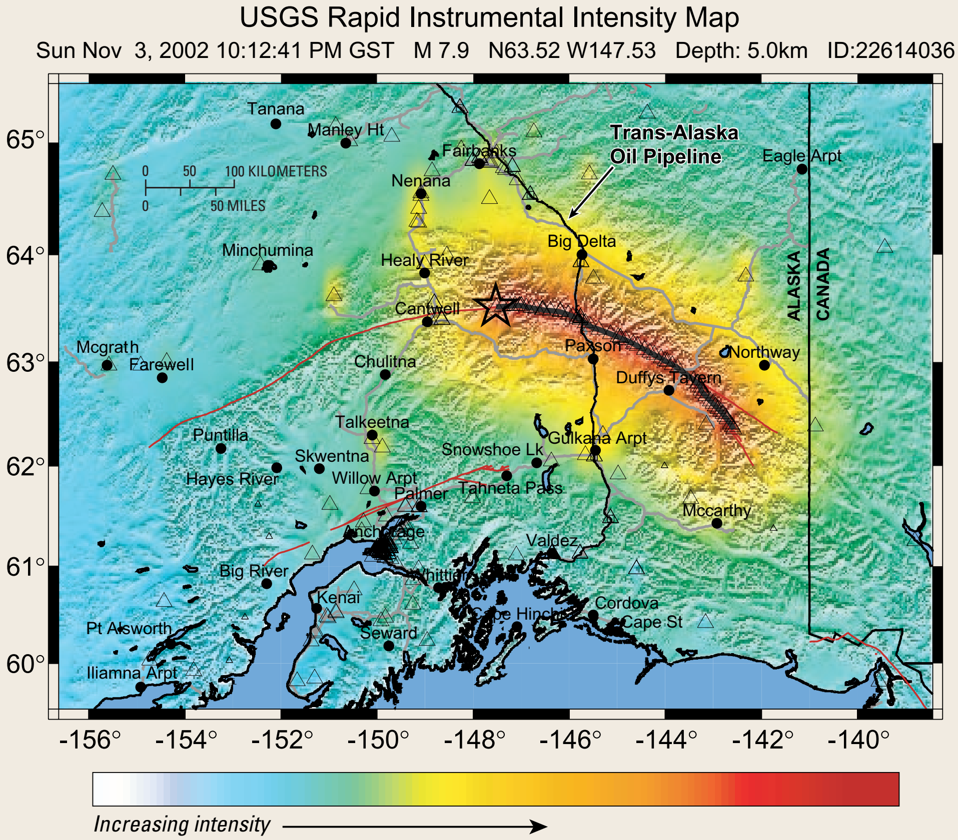
The 1857 California and 2002 Alaska earthquakes struck far from major cities, causing little or no loss of life. However, the 1906 earthquake near San Francisco killed at least 700 people (the actual death toll was probably 3 to 4 times greater). Many geologists who study evidence of ancient earthquakes in deposits and landforms along the

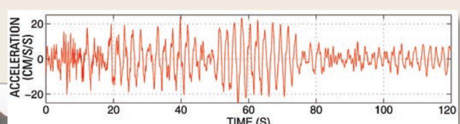
"SHAKEMAP" AND THE ADVANCED NATIONAL SEISMIC SYSTEM

A "ShakeMap" portraying shaking intensities during the November 3, 2002, Denali Fault earthquake (right) was released a few days after the quake by the U.S. Geological Survey (USGS) and the Alaska Earthquake Information Center (AEIC) at the University of Alaska Fairbanks. This ShakeMap, the first produced for Alaska, was created using data from about 50 seismic instruments across the State, including some managed by the Alyeska Pipeline Service Company at pump stations along the Trans-Alaska Oil Pipeline.

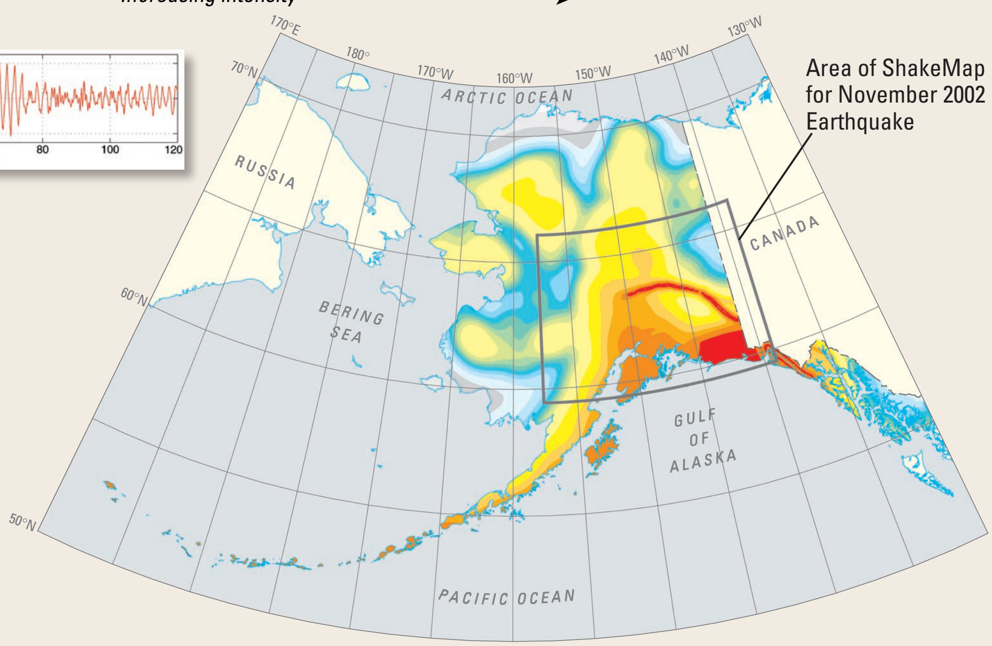
Because of the vast area shaken by the magnitude 7.9 quake and the relatively small number of seismic recordings from near the fault (two-thirds of the data were from Anchorage), this ShakeMap offers only a generalized picture of the intensity of the ground shaking. Nonetheless, this map shows a pattern for the Denali Fault region remarkably similar to that on a map of shaking hazard for Alaska that was produced by USGS scientists in 1999 (below right).

One purpose of ShakeMaps is to provide rapid information to aid emergency managers in responding to a quake. Another purpose of ShakeMaps is to reveal local variations in shaking that engineers can use to better design buildings to withstand earthquakes. To realize both these goals, the USGS and its cooperators have begun building a dense nationwide network, called the Advanced National Seismic System (ANSS), to consist of at least 7,000 sophisticated shaking monitors. These instruments are being placed both on the ground and in buildings. Because building failures are what kill the most people in earthquakes, the data that can be provided by ANSS will be crucial in saving lives in future quakes.





During the fall 2002 magnitude 7.9 Alaska earthquake, shaking monitors in this 14-story building in Anchorage recorded complex twisting and swaying motions. When analyzed, these records (including that shown above taken on the building's roof) will help engineers improve building designs.



USGS Seismic Hazard Map for Alaska

(areas of highest hazard in red)

1999

southernmost San Andreas Fault, where the 1685 earthquake occurred, have concluded that a major quake on this segment of the fault is likely to happen again in the near future. Should such a quake occur today, San Bernardino, Los Angeles, and other population centers in southern California could suffer heavy damage and loss of life.

Lessons Learned and Future Opportunities

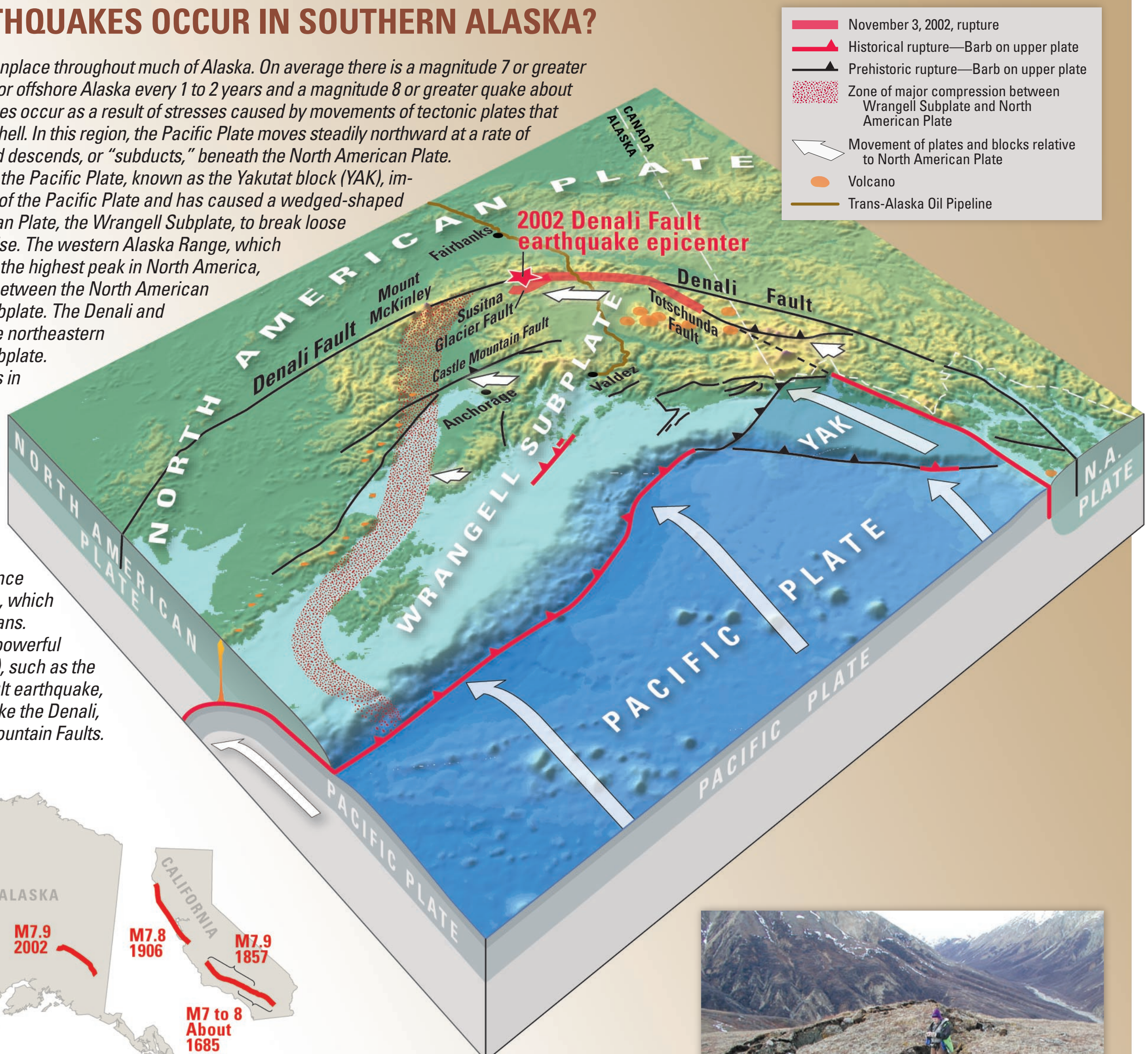
The survival of the Trans-Alaska Oil Pipeline in the 2002 Denali Fault earthquake demonstrates the value of combining careful geologic studies of earthquake hazards and creative engineering in designing and protecting such important structures and lifelines. Instrumental recordings of ground motion near earthquakes like the Denali

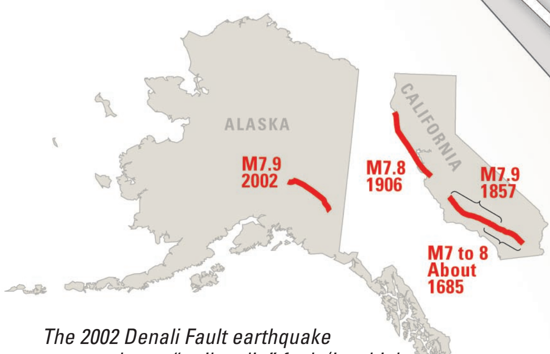
WHY DO EARTHQUAKES OCCUR IN SOUTHERN ALASKA?

Earthquakes are commonplace throughout much of Alaska. On average there is a magnitude 7 or greater earthquake somewhere in or offshore Alaska every 1 to 2 years and a magnitude 8 or greater quake about every 13 years. These quakes occur as a result of stresses caused by movements of tectonic plates that make up the Earth's outer shell. In this region, the Pacific Plate moves steadily northward at a rate of about 2 inches per year and descends, or "subducts," beneath the North American Plate.

An irregularity on top of the Pacific Plate, known as the Yakutat block (YAK), impedes smooth subduction of the Pacific Plate and has caused a wedged-shaped piece of the North American Plate, the Wrangell Subplate, to break loose and rotate counterclockwise. The western Alaska Range, which includes Mount McKinley, the highest peak in North America, is a zone of compression between the North American Plate and the Wrangell Subplate. The Denali and Totschunda Faults form the northeastern margin of the Wrangell Subplate.

The largest earthquakes in the region (magnitudes 8 and 9) occur along the subduction zone and often generate destructive tsunamis (seismic sea waves). These include the second largest quake ever recorded worldwide, the 1964 magnitude 9.2 Prince William Sound earthquake, which killed more than 100 Alaskans. Generally smaller but still powerful quakes (magnitudes 6 to 8), such as the November 2002 Denali Fault earthquake, occur inland along faults like the Denali, Totschunda, and Castle Mountain Faults.





The 2002 Denali Fault earthquake occurred on a "strike-slip" fault (in which the two sides slip horizontally past each other), like the San Andreas Fault in California. This Alaska quake was similar in magnitude (M) and in length of fault ruptured to three major quakes on the San Andreas Fault in the past few centuries.

This photo shows the 2002 Denali Fault rupture about 1.5 miles west of the Trans-Alaska Oil Pipeline. The ground on the left side of the cracks moved away from the viewer about 15 feet, causing this wide gap to open.

Fault quake are critical for improving engineering design, but such quakes do not occur often. Following the Denali Fault earthquake, adjacent fault segments have been stressed, increasing the likelihood of additional earthquakes on those segments. This presents a rare opportunity to catch a major earthquake in the act. However, full ANSS instrumentation on either end of the 2002 rupture is critical if this goal is to be achieved.

By studying earthquakes like the 2002 Denali Fault earthquake, scientists and engineers gain the knowledge necessary to reduce the vulnerability of buildings and other structures to damage in these inevitable and terrifying events. USGS studies of the Denali Fault earthquake are part of the National Earthquake Hazard Reduction Program's ongoing efforts to safeguard lives and property from the future quakes that are certain to strike in Alaska, California, and elsewhere in the United States.

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