Surface Rupture Map of the 2002 M7.9 Denali Fault Earthquake, Alaska; Digital Data

By Peter J. Haeussler

Data Series 422

2009

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

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Haeussler, P.J., 2009, Surface rupture map of the 2002 M7.9 Denali fault earthquake, Alaska; digital data: U.S. Geological Survey Data Series 422 [http://pubs.usgs.gov/ds/422/].

Contents

Abstract 1
Introduction 1
Purpose and Scope 4
Surface Rupture Digitization 4
Features Digitized 6
Files 8
Acknowledgments 8
References Cited 8

Figures

Figure 1. Map showing tectonic setting of the Denali and Totschunda Faults. 2
Figure 2. Small overview map showing the November 3, 2002, surface rupture on the Denali Fault System.. 3
Figure 3. Large overview map of the November 3, 2002, surface rupture on the Denali Fault System. ure. 3

Tables

Table 1. Digitized features related to the 2002 Denali fault earthquake surface rupture map.. ... 7

This page intentionally left blank

Surface Rupture Map of the 2002 M7.9 Denali Fault Earthquake, Alaska; Digital Data

By Peter J. Haeussler

Abstract

The November 3, 2002, M_w7.9 Denali Fault earthquake produced about 340 km of surface rupture along the Susitna Glacier Thrust Fault and the right-lateral, strike-slip Denali and Totschunda Faults. Digital photogrammetric methods were primarily used to create a 1:500-scale, three-dimensional surface rupture map, and 1:6,000-scale aerial photographs were used for three-dimensional digitization in ESRI's ArcMap GIS software, using Leica's StereoAnalyst plug in. Points were digitized 4.3 m apart, on average, for the entire surface rupture. Earthquake-induced landslides, sackungen, and unruptured Holocene fault scarps on the eastern Denali Fault were also digitized where they lay within the limits of air photo coverage. This digital three-dimensional fault-trace map is superior to traditional maps in terms of relative and absolute accuracy, completeness, and detail and is used as a basis for three-dimensional visualization. Field work complements the air photo observations in locations of dense vegetation, on bedrock, or in areas where the surface trace is weakly developed. Seventeen km of the fault trace, which broke through glacier ice, were not digitized in detail due to time constraints, and air photos missed another 10 km of fault rupture through the upper Black Rapids Glacier, so that was not mapped in detail either.

Introduction

The November 3, 2002, M_w7.9 Denali Fault earthquake was the largest strike-slip earthquake in North America in more than 150 years and produced effects felt up to 3,500 km from the epicenter (Eberhart-Phillips and others, 2003). It was also one of a few M_w7.8 or larger strike-slip earthquakes of the past century. Thus, although the Denali Fault earthquake occurred in a sparsely inhabited region, it is an excellent analog for understanding earthquakes on other significant strike-slip faults, such as the San Andreas fault, near population centers.

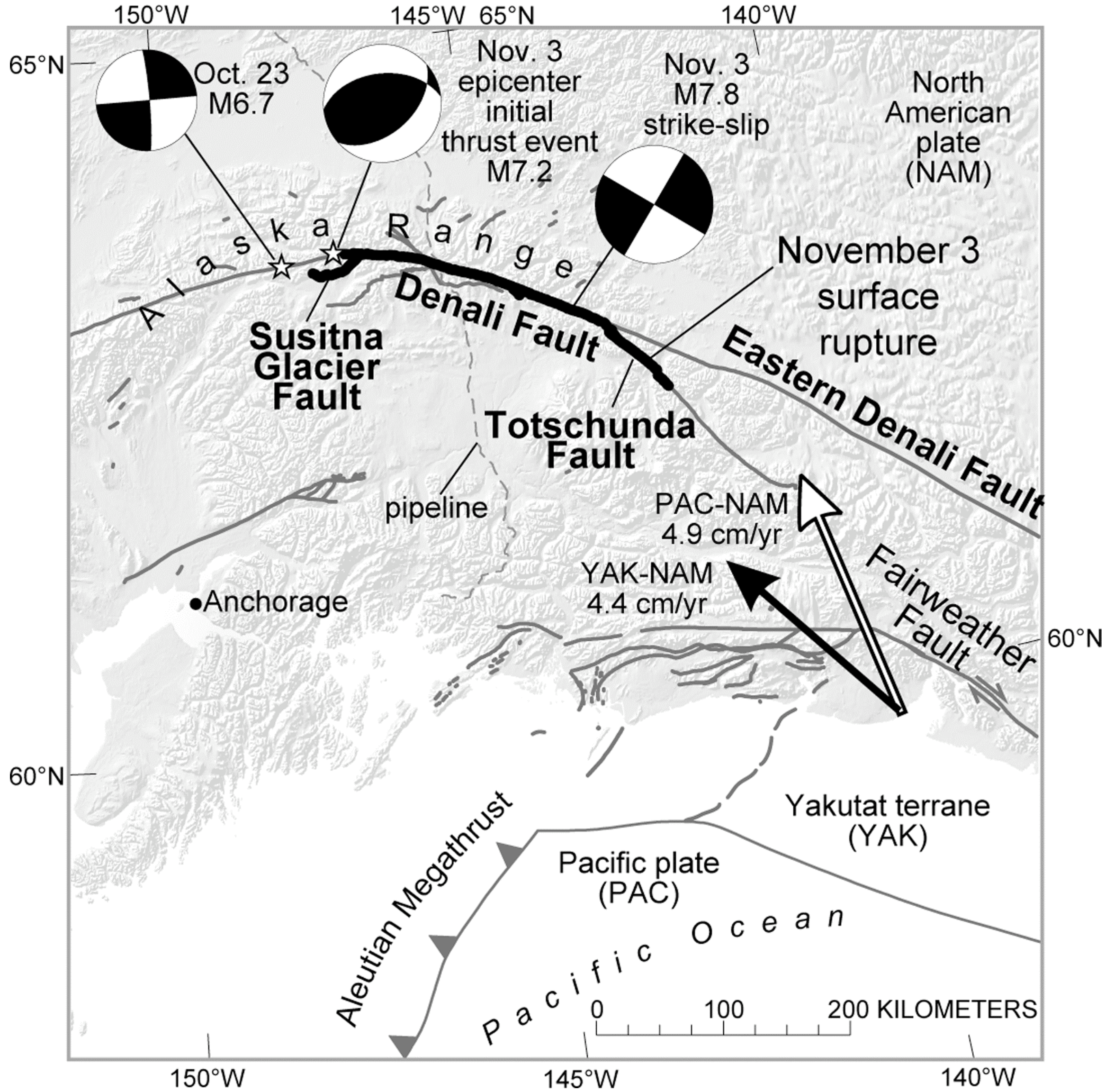

Figure 1. Map showing tectonic setting of the Denali and Totschunda Faults. Active faults are shown with gray lines (Plafker and others, 1994), and the 2002 Denali Fault earthquake surface rupture is shown with thick black lines. The GPS-measured motion of the Yakutat terrane relative to Fairbanks, Alaska, is shown with the solid black arrow (Fletcher and Freymueller, 1999). The relative motion between the Pacific Plate and the North American Plate is shown with the white arrow (DeMets and others, 1994). Figure modified from Haeussler and others (2004).

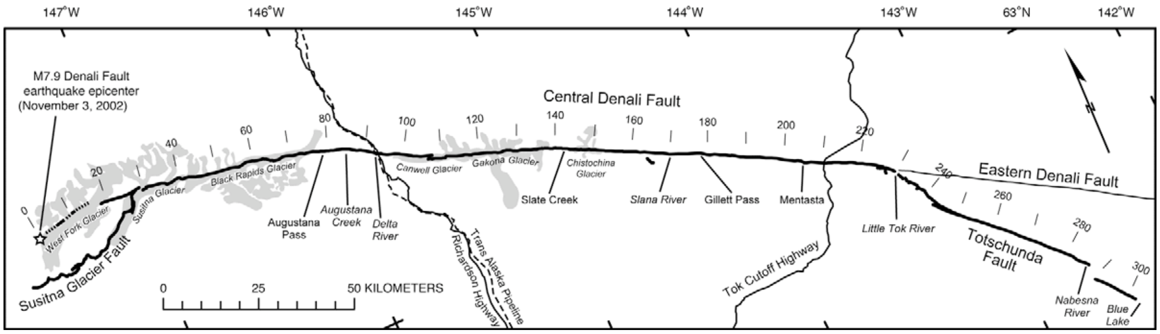

Figure 2. Small overview map showing the November 3, 2002, surface rupture on the Denali Fault System. Continuous surface rupture shown with black line. Dashed line at west end shows extent of ground cracks observed in the summer of 2003 on high mountain ridges north of West Fork Glacier. The Eastern Denali Fault, which did not rupture in 2002, is shown with thin black line. Glaciers are shown in light gray. Distances east of the epicenter are in kilometers. Note that the north direction is tilted to the left. Figure modified from Haeussler and others (2004).

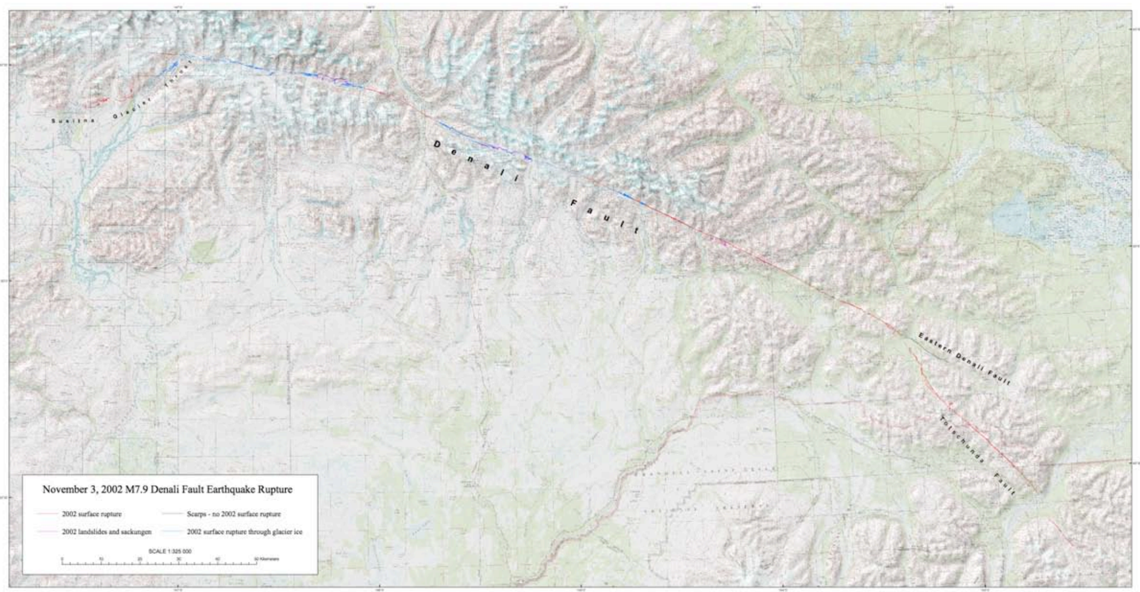

Figure 3. Large overview map of the November 3, 2002, surface rupture on the Denali Fault System. Map shows linework associated with geologic features in the digital database associated with this report. Lines are colored to show the major classifications of the data: 2002 surface rupture, lines are red; 2002 surface rupture through glacier ice, lines are blue; 2002 landslides and sackungen, lines are purple; fault scarps without 2002 surface rupture, lines are black. Click on the map for full-sized figure [http://pubs.usgs.gov/ds/422/ds422_fig3_DF_bigmap.pdf].

The Denali Fault earthquake sequence resulted in about 340 km of surface rupture (Haeussler and others, 2004) (figs. 1–3), which began with thrust faulting on a 48-km length of the previously unknown Susitna Glacier Thrust Fault. Slip on the thrust averaged about 4 m (Crone and others, 2004). The rupture then proceeded along a 226 km length of the central Denali Fault, with average right-lateral offsets of about 5 m and a maximum offset of 8.8 m near its eastern end. The Denali fault rupture was commonly north side up. Slip then transferred southeastward onto the Totschunda Fault and continued for another 66 km where right-lateral offsets averaged about 1.7 m. The transition from the Denali Fault to the Totschunda Fault occurs over a complex 25-km-long transfer zone of mosly right-lateral and subsidary normal faulting. Seismological studies indicate three pulses of moment release during the earthquake sequence (Frankel, 2004). The first pulse of about M_w7.2 is associated with the Susitna Glacier Thrust Fault rupture; the second pulse occurred about 100 km east of the epicenter and may be associated with a slight increase in surface offset. The third pulse of about M_w7.2 is correlated with the region of high slip on the Denali Fault, which is located just west of the intersection with the Totschunda Fault.

Purpose and Scope

The purpose of this paper is to publish digital data for a high-resolution, three-dimensional, surface-rupture map of the 2002 Denali Fault Earthquake and to describe the methods used to create it. A low-resolution, and preliminary, version was released by Eberhart-Phillips and others (2003). A higher-resolution map, with some detailed inset maps, was shown in Haeussler and others (2004), but it did not contain the digital data. In addition to the locations of the surface breaks, this dataset maps earthquake-induced landslides and sackungen. This dataset does not include surface-slip measurements, which were published by Haeussler and others (2004).

This surface-rupture map is the first to contain the entire rupture digitized in three dimensions. This was made possible by the recent development of affordable hardware and software for digital, or softcopy, photogrammetry (for example, Linder, 2003). This paper also describes the hardware and software I used for generating the three-dimensional rupture map. Although a two-dimensional view of the data is interesting, there is much more to be gained by looking at the rupture in three dimensions. For example, the dip of the Denali Fault can be determined where it crosses mountain passes, and the dip of the toe of different segments of the Susitna Glacier Fault can be measured.

The version of the surface-rupture map presented here should be considered close to a final version. A few areas with fault rupture through glacier ice could be improved, and a few areas had substandard digitizing because of various technical problems related to positioning the photographs. Details of these issues are described in subsequent sections.

Surface Rupture Digitization

Most of the surface rupture map is based upon mapping using vertical-incidence aerial photographs, henceforth termed air photos. The U.S. Geological Survey (USGS) contracted with Anchorage-based Aeromap, Incorporated (now renamed “Aero-metric, Inc.”) to acquire these photographs. Air photos were taken at a scale of 1:6,000 over the surface rupture between November 12 and 18, 2002. The weather was stable between the earthquake on November 3 and the photography. Less than 5 cm of snow accumulated in a few areas along the fault trace in this time period, but the surface breaks were well exposed. The high contrast between the generally white ground surface and the dark-colored cracks made the surface rupture easy to recognize. Additional photography at 1:25,000 scale was also planned, but, due to weather and contractor delays, only photographs over the Totschunda Fault and the transfer zone between the Denali and the Totschunda Faults were taken on December 1. Aircraft orientation (pitch, roll, yaw) and position (latitude, longitude, elevation) data were collected with each photograph. A total of 883 photographs were taken.

Several subsequent steps allowed for digitizing features with a digital photogrammetry setup. The photographs were scanned on a photogrammetric-grade, high-resolution scanner (at 24 microns, or 1,750 dpi), resulting in TIFF images that are about 275 MB each. The vendor (Aeromap, Incorporated) then completed aerotriangulation of the images with their aircraft orientation data and expected the absolute accuracy of the oriented photographs to be within about 1 m. There were a few lines that were not aerotriangulated by the vendor, likely because of issues related to positioning of the aircraft. We were able to satisfactorily orient most of these photographs, using the vendor-supplied aircraft orientation data and Leica Photogrammetry Suite software. The vendor supplied the USGS with Leica block (.blk) files, which give the air photo orientation and camera data for each frame of each flight line. These block files and the scanned air photos are available upon request.

Special computer hardware and software are needed for digital photogrammetry. For computer hardware, a good-quality computer with a large-capacity hard drive capable of running GIS software is needed. For heads up viewing the air photos in stereo, I used a StereoGraphics brand shutter screen system and, to drive this monitor, a stereo enabled graphics card is needed for the computer. For GIS software, I used ESRI's ArcMap version 9.1, which only runs on the Microsoft Windows Operating System. For viewing and digitizing the air photos, I used Leica's StereoAnalyst plug in to ArcMap. I also used Leica's photogrammetric mouse, with a Z wheel, which makes digitization much quicker.

This digital system for viewing and digitizing air photos has considerable advantages over conventional analog systems, because the user can zoom in and out over an infinite range and the brightness and contrast of each image can be manipulated. Moreover, features on the air photos are digitized in three dimensions. I found the system worked very well. It was straightforward to digitize where the original air photos had good lighting and contrast, but it was a challenge to observe features in dark shadows. Thus, the quality of the original photographs is still of primary importance.

The surface rupture map from digital photogrammetry is high resolution. Points were digitized along each identified feature 4.3 m apart, on average, with a standard deviation of 8.3 m. The scale of the map is good to 1:500. I likely spent between 300 and 600 hours digitizing the photographs.

One unusual aspect of the 2002 earthquake was that about 99 km of the 340 km of surface rupture was through glacier ice. The fault rupture through glaciers is commonly expressed as a shattered zone 50-500 m wide, which is much broader than the surface trace elsewhere (Haeussler and others, 2004). I digitized a 72 km length of the rupture through the glacier ice, although it is very tedious to do completely. For comparison, for one pair of stereo air photos, it would take between 15 and 45 minutes to digitize the surface rupture where it was not through glacier ice. In contrast, where the surface broke through glacier ice, it would take 4–8 hours to digitize a stereo pair. It became time-prohibitive to complete this task, and I did not digitize 17 km of the most complicated fault trace through glacier ice in detail. Although this task could be completed, it would not add much useful information, because the surface rupture through glacier ice is much wider than that recognized on land. The surface rupture is influenced by a glacier's ice fabric and by medial moraines and ogives (Haeussler and others, 2004), therefore the true character of the surface rupture is obscured.

In one area, the air photos missed the main fault. A 10-km length of the fault trace on the upper Susitna Glacier is not covered by the air photos, and reconnaissance GPS data was used to roughly locate the fault trace. In the region between the Delta River and the Canwell Glacier, the fault trace was obscured in thick forest. Similarly, the fault trace was obscured by trees in part of the region west of Mentasta. In these areas, I walked along the fault trace and recorded waypoints along the surface breaks with a handheld GPS device. These points were then brought into the GIS software, and the fault segments were digitized.

Features Digitized

Features digitized from the air photos were differentiated into 37 categories (table 1). Thirty-two of these catagories are related to the 2002 rupture (the "2002/pre2002" column in table 1), and these features were classified into three types of features: scarp, landslide, or sackung ("Feature" column in table 1). Scarp features are those that mark the surface rupture of the 2002 earthquake, or cracking of the ground, along the surface trace. Landslide features outline landslides that occurred in the 2002 earthquake, and sackung features define sackungen that formed during the 2002 earthquake

Scarp descriptions have modifiers that define their location on land or glacier, their sense of displacement (if known), their confidence in identification, and the certainty of their location (table 1). Confidence in identifying scarps was divided into either certain or questionable. Scarp identification was considered questionable when a feature was identified, but due to poor image quality it was difficult to determine if it was fault related. Scarp location was classified as either accurate or approximate. Identification was considered approximate if (1) the surface trace was generalized over numerous cracks over a broad area, (2) poor, particularly dark, image quality hindered accurate location, (3) dense forest hid the exact location, or (4) problems with air photo orientation resulted in some mismatch in the stereo pair and difficulty in precise digitizing. Scarp sense-of-displacement was classified as unknown, vertical, normal, and thrust. If the sense-of-displacement was considered unknown then no vertical offset was observed, which means it was less than 1 m. Most of these features likely have some right-lateral offset, but on the scale of the air photos this was rarely seen. If the sense-of-displacement was vertical, then the ground surface was higher on one side of the scarp than on the other. These are the features that have displacement in their shortlinename in the geodatabase. Scarps were considered to have normal displacement when a low-angle scarp face was observed. These were only seen in the transfer zone between the central Denali Fault and the Totschunda Fault. Scarps were considered to be the result of thrusting, if one side was clearly pushed over the other. When scarps broke through

Table 1. Digitized features related to the 2002 Denali Fault earthquake surface rupture map.

Feature	Land/ glacier	2002/ pre2002	Sense of displacement	Confidence in identification	Location accuracy	Shortlinename	Linetype
scarp	land	2002	unknown	certain	accurate	scarp, certain, accurate	fault scarp, 2002 rupture, identity and existence certain, location accurate
scarp	land	2002	vertical	certain	accurate	scarp, certain, accurate, displacement	fault scarp, 2002 rupture, identity and existence certain, location accurate, hachures point downscarp, which is to the right in the direction digitized
scarp	land	2002	unknown	certain	approximate	scarp, certain, approx	fault scarp, 2002 rupture, identity and existence certain, location approximate
scarp	land	2002	vertical	certain	approximate	scarp, certain, approx, displacement	fault scarp, 2002 rupture, identity and existence certain, location approximate, hachures point downscarp, which is to the right in the direction digitized
scarp	land	2002	unknown	certain	approximate	scarp, certain, located by GPS	fault scarp, 2002 rupture, identity and existence certain, location is approximate because rupture trace located by handheld GPS
scarp	land	2002	unknown	questionable	accurate	scarp, questionable, accurate	fault scarp, 2002 rupture, identity or existence questionable, location accurate
scarp	land	2002	vertical	questionable	accurate	scarp, questionable, accurate, displacement	fault scarp, 2002 rupture, identity or existence questionable, location accurate, hachures point downscarp, which is to the right in the direction digitized
scarp	land	2002	unknown	questionable	approximate	scarp, questionable, approx	fault scarp, 2002 rupture, identity or existence questionable, location approximate
scarp	land	2002	normal	certain	accurate	normal scarp, certain, accurate	normal fault scarp, 2002 rupture, identity and existence certain, location accurate, hachures point downscarp, which is to the right in the direction digitized
scarp	land	2002	thrust	certain	accurate	thrust scarp, certain, accurate	thrust fault scarp, 2002 rupture, identity and existence certain, location accurate, teeth point toward the hanging wall, which is to the right in the direction digitized
scarp	land	2002	thrust	certain	approximate	thrust scarp, certain, approx	thrust fault scarp, 2002 rupture, identity and existence certain, location approximate, teeth point toward the hanging wall, which is to the right in the direction digitized
scarp	land	2002	thrust	certain	accurate	thrust scarp, on glacier, certain, accurate	thrust fault scarp, 2002 rupture on glacier ice, identity and existence certain, location accurate, teeth point toward the hanging wall, which is to the right in the direction digitized
scarp	land	2002	thrust	certain	approximate	thrust scarp, on glacier, certain, approx	thrust fault scarp, 2002 rupture on glacier ice, identity and existence certain, location approximate, teeth point toward the hanging wall, which is to the right in the direction digitized
scarp	land	2002	thrust	questionable	accurate	thrust scarp, on glacier, questionable, accurate	thrust fault scarp, 2002 rupture on glacier ice, identity or existence questionable, location accurate, teeth point toward the hanging wall, which is to the right in the direction digitized
scarp	land	2002	thrust	questionable	approximate	thrust scarp, on glacier, questionable, approx	thrust fault scarp, 2002 rupture on glacier ice, identity or existence questionable, location approximate, teeth point toward the hanging wall, which is to the right in the direction digitized
scarp	land	2002	thrust	questionable	accurate	thrust scarp, questionable, accurate	thrust fault scarp, 2002 rupture, identity or existence questionable, location accurate, teeth point toward the hanging wall, which is to the right in the direction digitized
scarp	on glacier	2002	unknown	certain	accurate	scarp, on glacier, certain, accurate	fault scarp, 2002 rupture on glacier ice, identity and existence certain, location accurate
scarp	on glacier	2002	vertical	certain	accurate	scarp, on glacier, certain, accurate, displacement	fault scarp, 2002 rupture on glacier ice, identity and existence certain, location accurate, hatchures point downscarp, which is to the right in the direction digitized
scarp	on glacier	2002	unknown	certain	approximate	scarp, on glacier, certain, approx	fault scarp, 2002 rupture on glacier ice, identity and existence certain, location approximate
scarp	on glacier	2002	vertical	certain	approximate	scarp, on glacier, certain, approx, displacement	fault scarp, 2002 rupture on glacier ice, identity and existence certain, location approximate, hachures point downscarp, which is to the right in the direction digitized
scarp	on glacier	2002	unknown	certain	approximate	scarp, on glacier, certain, located by GPS	fault scarp, 2002 rupture on glacier ice, identity and existence certain, location approximately located by GPS waypoints taken in an aircraft
scarp	on glacier	2002	---	certain	accurate	scarp, on glacier, contractional pop up, certain, accurate	contractional pop up structure, 2002 rupture on glacier ice, identity and existence certain, location accurate
scarp	on glacier	2002	---	certain	approximate	scarp, on glacier, contractional pop up, certain, approx	contractional pop up structure, 2002 rupture on glacier ice, identity and existence certain, location approximate
scarp	on glacier	2002	unknown	questionable	accurate	scarp, on glacier, questionable, accurate	fault scarp, 2002 rupture on glacier ice, identity or existence questionable, location accurate
scarp	on glacier	2002	vertical	questionable	accurate	scarp, on glacier, questionable, accurate, displacement	fault scarp, 2002 rupture on glacier ice, identity or existence questionable, location accurate, hachures point downscarp
scarp	on glacier	2002	unknown	questionable	approximate	scarp, on glacier, questionable, approx	fault scarp, 2002 rupture on glacier ice, identity or existence questionable, location approximate
landslide	land	2002	---	certain	accurate	landslide scarp, certain, accurate	landslide scarp, 2002, identity and existence certain, location accurate, hachures lie on the side of the landslide, which is to the right in the direction digitized
landslide	land	2002	---	certain	approximate	landslide scarp, certain, approx	landslide scarp, 2002, identity and existence certain, location approximate, hachures lie on the side of the landslide, which is to the right in the direction digitized
landslide	land	2002	---	certain	accurate	landslide toe, downslope to left	landslide toe, downslope to left, 2002 slide, existence and identity certain, location accurate
sackung	land	2002	---	certain	accurate	sackung scarp, certain, accurate	sackung scarp, 2002, identity and existence certain, location accurate, hachures point downscarp (uphill), which is to the right in the direction digitized
sackung	land	2002	---	certain	approximate	sackung scarp, certain, approx	sackung scarp, 2002, identity and existence certain, location approximate, hachures point downscarp (uphill), which is to the right in the direction digitized
sackung	land	2002	---	questionable	accurate	sackung scarp, questionable, accurate	sackung scarp, 2002, identity or existence questionable, location accurate, hachures point downscarp (uphill), which is to the right in the direction digitized
scarp	land	pre2002	unknown	certain	accurate	scarp, no 2002, certain, accurate	fault scarp, no 2002 rupture, identity and existence certain, location accurate
scarp	land	pre2002	vertical	certain	accurate	scarp, no 2002, certain, accurate, displacement	fault scarp, no 2002 rupture, identity and existence certain, location accurate, hachures point downscarp, which is to the right in the direction digitized
scarp	land	pre2002	unknown	certain	approximate	scarp, no 2002, certain, approx	fault scarp, no 2002 rupture, identity and existence certain, location approximate, which is to the right in the direction digitized
scarp	land	pre2002	unknown	questionable	accurate	scarp, no 2002, questionable, accurate	fault scarp, no 2002 rupture, identity or existence questionable, location accurate
scarp	land	pre2002	unknown	questionable	approximate	scarp, no 2002, questionable, approx	fault scarp, no 2002 rupture, identity or existence questionable, location approximate

glacial ice, this relation could be observed easily (Crone and others, 2004). Also, along the Susitna Glacier Thrust Fault there were large rollovers in the tundra at the toe of the fault scarp (Crone and others, 2004), which also demonstrated shortening and thrust motion.

Features listed as pre-2002 are Holocene fault scarps. Most are on the eastern Denali Fault east of the junction between the Central Denali Fault and the Totschunda Fault (figs. 1, 2). A few are along the Susitna Glacier Thrust Fault. The scarps on the Eastern Denali Fault help to show the relationship between the 2002 rupture on the Central Denali and Totschunda Faults and on the eastern Denali Fault.

Landslides generated during the 2002 earthquake were very large and covered broad sections of the fault trace on glaciers. About 6.3 km of the fault trace on glaciers were covered by landslides. Sackungen are uphill-facing scarps related to collapse of mountaintops. Their origin is sometimes, but not always, attributed to seismic shaking. It is clear in this case that these fractures formed only during the 2002 earthquake.

Files

The accompanying geodatabase, shapefiles, and KML files should allow most users to be able to easily view, plot, and manipulate the data collected while mapping the surface rupture of the 2002 Denali fault earthquake. This is the most detailed surface rupture map of a large (M_w7.8 or larger) strike-slip earthquake yet produced, and the only one digitized in three dimensions.

Acknowledgments

I thank Aeromap, Incorporated for collecting excellent postearthquake air photos and for working with the USGS in this foray into digital photogrammetry. Thanks to Marco Ticci for volunteering for the USGS and orienting some of the air photos. Thanks also to Keith Labay and Evan Thoms for various help on GIS throughout this project. Luke Blair and David Schwartz provided constructive reviews of this manuscript and data.

References Cited

Crone, A.J., Personius, S.F., Craw, P.A., Haeussler, P.J., Staft, L.A., 2004, The Susitna Glacier thrust fault—Characteristics of ruptures that initiated the 2002 Denali fault earthquake: Bulletin of the Seismological Society of America, v. 94, no. 6B, p. S5-S22.

DeMets, Charles, Gordon, R,G., Argus, D.F., Stein, Seth, 1994, Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions: Geophysical Research Letters, v. 21, p. 2191–2194.

Eberhart-Phillips, D., Haeussler, P.J., Freymueller, J.T., and 26 others, 2003, The 2002 Denali fault earthquake, Alaska—A large magnitude, slip-partitioned event: Science, v. 300, no. 5622, p. 1113-1118.

Fletcher and Freymueller, 1999, New GPS constraints on the motion of the Yakutat block: Geophysical Research Letters, v. 26, p. 3029-3032.

Frankel, A., 2004, Rupture process of the M7.9 Denali Fault, Alaska, earthquake—Subevents, directivity, and scaling of high-frequency ground motions: Bulletin of the Seismological Society of America v. 94, no. 6B, p. S234-S255 (doi:10.1785/0120040612).

Haeussler, P.J., Schwartz, D.P., Dawson, T.E. and 8 others, 2004, Surface rupture and slip distribution of the Denali and Totschunda Faults in the 3 November 2002 M 7.9 Earthquake, Alaska: Bulletin of the Seismological Society of America, v. 94, no. 6B, p. S23-S52.

Linder, Wilfred, ed., 2003, Digital photogrammetry—Theory and applications: Elsevier, Netherlands, v. XI, 189 pp.

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

November 3, 2002 M7.9 Denali Fault Earthquake Rupture
2002 surface rupture
Scarps - no 2002 surface rupture
2002 landslides and sackungen
2002 surface rupture through glacier ice
SCALE 1:325 000
0 10 20 30 40 50 Kilometers
Denali Fault
Eastern Denali Fault
Totschunda Fault
Susitna Glacier Thrust
WRANGELL - SAINT ELIAS NATIONAL PRESERVE
147°0' 146°0' 145°0' 144°0' 143°0'
63°30' 63°0' 62°30'