Paleoseismic study of the Cathedral Rapids fault in the Northern Alaska Range near Tok, Alaska

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1 Introduction

Over the last several years the Alaska Division of Geological & Geophysical Surveys (DGGS) has performed geologic field studies along the Alaska Highway corridor from Delta Junction to the Canadian border including identification and characterization of active faults (Figure 1). These studies were performed in order to provide baseline geologic information to assist engineering design decisions related to the proposed Alaska-Canada natural gas pipeline and other developments within the corridor.

Along the corridor, a series of south-dipping imbricate thrust faults bound the northern flank of the Alaska Range including the Dot "T" Johnson and Cathedral Rapids faults among others (Figure 1). Previous paleoseismic trenching studies along these faults have determined that the faults are active and were the source of several Holocene earthquakes (Carver and others 2010).

Thus, in an effort to better characterize the Cathedral Rapids fault, we performed a trench investigation across an ~2.5-m-high scarp observed in the field and on LIDAR imagery that was interpreted to be the extension of the fault in alluvium. We present the results of the trenching investigation and discuss several lines of evidence that may support a tectonic origin for the scarp.

2 Tectonic Setting

Compression and shear in interior Alaska is driven by north-northwest relative motion (~65 mm/yr) between the Pacific and North American plates along the Fairweather fault and Aleutian subduction zone. Subduction of the relatively buoyant Yakutat microplate has resulted in development of the Chugach-St. Elias fold and thrust belt and counterclockwise rotation of the Wrangell microplate, the region of crust between the Chugach Mountains and the Alaska Range. The Denali-Totchunda fault system accommodates this rotation by dextral transpressive shear along the arcuate southern margin of the Alaska Range and was the source of the 2002 Mw=7.9 Denali fault earthquake which ruptured 340 km along the Susitna Glacier Thrust, Denali fault, and Totschunda faults (Eberhart-Phillips et al., 2003; Haeussler et al.,2004). Geodetic, InSar, geochronologic, and paleoseismic studies indicate a right-lateral slip rate of ~9-14 mm/yr (Fletcher, 2002; Biggs et al., 2007; Matmon et al., 2006; Meriaux et al., 2009).

Although the dominant sense of slip on the Denali fault is dextral, drainages of the Nenana and Delta rivers flow north across the crest of the Alaska Range indicating that they are antecedent to regional uplift. Additionally, the Pliocene Nenana Gravel outcrops on both sides of the range and was deposited by north flowing rivers (Wahrhaftig et al.,1969; Thoms, 2000; Ridgeway et al., 2007). Thus, the Denali fault system is characterized by restraining transpressional geometry with associated thrust faults and folds that have played a significant role in the deformation and uplift of the Alaska Range.

A system of south-dipping imbricate thrust faults bound the northern flank of the Alaska Range and are responsible for Quaternary active uplift and folding. West of the Delta River, the system comprises the Northern Foothills Fold and Thrust Belt (NFFTB), a 50-km-wide zone of east-west trending thrust faults that warp and displace late Neogene and Quaternary alluvial surfaces and fluvial terraces and have accommodated ~3 mm/yr of shortening since latest Pliocene time (Ridgway and others, 2002; Bemis, 2004; Carver and others, 2008). East of the Delta River faults of the system include the Donelley Dome, Granite Mountain, Canteen, Dot "T" Johnson, and Cathedral Rapids faults.

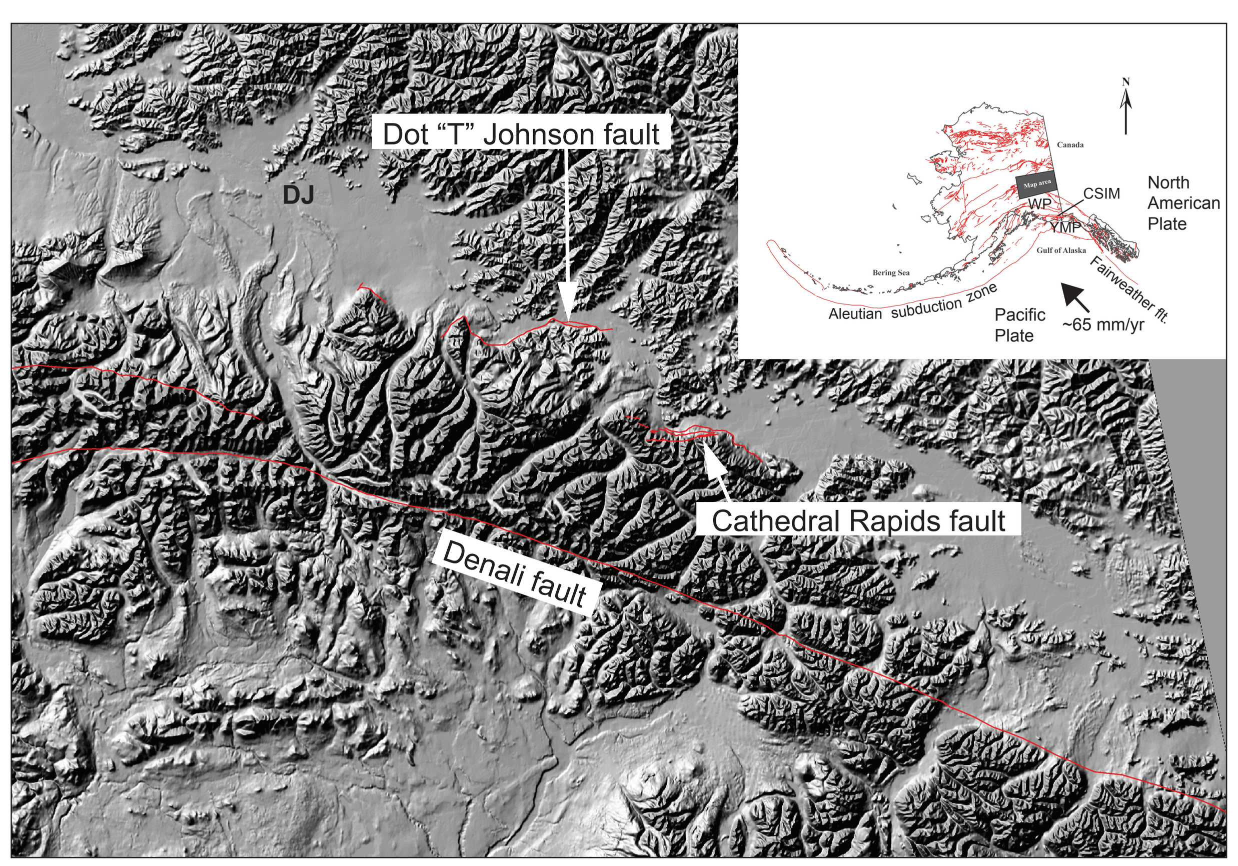
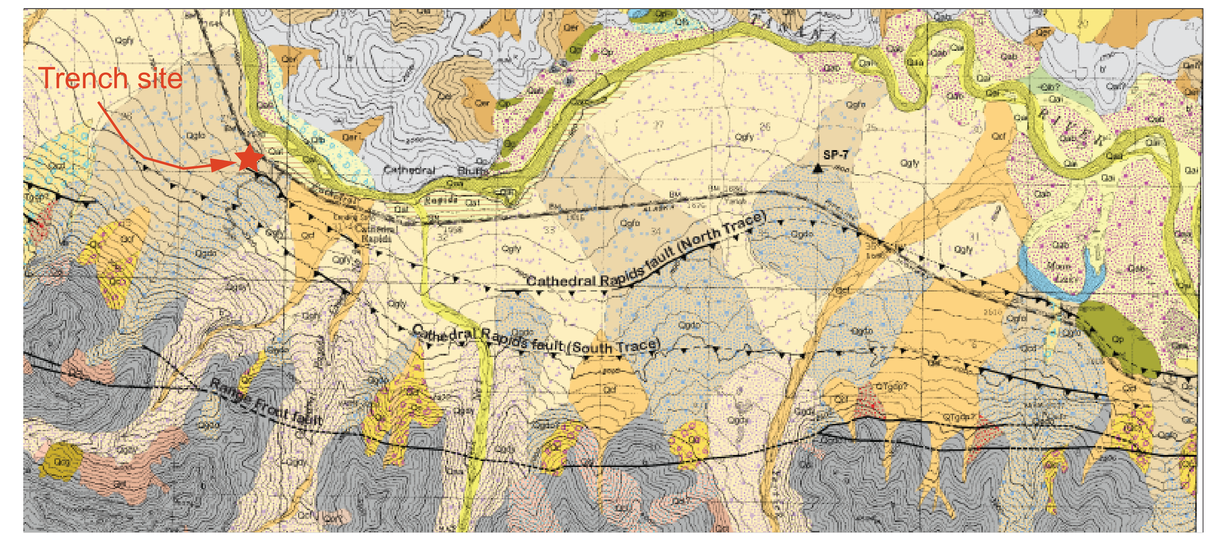


Figure 1. DEM of the Alaska Range showing the Denali fault and thrust faults that bound the north side of the Alaska Range. Inset shows location of study area and regional geologic boundaries. WP, Wrangell microplate; YMP, Yakutat microplate; CSIM, Chugach-Saint Elias Mountains.

3 Cathedral Rapids fault and site geology

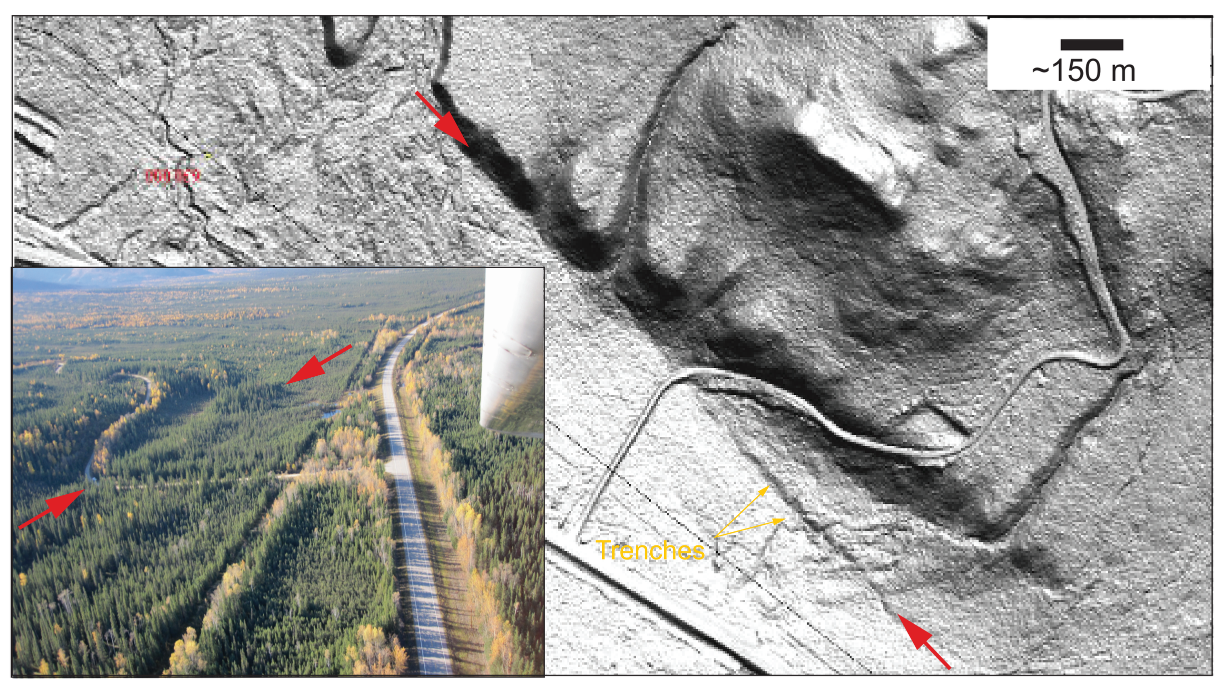
The Cathedral Rapids fault extends ~40 km between the Tok and Robertson River valleys and is interpreted to be the eastern extension of the Northern Foothills Fold and Thrust Belt. The western part of the fault extends 21 km from Sheep Creek to Moon Lake and is characterized by well-developed triangular facets and three roughly parallel sinuous south dipping imbricate thrust splays. The faults offset glacial deposits of the Illinoian to early Wisconsinan Delta glaciations and the late Wisconsinan Donnelly glaciation, as well as, Holocene alluvial deposits.

The eastern part of the fault extends ~16 km east of Moon Lake and is characterized by a large, sinuous growth anticline that extends across coalesced alluvial fans north of the range front. Progressively offset and tilted alluvial terraces, incised stream profiles that steepen across the anticline, and excavations are consistent with late Pleistocene and Holocene growth of the anticline (Carver and others, 2010). Based on a paleoseismic study of an exposure of a bending moment graben at the crest of the anticline, Carver and others (2010) documented colluvial fills interpreted to be related to extension in the hinge of the anticline during four latest Pleistocene earthquakes. An additional exposure in a trench across a small scarp at the base of the fold scarp indicated that the most recent earthquake occurred after AD 1650 (Carver and others, 2010).



Geologic map of the trench site vicinity showing trench location (red star). Taken from Reger and others, 2010. Geologic mapping by DGGS indicates that the site geology consists of outwash (Qgfo) and till and associated morainal deposits (Qgdo) of the Delta glaciation. Terraces and floodplain deposits of the Tanana River occur along the north side of the site and bury the glacial deposits. The trench site is characterized by an oversteepened, ~2.5-m-high scarp that obliquely cuts an outwash fan and projects along the rangefront to the east. Alluvial channels have incised the scarp and deposited alluvial fans at the base of the scarp.

4 LIDAR Imagery of trench site



LIDAR image and aerial photograph (inset) of scarp shown between red arrows in each image.

5 Trench stratigraphy

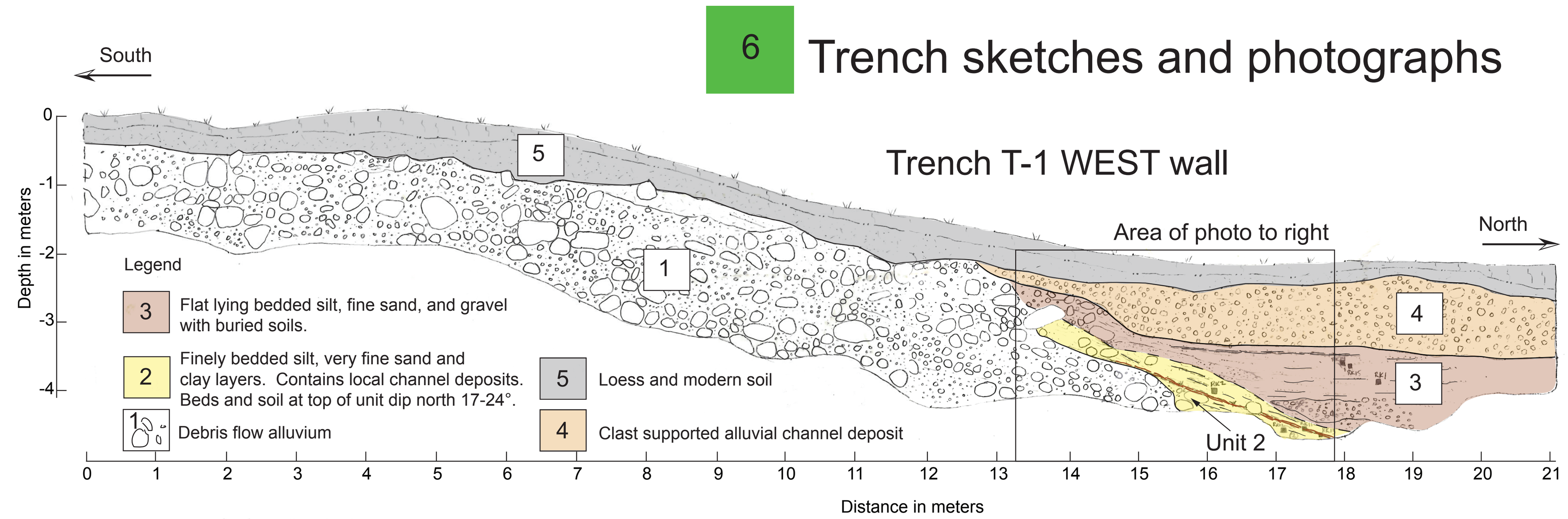
The dominant unit exposed in both trenches is a boulder-cobble diamicton (Unit 1), consisting of a coarser lower bouldery unit and a finer upper cobbley unit. Both sub-units are characterized by matrix supported, subangular to subrounded boulders and cobbles of Alaska Range lithologies up to ~40 cm in diameter. Rare large clasts are weathered, suggesting that the unit was derived from nearby till of Delta age. Deformed sand bodies within the diamicton are consistent with dewatering of a debris flow derived from till upslope (D. Reger, pers. comm.). The diamicton layers are crudely bedded and imbricated to the north. The layers are generally parallel to the relatively flat surface south of the scarp and gradually change orientation, sloping parallel to the scarp face. The diamicton projects through the floor of the trench and was not encountered in a 1-m-deep test pit in the floor of the northern side of the trench.

The north end of the trench exposed a relatively younger alluvial package. The basal deposit (Unit 2) consists of interbedded, nonmicaceous fine sand and clay layers that rest on the diamicton and dip 17-24° to the north parallel to the scarp face and the slope of the diamicton upslope. A prominent buried soil delineates the top of Unit 2 and represents a former ground surface and angular unconformity overlain by flat-lying interbedded micaceous sands and silts (Unit 3) and alluvial gravels (Unit 4). A thick loess and peat mat extends across the upper part of the exposure (Unit 5).

Neither offset bedding, faults, or shears were observed in the trench.

Abundant burned charcoal fragments occur in the younger alluvial package (Units 2, 3, and 4), as well as within the buried soil at the top of Unit 2. Radiometric analyses of 25 samples are in progress and will provide a minimum age for the diamicton and maximum and minimum ages for the dipping buried soil.

6 Trench sketches and photographs



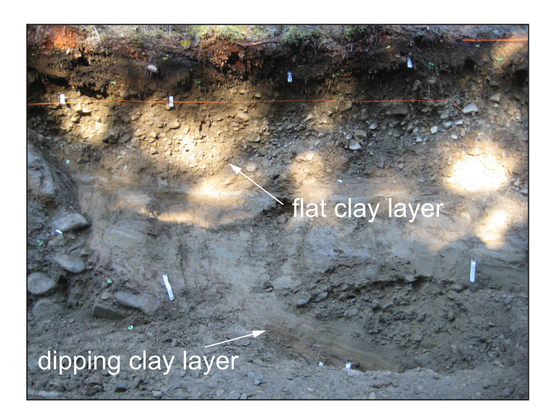


Photo of west wall showing basal unit with north-dipping red clay layer overlain by flat-lying sand and clay.

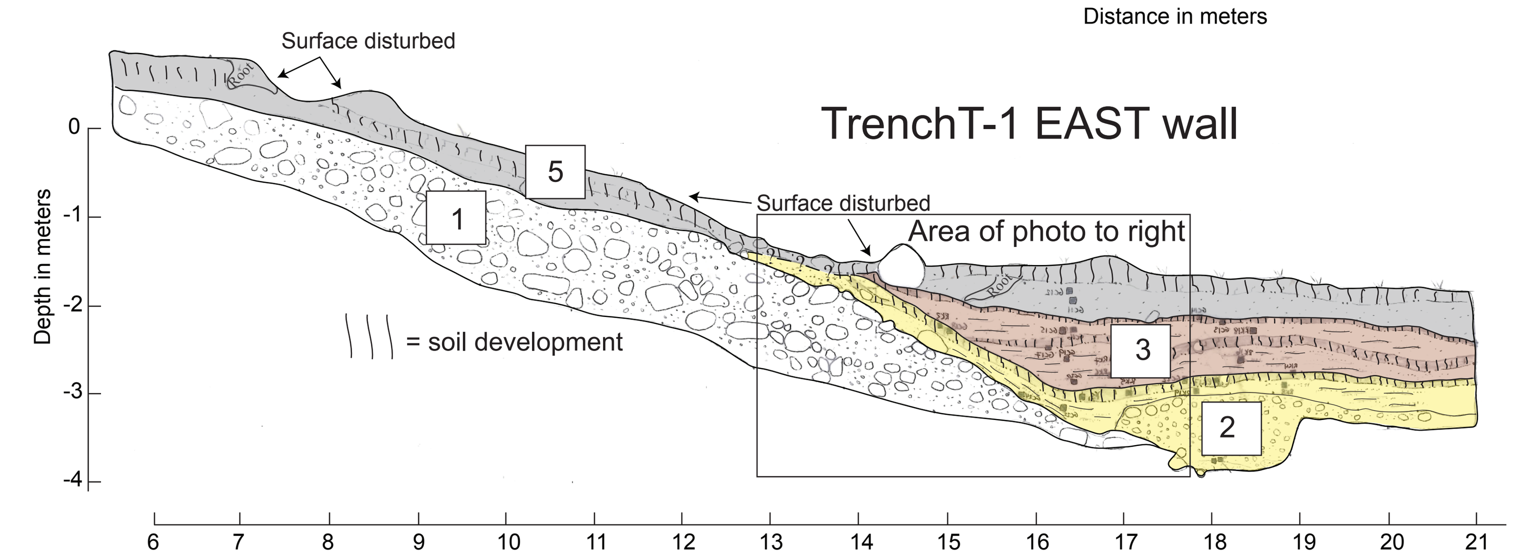


Photo of east wall showing dipping buried soil angular unconformity overlain by interbedded flay lying sand and silt layers.

7 Origin of the scarp

Explanations for the origin of the scarp include an alluvial fan cut margin sourced from the stream valley to the east, a flood scarp related to the Tanana River floodplain, and deformation related to the Cathedral Rapids fault.

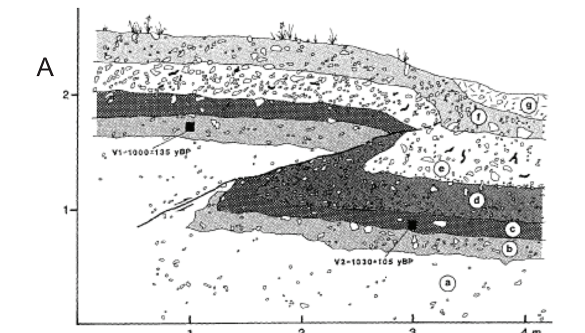
The stream valley to the east of the scarp is associated with a small late Holocene alluvial fan that extends from the mouth of the canyon and does not bend to the west discounting a fan cut margin origin for the scarp.

Mica fragments in the upper sand deposit (Unit 3) suggest deposition by a flooding Tanana River. However, definitive evidence that the scarp was cut by fluvial events such as a cut bank in the diamicton (Unit 1) was not observed. Instead, the upper sand deposits lap against the lower sand and buried soil (Unit 2) suggesting that the scarp and basal sand unit existed prior to burial along its base by flood deposits.

Based on indirect evidence of imbricated cobbles that parallel the slope of the scarp, tilting of quiet water sands and silts (Unit 2), the lack of a clear fault plane, and proximity and alignment with the north trace of the Cathedral Rapids fault, we infer that the most likely explanation for the origin of the scarp is tilting or folding during one or more displacements along a blind thrust fault at depth.

8 Discussion and possible analogues

Our interpretation is consistent with well-documented studies of blind thrust-fault scarps created during earthquakes in Algeria in 1980 (Meghraoui and others, 1988) and Taiwan in 1999 (Kelson and others, 2001). In Taiwan, the folding was observed in areas of thick monsoon cobbles that acted to absorb the rupture. These deposits are similar to the debris flow fan deposits at the Cathedral Rapids trench site. These possible analogues are shown below.



Exposure of the 1980 Ageria rupture showing blind thrust fault and associated folding.

Upper part of the 1980 Ageria rupture exposure is similar to our exposure on the Cathedral Rapids fault.

Folding at the Wu Feng middle school Taiwan, 1999.

Studies of the Seattle fault on Bainbridge Island, WA showed that the surface expression of a Holocene earthquake transitioned from surface folding to surface fault rupture over a distance of less than 100 meters (Nelson and others, 2003). Thus, additional trenching on the Cathedral Rapids fault, particularly to the east along the rangefront may have greater potential to encounter the thrust tip and lend further support to a tectonic origin for the scarp.

Based on previous paleoseismic studies to the east and west of our site that document multiple latest Pleistocene and Holocene earthquakes, and the indirect evidence of blind thrust faulting presented here, we infer that the Cathedral Rapids fault plays an active role in accommodating regional shortening across the Alaska Range and may represent the eastern extension of the Northern Foothills Fold and Thrust Belt. Pending radiocarbon analyses may constrain the timing of at least one folding event.

9 References

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