J. H. STOUT }
J. B. BRADY } *Department of Geology, University of California, Los Angeles, California 90024*
F. WEBER *U.S. Geological Survey, Box 80586, College, Alaska 99701*
R. A. PAGE *U.S. Geological Survey, National Center for Earthquake Research, 345 Middlefield Road, Menlo Park, California 94025*

# Evidence for Quaternary Movement on the McKinley Strand of the Denali Fault in the Delta River Area, Alaska

## ABSTRACT

Offset Holocene alluvial fans and drainages along the McKinley strand of the Denali fault near the Delta River in the east-central Alaska Range indicate as much as 50 to 60 m of right-lateral displacement during the last 10,000 yrs. Vertical movement of 6 to 10 m during the same time interval is reflected by south-facing scarps along the trace of the fault. All but possibly 1 m of the lateral movement is thought to predate the 1830 neoglacial ice advance. Older drainages have been offset in a right-lateral sense since early Wisconsin or Illinoian time by as much as 6.5 km or, alternatively, by as little as 1 km.

## INTRODUCTION

As modern concepts of crustal tectonics gain general acceptance, added attention is being given to the largest faults in the circumpacific region as possible boundaries between rigid continental and oceanic plates. Perhaps least is known of the Denali fault system, a pronounced lineament that extends at least 2,000 km along strike from the Bering Sea to coastal southeast Alaska (Fig. 1). For at least 500 km along strike, the fault separates rocks whose lithologies, ages, and degrees of metamorphism are grossly dissimilar suggesting that the net movement on the fault has been great.

Most investigators agree that movement is right-lateral along those parts of the fault that have been studied, but estimates of the total displacement through time vary widely. St. Amand (1957) first postulated about 250 km of apparent right-lateral separation based on offset geomorphic features. Although some doubt has been cast on this figure (Grantz, 1966), right-lateral separations of 190 km (Lathram, 1964), 100 km (Cady and others, 1955), and 80 km (Brew and others, 1966) along various parts of the fault system, as defined by St. Amand, have been demonstrated. There seems to be less agreement on the sense of vertical movement (Muller, 1967; Twenhofel and Sainsbury, 1958; Loney and others, 1967), although the presence of generally older rocks along much of the north side of the Denali fault would suggest that the net vertical slip has been north side up.

Recent studies by Richter and Matson (1971) along the Totschunda fault system in the eastern Alaska Range (Fig. 1) and along the Denali fault near its junction with the Totschunda system produced convincing evi-

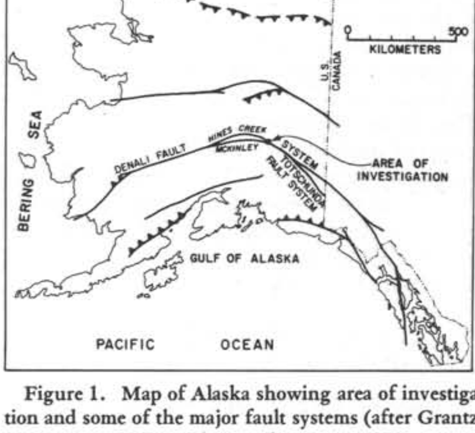


**Figure 1. Map of Alaska showing area of investigation and some of the major fault systems (after Grantz, 1966; King, 1969; Richter and Matson, 1971).**

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dence for right-lateral separation since the end of the Pleistocene and established minimum rates of movement of between about 1.0 and 3.5 cm per yr. Their evidence indicates that the Denali fault east of its junction with the Totschunda fault system (Fig. 1) has been relatively inactive since Illinoian time and suggests that the Denali fault west of the junction has moved with the Totschunda system since about 2 m.y. ago. The Totschunda lineament may represent the trace of a new transform fault separating the North American and Pacific plates.

The Denali fault system in the central Alaska Range is divided into two major strands. The northern segment, the Hines Creek fault, was first recognized and described by Wahrhaftig (1958). The other segment, 15 to 20 mi to the south, called the McKinley strand by Grantz (1966, p. 17), has long been recognized as a major fault in this section of the range (Moffit, 1915; Capps, 1940; Wahrhaftig, 1958). The trace of the southern fault is marked by a strong lineament, trough, or zone of weakness cutting through mountainous areas and is occupied in many places by present-day glaciers and old glaciated valleys. The two strands apparently converge in the vicinity of the lower end of the Canwell Glacier, east of the Delta River. Detailed mapping along an unusually well exposed portion of the McKinley strand of the Denali fault 120 km west of the Totschunda junction provides additional data on Pleistocene and Holocene movements and forms the basis for the present study.

The bedrock geology of the area southwest of the junction of the two strands was first mapped in detail by Stout (1965). Figure 2 is a summary of this and later mapping. The McKinley strand in this area is well exposed (Fig. 3) and separates medium- to high-grade schists of probable Mesozoic age (Smith, 1971; Smith and Lanphere, 1971) on the south from slightly metamorphosed Paleozoic sediments on the north for a distance of approximately 16 km. Farther west, the fault trace is obscured by the Black Rapids Glacier.

## HOLOCENE EXPRESSION AND MOVEMENT

### Evidence for Right-Lateral Movement

The most obvious expressions of right-lateral displacements on the Denali fault system since the end of the Pleistocene are recent scarps and offset stream channels. At least 20 drainages crossing the trace of the McKinley strand between the Delta River and Black Rapids Glacier exhibit right-lateral displacements. In some cases, the deviation is only slight, but in other cases such as locality D in Figure 4, bedrock-incised streams show abrupt offsets that can be attributed only to movement on the fault. The magnitude of displacements ranges from 5 to 60 m. At least one alluvial fan, shown at locality A in Figure 4, exhibits 50 to 60 m of right-lateral offset along the same fault trace (Fig. 5).

Many of the streams that cross the fault trace show no obvious lateral offsets, while other channels a few hundred meters away obviously do. This may be readily explained by the unconsolidated nature of most of the recent sediments adjacent to the fault on its north side. Some of the stream channels incised in bedrock on the south side of the fault apparently had little difficulty re-establishing their channels in the more easily erodable deposits on the north side. The presence of truncated and abandoned stream channels adjacent to the apparently undeviating courses of presently active channels, as well as the absence of channels that deviate in a left-lateral sense, supports this conclusion.

### Evidence for Vertical Movement

Along several parts of the McKinley strand trace, conspicuous scarps in unconsolidated material are seen. The scarps face south and reach a maximum of approximately 10 m in height (Fig. 6), indicating that the north side of the fault may have been uplifted by as much as that amount. The vertical scarps in some areas (locality D, Fig. 4) are on the fault trace across which stream channels exhibit the most convincing lateral offset, suggesting that the net slip on the fault since the formation of the offset features has had both horizontal and vertical components. Figure 5B illustrates a 6-m escarpment presumably related to the 50- to 60-m lateral offset shown in Figure 5A.

Additional evidence for uplift on the north side of the fault is dissected alluvial fans that originate from valley walls on both sides of Augustana Creek (locality B, Fig. 4, and locality B, Fig. 6). In this area, upper surfaces of the fans are now as much as 15 m above the present stream level, implying that the stream has dissected the fans in an attempt to establish a new base level.

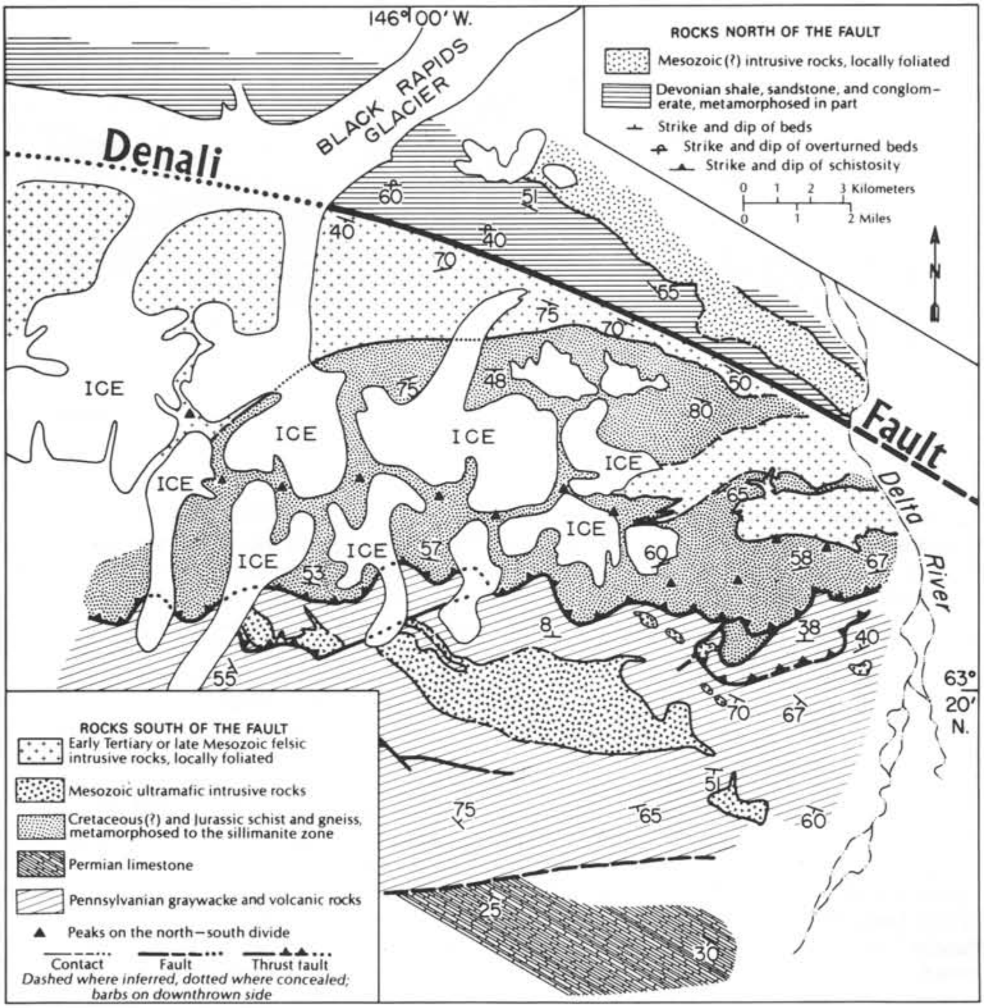


**Figure 2. Simplified summary geologic map of the Delta River area, Alaska.**

## Age of Holocene Movement

Studies by Péwé (1951, 1957) in the Delta River area have established a chronology of regional neoglacial ice advances on the Black Rapids Glacier and the nearby Castner and Canwell Glaciers. Two distinct regional advances, dated as 1650(?) and 1830 by dendrochronology and lichenometry (Reger and Péwé, 1969), have deposited lateral and terminal moraines characterized by fresh, essentially unmodified topography compared to older, Pleistocene drift.

The projected trace of the fault crosses the 1830 end moraine of the Canwell Glacier, at B in Figure 3, but no visible sign of a recent scarp exists in the moraine, the outwash in front of it, or in the course of the Delta River. Therefore, the moraine, outwash, and active Delta River channel deposits cover any evidence of movement and are younger. Trees on the moraine and outwash are 100 to 140 yrs old, but deposition could have preceded tree growth by as much as 30 yrs (Viereck, 1972, oral commun.) in this marginal environment. Glacier deposits covering the fault could be at least 170 yrs old. Lateral and vertical offsets greater than about 1.0 and 0.2 m, respectively, would probably have been observed if they had been present, hence 1.0 and 0.2 m are maximum estimates of possible fault slip during the last 170 yrs. The only other area in which


**Figure 3. Panorama along the McKinley strand of the Denali fault west of the Delta River. Dotted line indicates trace of the fault. Augustana Creek is in foreground and Augustana Glacier is in the background to the**

the fault trace crosses neoglacial moraines is at locality C in Figure 4. Lateral moraines of at least two distinct neoglacial advances are preserved, and neither is visibly offset by the fault. The resolution of this observation on the lower moraine is about 1 m for both lateral and vertical offsets. The moraine may be traced continuously to the terminal moraine of the 1937 glacial surge (Péwé, 1951). The higher moraine is poorly preserved, and probably represents deposition during either the 1650(?) or 1830 ice advances. The 1650(?) advance was the most extensive (Péwé, 1951; Reger and Péwé, 1969) and probably left the highest lateral moraines in the vicinity of the Denali fault. Because of a poorly preserved trimline and extensive erosion by an active stream, the resolution of offset on the higher moraine is difficult to estimate. It is thought, however, that lateral or vertical offsets of more than a few meters would be observable. The absence of conspicuous scarps on older moraines elsewhere on the Black Rapids Glacier and the Canwell Glacier is consistent with this estimate.

Identical neoglacial moraines, recognized by their similar unmodified form, are found 70 to 150 m above the present surface of Augustana Glacier. The neoglacial trimline on the west side of the glacier is readily traced northward to the Denali fault where its exact relation with the fault is obscured by a large landslide (locality E, Fig. 4).

Geodetic and seismic observations are consistent with the apparent lack of significant movement on the fault since the neoglacial advances. Comparison of geodetic surveys made in 1942 and 1970 along the Richardson Highway indicates no significant lateral slip; the resolution of the comparison is 5 cm (Page, 1972). Furthermore, the seismic history for Alaska (Davis and Echols, 1962; U.S. Coast and Geodetic Survey, 1970) includes no earthquake that could be associated with displacements greater than about 1 m on this segment of the fault in about the last 50 yrs. Based on the lack of offset on 1830 moraines, it is unlikely that there has been as much offset (greater than 5 m) in the last 170 yrs as would be associated with an earthquake of magnitude 8 on the fault.

Several alluvial fans on the south side of the fault near the terminus of Augustana Glacier cut across the neoglacial drift and thus postdate it. These fans are active and unvegetated in contrast to the somewhat larger offset fan shown in Figure 5A. Minor vegetation on the fan shown in Figure 5A indicates that it is not presently active, and thus is probably older than the unvegetated fans that cut the recent moraines. It seems probable, then, that this fan as well as drainages that exhibit offset of

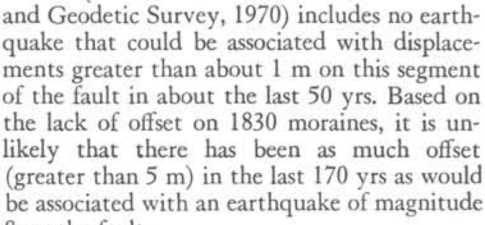


**Figure 4. Locations of offset features along the McKinley strand of the Denali fault in the Delta River area. Localities are discussed in the text.**


**west. Offset alluvial fan at A is shown in Figure 5.**

similar magnitude are older than neoglacial ice advances, but certainly no older than the end of the Pleistocene epoch (10,000 yrs).

The minimum rate of Holocene lateral movement is 0.5 to 0.6 cm per yr for as much as 50 to 60 m of right-lateral displacement in the last 10,000 yrs. A minimum rate of vertical movement based on a maximum dissection of 15 m in alluvial fans along Augustana Creek is 0.15 cm per yr, assuming again that the fans are younger than 10,000 yrs.

## PLEISTOCENE EXPRESSION AND MOVEMENT

### Evidence for Right-Lateral Movement

A possible expression of offset along the Denali fault in Pleistocene time is the present course of Augustana Creek, which originates at the terminus of Augustana Glacier and drains to the Delta River (Figs. 3 and 4). The glacier, which originates on the south side of the fault, trends northward until its drainage intersects the Denali fault trace. There, the stream changes its course in a right-lateral sense and parallels the fault for approximately 6.5 km before abruptly changing its course again to due north. Such deviations from normal stream behavior are common elsewhere along the Denali fault (Grantz, 1966; Richter and Matson, 1971) and have been interpreted as expressions of right-lateral movement.

Additional evidence to suggest Pleistocene movement is a well-developed U-shaped valley opposite Augustana Glacier on the north side of the fault. This valley may have been detached from its original drainage basin by movement on the fault (locality F, Fig. 4). The present valley floor is now approximately 275 m above Augustana Creek, which parallels the fault on its north side. The valley is nearly 2 km long and must have had a much greater drainage basin at its source than it has at present. Although there is some evidence of recent stream capture, present drainage is confined to the surrounding slopes that provide insufficient runoff to maintain more than a small stream in the valley. There are no structural peculiarities in the surrounding bedrock that would enable the valley to form more rapidly in this locality than elsewhere (Fig. 2).

Even though the valley referred to above was originally established by normal erosional processes, its present form is at least partially due to modification by Pleistocene ice. In addition to the well-developed U-shaped profile, large isolated erratics are found on the floor and slopes of the valley between 1,300 and 1,700 m elevation. The erratics are of only one lithology, a medium-grade biotite schist with distinctive porphyroblasts of staurolite, andalusite, and garnet in a matrix of quartz, plagioclase, and minor graphite. They are unlike any bedrock found on the north side of the Denali fault anywhere in the Alaska Range, and could have been derived only from the medium- to high-grade metamorphic rocks from the south side of the fault (Fig. 2). Petrologic studies in progress indicate that the porphyroblastic schists that comprise these erratics are common south of the fault, and are the principal lithology found in the till of neoglacial advances of both Augustana Glacier and the first tributary glacier of the larger Black Rapids Glacier. No

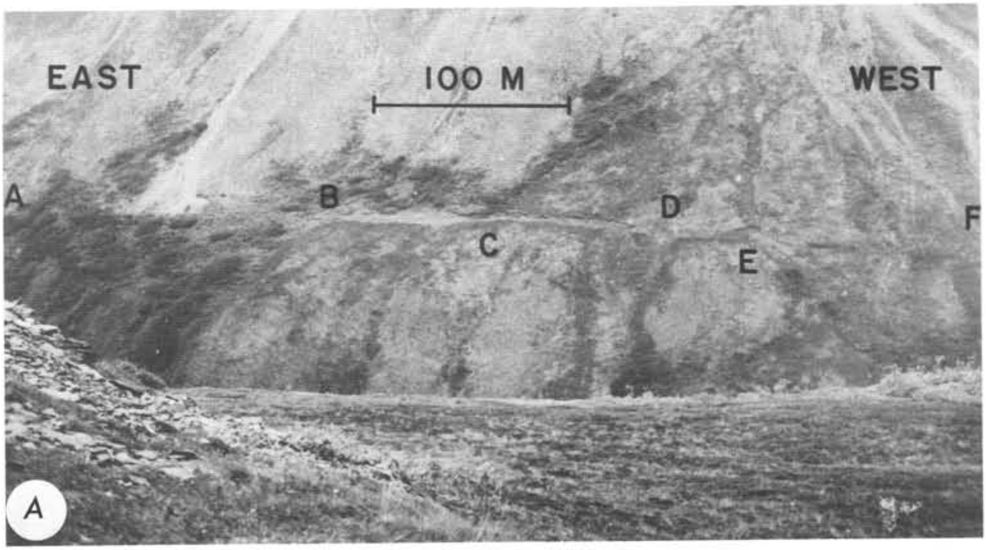


**Figure 5A.** Trace of the McKinley strand of the Denali fault (A–F) at locality A, Figures 3 and 4. The eastern margin of the fan is offset from B to C, and an incised drainage is offset approximately 50 m from D to E.


**Figure 5B.** South-facing, 6-m-high escarpment viewed from D toward C in Figure 5A. Man standing on the fault trace (dotted line) for scale.

rocks of this type are found in the moraines of tributaries farther west because the schists crop out only on the south side of the range in this area and thus are not available as a source of till to ice moving north (Fig. 2). It follows then that the erratics now found in the U-shaped valley on the north side of the fault could have been deposited only by ice flowing north from Augustana Glacier or the first tributary to the Black Rapids Glacier. These limitations provide maximum and minimum offsets since the glacial period during which the erratics found in the U-shaped valley were deposited.


**Figure 6. Denali fault trace (dotted line) as viewed to the west from locality C, Figure 3. Eroded alluvial fans on the uplifted northern side of the fault are shown at B.**

Assuming the maximum possible offset, it is instructive to restore the north side of the fault 6.5 km west relative to the south side (Fig. 7). The resultant drainage pattern eliminates the right-lateral deviation of Augustana Creek and at the same time provides a suitable drainage basin for the U-shaped valley. The restoration is also consistent with one of the only two source areas from which the erratics of porphyroblastic gneiss could have been derived.

Although the restoration suggested in Figure 7 is consistent with the present observations, the alternative model based on the minimum possible offset should be given equal consideration. It is possible that the lateral displacement is limited to less than 1 km (Fig. 7) and that the difference in elevation (275 m) between the base of the U-shaped valley and the base of Augustana Glacier is due to erosion following stream capture in an interstadial period. Additional evidence that may support this alternative interpretation is found in the distribution of bedrock along the western edge of the Delta River. As illustrated by the 900-m contour in Figure 7, the edge of the bedrock channel deviates from a straight course in a right-lateral sense, and may represent lateral offset of less than 1 km.

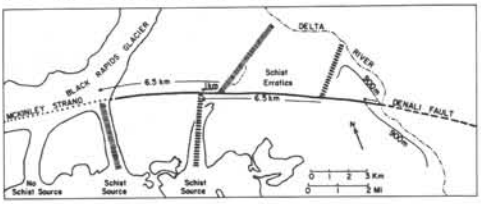


**Figure 7. Alternative topographic restorations of major drainages along the McKinley strand of the Denali fault. Heavily shaded bands correspond to Augustana Glacier and north-trending segment of Augustana Creek 2 km east of locality B in Figure 4. Lightly shaded bands correspond to the first tributary to the Black Rapids Glacier and the "beheaded" U-shaped valley at locality F, Figure 4. Also shown is 900-m-elevation contour. Arrows indicate possible restorations of topographic features.**

## OLDER MOVEMENT ON THE DENALI FAULT

There is some evidence that the apparent offset of 6.5 km referred to earlier approximates the maximum possible offset on the Denali fault since the late Tertiary. Evidence cited by Wahrhaftig (1971, oral commun.; and in Grantz, 1966) indicates that net slip on the Denali fault could not have been more than 5 to 10 km since the initial uplift of the present Alaska Range in late Miocene or Pliocene time. The present course of the Delta River, possibly established at that time in a structural downwarp in coal-bearing mid-Oligocene rocks (Grantz, 1966), passes through the Alaska Range with no significant deviation. The reconstruction suggested in Figure 7 still maintains a reasonable channel for the Delta River, whereas alternative reconstructions based on much greater offsets do not.

## REGIONAL IMPLICATIONS

Right-lateral movement along the Denali fault has been demonstrated by several authors, including Richter and Matson (1971) and Grantz (1966). The most detailed study was made by Richter and Matson, who concluded that there has been no significant lateral movement on the Denali fault east of its intersection with the Totschunda fault system since at least Illinoian time. Richter and Matson's proposal that the Denali fault system west of that region be coupled with the Totschunda fault system is for the most part consistent with our data. Data from the Delta River area suggest that the net slip on the McKinley strand of the Denali fault could not have been more than about 10 km since late Tertiary (Wahrhaftig, 1971, oral commun.) and not more than about 6.5 km since early Wisconsin or Illinoian time.

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## REFERENCES CITED

Brew, D. A., Loney, R. A., and Muffler, L.J.P., 1966, Tectonic history of southeastern Alaska, *in* A symposium on tectonic history and mineral deposits of the western Cordillera in British Columbia and neighboring parts of the United States: Canadian Inst. Mining and Metallurgy Spec. Vol. 8, p. 149–170.

Cady, W. M., Wallace, R. E., Hoare, J. M., and Webber, E. J., 1955, The central Kuskokwim region, Alaska: U.S. Geol. Survey Prof. Paper 268, 132 p.

Capps, S. R., 1940, Geology of the Alaska Railroad region: U.S. Geol. Survey Bull. 907, 201 p.

Davis, T. N., and Echols, C., 1962, A table of Alaskan earthquakes, 1788–1961: Alaska Univ. Geophys. Inst. Research Rept. 8.

Grantz, Arthur, 1966, Strike-slip faults in Alaska: U.S. Geol. Survey open-file rept., 82 p.

King, P. B., 1969, Tectonic map of North America: U.S. Geol. Survey Map, scale 1:5,000,000.

Lathram, E. H., 1964, Apparent right-lateral separation on Chatham Strait fault, southeastern Alaska: Geol. Soc. America Bull., v. 75, p. 249–252.

Loney, R. S., Brew, D. A., and Lanphere, M. A., 1967, Post-Paleozoic radiometric ages and their relevance to fault movements, northern southeastern Alaska: Geol. Soc. America Bull., v. 78, p. 511–526.

Moffit, F. H., 1915, The Broad Pass region, Alaska: U.S. Geol. Survey Bull. 608, 80 p.

Muller, J. E., 1967, Kluane Lake map-area, Yukon Territory: Canadian Geol. Survey Mem. 340, 137 p.

Page, R., 1972, Crustal deformation on the Denali fault, Alaska, 1942–1970: Jour. Geophys. Research, v. 77, p. 1528–1533.

Péwé, T. L., 1951, Recent history of Black Rapids Glacier, Alaska [abs.]: Geol. Soc. America Bull., v. 62, p. 1558.

—— 1957, Recent history of Canwell and Castner glaciers, Alaska [abs.]: Geol. Soc. America Bull., v. 68, p. 1779.

Reger, R. D., and Péwé, T. L., 1969, Lichenometric dating in the central Alaska Range, *in* Péwé, T. L., ed., The periglacial environment: McGill-Queen's Univ. Press, p. 223–247.

Richter, D. H., and Matson, N. A., Jr., 1971, Quaternary faulting in the eastern Alaska Range: Geol. Soc. America Bull., v. 82, p. 1529–1540.

St. Amand, P., 1957, Geological and geophysical synthesis of the tectonics of portions of British Columbia, the Yukon Territory, and Alaska: Geol. Soc. America Bull., v. 68, p. 1343–1370.

Smith, T. E., 1971, Geology, economic geochemistry, and placer gold resources of the western Clearwater Mountains, east-central Alaska [Ph.D. thesis]: Reno, Univ. Nevada.

Smith, T. E., and Lanphere, M. A., 1971, Age of the sedimentation, plutonism, and regional metamorphism in the Clearwater Mountains region, central Alaska: Isochron/West, no. 2, p. 17–20.

Stout, J. H., 1965, Bedrock geology between Rainy Creek and the Denali fault, eastern Alaska Range, Alaska [M.S. thesis]: College, Univ. Alaska, 75 p.

Twenhofel, W. S., and Sainsbury, C. L., 1958, Fault patterns in southeastern Alaska: Geol. Soc. America Bull., v. 69, p. 1431–1442.

U.S. Coast and Geodetic Survey, 1970, Seismicity of Alaska: National Earthquake Information Center Map 3011: Washington, U.S. Dept. Commerce.

Wahrhaftig, Clyde, 1958, Quaternary geology of the Nenana River valley and adjacent parts of the Alaska Range: U.S. Geol. Survey Prof. Paper 293-A, 68 p.

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PRESENT ADDRESS (STOUT): DEPARTMENT OF GEOLOGY AND GEOPHYSICS, UNIVERSITY OF MINNESOTA, MINNEAPOLIS, MINNESOTA 55455