S72F-1329 1330 h POSTER

Trans Alaska Pipeline Design Accommodates November 3, 2002, Magnitude 7.9 Earthquake

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During the early 1970s, a 48-inch-diameter pipeline was proposed to bring crude oil from Prudhoe Bay to the Port of Valdez, Alaska, traversing 1280 km of spectacular wilderness country, three mountain ranges, and four active faults. Detailed fault rupture evaluations were completed by a team of earthquake geologists, led by co-Project Directors Lloyd S. Cluff and David B. Slemmons, for the Alyeska Pipeline Service Company. The comprehensive studies of the entire proposed pipeline route concluded that four active faults would require special design to protect the integrity of the pipeline. The Denali fault, the most active of the three, which traverses east-west near the center of the Alaska Range, was determined to be the most dangerous.

The Denali fault was assessed to have the potential of releasing a magnitude 8.0 earthquakes due to a rupture estimated to extend more than 250 km, with surface rupture ranging from a few feet to a maximum of 30 feet horizontal and 8 feet vertical. The recommended design at the pipeline fault crossing was 20 feet horizontal and 5 feet vertical. The design engineers, Nathan M. Newmark, William J. Hall, and Jim Maple, assisted by Douglas Nyman, the pipeline' s seismic design coordinator, developed an innovative design consisting of very long concrete footings coated with Teflon that would allow the footings to move beneath the pipeline and the pipeline to slide freely, extending, compressing, or shifting laterally to accommodate the expected fault rupture.

On November 3, the M 7.9 earthquake on the Denali fault ruptured west to east along strike for at least 270 km. At the pipeline fault crossing, surface displacement and related fault deformation of 12.5 feet horizontal and 2.5 feet vertical occurred. The rupture caused the pipe to slide sideways on the Teflon-coated footings without loosing its structural integrity or spilling oil. There were some areas of minor damage, but the pipeline was resilient and performed as the design intended. The pipeline was shut down 3 days for inspection and bracing where some minor damage occurred. Reasonably conservative design fault displacement parameters, and a unique design allowed the pipeline to survive the earthquake without disruptive damage.

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Geotechnical Reconnaissance of the 3 November 2002, Mw 7.9, Denali- Earthquake, Alaska

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Following the Mw 7.9 earthquake on the Denali and Totschunda faults on 3 November 2002, we conducted a reconnaissance of the region to investigate geotechnical and surface rupture features of the event. The focus of our investigation was to characterize the spatial extent and amplitude of ground failures and fault displacements, and assess damage to structures.

As a first step, our team flew along the Denali fault from the Black Rapids Glacier, west of the Richardson Highway, to the Glenn Highway (Tok Cut-off). We also conducted a brief air reconnaissance of the southern part of the Totschunda fault northwest of the Nabesna River, and brief ground surveys where the fault intersected the highways and the TAPS pipeline. The most noteworthy aerial observations were that geotechnical and structural damages appeared to be focused towards the eastern end of the Denali-fault rupture area. For example, liquefaction features in the bars of the Tanana River, north of the fault-break, are sparsely located from Fairbanks to Delta, but are pervasive throughout the eastern area of the break to Northway Junction, the eastern limit of our survey. Likewise, for the four glacier-proximal rivers draining toward the north, little or no liquefaction was observed on the western Delta and Johnson Rivers whereas, the eastern Johnson and Tok Rivers and, especially, the Nabesna River had observable-to-abundant fissures and sand vents. Another curious aspect of the apparent differences in strong motion along and across the fault was the abundance of landslide and rock avalanche features on the south side of the fault and a dearth of these features on the northern side. Ice on frozen lakes and ponds were shattered within about 30-40 km of the fault along the western part of the surface rupture and to the east became more widespread. In the Northway region ice on most lakes was broken at distances of more than 100 km.

The surface rupture was very linear, continuous, and confined to a relatively narrow zone composed over much of its length by closely spaced en-echelin breaks. Few significant branches or splays were observed. The apparent slip on the Denali Fault was also observed to increase to the east from Black Rapids Glacier toward the Mentasta Village area. , On the Totschunda fault, the rupture decreased in slip before dying out approximately 5 kilometers northwest of the Nabesna River. Where the fault crossed the trans-Alaska pipeline, dislocation occurred along a series of en echelon fissures. One of these en echelon breaks intersected the end of one of the Teflon surfaced skids (sleepers) that supports the pipe in the fault zone, displacing it about a meter but not damaging the pipe. Strong shaking and movement of the pipe resulted in damage to 8 horizontal support members, and 9 anchored supports near the fault crossing. These affects were not critical to the integrity of the pipeline, which performed well during the event.

This reconnaissance was supported by the National Science Foundation (NSF) and the US Geological Survey (USGS).

S72F-1331 1330 h POSTER

Bridge Structure, Foundation and Approach Embankment Performance for the October-November 2002 Earthquake Sequence on the Denali Fault, Alaska

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More than two dozen major bridges were subjected to severe ground motions during the October-November 2002 Earthquake Sequence on the Denali Fault, Alaska. The bridges represented a number of conventional designs constructed over the past three to four decades. The objective of the field investigation presented herein was to determine the extent of the damage, if any, to the bridge structures, foundations and approach embankments. This was accomplished by direct inspection of the bridges by the authors (or employees of their organizations) along the Richardson, Alaska, Parks, and Denali Highways, the Tok Cutoff, and the railroad bridges for the railroad alignment between Trapper Creek and Fairbanks.

More specifically, the members of the investigation team (represented by the authors) conducted more than three days of field inspections of bridges within the zone of severe ground shaking during the M6.7 and M7.9 Denali fault events. The primary conclusion noted was that while a substantial number of bridges were subjected to intense shaking they all performed very well and were not damaged to the extent that remedial repairs to the bridge structure were necessary. There were occurrences of lateral spreading/liquefaction related damage to the approach embankments and slight separation of the approach embankment from the abutment foundation systems. Overall, considering the severity of ground shaking, much greater damage to the bridge structures, foundations and approach embankments would be predicted. Had the earthquakes occurred during winter when the ground was frozen and the ductility of the structures was substantially reduced events comparable to the October-November 2002 Earthquake Sequence on the Denali Fault, Alaska could have resulted in significant damage to bridges.

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The 7.9 Denali Fault Earthquake: Damage to Structures and Lifelines

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In the early afternoon of Sunday, November 3rd, the residents of many interior Alaska towns were shaken up by a magnitude 7.9 earthquake. The shaking lasted an average of three minutes and when it stopped, nearly 300 km of the Denali Fault had ruptured. In the hours that followed, the Alaska Earthquake Information Center (AEIC) fielded reports of structural damage from Cantwell to Tok and other earthquake effects as far away as Louisiana. Upon investigation, the most severe effects were found in the village of Mentasta where basic utilities were interrupted and the school and several houses suffered major damage. Almost 3000 reports submitted to a community internet intensity map show a maximum Mercalli intensity VIII along the eastern end of the rupture area.

The Richardson and Parks Highways, two main north-south thoroughfares in Alaska, both buckled and split as a result of the fault rupture. Traffic was stopped for a few hours while repairs were made. Between the Richardson Highway the Tok Cutoff, a section of the Glenn Highway that connects Tok and Glennallen, the maximum offsets on the Denali Fault were observed.

Designed to withstand a magnitude 8.5 earthquake at the Denali Fault crossing, the 800-mile long Trans-Alaska Pipeline suffered relatively minor damage. According to Alyeska Pipeline Service Company press releases, the pipeline was shut down shortly after the earthquake occurred. Repairs to pipeline supports and engineering evaluations began immediately thereafter, and oil began flowing through the pipeline Thursday, November 7th .

Through it all, the AEIC has collected and archived many photographs, emails, and eyewitness accounts of those who experienced the destruction firsthand. We will detail the effects that the M7.9 Denali Fault earthquake had from near and far.

S72F-1333 1330 h POSTER

Activity of the Northern Foothills Thrust Fault: Strain Partitioning Related to the Denali Fault, Central Alaska

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Compression and uplift occurring in the foothills of the Alaska Range north of the Denali fault is attributed to significant strain partitioning that occurs along the central reach of the Denali fault. In the proposed model, oblique slip is transferred from steeply-dipping faults along and adjacent to the Denali fault to the north-vergent Northern Foothills thrust system. This informally named thrust system appears to extend for more than 200 km along the Northern Foothills of the Alaska Range from the Delta River westward to the Kantishna Hills. The inferred geometries suggest that the transfer of strain is accommodated in part by aseismic processes at depths below the seismogenic crust (deeper than ~ 20 km). Relatively uniform uplift occurs between the Denali fault and the Hines Creek fault above the steeper part of the inferred ramp. The ramp extends north to the Northern Foothills, where the thrust is inferred to steepen upward to the edge of the foothills at boundary of the Kuskokwim and Tanana Lowlands. A wedge geometry is suggested by the relationship of an active back thrust (the Healy Creek fault) to the Northern Foothills thrust fault in the area along the Nenana River. In this model, the Healy fault is modeled as a secondary splay of the Healy Creek fault. The Northern Foothills thrust consists of an emergent fault that borders the northernmost outcrops of Nenana Gravel east of the Nenana River. Locally, a secondary splay appears to have developed outboard of the main fault trace.

The location and late Pleistocene slip rate for the Northern Foothills thrust fault in the vicinity of the Nenana River is based on review of previous detailed Quaternary geologic mapping and topographic profiles of the glacial outwash terraces along the Nenana River, photogeologic interpretation, and limited field reconnaissance. A long term average vertical slip rate of 0.1 to 0.4 mm/yr is estimated based on the apparent structural relief of the Nenana gravels (deposited between 8.4 to 2.8 Ma). Topographic profiles of the Healy outwash plain surface (~34 to 72 ka) show evidence for deformation across two possible traces of the fault. A vertical slip rate of 0.13 to 0.5 mm/yr is estimated for the southernmost trace of the thrust fault that appears to be associated with post-Healy outwash surface normal faulting in the hanging wall. A vertical slip rate of 0.13 to 0.26 mm/yr is estimated for a possible northern splay.

S72F-1334 1330 h POSTER

Effects of the M7.9 Denali Fault Earthquake on glaciers in the Alaska Range

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Surface rupture associated with the Denali fault was observed on the Susitna, Black Rapids, Canwell, Gakona, and Chistochina Glaciers. In addition, offset glacial ice was observed near the terminus of the West Fork glacier where the Susitna Glacier fault (SGF), a newly discovered fault, intersects the glacier. Alaska Range glaciers are present in many valleys aligned with the Denali fault. As a result, more than 40 % of the surface rupture resulting from November 3, 2002 M7.9 event is on glaciers.

Offsets resulting from the Denali Fault Earthquake in glacial ice have variable morphologies. The earthquake epicenter was located near an icefall in a tributary of the West Fork Glacier. Almost all seracs in the icefall fell during the event. The Denali fault offset pre-existing crevasses on the north side of the Canwell Glacier and vertical offset was observed at many localities. At some locations, one or more, long linear cracks can be traced along the glacier surface, often following moraines that presumably form areas of weakness. The SGF appears to make a sharp turn to the west where it follows a looped moraine across the glacier. At some locations along the Denali fault cracks in the ice are oriented perpendicular to the fault trace. These observations suggest that careful examination of glacier morphology must be considered while delineating fault traces in glaciers.

The most dramatic changes to glaciers result from rock, ice and snow avalanches released by the earthquake. Three rock falls from the south wall of the Black Rapids Glacier cover about 13 km^2 of the ablation area. This is about 5 % of the total glacier area. The blanketing effect of these rock falls will increase the glacier's mass balance by about 0.2 $m\,a^{-1}$. A large rock and ice fall also occurred on the upper Gakona Glacier. The rock and ice fall will not affect the glacier's mass balance directly, due to the fact that it was deposited onto the glacier's accumulation area. These rock falls will be a readily visible surface feature for the next 200 to 400 or more years. Prior to the November 3 event, large rock and ice fall debris cover was not evident on the glaciers of the region. This suggests that an event of similar consequences has not occurred in the recent past.

S72F-1335 1330 h POSTER

Character and Significance of Surface Rupture Near the Intersection of the Denali and Totschunda Faults, M7.9 Denali Fault Earthquake, Alaska, November 3, 2002

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Preliminary observations suggest that right-lateral strike-slip on the Denali fault is transferred to the Totschunda fault via an extensional bend in the Little Tok River valley. Most of the surface rupture during the Denali fault earthquake was along an east- to east-southeast striking, gently curved segment of the Denali fault. However, in the Little Tok River valley, rupture transferred to the southeast-striking Totschunda fault and continued to the southeast for another 75 km. West of the Little Tok River valley, 5-7 m of right-lateral slip and up to 2 m of vertical offset occurred on the main strand of the Denali fault, but no apparent displacement occurred on the Denali fault east of the valley. Rupture west of the intersection also occurred on multiple discontinuous strands parallel to and south of the main strand of the Denali fault. In the Little Tok River valley, the northern part of the Totschunda fault system consists of multiple discontinuous southeast-striking strands that are connected locally by south-striking stepover faults. Faults of the northern Totschunda system display 0-2.5 m of right-lateral slip and 0-2.75 m of vertical offset, with the largest vertical offset on a dominantly extensional stepover fault. The strands of the Totschunda system converge southeastward to a single strand that had up to 2 m of slip. Complex and discontinuous faulting may reflect in part the immaturity of the northern Totschunda system, which is known to be younger and have much less total slip than the Denali. The Totschunda fault forms an extensional bend relative to the dominantly right-lateral Denali fault to the west. The fault geometry and displacements at the intersection suggest that slip on the Denali fault during the earthquake was accommodated largely by extension in the northern Totschunda fault system, allowing a significant decrease in strike-slip relative to the Denali fault. Strands to the southwest in the area of the bend may represent shortcut faults that have reduced the curvature at the intersection of the two fault systems.

S72F-1336 1330 h POSTER INVITED

Surface Rupture on the Susitna Glacier Fault Associated with the M 7.9 Denali Fault Earthquake.

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Surface ruptures from the November 3, 2002, M7.9 earthquake occurred on the Denali fault and at least two other connected faults that have a combined rupture length of about 320 km. The Susitna Glacier fault (SGF), a newly discovered fault, forms the westernmost 49 km of the surface rupture. Analyses of teleseismic data indicate that the initial phase of rupture for the earthquake involved thrusting on NE-SW oriented nodal planes. Field observations of south-directed-thrust surface rupture along the SGF are consistent with the initial fault motions. Discovery of the SGF demonstrates that strike-slip displacement on the Denali fault may be accommodated by thrust faults to the south, and that strike-slip rupture may terminate at such thrusts.

The SGF is expressed as an east-trending scarp or scarps on glacial till and colluvium, from west of the West Fork valley eastward along the base of unnamed hills that form the northern margin of Monahan Flat. The ruptures continue northeastward as nearly planer fractures across the lower part of the Susitna Glacier before intersecting the Denali fault beneath the glacier at about 63.52°N, 146.975 W (Healy 1:250,000 quad.). The ruptures, which have a sinuous trace that is typical of thrust faults, indicate that the SGF dips about 25-30º NNW in the shallow subsurface. The morphology of the thrust scarps vary greatly depending on the width of the deformation zone, the amount of folding and warping, the number of adjacent strands, and the type of material that was faulted. Surface ruptures are present on glacial ice, till, and slope colluvium that is covered by tundra. The zone of deformation varies in width from a few meters to tens of meters, and scarps range in height from <1 m to, locally, more than 6 m. Large scarps are the product of upwarps in the hanging wall and downwarps in the footwall. Even though these large scarps are tectonic, the maximum vertical tectonic offset on the fault was about 1.5 m. In one place, the width of a slab of consolidated snow that became detached from the underlying tundra during the faulting event indicated 1.2 m of shortening. The ruptures are characterized by second-order structures including hanging-wall grabens, tension cracks oriented normal to the scarp, local backthrusts, and ramps between adjacent strands. Accurately determining the tectonic offset across these complex ruptures and the associated deformation will require long topographic profiles across the rupture zone.

Faulted glacier ice provided sharp, planar surfaces to measure the strike, dip, and vertical offsets, but because some offsets in the ice closely follow ice layering, it is unclear how accurately the scarp morphology in ice corresponds to that in underlying rocks and sediment. In many places, the 2002 ruptures did not appear to coincide with pre-existing fault scarps, but further work is needed to determine if some of the larger scarps are related to superposition of 2002 ruptures on older scarps.

S72F-1337 1330 h POSTER INVITED

Initial observations and implications of surface rupture and slip distribution associated with the Mw7.9 Denali fault earthquake

Denali Earthquake Geologic Field Team

Initial observations of the surface ruptures resulting from the Mw 7.9 Denali fault earthquake of November 3, 2002, reveal three distinct breaks with a combined rupture length of about 320 km. The earthquake was located at 147.53° W and ruptured unilaterally to the east along the Denali and related faults. The western end of the ruptures is at 147.66°, 20 km south of the epicenter, along a previously unknown southwest-striking, north-dipping thrust fault herein named the Susitna Glacier fault. This fault is about 40 km long, intersects the Denali fault at 146.98° W, and has average vertical displacements of about 1.5 m. The principal rupture of the earthquake is along a ~210 km segment of the Denali fault, which arcs from 147.16° W to 143.25°W. Right-lateral offsets average about 4 m and reach values as high as 8.8 m, 170 km from the epicenter; vertical offsets are commonly about 20% of the strike-slip values and alternate from north-side-up to south-side-up. Right-lateral slip drops dramatically from about 5 m to about 2 m across a broad structural stepover where rupture transferred from the Denali to the Totschunda fault, which is oriented about 20° more northwesterly than the Denali. Rupture continued for about 75 km on the Totschunda fault, terminating near 142.55°. Several aspects of the November 2002 rupture are significant: First, it ranks among the largest strike-slip ruptures of the past two centuries and its length and slip magnitudes are comparable with those of the great California earthquakes of 1906 and 1857). Second, rupture did not extend west of the epicenter, perhaps impeded by a 20° bend in the Denali fault. The large stretches of the Denali fault that did not rupture to the west, has not ruptured for several hundred years and lead us to speculate whether this event will be the first in a cluster of large events involving the rest of the Denali system. Third, The reason for rupture transfer from the Denali fault to the Totschunda fault is unclear, but pre-existing scarps in the stepover region attest to recurring activity at this junction. Fourth, the pattern and magnitude of surface rupture are broadly consistent with source parameters estimated from initial modeling of seismographic waveforms and will provide important constraints on new models of the rupture. Fifth, the involvement of a thrust fault in the rupture suggests the need to better understand the role of the Denali fault and related thrust faults in the ongoing construction of the Alaska Range.

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Historical Seismicity of the Denali Fault System

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Historical (1912-1963) and recent (1964-2001) seismicity of the Denali fault system (events located within 50 km of the main fault trace at depths less than 50 km) indicates that the western fault system (147 W to 154 W) has experienced more seismic activity than the eastern fault system (140 W to 147 W), although the largest historical event (M 7.2 in 1912) is associated with the eastern fault system. Relocation, first motion and waveform modeling studies of events occurring between 1932 and 1964 in a region between 151 and 154 W suggest that many of the historical events do not represent motion along the Denali fault. The 1932 (Mw 7.0) event appears to have involved strike-slip faulting at 30-40 km depth along a structure transverse to the Denali fault, while a M 6.4 event was associated with rupture at 30-40 km depth along a thrust fault, possibly an extension of the Pass Creek fault. More recently, the October 22, 1996 Mw 5.8 earthquake (at 145.29 W) occurred along a thrust fault located within 10 km of the main Denali fault trace. These observations suggest that other historical events with magnitudes greater than 5.5 that have been thought to be associated with rupture along the main Denali fault trace may also have occurred on these compensating thrust and strike-slip fault systems.

S72F-1339 1330 h POSTER

The Nenana Mountain Magnitude 6.7 Earthquake of October 23, 2002

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On October 23, 2002 around 3:30 am AST, people of interior Alaska were awakened to strong shaking caused by a magnitude 6.7 earthquake in the central region of Alaska. The epicenter was located on the Denali Fault at 63.5 N latitude, –147.9 W longitude and depth of 4.2 km. The quake was 28 mi (44 km) northeast of the Denali Park entrance and 91 mi (146 km) south of Fairbanks. Damage from this quake was limited to a small area around the epicenter, and consisted of mainly road damage and a few items falling off shelves in Cantwell. The focal mechanism shows right-lateral motion on a vertical east-west plane. This quake could be either a foreshock or the trigger to the magnitude 7.9 earthquake, that occurred on November 3, 2002 at 1:12 AST, at the eastern end of the magnitude 6.7 rupture zone.

The largest aftershocks attributed to this earthquake were two magnitude 3.8 events; the first occurred 3 hours after the main event, 41.2 km east and the second occurred 3 days, 4.4 km west of the main shock. Over 690 aftershocks ranging from 0.5 to 3.8 ml have been located since the 6.7 main shock, until the M 7.9 earthquake. The aftershock sequence has a magnitude of completeness of 1.6, a b-value of 0.8 and an a-value of 3.8. Aftershocks have been relocated with a double difference algorithm to minimize the scatter. The rupture zone, as defined by the aftershocks, is 40 km along fault trace. The majority of the aftershocks are located between o and 10 km deep. The relocated aftershocks define a WNW-ENE striking plane slightly dipping to the north.

S72F-1340 1330 h POSTER

Rupture Process of the M7.9 Denali Fault, Alaska, Earthquake Determined from Strong-Motion Recordings

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We have analyzed and modeled strong-motion recordings available to date of the M7.9 Denali Fault earthquake of November 3, 2002. The data are from instruments at epicentral distances of 60-290 km operated by the USGS National Strong Motion Network, the Advanced National Seismic System, and the Geophysical Institute of the University of Alaska. We have identified and located three major sub-events of the earthquake using the displacement waveforms from these stations. The first sub-event occurred near the hypocenter and waveform modeling of the strong-motion records indicates that it is characterized by thrust faulting on a fault striking east-northeast. The second sub-event is centered about 70-80 km east of the hypocenter and is dominated by right lateral strike-slip motion. This sub-event is located in the area where substantial strike slip surface offset is observed. The third sub-event, clearly observed only at Valdez, is centered approximately 170 km east of the hypocenter, based on a rupture velocity of 3 km/sec. This is the approximate location of the largest surface displacements. At Valdez, which is equidistant from the three sub-events, the largest accelerations are associated with the first two sub-events. Peak acceleration values for the available stations were modest: about 10%g for portable stations 60-70 km west of the hypocenter, 9%g for Fairbanks about 150 km from the hypocenter, and about 2%g or less for Anchorage at about 280 km hypocentral distance. At the meeting, we will show an animation of ground motions recorded by stations across Anchorage.

S72F-1341 1330 h POSTER

Rupture Processes of the November 3, 2002 Denali (M=7.9) Earthquake

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The Ms = 7.9 earthquake that struck central Alaska on Nov. 3, 2002 was preceded 11 days earlier by an M=6.7 strike-slip foreshock on Oct. 23, 2002. Both events occurred on the Denali fault, located approximately 180 miles north of Anchorage. Dominant faulting mechanisms for both events are consistent with right-lateral strike slip motion, which is consistent with large surface offsets observed as a result of the mainshock. However, first motion focal mechanism (University of Alaska, Fairbanks), and teleseismic body-wave rupture models by Kickuchi and Yamanaka indicate that the mainshock began with a relatively small rupture on a northeast-striking reverse fault, before breaking out for 300 km of right-lateral strike-slip rupture. Aftershock patterns suggest that the foreshock ruptured the west of the main shock, which began near the eastern extent of the foreshock sequence and proceeded east-southeast. Although the main shock rupture direction is significantly rotated relative to the foreshock, we apply an empirical Green_s function (EGF) technique utilizing the foreshock as an EGF for the large event. This technique can correct teleseismic observations for propagation effects and allows for utilization of surface waves between the period of 20 to 150 s. Surface-wave phase velocity similarity with rupture velocity makes them highly sensitive to horizontal rupture directivity that dominates the kinematics of a large, shallow strike-slip events. The large size of the foreshock limits our resolution of the shortest periods but we can resolve longer period characteristics of the strike-slip component of the main event. The mechanism rotation limits EGF application near radiation pattern nodes but otherwise should only affect relative source time function amplitudes, which we correct by requiring uniform seismic moment release. Our preliminary results indicate that the event ruptured unilaterally to the east-southeast, with the highest energy release near the end of a 91 s long rupture. These results are consistent with the preliminary surface-offset data, which show the large offsets in the southeast. The duration and length of rupture suggest an average rupture velocity of approximately 3.2 km/s.

S72F-1342 1330 h POSTER

Source Process of the November 3, 2002 Denali Fault Earthquake (Central Alaska)

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The November 3, 2002 Denali fault earthquake which occurred along the arcuate segment of Denali fault, is the largest inland event ever recorded in central Alaska where oblique convergence between Pacific and North American plates is partitioned between subduction and right-lateral strike-slip motion. The rupture process of this event is examined by using the teleseismic body wave data collected by IRIS-DMC stations. The P-wave first motion polarities (FMP) indicate a substantial reverse component implying a change in focal mechanism during rupture. The inversion of P-waveforms using a finite fault source for fixed focal mechanisms also showed clear evidence for a significant reverse component at the beginning of the rupture that can not be fit with a vertical fault plane. The best fit to the overall waveforms are obtained by using a fault plane dipping to the north with an oblique component: (strike,dip,rake)=(290^o,60^o,155^o) and results in a total seismic moment of of $5e10^{20}$ Nm (Mw = 7.7). We found that the rupture process can be divided into two subevents. During the initial subevent, rupture occurred near the hypocenter with a dominant reverse component and released a moment of $1.3e10^{20}$ Nm within 15 sec. After 10 sec, the second subevent (Mo = $3.7e10^{20}$ Nm) ruptured unilaterally to the east with an average rupture velocity of ~ 3.1 km/s and released most of the seismic moment along an energetic asperity located 160 km east of the hypocenter where the largest resolvable slip reaches up to 9 m. This subevent lasted for 100 sec with an almost pure strike-slip motion and ruptured a length >200 km. Using simplified rupture dimensions, we calculate average displacement as 5 m and average static stress drop as 7 MPa. Comparison of this event with similar magnitude 2001 Kunlun earthquake (Tibet) in terms of rupture length, number and location of aftershocks, amount of radiated seismic energy, static stress drop and tectonic setting; implies stronger seismic coupling along the Denali fault than the Kunlun fault.

S72F-1343 1330 h POSTER

Source Kinematics and Dynamics of the 3 November, 2002 Mw7.9 Denali Fault, Alaska Earthquake

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The source kinematics and dynamics of the rupture process of the November 3, 2002 Mw7.9 Denali earthquake is investigated. The epicenter of the event is located near the northern point of the curved Denali fault. The first motion focal mechanism (University of Alaska, Fairbanks), and teleseismic body waves analyzed by Kikuchi and Yamanaka indicate that the event began as a northeast striking reverse fault, and evolved into a 300 km right-lateral strike-slip rupture. Aftershock locations and surface slip observations indicate that the rupture was predominantly unilateral in the eastward direction with the strike of the fault undergoing as much as 40-degree clockwise rotation over the ruptured length. We estimated a seismic moment tensor for the mainshock by inverting long-period waves (100 to 300 sec) recorded at teleseismic distances. A scalar moment of 9.3e20 Nm was obtained, and the focal parameters indicate a strike, dip and rake of 289-degrees, 74-degrees, 148-degrees, respectively. Inversion of displacements from 11 continuous Alaska Deformation Array sites, and horizontal displacement records for the UAF and Anchorage City Hall strong motion sites result in a scalar moment of 6.3e20 Nm. The kinematic inversion results and forward modeling of the strong motion records support the initial reverse motion and overall length of the rupture, however they also suggest that significant slip occurred immediately east of the epicenter; however, it appears to be fairly uniform. Preliminary dynamic modeling using a 2D approximation (no vertical extent) indicates that given the regional tectonic stress field, the central/southeast-striking segment of the Denali fault is most favorably oriented. Furthermore, only a narrow range of stress configurations appears able to produce rupture across the entire fault. The dynamic models indicate that the greatest slip should occur in the central region, which is consistent with the kinematic results of Kikuchi and Yamanaka, our kinematic inversion results and the surface offset data.

S72F-1344   1330 h POSTER

Preliminary slip history of the 2002 Denali earthquake

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Rapid slip histories for the 2002 Denali earthquake were derived from the IRIS global data before geologists arrived in the field. We were able to predict many of the features they observed. Three models were produced indicating a step-wise improvement in matching the waveform data applying a formalism discussed in Ji et al. (2002). The first model referred to as Phase I is essentially an automated solution where a simple fault plane (300 km long) is fixed agreeing with CMT (Harvard) solution (strike 298 dip =86) assuming the PDE epicenter. The fit to the initial P waves does not work since they do not display a strike-slip polarity pattern. Thus, to continue we added a thrusting event (Phase II) following roughly the fault geometry of the Denali fault based on DEM topography map. While this produced some improvements, major misfits still remained. Before proceeding with Phase III, we did some homework on a foreshock, the Mw=6.7 Nenana event. After modeling this strike-slip event as a distributed fault, we used this relatively simple event to calibrate paths where shifts in P-waves and SH-waves ranged up to 4 and 8 sec respectively. Applying these corrections revealed some discrepancies in the rupture initiation. To produce a consistent picture requires 4 fault segments A, B, C and D. A weak rupture may initiate on a strike-slip Denali fault branch A at a depth of 10 km where a low angle thrust fault plane B intersects A. After about 2 sec, a major event occurred on plane B (strike=221, dip=35) and dominated the rupture of next 8 sec. When rupture B reaches the surface at about 10 sec after initiation, the major portion of the Denali fault (segment C) ruptured eastward with a relatively fast velocity (3 km/sec) producing a large slip concentration (up to 9 m at a depth of 10 km). The surface slip is about 7 km at a 20 km long segment. This feature is near the intersection of the Denali fault and the Totichunda fault (branch D). The rupture on D is relatively shallow (less than 15 km) while the extension beyond the intersection on the Denali fault displays deeper slip. All these features agree with what was observed in the region. The event has an overall moment of 1.0e+28 dyne.cm with a centroid depth of 15 km. The entire rupture extends over 90 sec. These models were used to predict the velocity and intensity field along the fault. Relatively low values were obtained in the valley containing the Pipeline (4 meter of displacement and about 1 m/sec velocity). The peak velocities of over 2 m/sec occurred about the major surface offsets. Above result is preliminary (entirely based on teleseismic data), and will be greatly strengthened with the additional regional and strong motion as well as geodetic and ground breakage data in the future inversion.

S72F-1345 1330 h POSTER INVITED

The 7.9 Denali Fault Earthquake: Aftershock Locations, Moment Tensors and Focal Mechanisms from the Regional Seismic Network Data

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The largest earthquake ever recorded on the Denali fault system (magnitude 7.9) struck central Alaska on November 3, 2002. It was preceded by a magnitude 6.7 foreshock on October 23. This earlier earthquake and its zone of aftershocks were located slightly to the west of the 7.9 quake. Aftershock locations and surface slip observations from the 7.9 quake indicate that the rupture was predominately unilateral in the eastward direction. Near Mentasta Lake, a village that experienced some of the worst damage in the quake, the surface rupture scar turns from the Denali fault to the adjacent Totschunda fault, which trends toward more southeasterly toward the Canadian border. Overall, the geologists found that measurable scarps indicate that the north side of the Denali fault moved to the east and vertically up relative to the south. Maximum offsets on the Denali fault were 8.8 meters at the Tok Highway cutoff, and were 2.2 meters on the Totschunda fault.

The Alaska regional seismic network consists of over 250 station sites, operated by the Alaska Earthquake Information Center (AEIC), the Alaska Volcano Observatory (AVO), and the Pacific Tsunami Warning Center (PTWC). Over 25 sites are equipped with the broad-band sensors, some of which have in addition the strong motion sensors. The rest of the stations are either 1 or 3-component short-period instruments. The data from these stations are collected, processed and archived at the AEIC. The AEIC staff installed a temporary network with over 20 instruments following the 6.7 Nenana Mountain and the 7.9 events. Prior to the M 7.9 Denali Fault event, the automatic earthquake detection system at AEIC was locating between 15 and 30 events per day. After the event, the system had over 200-400 automatic locations per day for at least 10 days following the 7.9 event. The processing of the data is ongoing with the priority given to the larger events. The cumulative length of the 6.7 and 7.9 aftershock locations along the Denali and Totschunda faults is about 300 km. We will present the aftershock locations, first motion focal mechanisms for M4+ events and regional moment tensors for M4.5+ events. The first motion focal mechanism for the main event indicates thrusting on the NE-trending plane with a dip of 48 degrees. We will present results of the double difference relocation of the aftershocks of the M7.9 event. The relocated aftershocks indicate a NW-dipping fault plane in the epicentral area of the event and a vertical plane along the rest of the rupture length.

S72F-1346 1330 h POSTER

Additional Aftershocks Identified After the Mw7.9 Denali Fault Earthquake

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The Mw7.9 Denali fault earthquake of November 3, 2002 had a vigorous initial aftershock sequence. However, every short-period station within several hundred km was clipped for several hours, so routine methods of determining locations and magnitudes could not recover all of the aftershocks. We examined data from 16 broadband seismometers for nearly two hours after the main shock, and found 18 additional earthquakes with M from ~4.0 to 5.1. We filtered the broadband data to produce a simulated Wood-Anderson response, then forced the amplitude scale to be fixed. Next we plotted the records at sufficient time scale (30 min = 20 cm) so that we could reliably determine both P and S phases. We logged the times all earthquakes that had clear P and S phases on 3 or more stations, then compared earthquakes with known locations and magnitudes to estimate magnitudes for the 18 newly identified aftershocks. Of particular interest are 9 earthquakes, three of which had M ranging from 4.9 to 5.1, that occurred in the first 15 minutes after the mainshock. All these events occurred before the M5.8 largest aftershock 19 minutes after the mainshock. Many additional smaller earthquakes remain that would be able to be identified and located with appropriate filtering and enhancement. With a modest effort we greatly increased the number of initial aftershocks available for analysis. After this analysis the waveform data have been examined again and 18 additional aftershocks with magnitudes between 3.3 and 5.2 have been located. This has implications for probability estimates made shortly after the mainshock that rely on complete catalogs at or above a particular threshold. Broadband data fundamentally improve the ability to respond to large earthquakes.

S72F-1347 1330 h POSTER

Deployment of Seismic Instruments Following the Denali Fault Earthquake Sequence 2002

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The series of earthquakes rupturing the Denali Fault in central Alaska during the end of October and beginning of November 2002 has generated extensive opportunities for seismic research. In order to obtain quality seismic data from the main events and aftershocks, a substantial field effort is necessary to efficiently deploy temporary seismic stations in remote central Alaska. Following the M6.7 earthquake on October 23, 2002, the Alaska Earthquake Information Center (AEIC) installed 3 strong motion stations (Guralp 5TD) and 4 PASSCAL broadband stations (Guralp 40T) on the Parks Highway and Denali Highway in central Alaska, prior to the M7.9 on November 3, 2002. When the M7.9 earthquake occured three AEIC representatives were servicing stations on the Denali Highway, only 30 km from the epicenter! The field response team quickly re-assembled and departed to deploy more instruments toward the eastern end of the Denali Fault where aftershocks have propagated southward along the Totschunda Fault. Currently, we have a total of 26 seismic stations installed, 12 of which are strong motion sensors. The remaining 16 stations are broadband sensors recording on RefTek digitizers and hard drives. Installation of these stations has been through the efforts of AEIC, with equipment provided by AEIC, PASSCAL, and the USGS. These temporary stations situated within 100 km of the Denali Fault complement permanent stations of AEIC to help constrain aftershock locations.

S72F-1348 1330 h POSTER

Comparison of the November 2002 Denali and November 2001 Kunlun Earthquakes

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Major earthquakes occurred in Tibet on the central Kunlun fault (**M** 7.8) on November 14, 2001 (Lin and others, 2002) and in Alaska on the central Denali fault (**M** 7.9) on November 3, 2002. Both earthquakes generated large surface waves (Kunlun Ms 8.0 (USGS) and Denali Ms 8.5). Each event occurred on east-west-trending strike-slip faults and exhibited nearly unilateral rupture propagating several hundred kilometers from west to east. Surface rupture length estimates were about 400 km for Kunlun, 300 km for Denali. Maximum surface faulting and moment release were observed far to the east of the points of rupture initiation. Harvard moment centroids were located east of USGS epicenters by 182 km (Kunlun) and by 126 km (Denali). Maximum surface faulting was observed near 240 km (Kunlun, 16 m left lateral) and near 175 km (Denali, 9 m right lateral) east of the USGS epicenters. Significant thrust components were observed in the initiation of the Denali event (ERI analysis and mapped thrust) and in the termination of the Kunlun rupture, as evidenced by thrust mechanisms of the largest aftershocks which occurred near the eastern part of the Kunlun rupture. In each sequence the largest aftershock was about 2 orders of magnitude smaller than the mainshock.

Moment release along the ruptured segments was examined for the 25-year periods preceding the main shocks. The Denali zone shows precursory accelerating moment release with the dominant events occurring on October 22, 1996 (**M** 5.8) and October 23, 2002 (**M** 6.7). The Kunlun zone shows nearly constant moment release over time with the last significant event before the main shock occurring on November 26, 2000 (**M** 5.4). Moment release data are consistent with previous observations of annual periodicity preceding major earthquakes, possibly due to the evolution of a critical state with seasonal and tidal triggering (Varnes and Bufe, 2001). Annual periodicity is also evident for the larger events in the greater San Francisco Bay region over several decades preceding the 1906 San Francisco earthquake (**M** 7.8). Both the Kunlun and the Denali mainshocks occurred at new moon.

S72F-1349 1330 h POSTER

Blind Prediction of Near-Fault Strong Ground Motions

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The Mw 7.9 Alaska earthquake provides an unprecedented opportunity to analyze strong ground motion recordings obtained very close to a large magnitude crustal earthquake. Several strong motion sites are located along the route of the Alaska Pipeline which crosses roughly perpendicular to the fault rupture about 85 km east of the epicenter. The closest site is located about 3 km from the fault. Prior to the release of these data, we conducted a blind prediction experiment to estimate the ground motion waveforms at this closest recording site. Ground motions are computed using the both one realization of the stochastic composite source simulation methodology of Zeng (1994) and the deterministic simulation of Somerville et al. (1994). Both techniques utilize full waveform Greens functions calculated for plane layered velocity structures. Due to uncertainty in the distribution of slip during the event, the deterministic simulation used both uniform and heterogeneous models of the slip distribution. Predictions were made without accurate knowledge of site conditions or fault-station geometry. In all cases, the simulated motions are characterized by pulse-like motions that exhibit strong rupture directivity effects. Peak fault-normal ground velocities and displacements are about twice as large as corresponding peak fault-parallel motions. For the heterogeneous slip models, peak velocities for the two simulation methodologies are 50-95 cm/s, and peak dynamic displacements are 60-150 cm. In addition, these simulations predict static horizontal offsets of 50-170 cm, depending on the component. Plots of the simulated motions and more detailed descriptions of the parameterizations can be found at http://www.seismo.unr.edu/blind.

S72F-1350 1330 h POSTER

Strong ground motion in Central Alaska resulting from the Denali Fault M7.9 earthquake of November 3, 2002

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The USGS Geologic Hazards Program has coordinated with numerous agencies operating in the state of Alaska to produce a map of strong ground shaking that resulted from the November 03, 2002 M7.9 earthquake on the Denali fault system (DFS). We collected strong motion amplitudes from a wide variety of sources distributed throughout the state: the National Strong Motion Program (NSMP), the Alaska tsunami warning center (ATWC), the Advanced National Seismic System (ANSS), the Alyeska Pipeline service Company, the Alaska Earthquake Information Centers (AEIC) M6.7 aftershock deployment, and the University of Alaska Geophysical Institute strong motion network in Anchorage. We observe peak ground accelerations on the order of 30%g at stations located within a few kilometers of the fault, 10%g 90km from the DFS in Fairbanks, and 1%g for stations in Anchorage, approximately 200km from the DFS. We will present ShakeMaps based on combining observations with empirical predictions elsewhere, estimated from the distance to the DFS rupture, as well as maps based on combining observations with predicted peak amplitudes from a teleseismically-based finite fault model (Ji et al., this session). The coordinated effort to bring ShakeMap to Alaska has also resulted in the installation of numerous strong ground shaking sensors in the urban areas of Alaska, as part of the ANSS, with the goal of rapid notification to emergency services in the event of a large earthquake that affects the urban population centers.

S72F-1351 1330 h POSTER

The Denali Fault Earthquake of November 3, 2002, and the Probabilistic Seismic Hazard Map of Alaska

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The probabilistic seismic hazard map of Alaska completed in 1998 estimated the hazard from magnitude 8.0 and 7.7 characteristic earthquakes on the central Denali and Totschunda Faults, respectively. The recurrence intervals for these two faults were estimated as 700 and 400 years respectively. The earthquake of November 3 (magnitude 7.9) appears to be a realization of the postulated characteristic earthquakes, although it links both the central Denali and Totschunda segments. The aggregate rupture does not completely fill the mapped extent of Holocene displacement on the two faults. The slip rates for the two faults were assumed to be 10 and 11.5 mm/yr respectively. Interestingly, the earthquake rupture followed the splay onto the higher slip rate Totschunda Fault, rather than continue onto the more geometrically direct continuation from the central Denali to the southeast Denali fault, which has an estimated slip rate of only 2 mm/yr. Inasmuch as there was no historic record of major earthquakes on these faults, and these aspects of the hazard map were based almost wholly on geologic data, the occurrence of the November 3 earthquake validates the approach of relying on data from Quaternary geology.

An outstanding question is how the probabilistic map should be revised in the wake of the earthquake. The map was based on a time independent (Poisson) probability model of earthquake occurrence. In contrast, most time dependent models suggest that the probability of the recurrence of a characteristic earthquake in the next few decades would now drop to near zero. A countervailing phenomenon is that the probability of aftershocks, including those with magnitudes of 6 or more, is significantly higher over the next few decades, but decreasing as 1/t. Additionally, the effects of stress transfer could be considered in revising estimates of the hazard associated with faults in the surrounding region, including the regions to the west of the rupture along the Denali Fault, to the southeast of the rupture along and the southeast Denali and Totschunda Faults, and within the Yakataga Seismic Gap.

S72F-1352 1330 h POSTER

Remotely Triggered Seismicity at Alaskan Volcanoes Following the Mw 7.9 Denali Fault Earthquake

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The November 3, 2002, Mw 7.9 Denali Fault earthquake provided the largest source yet to investigate triggered earthquakes at Alaskan volcanoes. The Alaska Volcano Observatory (AVO) operates short-period seismic networks on 24 historically active volcanoes in Alaska, 280 – 2100 km distant from the mainshock epicenter. The magnitude detection thresholds for these networks range from M 0.1 to M 1.5. Previous instances of triggered seismicity in Alaska have been recorded in the Katmai Volcanic Cluster, where a number of triggered events occurred following two large earthquakes on December 6, 1999 (60 km distant, Mw 7.0), and January 10, 2001 (35 km distant, Mw 6.8).

We searched for evidence of triggered seismicity by examining the unfiltered waveforms for all stations in each volcano network for ~1 hour following the Mw 7.9 arrival. We looked for events within the mainshock coda with discrete P and S arrivals and/or arrivals on multiple stations. We also looked at filtered waveforms for time periods of several hours before and after the mainshock. We only found compelling evidence for triggering at the Katmai Volcanic Cluster (720-755 km SW of the mainshock), where two small earthquakes with distinct P and S arrivals appeared in the mainshock coda at one station. There was also a small increase in located earthquakes at Katmai over a period of several hours following the mainshock. Although it is certainly possible that triggered earthquakes occurred at other volcanoes while networks were clipped, our analysis indicates that any triggering was minimal. This is in striking contrast to triggered seismicity recorded at Yellowstone, Mammoth Mountain, The Geysers, Coso and possibly Mount Rainier following the Denali earthquake. The comparative lack of triggering could be a result of differences in size and/or activity of geothermal systems, directivity of the mainshock, the dominant frequency at each system, and/or local site conditions.

S72F-1353 1330 h POSTER

Intermediate-Term Declines in Seismicity at Two Volcanoes in Alaska Following the Mw7.9 Denali Fault Earthquake

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The Mw7.9 Denali Fault earthquake provided an opportunity to look for intermediate-term (days to weeks) responses of Alaskan volcanoes to shaking from a large regional earthquake. The Alaska Volcano Observatory monitors 24 volcanoes with seismic networks. We examined one station for each volcano, generally the closest (typically 5 km from the vent) unless noise, site response, or other factors made the data unusable. Data were digitally bandpass filtered between 0.8 and 5 Hz to reduce noise from microseisms and wind. Data for the period three days before to three days after the Mw7.9 earthquake were then plotted at a standard scale used for AVO routine monitoring. Shishaldin volcano, which has a background rate of several hundred seismic events per day on station SSLS, showed no change from before to after the earthquake. Veniaminof volcano, which has had recent mild eruptions and a rate of several dozen seismic events per day on station VNNF, suffered a drop in seismicity at the time of the earthquake by a factor of 2.5; this lasted for 15 days. We tested this result using a different station, VNSS, and a different method of counting (non-filtered data on helicorder records) and found the same result. We infer that Veniaminof's activity was modified by the Mw7.9 earthquake. Wrangell, the closest volcano, had a background rate of about 10 events per day. Data from station WANC could not be measured for 8 days after the Mw7.9 earthquake because the large number of aftershocks precluded identification of local seismicity. For the following eight days, however, its seismicity rate was 30 percent lower than before. While subtle, we infer that this may be related to the earthquake. It is known that Wrangell increased its heat output after the Mw9.2 Alaska earthquake of 1964 and again after the Ms7.1 St. Elias earthquake of 1979. The other 21 volcanoes showed no changes in seismicity from 3 days before to 3 days after the Mw7.9 event. We conclude that intermediate-term seismicity decreases occurred at two Alaskan volcanoes, in strong contrast to cases of triggered seismicity increases observed at volcanic systems such as Katmai, Mount Rainier, Mammoth Mountain, and Yellowstone. This suggests that fundamentally different mechanisms may be acting to modify or trigger seismicity at volcanoes.

S72F-1354 1330 h POSTER

The M=7.9 Alaska Earthquake of 3 November 2002: Felt Reports and Unusual Effects Across Western Canada

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The 3 November 2002 M=7.9 Alaska earthquake was one of the largest earthquakes recorded in North America during the past 100 years. This earthquake occurred at 2:12 p.m. PST (on a Sunday) and was located 330 km to the west of the Yukon-Alaska border. Surface rupture and aftershocks extended to within about 100 km of the Canadian border. More than 250 "felt" reports were submitted to the Geological Survey of Canada website (http://www.pgc.nrcan.gc.ca/seismo/table.htm) within a few days of the earthquake. Here, we summarize those reports which include typical high-frequency shaking effects to distances of about 1500 km, as well as numerous long-period effects, such as human effects (nausea), swaying highrises, telephone poles and chandeliers, seiches in lakes and inlets, water sloshing from swimming pools, and instances of dirty well-water to distances of nearly 3500 km across Western Canada. Felt intensities (MMI)of about IV were observed across the Yukon Territory at distances of 350 km to 750 km. There were a few reports of minor damage in this region, as well as numerous reports of items knocked from shelves and parked vehicles rocking noticeably. The most distant felt reports in western Canada were from southern Alberta (2400 km distance) where people in highrises felt the swaying. More than 30 reports of human effects were received. These ranged from people feeling dizzy, seasick or nauseated (to distances of 2400 km), to difficulty standing and maintaining balance (to distances of 1000 km). Long-period effects of houses "swaying", large signs flexing, and telephone poles and tall trees swaying were reported to distances of more than 1000 km. Swinging of chandeliers, hanging plants and lights were reported to distances of 2400 km. There were more than 30 reports of seiches. Most reports came from southern British Columbia (2200-2400 km) where, although no ground shaking was noticed, water surges up to 1 m were observed. In one case a cabin held by cables near the shoreline was pulled out into the lake and moved back and forth for about eight minutes. The detailed reports provided by some observers indicate that these effects correspond to the passage of the surface waves from this earthquake (peak recorded displacements of about +/- 10 cm in southwest BC).

S72F-1355 1330 h POSTER

Local Amplification of Seismic Waves from the Mw7.9 Alaska Earthquake and a Damaging Seiche in Lake Union, Seattle, Washington

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The Mw7.9 Alaska earthquake of 3 November, 2002, damaged a large number of houseboats by initiating a seiche in Lake Union in Seattle, Washington. These houseboats were possibly damaged by motion during the surface waves, which were the largest arrivals from this earthquake. To better understand the causes of this seiche and estimate its hazard in future earthquakes, we examined ground shaking on strong-motion recorders from the Pacific Northwest Seismic Network (PNSN).

Maps of peak ground acceleration on all three components of motion on the PNSN strong-motion instruments show substantially increased amplitudes coincident with the Seattle sedimentary basin. This basin is a 30km-wide by 90 km-long depression in the volcanic basement rocks, filled with up to 9 km of consolidated-to-unconsolidated sediments. The south edge of the basin is formed by the Seattle fault. Taking advantage of the long-period ground motion from this earthquake, we computed spectral ratios with respect to nearby bedrock sites at periods of 1 sec to 100 sec. The basin sites showed maximum amplification by factors of 8 to 10 at periods of 5 and 8 sec. Amplifications were greater than a factor of four throughout the band from 2.5-14.0 sec period.

The data thus show strong amplification of long-period waves by the Seattle basin compared to bedrock sites or sites on thin sediments immediately outside the basin. The recorded wave periods may be amplified in part by vertical resonance in the basin sediments (1-D effects), but we speculate that they are primarily amplified by horizontal resonance. The amplification and long duration were adequate to cause the damaging seiche.

S72F-1356 1330 h POSTER

Response of the Yellowstone Volcanic Field to the M 7.9 Denali earthquake

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The November 3, 2002, Alaska earthquake had a profound effect on the Yellowstone volcanic field including an unexpected increase in seismicity and pronounced changes in hydrothermal features. Following passage of the Denali main-shock surface waves, numerous earthquakes of $-1 < M < 2.7$, were recorded throughout Yellowstone National Park. In the first four hours following the main shock, more than 130 earthquakes were recorded. The seismicity rate diminished to ~35 events per day for the next few days, but earthquake swarms continued to occur for at least ten days. Waveform and spectral analysis from broadband seismographs indicate that the initial triggered earthquakes began at the onset of the first surface waves. These had a peak dynamic stress value of ~2 bars (~2 cm/sec.) at 20 sec. periods. Seismic activity was vigorous within the first hours, including spasmodic burst-like behavior with many high-frequency events with overlapping codas. Variations in spatial and temporal seismicity in Yellowstone are not unusual as earthquake swarms dominate much of the background seismicity. However, the seismicity following the Denali earthquake was markedly different from background Yellowstone seismicity. The earthquakes were extant over the entire Yellowstone volcanic field with notable activity in the vicinity of the southeast and northwest caldera. In addition, much of the triggered seismicity was associated with areas of hydrothermal activity and with unusual variations in geothermal activity. For example, visual observations at Norris Geyser Basin revealed rapid changes in normally non-boiling hot springs that caused geysering up to 90 cm and heavy boiling. Water temperatures increased rapidly from 42°C to 93°C and accompanied increases in pH at the time of the seismic wave passage. At the Upper Geyser Basin, one geyser decreased its eruption interval from ~2 hrs to one. These observations suggest that the Yellowstone hydrothermal field responded to the same large transient stresses from the Denali earthquake that caused the sudden increase in seismicity. The extensive triggered seismicity and systematic time decay suggests stress diffusion in the hydrothermal systems. Further analyses will focus on earthquake activity associated with geothermal areas to evaluate the role of fluids in dynamic earthquake triggering. Related information such as the triggered-event focal mechanisms, spatial-temporal moment variations across the entire Yellowstone system, the relationship of swarms to individual hydrothermal features, deformation data from continuous GPS network, and evidence of triggered seismic activity throughout the Intermountain region will be evaluated. We note that the residents in Yellowstone felt several of the larger triggered earthquakes. The Yellowstone Volcano Observatory responded by timely reporting of earthquakes and notation of significant changes in seismic activity to Yellowstone NPS and USGS officials.

S72F-1357 1330 h POSTER

Activity remotely triggered in volcanic and geothermal centers in California and Washington by the 3 November 2002 Mw=7.9 Alaska earthquake.

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The M=7.9 Alaska earthquake of 3 November 2002 was followed by bursts of remotely triggered earthquakes at several volcanic and geothermal areas across the western United States at epicentral distances of 2,500 to 3,660 km. Husen et al. (this session) describe the triggered response for Yellowstone caldera, Wyoming. Here we highlight the triggered response for the Geysers geothermal field in northern California, Mammoth Mountain and Long Valley caldera in eastern California, the Coso geothermal field in southeastern California, and Mount Rainier in central Washington. The onset of triggered seismicity at each of these areas began 15 to 17 minutes after the Alaska earthquake during the S-wave coda and the early phases of the Love and Raleigh waves with periods of 5 to 40 seconds and dynamic strains of a few microstrain. In each case, the seismicity was characterized by spasmodic bursts of small (M<2), brittle-failure earthquakes. The activity persisted for just a few minutes at Mount Rainier and Mammoth Mountain and roughly 30 minutes at the Geysers and Coso geothermal fields. Many of the triggered earthquakes at all three sites were too small for reliable locations (magnitudes M<1), although their small S-P times indicate hypocentral locations within a few km of the nearest seismic station. Borehole dilatometers in vicinity of Mammoth Mountain recorded strain offsets on the order of 0.1 microstrain coincident in time with the triggered seismicity (Johnston et al. this session), and water level in the 3-km-deep LVEW well in the center of Long Valley caldera dropped by ~13 cm during passage of the seismic wave train from the Alaska earthquake followed by a gradual recovery. The Geysers, Coso, and Mount Rainier have no continuous, high-resolution strain instrumentation. A larger earthquake swarm that began 23.5 hours later (21:38 UT on the 4th) in the south moat of Long Valley caldera and included nine M>2 and one M=3.0 earthquake may represent a delayed response to the Alaska earthquake.

S72F-1358 1330 h POSTER

Amplified Ground Response Across the Western U.S. Interior from the M7.9 Denali Earthquake

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It has been hypothesized that peak dynamic stresses from large earthquakes with large surface waves can trigger seismicity at great distances from the main shock. This effect has been observed earlier in the 1992 M7.4 Landers earthquake and the 1999 M7.1 Hector Mine earthquake. Unusually large surface waves of the M7.9 Denali earthquake triggered seismicity throughout the western U.S., especially in areas of hydrothermal activity These peak dynamic stresses are unusual in that they are so large at such great distances from the source. The known triggered earthquakes occurred at distances up to at least 3000 km away from the main shock and appeared to mostly effect areas of concentrated hydrothermal activity such as Yellowstone National Park and others, including Long Valley Caldera, The Geysers, CA, Mt. Rainer WA, and Coso Hot Springs, CA. Surface wave propagation effects, peak dynamic stresses (calculated from measurements of peak vector velocities) and peak displacements will be analyzed at localities throughout the western U.S. from both broadband and long period data. The data is primarily from the United States National Seismic Network (USNSN), the Advanced National Seismic System (ANSS), and regional seismograph arrays. The peak radiation values across the western U.S. will also be compared to areas of triggered seismicity. These data help to better understand how large earthquakes trigger seismicity at such large distances from the main shock and why areas of concentrated hydrothermal activity seem to be the most sensitive to such effects.

S72F-1359 1330 h POSTER

Triggered Seismicity in Utah from the November 3, 2002, Denali Fault Earthquake

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Coincident with the arrival of the surface waves from the November 3, 2002, Mw 7.9 Denali Fault, Alaska earthquake (DFE), the University of Utah Seismograph Stations (UUSS) regional seismic network detected a marked increase in seismicity along the Intermountain Seismic Belt (ISB) in central and north-central Utah. The number of earthquakes per day in Utah located automatically by the UUSS's Earthworm system in the week following the DFE was approximately double the long-term average during the preceding nine months. From these preliminary data, the increased seismicity appears to be characterized by small magnitude events (M = 3.2) and concentrated in five distinct spatial clusters within the ISB between 38.75°and 42.0° N. The first of these earthquakes was an M 2.2 event located ~20 km east of Salt Lake City, Utah, which occurred during the arrival of the Love waves from the DFE.

The increase in Utah earthquake activity at the time of the arrival of the surface waves from the DFE suggests that these surface waves triggered earthquakes in Utah at distances of more than 3,000 km from the source. We estimated the peak dynamic shear stress caused by these surface waves from measurements of their peak vector velocities at 43 recording sites: 37 strong-motion stations of the Advanced National Seismic System and six broadband stations. (The records from six other broadband instruments in the region of interest were clipped.) The estimated peak stresses ranged from 1.2 bars to 3.5 bars with a mean of 2.3 bars, and generally occurred during the arrival of Love waves of ~15 sec period. These peak dynamic shear stress estimates are comparable to those obtained from recordings of the 1992 Mw 7.3 Landers, California, earthquake in regions where the Landers earthquake triggered increased seismicity.

We plan to present more complete analyses of UUSS seismic network data, further testing our hypothesis that the DFE remotely triggered seismicity in Utah. This hypothesis is important to investigate because well-documented evidence for triggering of seismicity by distant earthquakes comes primarily from areas characterized by recent volcanic or geothermal activity. The regions of apparent triggered seismicity from the DFE in Utah fall into neither of these two categories.

S72F-1360 1330 h POSTER

Deformation and seismicity triggered beneath Mammoth Mountain, California, by surface waves from the M7.9 Denali fault, Alaska, earthquake of 3 November 2002.

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The November 3, 2002, M*W* 7.9 Denali Fault earthquake triggered deformational offsets and microseismicity in Long Valley Caldera, California some 3200 km from the earthquake. Such strain offsets and microseismicity were not recorded at other borehole strain sites along the San Andreas fault system in California. The Long Valley offsets were recorded on borehole strainmeter and tiltmeters at three sites around the western part of the caldera that includes Mammoth Mt. (MM) – a young volcano on the south-western rim of the caldera. The largest recorded strain offsets were 0.1 microstrain at POPA on the west side of MM, -0.05 microstrain at MX to the south-east of MM, and -0.025 microstrain at BS to the north-east of MM with negative strain contractional. High sample-rate strain data show initial triggering of the offsets began at 22:30 UT and within the S-wave coda and the early arriving surface waves from the Alaskan earthquake with peak dynamic strain amplitudes of ~2 microstrain. The strain offsets grew to their final values in the next 5-10 seconds. The associated triggered seismicity was centered at about 3 km beneath the south flank of MM and also began at 22:30 UT and died away over the next 15 to 30 minutes. This relatively weak seismicity burst included a dozen small events all with magnitude less than M=1. While poorly constrained, triggered slip and/or intrusive opening on a north-striking normal fault centered at a depth of 6 km with a moment of 3? **?**$^{??}$**?**m, or the equivalent of a M~4.3 earthquake is consistent with these data. The cumulative seismic moment for the associated seismicity burst was more than three orders of magnitude smaller. This model is similar to that for the triggered deformation and slip that occurred following the October 16, 1999, M7.1 Hector Mine, California, earthquake except that we have yet to see a decay of the strain offset following the Alaska earthquake. It is distinctly different from the more wide-spread and energetic seismicity and deformation triggered by the 1992 M7.3 Landers earthquake in the Long Valley Caldera. Each of the three instances of remotely triggered unrest in Long Valley caldera recorded to date differ in detail, although in each case, the deformation moment inferred from the strain meter data is an order of magnitude or more larger than the cumulative moment for the associated triggered seismicity.

S72F-1361 1330 h POSTER

Remotely Triggered Earthquakes in Southern California?

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Seismic waves from the Mw7.9 Denali earthquake of 3 November, 2002, clearly caused remotely triggered earthquakes in a number of regions in northern and central California, as well as in Yellowstone. Routine catalog analysis revealed no obvious triggered earthquakes within the southern California network. To investigate the possibility that triggered earthquakes were hidden within the mainshock signal we examined filtered data from broadband Trinet stations. This analysis revealed unrecognized events in the Coso geothermal region (see Hill et al.). In the Brawley Seismic Zone and at Indio, where remotely triggered earthquakes were observed following both the 1992 Landers and the 1999 Hector Mine earthquakes, no evidence of triggering is seen. We estimate the dynamic stress changes caused by the Denali mainshock, which provides a lower bound for the threshhold of stress change required to trigger earthquakes in these locations. From the filtered broadband data we did identify one M2.5 event outside of Coso that had not been identified from routine catalog analysis because its signal was obscurred by surface waves. It was located approximately 90 km offshore of Oceanside, California. Events of this magnitude occur on average about once every 12 hours in southern California. The odds that the event occurred by random chance within an hour of the Denali mainshock are thus about 8%, suggesting (albeit weakly) that the earthquake may have been triggered. This result--and its uncertainty-- reflect the challenge associated with the identification of remotely triggered earthquakes that do not occur as part of pronounced sequences at geothermal/volcanic areas. That is, stray individual triggered earthquakes may be obscured within regional mainshock signals and statistical significance may be hard to prove.

S72F-1362 1330 h POSTER

Stress-triggering of the 3 November 2002 M=7.9 Denali earthquake by the 23 October 2002 M=6.7 Nenana Mountain shock

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The 10-day time period and 25-km distance between the 23 October 2002 M=6.7 and 3 November 2002 M=7.9 Denali main shocks invites investigation of their possible interaction. Both events produced right-lateral slip on the Denali transform fault, although the northward-dipping Susitna Glacier thrust, whose trace lies 10-12 km south of the Denali fault, also ruptured during this sequence. We used the reviewed 23 October-4 November AEIC solutions (courtesy of Donna Eberhart-Phillips) which exhibit a b-value of ~1, but is complete only to M=4.0. We find that aftershocks of the M=6.7 event appear to migrate eastward into the future M=7.9 epicentral site. The 55-km-long M=6.7 aftershock zone evident by October 24 does not expand to the west during the succeeding 9 days, but seismicity develops up to 35 km eastward during October 27-30. To study the static stress transfer, we use the Kikuchi and Yamanaka source models, derived from inversion of teleseismic broadband records, for both the M=6.7 and M=7.9 events (EIC Seismological Note 129, Rev. 02/11/05). We find that the 23 October event brings the site of the future 3 November epicenter 1.0-1.5 bars closer to Coulomb failure for right-lateral slip on the Denali fault (regardless of assumed friction). However, the first sub-event of the 3 November event appears to have struck on a northeast-striking thrust fault, which we tentatively assign to the north-dipping Susitna Glacier fault. The 23 October event promotes failure on thrust faults of this orientation near or north of the Denali fault, but not south of it. At most, the northeast portion of the thrust might have been brought 1.0 bar closer to failure. Applying this sudden stress increase to a rate- and state- formulation, and assuming a time-dependent conditional probability (lognormal function for a 600±300-yr inter-event time and a 600 yr elapsed time), the 10-day probability of a M=7.9 shock following the M=6.7 event jumped by a factor of 100 over the background rate. Kikuchi and Yamanaka found that the second 3 November sub-event is right-lateral, ~250 km long, and begins 30 sec after the thrust event. Once the thrust slip occurs, we find that the 20 km of the Denali fault immediately to the east of the Susitna thrust falls under a stress shadow for right-lateral slip. There is a corresponding dearth of surface rupture and aftershocks of the 3 November event in this area. Some 30 km east of the thrust, we find a 1.4-bar stress right-lateral increase, which may have triggered the second and larger sub-event. Finally, at the eastern end of the 3 November rupture, both the unslipped part of the Totschunda and the main Denali faults are brought closer to Coulomb failure, and so the sequence could continue to propagate. Thus many, but not all, of the features of this enigmatic earthquake sequence are amenable to a preliminary stress transfer analysis.

S72F-1363 1330 h POSTER

Static stress transfer modeling and aftershock statistics for the 2002 Nenana Mountain-Denali Park, Alaska, sequence

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On October 23, 2002, the Mw 6.7 Nenana Mountain earthquake occurred in central Alaska. While this was a significant event, it became even more interesting as a foreshock to the Mw 7.9 Denali Park mainshock of November 3, 2002, which was the largest earthquake to occur on land in the United States since the 1857 Fort Tejon earthquake in southern California. Using a finite-fault rupture model and the theory of deformation from dislocations in an elastic half-space, we have modeled static Coulomb stress transfer from the Nenana Mountain event to the hypocentral region of the Denali Park event and find that the Nenana Mountain event transferred about 0.05--0.1 MPa (0.5--1 bar) of Coulomb stress to that area, encouraging failure of the later event. We have also computed the combined stress transferred to several large regional faults from the Nenana Mountain and Denali Park events using our Nenana Mountain and Denali Park rupture models. We find that the two main events combined transferred more than 0.05 MPa (0.5 bar) of Coulomb stress to the northern 50 km of the Cross Creek fault, a 150-km-long right-lateral strike slip fault in east-central Alaska, and up to 0.05 MPa of Coulomb stress to the Muldrow segment of the Denali fault, west of the Nenana Mountain rupture. It is worth noting, however, that these faults are nearest to the mainshock rupture and thus most prone to errors in the stress transfer modeling. Other major faults in the region, including the Tonzona, Farewell, and Boss Creek segments of the Denali fault, the Castle Mountain fault near Anchorage, and the Yakataga subduction interface, experienced insignificant static Coulomb stress changes, though dynamic stresses were probably much larger.

Although the stress changes from these events are significant, the rates of aftershocks triggered by the Nenana Mountain foreshock and by the Denali Park mainshock are extremely low. We describe the rate of aftershocks with the Reasenberg and Jones formulation for earthquake rates or $R = 10^{[a+b(M-M_m)]} (t+c)^p$, where R is the rate, a and b are the constants of the Gutenberg-Richter relation, p is the decay constant of Omori's Law, M_m is the mainshock magnitude, t is time, and M is the aftershock magnitude. Both the Nenana Mountain and Denali Park earthquakes had a-values below -3.5. By comparison, the smallest a-value recorded for a California mainshock of M ? 5 in the last 70 years is -3.4 (1984 Morgan Hill). The b-values are high (1.2) and the decay rates close to average.

S72F-1364 1330 h POSTER

Testing Theory for Fault Branching: Denali to Totschunda, Alaska, November 3, 2002

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Theoretical stress analysis for a propagating shear rupture shows that the propensity of the rupture path to follow a fault branch is determined by rupture speed, branch angle and preexisting stress state (Poliakov, Dmowska and Rice [JGR, 2002], http://esag.harvard.edu/dmowska/PDR.pdf, and Kame, Rice and Dmowska [JGR in press, 2003], http://esag.harvard.edu/dmowska/KRD.pdf). The major transfer of rupture from the Denali to Totschunda fault, during the Denali M 7.9 November 3, 2002 earthquake, is a branch through about 15 degrees to the extensional side. Such branch geometry is predicted to always capture the rupture path when the tectonic pre-stress has maximum compression at a steep angle to the fault, say, 55 degrees or more, and to capture the path exclusively (no continuation of rupture along the initial fault) when the stress angle is very steep, say, 70 degrees or more or when the rupture velocity is not very close to the Rayleigh speed limit.

We have no evidence on pre-stress directions very near the branch, but Ratchkovski and Hansen [BSSA, 2002] have recently evaluated stress directions for interior Alaska including near the Denali fault, showing that the maximum principal compression direction rotates clockwise from NW to NNE as one moves from west to east along the fault, whose normal rotates in the same sense. The principal stress direction in the measurement sector closest to the branch makes an angle of 70 degrees with the local direction of the Denali fault at the Totschunda branch site. Further, the average rupture velocity seems to be about 0.8 of the shear wave speed (M. Kikuchi and Y. Yamanaka), although the velocity as the branch was approached is not yet constrained.

We have simulated those parameters by the methodology of Kame et al. [JGR, 2003] which uses a 2D elastodynamic boundary integral equation model of mode II rupture with self-chosen path along a branched fault system. Strength of the faults is assumed to follow a Coulomb law with friction coefficient which slip-weakens from its static to dynamic value. Our simulations predict definitively that the rupture path should follow the Totschunda branch and not continue along the Denali fault. At least to judge from aftershocks and (at the time of writing) limited reports of surface slip, this seems consistent with what occurred.

S72F-1365 1330 h POSTER INVITED

An Unparalleled Opportunity to Study Postseismic Processes

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The October-November 2002 earthquake sequence on the Denali Fault, central Alaska provides us with an unparalleled opportunity to study the postseismic processes triggered by a very large earthquake. From basic physical principles, we expect that the Mw 7.9 mainshock has triggered afterslip on the fault plane, and viscous relaxation of the upper mantle and possibly lower crust. However, the relative importances of these components of postseismic deformation are not known and are subject to considerable debate. Which mechanisms dominate the response depends on the properties of the fault zone, and the rheology of the crust and upper mantle. Through this earthquake, nature has set in motion an experiment that will allow us to determine these properties. It will be particularly instructive to compare the postseismic response of this earthquake to that of much smaller events such as the Landers and Hector Mine earthquakes in California. This large event will provide a much greater signal to noise ratio that will allow us to test inferences of power law flow or other non-linear viscosities that have been made from the California earthquakes.

Roads run parallel and normal to the rupture zone of the Mw 7.9 mainshock, allowing us to collect a rich geodetic data set for the study of postseismic displacements. In addition, the pre-earthquake deformation field is well-known over most of the region, allowing us to unambiguously identify changes in the deformation field. We had several campaign GPS sites running at the time of the earthquake, and in the week after the earthquake had surveyed approximately 30 sites. Eight to ten sites are being converted to continuous observations. These data and repeat surveys of the campaign sites will provide spatially dense observations of both the immediate short-term components of postseismic deformation and long-lived components. Postseismic deformation of at least several cm and possibly more has been observed within the first week following the earthquake.

S72F-1366 1330 h POSTER

Southern Alaska Tectonics: How the M_W 7.9 Denali earthquake fits into the puzzle

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GPS measurements have been made at almost 100 sites in interior and southern Alaska over the past few years. Based on these measurements, we have constructed new quantitative tectonic models for Alaska. The November 3, 2002 M_W 7.9 Denali earthquake confirms that the Totschunda fault is an active structure, as proposed in the models. This information, combined with a high slip rate determined for the Fairweather fault (~46 mm/yr) add weight to the idea of a Fairweather-Totschunda connecting fault, as first proposed by Lahr and Plafker [1980]. The slip rate estimated for the eastern Denali fault is low (~5 mm/yr), which also agrees with transfer of slip to the central Denali fault via the Totschunda.

We will present the pre-earthquake GPS data, the estimated fault parameters (slip rate and locking depth) for the Denali and Fairweather faults, and our tectonic models.

Lahr, J. C. and G. Plafker, Holocene Pacific-North American Plate interaction in southern Alaska; Implications for the Yakataga seismic gap, *Geology, 8,* 483-486, 1980.

S72F-1367 1330 h POSTER

Temporal variations in the motion of GPS stations proximal to the epicentral region of the 2002 Denali Fault sequence

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Within hours of the 23Oct02 Mw 6.7 event, UAF-Geophysical Institute personnel began installing GPS receivers on a network of 13 survey points near the epicentral region, all of which had previously been occupied in multiple campaigns. Several of these stations continuously collected data through the period leading up to the 3Nov02 Mw 7.9 event. Preliminary processing and analysis of these data indicate that at least 3 of these stations exhibit significant temporal variations in their ITRF97 positions, with displacements on the order of 2 cm, over the period between the Mw 6.7 and Mw 7.9 events. Two hypotheses for these observations will be explored (1) "ordinary" postseismic deformation following the Mw 6.7 event, and (2) slow slip occurring on a structure differing from the Mw 6.7 aftershock zone.

Many additional GPS stations were deployed following the 3Nov02 Mw 7.9 event, and preliminary processing and analysis of these data show postseismic motions at 4 sites in the range of 2-6 cm over the first 10 days following the earthquake.

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Coseismic Displacements From the M_W 6.7 and M_W7.9 Denali Fault Earthquakes and Resulting Coulomb Stress Change on Faults in Alaska

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Following the October 23 M_W6.7 earthquake GPS measurements were repeated at 13 existing stations on the Parks Hwy (N-S profile west of epicenter) and on the Denali Hwy (E-W profile south of epicenter) in order to estimate coseismic slip at these stations from the earthquake. Several of these stations were still running on the 3 of November when a M_W7.9 ruptured the Denali fault to the east of the M_W6.7 rupture. Including these GPS stations more then 28 existing points were measured around the rupture zone following the M_W7.9 earthquake. We will present the coseismic displacement from the M_W6.7 and M_W7.9 Denali fault earthquakes for these station in addition to existing permanent GPS stations in the area. We will also estimate a slip model based on these measurements and compare to slip models based on seismic observations. Resulting Coulomb stress changes on faults in Alaska will be presented.

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InSAR Measurements of Surface Deformation in the Epicentral Region of the Nenana Mountain and Denali Fault Earthquakes of Oct.27 & Nov. 3, 2002

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We are using InSAR to investigate regional surface deformation surrounding the epicenters of the Oct. 27 (M=6.7) and Nov. 3 (M=7.9), 2002 earthquakes on the Denali fault in the Alaska Range. Our goal is to study relationships between fault structure and earthquake processes in this transpressional fault system. The earthquake epicenters are located near a large bend in the trace of the Denali fault that is located at 147^0 W. The component of surface displacement in the radar range-direction is found over an area of about $\sim 2x10^4$ km^2 by interferometric analysis of repeat-pass, C-band synthetic aperture radar data (InSAR). We have successfully constructed an interferogram that shows the cumulative displacement field caused by the M=6.7 and M=7.9 earthquakes. The interferometric fringes on the north side of the Denali fault trend from east-northeast to northwest creating a broad fan-like pattern of displacement contours that are broadly consistent with dilatational deformation at the end of a transpressional right-lateral fault dislocation. Deformation is more localized along the south side of the Denali fault where the fringes trend west-northwest and the displacement gradient is significantly greater than on the north side of the fault, possibly caused by vertical displacement associated with a mapped thrust fault. Overall, fringe patterns appear to reflect a mixture of right-lateral and thrust faulting that is consistent with seismological and geological observations of earthquake deformation.

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Coseismic Deformation of the 2002 Denali Fault (Alaska) earthquakes from InSAR: preliminary results and prospects

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Since the launch of the European satellite ERS-1 in 1992, InSAR has been used to map the coseismic deformation of around 30 continental earthquakes, including several large events on strike-slip faults (1992, Landers earthquake; 1997 Manyi earthquake; 1999 Izmit earthquake; 1999 Hector Mine earthquake). Because InSAR does not require any equipment on the ground, it is ideally suited to mapping deformation from quakes in remote areas, where conventional geodesy is more challenging. InSAR may be the only way of capturing the coseismic deformation caused by the recent earthquakes on the Denali Fault.

At 63 degrees north, the ground tracks of polar-orbiting satellites are closely spaced – the ~300 km extent of the November 3 event is covered by around 18 ERS ground tracks (9 ascending, 9 descending). New ERS-2 images covering part of the rupture can therefore be obtained every 2 days on average. In addition, data from the Canadian Radarsat satellite are also being actively acquired. These data are being added to an extensive archive for this area at the Alaska SAR Facility.

We hope to present interferograms showing the surface deformation that occurred during the Denali Fault earthquake sequence. If recent acquisitions prove useable, we will present source models for the earthquakes based on these data. Several ERS-2 images were acquired in the 10-day period between the M6.7 "foreshock" and the M7.9 event, so it may be possible to isolate the deformation from the first event. This would enable us to determine whether, as appears likely, stress changes induced by the M6.7 event encouraged the later M7.9 event.

In our experience, the onset of winter snow and ice may mean we fail to produce a useful interferogram using recent images. However, it is likely that summer-to-summer interferograms will be coherent. We will present results of the analysis of images from the ERS catalogue to test the coherence in this area over intervals of 1 to 3 years.

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Mid-infrared emission prior to the October-November 2002 Earthquake Sequence on the Denali Fault, Alaska analyzed by remote sensing data

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Earth-atmosphere interactions during and prior to the 2002 Denali (Alaska) earthquake sequence are the subject of this preliminary study. Slow changes in temperature before large earthquakes have been reported for a long time [Milne, 1913]. Global satellite thermal imaging data indicate long-lived thermal fields associated with large linear structures and fault systems [Carreno at al, 2001] but also short-lived "thermal anomalies" prior to major earthquakes. There is still is no comprehensive explanation for this short-lived increase in IR emission that has been accepted in the science community.

A new mechanism has recently been proposed BASED ON the appearance of hole-type electronic charge carriers in rocks subjected to transient stress [Freund, 2002]. If such charge carriers are activated in a stressed rock volume and reach the earth's surface, they should lead to an enhanced emission in the 8-12 µm region similar to the "thermal anomalies"[Tronin, 2000, Ouzounov and al, 2002] and to the laboratory rock deformation experiments [Geng et al., 1999, Freund at al, 2002].

Using data from MODIS (Moderate Resolution Imaging Spectroradiometer) onboard NASA's TERRA satellite, we have begun analyzing surface emissivity and land surface temperatures for THE entire Alaska region during 2002. Specifically, we look for correlations between atmospheric dynamics and solid Earth processes prior to the Oct. 23 and Nov. 3, 2002 earthquakes. With TERRA/MODIS covering the entire Earth every 1-2 days in 36 wavelength bands (20 visible and 16 infrared) we find evidence for anomalous thermal emission pattern apparently related to pre-seismic activity along the Denali. We also find changes in the aerosol content and in atmospheric instability parameters, possibly due to ion emission and to changes in the ground surface potential.