NEOTECTONICS OF THE CENTRAL ALASKA RANGE: A GUIDEBOOK FOR THE 2005 ALASKA CELL - FRIENDS OF THE PLEISTOCENE FIELD TRIP

Edited by
Evan Thoms

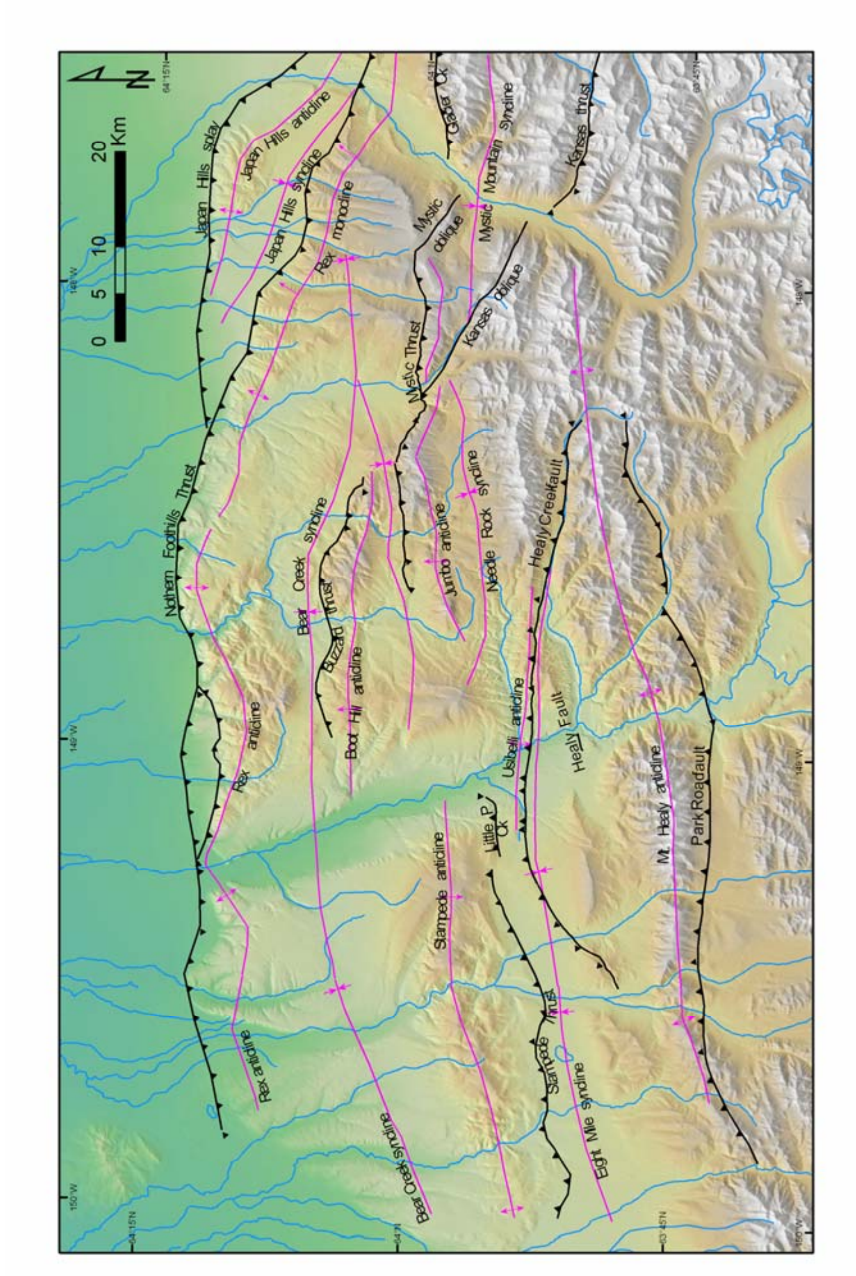
Photo by Sean Bemis
View looking east over the northeastern part of the northern foothills of the central Alaska Range. Tatlanika Creek is in the left foreground, Japan Hills are the isolated uplands in the left center, and an east trending ridge of Totalanika Schist is in the lower right. Note the recently uplifted north-trending ridges of Nenana Gravel – the Pliocene foreland basin fill of the Alaska Range — and the beveled surface of the ridge of schist which may either be related to a pre-Tertiary unconformity or to the top of the Nenana Gravel.

ALASKA CELL – FRIENDS OF THE PLEISTOCENE INAUGURAL FIELD TRIP

SEPTEMBER 3-5, 2005

NEOTECTONICS OF THE CENTRAL ALASKA RANGE

Focusing on recent research in the tectonics, geomorphology, stratigraphy, and glacial history of the central Alaska Range and Northern Foothills



Neogene structures in the northern foothills of the Central Alaska Range as mapped by Bemis (2004)

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INTRODUCTION

The Friends of the Pleistocene (FOP) is a loosely knit group of Quaternary science enthusiasts that has been active for over 35 years. Regional cells generally host one field trip a year organized by volunteers. There are no dues or officials. An administrative meeting is held the second night of the annual field trip during which time a leader and topic for the next year's field trip is chosen.

The Alaska Cell of the FOP came into being at the end of the Alaska Quaternary Center's 2004 Annual field trip. That trip focused on the effects of the November 3, 2002 M 7.9 Denali Fault earthquake at locations accessible from the Richardson Highway. During the trip, it was suggested by some who had participated in FOP trips Outside that there should be an Alaska Cell of the Friends of the Pleistocene (FOP). By the innate power invested in all potential Friends, the Cell was created by a simple declaration and a photograph was taken of those present standing on the upthrown side of a scarp along the Denali Fault near the Canwell Glacier (Fig. 1).

Figure 1. The congress of attendees during the creation of the Alaska Cell of the Friends of the Pleistocene, September 6, 2004.

Because we had just focused on sites along the Richardson Highway, the Parks Highway was an easy target for the next trip and the topic was expanded to include more of the Quaternary. I was chosen to lead the trip partly due to my familiarity with the geology of the Central Alaska Range but mostly because no one else was seriously nominated. Remember that your attendance of an FOP field trip automatically validates you to lead the next year's trip.

ACKNOWLEDGEMENTS

Many thanks to all contributors (of ideas through discussion if not actual materials) and supporters:

Bob Anderson, Jim Begét, Sean Bemis, Patty Burns, Phil Brease, Gary Carver, Michelle Coombs, Peter Haeussler, Marla Hood (for her excellent website support), Ari Matmon, Ken Ridgway, David Schwartz, Don Triplehorn, and Dylan Ward.

OVERVIEW

This field trip is principally organized around 3 recently completed or currently active projects: my own master's thesis on the stratigraphy of the Central Alaska Range foreland deposits (Thoms, 2000), Sean Bemis' master's thesis on the neotectonic structures of the northern-central Alaska Range foothills (Bemis, 2004) (referred to hereafter as the 'northern foothills') and his ongoing research in this area, and work by Alyeska Pipeline, USGS, and Alaska State Division of Geological and Geophysical Surveys (ADGGS) personnel focusing on the paleoseismology of the Denali Fault (e.g. Haeussler et al., 2004). Additional topics are based on recent work by Ken Ridgway and members of his Basin Analysis Group at Purdue University (detailed mapping, sedimentology, stratigraphy, geomorphometry), Bob Anderson and Dylan Ward from the University of Colorado, Boulder (cosmogenic dating of sediments and terraces); and Jim Begét, Mary Keskinen, and Don Triplehorn from the University of Alaska, Fairbanks (stratigraphy, tephrochronology and glacial history). Of course, all of our work is based strongly on the foundation laid by Clyde Wahrhaftig of the USGS who originally mapped several 1:63,360 quads in the area.

Each day we will visit a number of easily accessible sites, none of which require much walking, although some of the walking does require rubber boots. Keep in mind that much of the research we will be discussing has been conducted far from the road system, so the stops we have picked may be merely representative of the topic at hand, that is, some of the stops will be administered with a healthy dose of armwaving. Hopefully, the maps and text in this guidebook will be enough to foster some lively discussions that may make up for the lack of exposure. The flip side is that we will also visit a couple stops where rocks are well exposed, but have no detailed description. Perhaps these will serve as catalysts for future studies.

We will camp for the two nights in a comfortably large, if not tidy, gravel pit just south of Panguingue Creek and a few miles north of the town of Healy.

GEOLOGIC SETTING

The central Alaska Range is positioned at the northern apex of a roughly 1000 km-long arcuate swath of high relief that includes the highest mountain in North America, Denali, at 6194 m (20,320 ft). Other high peaks include Mt. Foraker (5,304 m/17,400 ft) and Mt. Hunter (4,442 m/14,570 ft), both situated near Mt. McKinley; and Mt. Deborah (3,761 m/12,339 ft), Mt. Hess (3,667 m/12,030 ft) , and Mt. Hayes (4,216 m/13,882 ft) in the eastern Alaska Range. Positioned within the range along its strike is the Denali fault, a major right lateral fault with possibly as much as 400 km of offset since the Late Cretaceous (Eisbacher, 1976; Jones et al., 1982; Plafker et al., 1989). Rivers draining the north side of the central Alaska Range collect in the west-flowing Tanana River, a tributary of the Yukon, which empties into the Bering Sea. On the south side of the range, rivers flow into either the Susitna or Copper rivers, ultimately making their way to the northern Pacific.

It is now largely agreed that the geology of south-central Alaska represents the accretion of an exotic island arc assemblage (the Wrangellia composite terrane) to the North American continental margin beginning sometime in the Late Mesozoic (Coney et al., 1980; Jones et al., 1982; Plafker and Berg, 1994). The collision collapsed a marine basin of flysch deposits, the now wide-spread Kahiltna assemblage (Fig. 2), and resulted in a broad zone of deformation (Csejtey et al., 1992) referred to by Ridgway et al., (2002) as the Alaska Range suture zone. The Denali fault system and Hines Creek fault are thought by some to have originated at this time as north vergent thrust faults that later experienced dextral slip (Csejtey et al., 1982; Nokleberg et al., 1992; Ridgway et al., 1997; Cole et al., 1999). Nearly 7,000 m of sediments and volcanic rocks were deposited over roughly 35 m.y. within the Cantwell basin (Fig. 3), which formed in the northern part of the suture zone (Cole et al., 1999). By the Oligocene, the relief of the Late Cretaceous orogeny had been reduced so that regional stream flow was to the south and much of the previously uplifted area was covered by swamps and low-energy depositional systems, represented today by the coal-bearing Usibelli Group (Wahrhaftig, et al., 1969; Ridgway, et al., 1999). Uplift of the present day Alaska Range began between 6.7 and 5.4 Ma (Fitzgerald et al., 1995; Triplehorn, et al., 1999) as a result of either a change in relative plate motion between the North American and Pacific Plates (Fitzgeral et al., 1993; Redfield and Fitzgerald, 1993) or a change in the degree of coupling between the Pacific Plate and the Yakutat terrane in SE Alaska (Plafker et al., 1992). The southward flowing streams were diverted to the north and rocks eroded from within the range were deposited within alluvial braidplains and fans up to a thickness of nearly 1500 m (Wahrhaftig and Black, 1958). The upper age limit of this deposit, the Nenana Gravel, is given by the intrusion of Jumbo Dome at 2.8 Ma (Wahrhaftig et al., 1969; Albanese, 1980). Glaciations of the northern foothills, beginning perhaps as early as the Late Pliocene, have further sculpted the Alaska Range and left a complex record of moraines and terraces (Table 1) (Thorson, 1986).

Revised^ Nenana River valley glacial events	Inferred age
Riley Creek	17-25 ka
Healy glaciation	70 ka[#]
Lignite Creek glaciation*	140 ka[~]
Bear Creek glaciation*	
Browne glaciation	Early to Middle Pleistocene*
Teklanika glaciation*	Late Tertiary or Early Pleistocene*

* Thorson (1986)
[#] Beget and Keskinen (1991)
[~] Beget (2001)
^ sequence updated from Wahrhaftig (1958) and Ten Brink (1983)

Table 1. Revised ages of glacial events in the Nenana valley area (Bemis, 2004).

Dominating the tectonic features of interior Alaska, the Denali and Tintina fault systems are commonly regarded as right-lateral strike-slip fault systems transecting Alaska (Grantz, 1966; Reed and Lanphere, 1974; Lanphere, 1978; Stout and Chase, 1980) (Fig. 4). Based on spatial changes in Bouguer gravity, seismicity, aeromagnetic resistivity, and geologic field relationships, Newberry and others (1995) identified a series of NE-trending "bookshelf" faults with sinistral offset that presumably result from clockwise rotation of crustal blocks trapped between the Denali and Tintina fault systems (Forbes et al., 1982; Page, et al., 1995). The postulated Northern Foothills thrust (Fig. 4.) delineates the northernmost extent of the central Alaska Range foothills from the southern extent of the Tanana basin (Geomatrix Consultants, 1997; Bemis, 2004). Bemis (2004) has mapped a number of structures within the northern foothills (Fig. 5), including the Healy fault near the town of Healy with evidence for significant vertical Holocene movement (Bemis, 2004; personal communication, 2005).

The region has experienced three >M7 historic earthquakes, as well as numerous M5-6 tremors. Records of seismicity suggest the presence of unidentified structures (Page et al., 1995). Recent geodetic (Fletcher, 2002) and seismological (Ratchkovski and Hansen, 2001) (Fig. 6) studies argue for continued north-south contraction throughout the central Alaska Range and northern foothills.

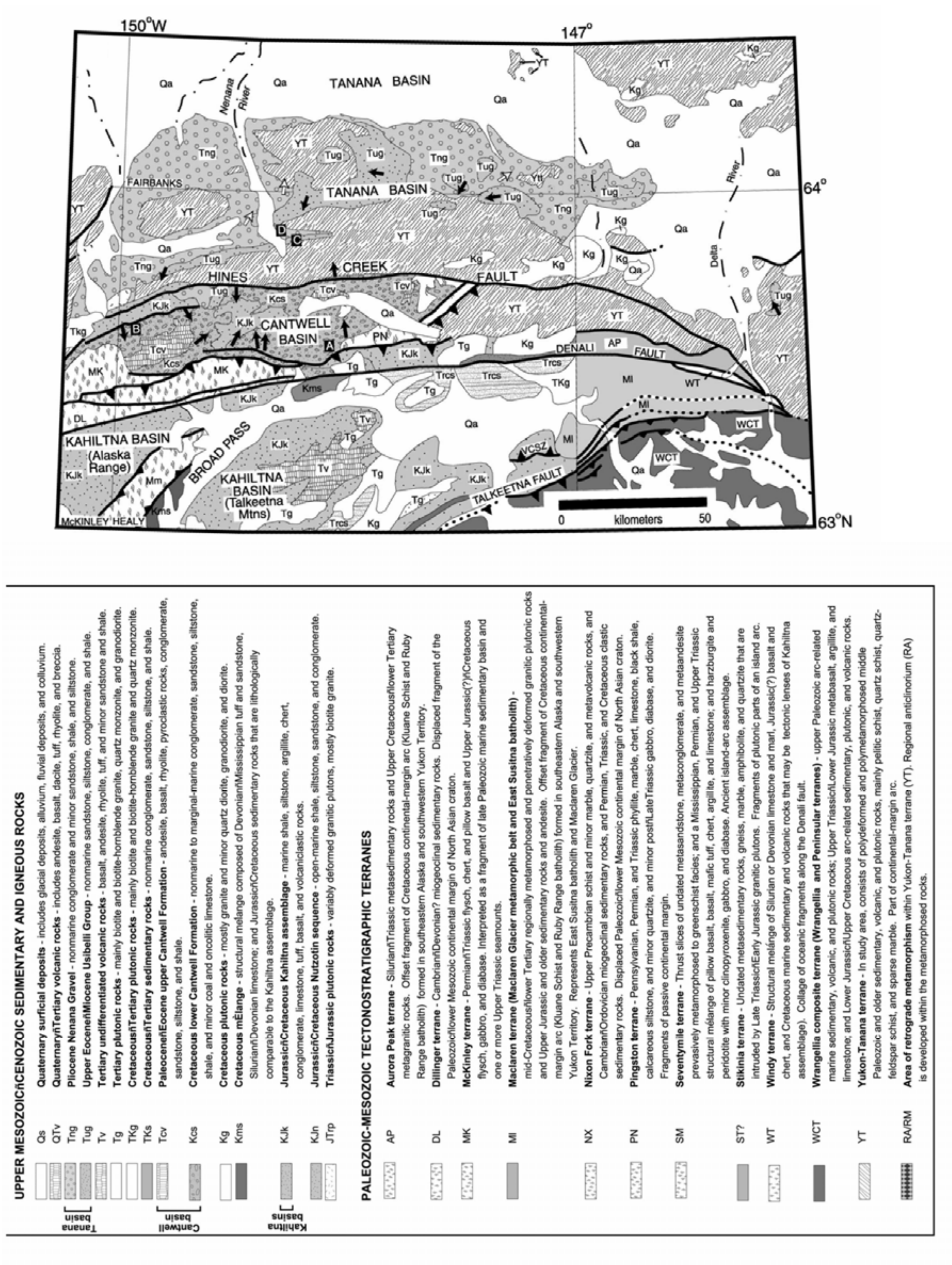

Figure 2. Geology of the Tanana, Cantwell, and Kahiltna basins (Ridgway et al., 2002). Note that not all of the listed rocks appear in the map. Arrows represent paleo-flow direction.

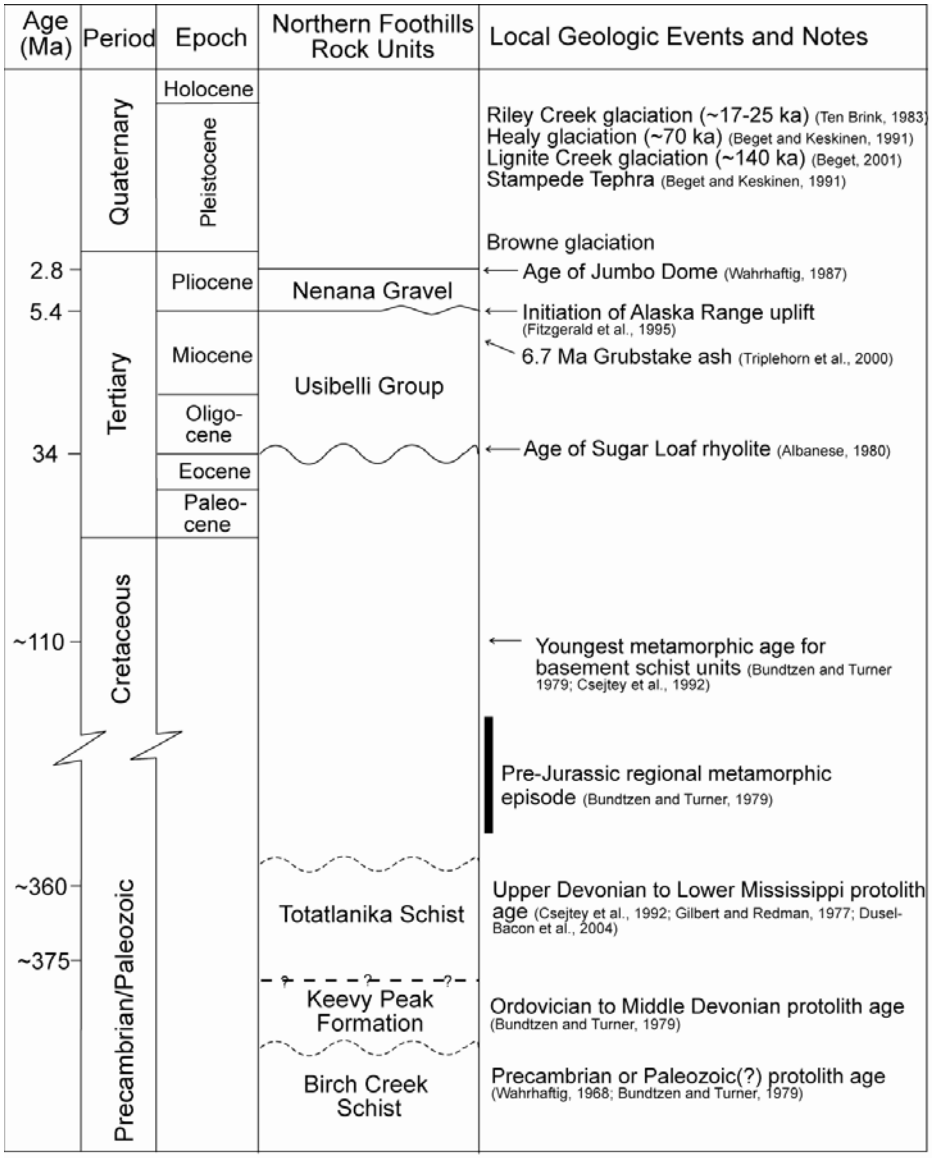

Figure 3. Timeline for the general geologic evolution of the northern foothills. Note that the figure is not scaled by absolute age (Bemis, 2004)

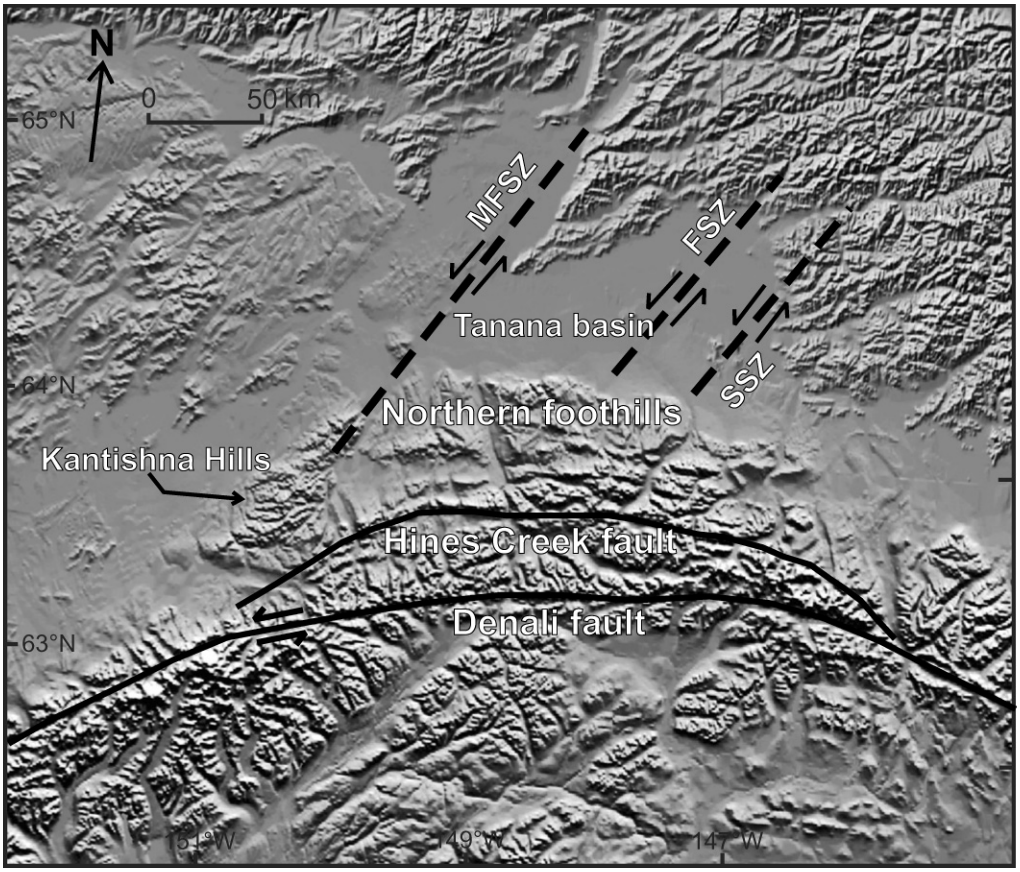

Figure 4. Regional tectonic elements of interior Alaska. MFSZ = Minto Flats Seismc Zone, FSZ = Fairbanks Seismic Zone, SSZ = Salcha Seismic Zone. Note how the MFSZ separates the E-W topographic grain of the northern foothills from the more NE-trending topography of the Kantishna Hills. (Bemis, 2004).

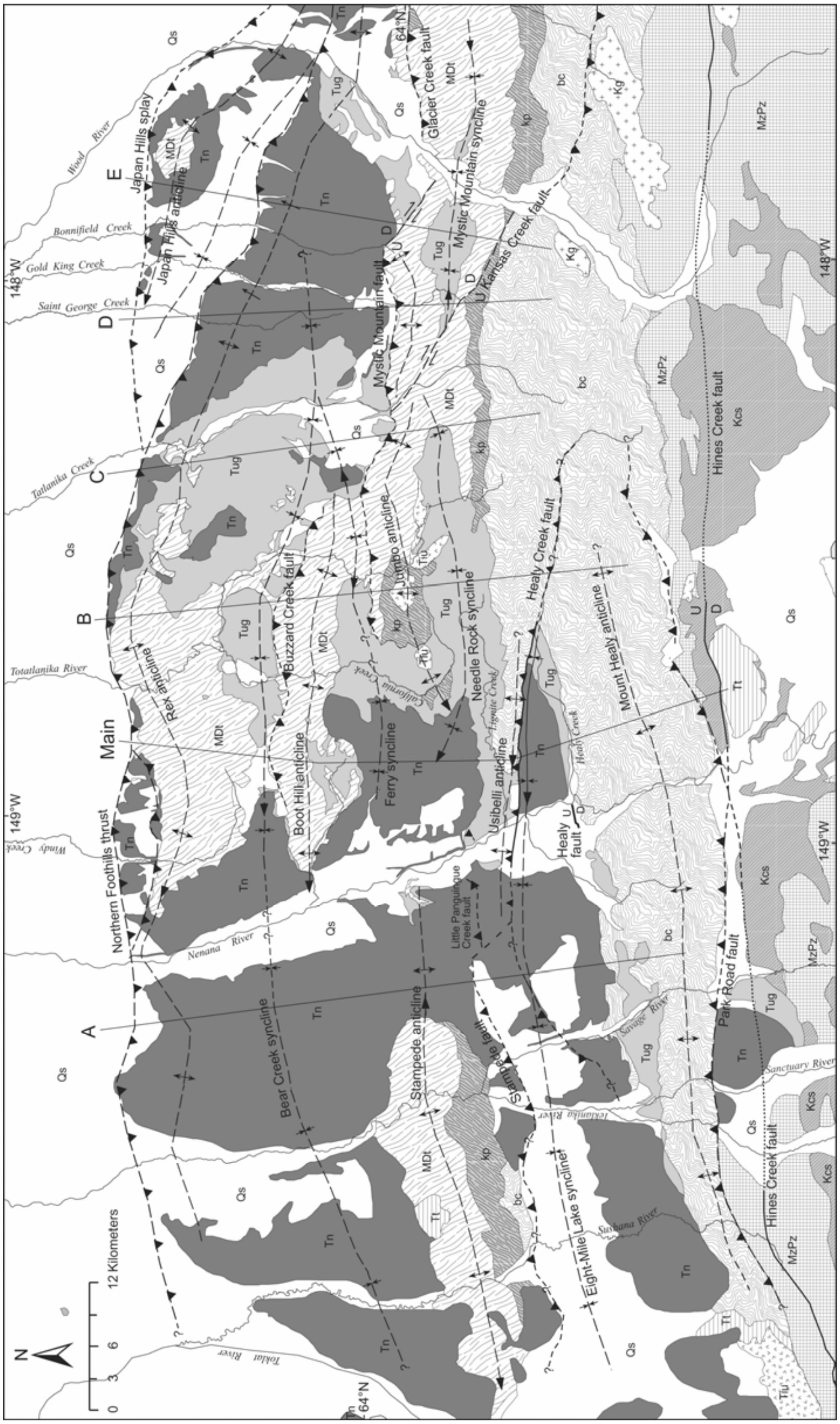

Figure 5a. Map of geologic and neotectonic features in the central Alaska Range northern foothills (Bemis, 2004). Lines labeled A through E and 'Main' indicate the locations of cross sections in Fig 5b.

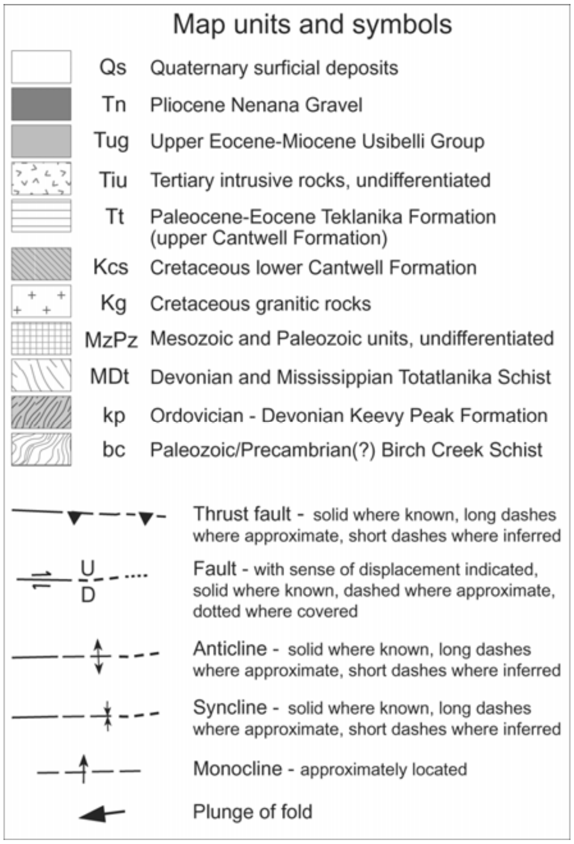

Figure 5a (continued).

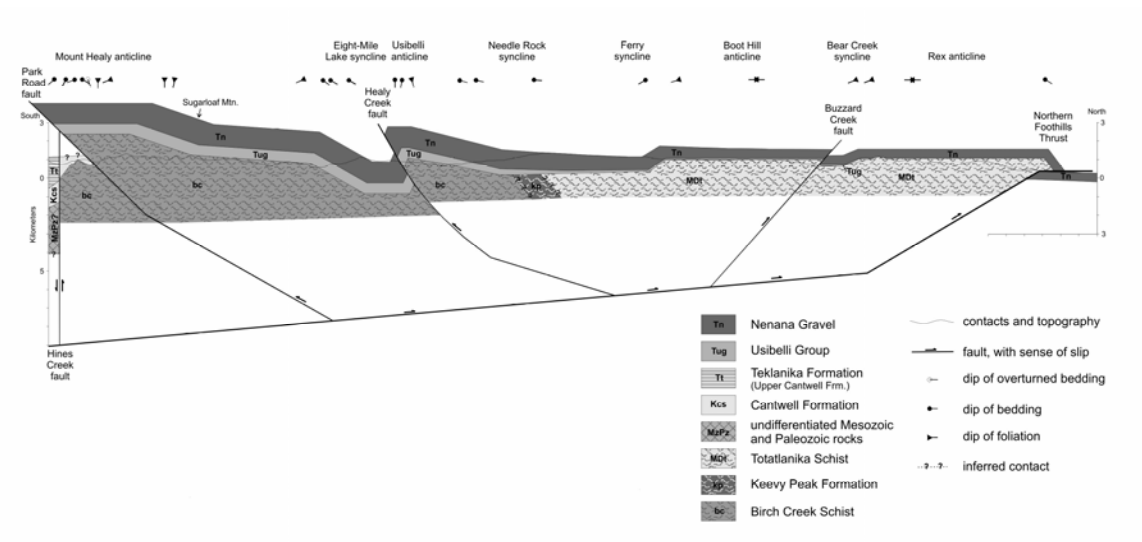

Figure 5b. Balanced geologic cross section along line labeled 'Main' in Fig. 5a.(Bemis, 2004)

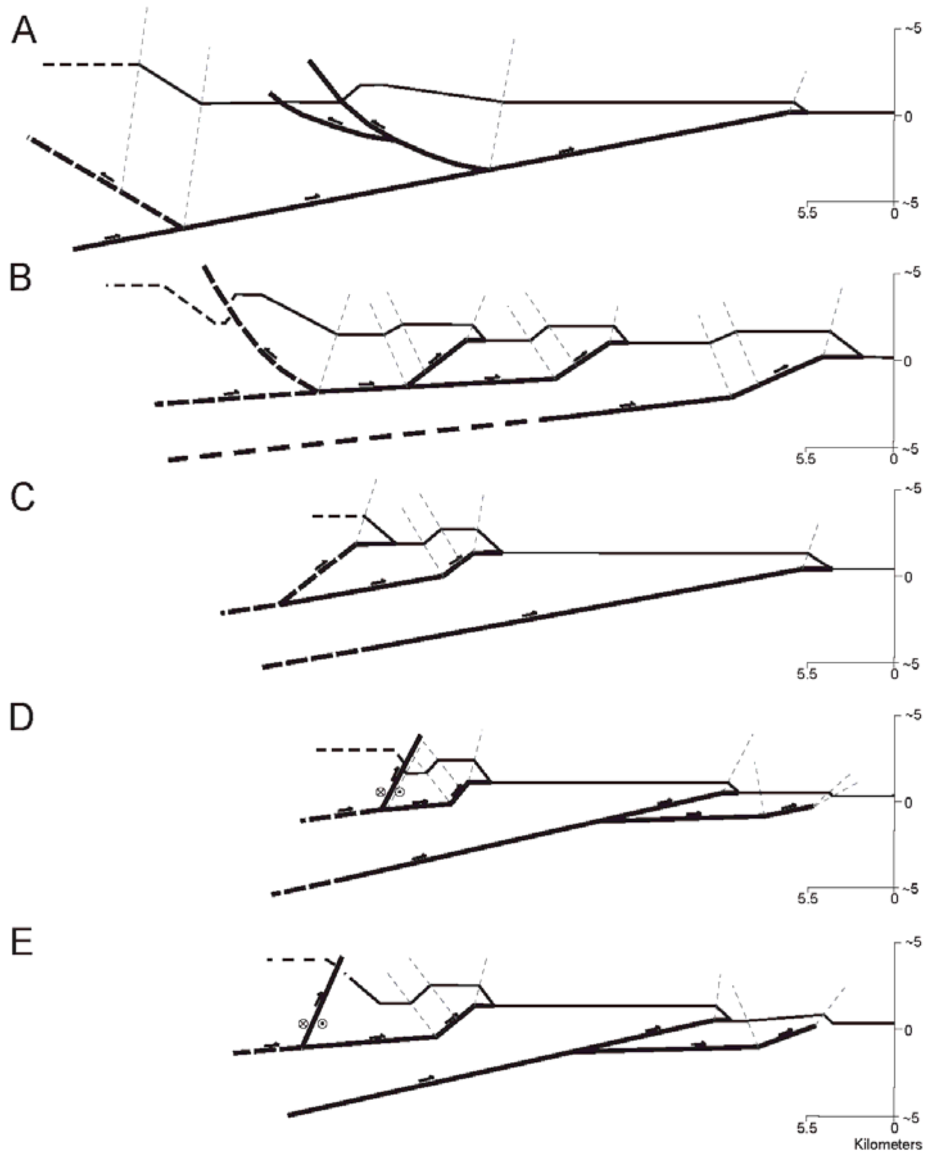

Figure 5b (continued). Schematic structural cross sections along lines labeled with letters in Fig 5a. Heavy lines are faults and thinner lines are the estimate surface of the Nenana Gravel. These are dashed under regions with no Tertiary sedimentary rocks or obvious unconformity surfaces. Thin, gray dashed lines are approximated fold bisectors.

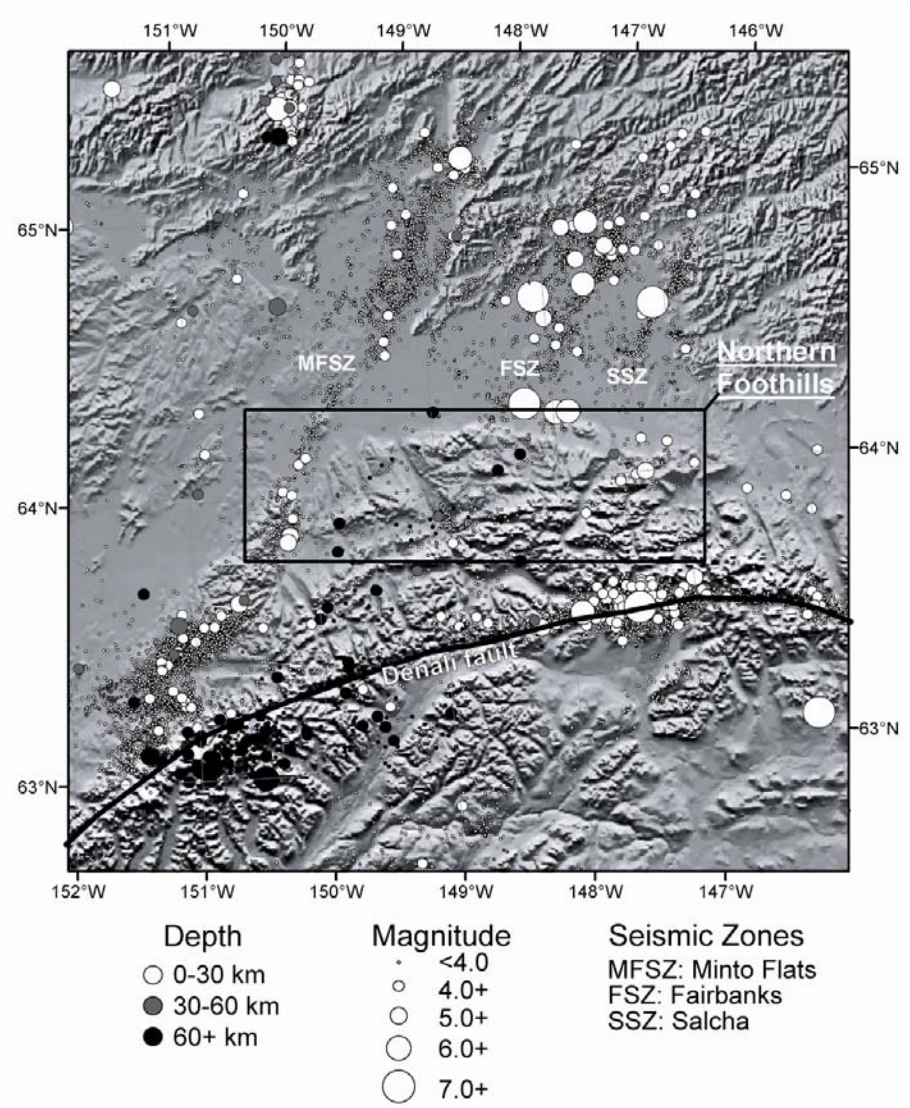

Figure 6. Seismicity map of interior Alaska. Note the predominance of shallow earthquakes north of the Alaska Range and the deeper earthquakes associated with the subduction zone beneath the Alaska Range (Bemis, 2004).

DAY 1

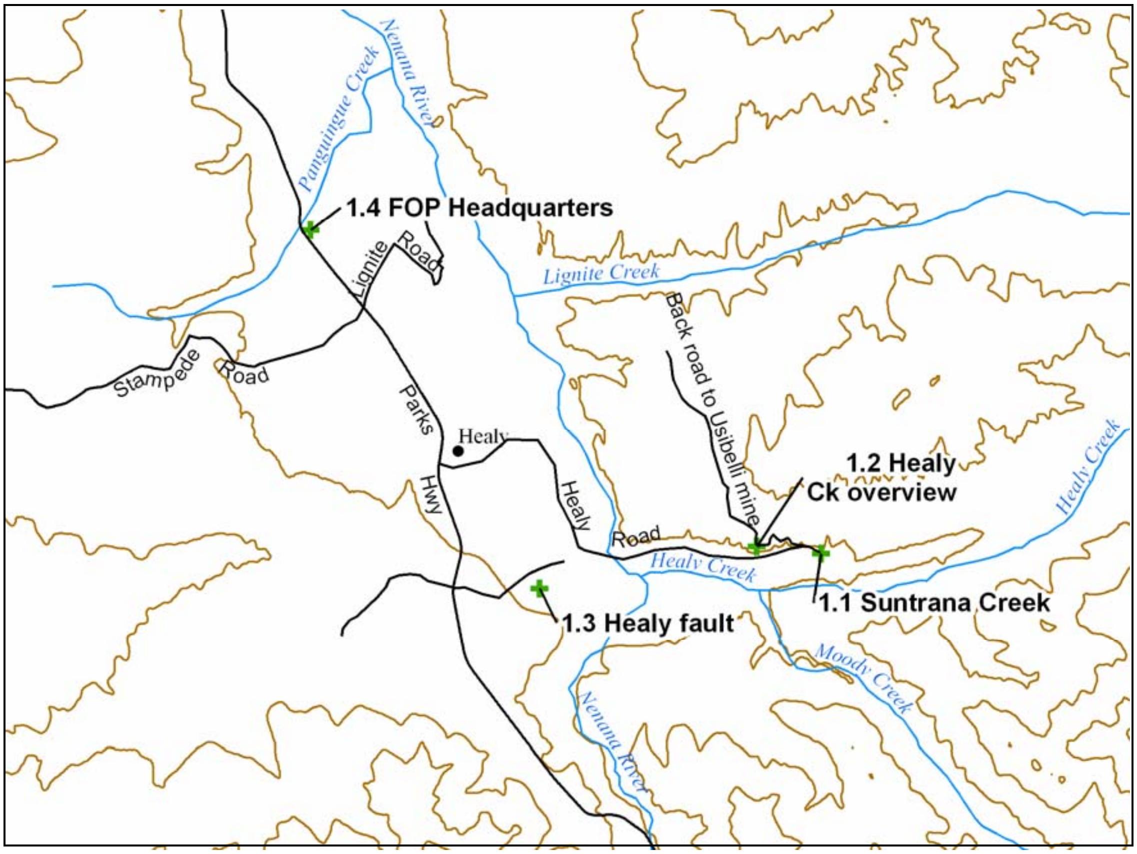

Figure7. Map of stops on Day 1.

Day 1 road log

Day 1 will begin in Fairbanks although there are no stops until Suntrana Creek east of Healy. As you approach the Nenana River valley (hereafter termed the Nenana valley) from the north, look for the Teklanika Trading Post store and campground on the south side. Shortly after this point, you cross the Nenana River on a bridge. Mileages in the table below are based on distances from either the west end of that bridge or, in parentheses, from the intersection of the Parks Highway and Healy Road in Healy (in case you are traveling from the south).

0.0 (27.8)	West end of bridge over the Nenana River north of the mouth of the Nenana valley.
1.2 (26.6)	Parks Highway crosses the trace of the Northern Foothills Thrust which brings Nenana Gravel to the surface to form the bluffs defining the mouth of the valley.
2.4 (25.4)	Axis of the Rex anticline. Growth of this anticline has

brought Mississippian aged schist to the surface 5 miles east of here.

2.8 (25.0) Birch Creek crossing. Thorson (1986) interpreted the valley that Birch Creek flows down as a meltwater channel that formed along a moraine of the Browne glaciation. Erratics litter the bluff to the west.

4.1 (23.7) Pullout

6.0 (21.8) Bear Creek crossing. Thorson (1986) interpreted the Bear Creek valley as a meltwater channel defining the extent of the Bear Glaciation.

6.6 (21.2) Bear Creek rest area. Pit toilets.

9.3 (18.5) Axis of the Bear Creek syncline

11.1 (16.1) Pullout

12.0 (15.8) Due east across the Nenana River is the western extent of the Boot Hill anticline. Like the Rex anticline to the north it also brings basement schist to the surface.

14.5 (13.3) Parks Pond. Exposure of fine-grained facies of Nenana Gravel capped by outwash gravel of Healy age, as mapped by Wahrhaftig (1970).

14.7 (13.1) Pullout south of Rock Creek Road.

16.2 (11.6) Ferry Road. On the drive south of Ferry look to the west for views of Mt. Walker which is underlain by Nenana Gravel.

17.8 (10.0) Slate Creek. A former meltwater channel possibly representing a recessional stage of the Bear Creek glaciation. Also, exposed within this drainage is the schist at the core of the Stampede anticline.

21.7 (6.1) Trace of the Little Panguingue Creek fault. This fault appears to offset a surface (either the top of the Nenana Gravel or a younger surface) on either side of the creek.

23.2 (4.6) Panguingue gravel pit. FOP headquarters. The entrance is on the east side of the road just at the top of the south Panguingue creek bank. Go slowly and look carefully.

23.9 (3.9)	Axis of the Usibelli anticline
24.4 (3.4)	Stampede road and Lignite road intersection. Trace of the Healy Creek fault. Site of Stop 2.3.
25.4 (2.4)	Axis of the Eight Mile syncline
27.8 (0)	Healy Road.Turn east and zero odometer.

Stop 1.1 Suntrana Creek (Evan Thoms)

Directions:
Drive approximately 6.7 miles along Healy Road to the mouth of Suntrana Creek. The road is now gated beyond the creek, so you can't miss it. Park on the west side of the creek even if the creek looks passable. Debris flows sometimes fill in the creek and present a deceptive surface that may, in fact, have the consistency of quicksand.

Overview:
At this stop we will discuss the geologic setting of the central Alaska Range and become familiar with some of the stratigraphy we will be talking about for the remainder of the trip. The section exposed here has been described by many people and visited by many more.

Before you begin walking up the creek, notice the knob of schist about 0.3 mile to the SE (Fig. 8).The schist, colloquially called the Birch Creek schist, is mostly Paleozoic in age and belongs to the same regional-scale package of rocks that make up the Yukon-Tanana uplands north of the Tanana River. The overlying deposits, from our vantage point the deposits to the left of the knob, were deposited unconformably onto the schist beginning in the Early Miocene in generally swampy and low-energy depositional systems (Wahrhaftig et al., 1969; Buffler and Triplehorn, 1976; Ridgway et al., 1999). There are 5 separate formations in this section, but the entire assemblage is known as the Usibelli Group. Not only are the deposits indicative of low-energy depositional environments, but paleocurrent measurements indicate the regional stream direction was to the south, indicating the present day Alaska Range did not exist at the time of deposition. In fact, these streams apparently flowed all the way to Cook Inlet because garnets most likely sourced from the Yukon-Tanana uplands have been described from within the Usibelli Group-correlative Hemlock and Tyonek Formations (Kirschner and Lyon, 1973). Thick coal beds in the Usibelli Group presumably record periods of subsidence related to periods of regional shortening (Ridgway et al., 2002).

The youngest formation in the Usibelli Group, the Grubstake, records the formation of a large lake within the northern foothills, presumably due to ponding of south flowing streams against the rising Alaska Range. A volcanic ash which fell into the lake has yielded an $^{40}Ar/^{39}Ar$ age of 6.7 ± 0.1 Ma

(Triplehorn et al., 1999) (Fig. 9). At this section, the ash first appears about 20 m from the upper, nearly conformable, contact with the Nenana Gravel, so we have a maximum age for the beginning of Nenana Gravel deposition. Fitzgerald and others (1995) used fission track thermochronology to arrive at a similar age of 5-6 Ma for the beginning of rapid uplift and erosion of the Denali region. Last year, Dylan Ward and Bob Anderson from the University of Colorado, Boulder collected samples from the Nenana Gravel that they will try to date using cosmogenic isotopes. Results are pending.

The best estimate of when deposition ended within the Nenana Gravel system comes from a K/Ar age of 2.8 $\pm$ 0.3 Ma from Jumbo Dome, a rhyolitic plug that intrudes and deforms the post-Nenana Gravel surface (Wahrhaftig, 1969; Albanese, 1980). I do not believe the field relations have been reviewed since Wahrhaftig first mapped in the area and the intrusion has certainly not been redated.

Between 1944 and 1958 Clyde Wahrhaftig made over 500 pebble counts at 80 exposures of the Nenana Gravel throughout the northern foothills enabling him to interpret a sequence of erosion within the Alaska Range. I later revised his interpretations based on recent mapping and some new data from $^{40}Ar/^{39}Ar$ dating (Table 2) of detrital feldspar grains. Briefly, the data suggest a northward progression of source areas starting with rocks located south of the Denali fault and present day range divide, later including plutonic rocks in the eastern Alaska Range, and finishing with the nearby Birch Creek Schist and the underlying Usibelli Group. Ridgway and others (1999) came to similar, though slightly less detailed, conclusions about the Alaska Range unroofing sequence from their analyses of compositional changes within the Usibelli Group and Nenana Gravel. A particularly interesting interpretation from their work is that changes in paleoclimate may have significantly influenced sandstone compositions within the Usibelli Group. That is, quartz is enriched relative to other constituents in sandstones deposited during warm and humid paleoclimates. In sandstones deposited during cooler and dryer paleoclimates, the relative amount of feldspars and lithic fragments is higher (Figs. 10 and 11).

As you walk up the creek, look for these features:

- So-called ‘burned shale’ which results from fires within the coal seams. On damp days, you can sometimes see, and almost always smell, smoke rising from active fires in the area. This “lithology” appears in the uppermost beds of Nenana Gravel indicating Usibelli Group deposits were being eroded not far upstream
- Current direction indicators.
- Clastic dikes cutting across stratigraphy which may be indicators of paleoseismiscity.
- Above the No. 6 coal bed in the Suntrana Formation (Fig. 8), look for a strongly weathered ash bed, or tonstein. Recent $^{40}Ar/^{39}Ar$ dating of crystals from this ash has resulted in an age of ~35 Ma which is much too old

based on extensive stratigraphic control. Interestingly, this is the same age currently given for the eruption of Sugar Loaf Mountain, a ryholitic plug in Mt Healy ridge a few miles SW of here. See the Sugar Loaf discussion in Stop 1.2 for more on this.

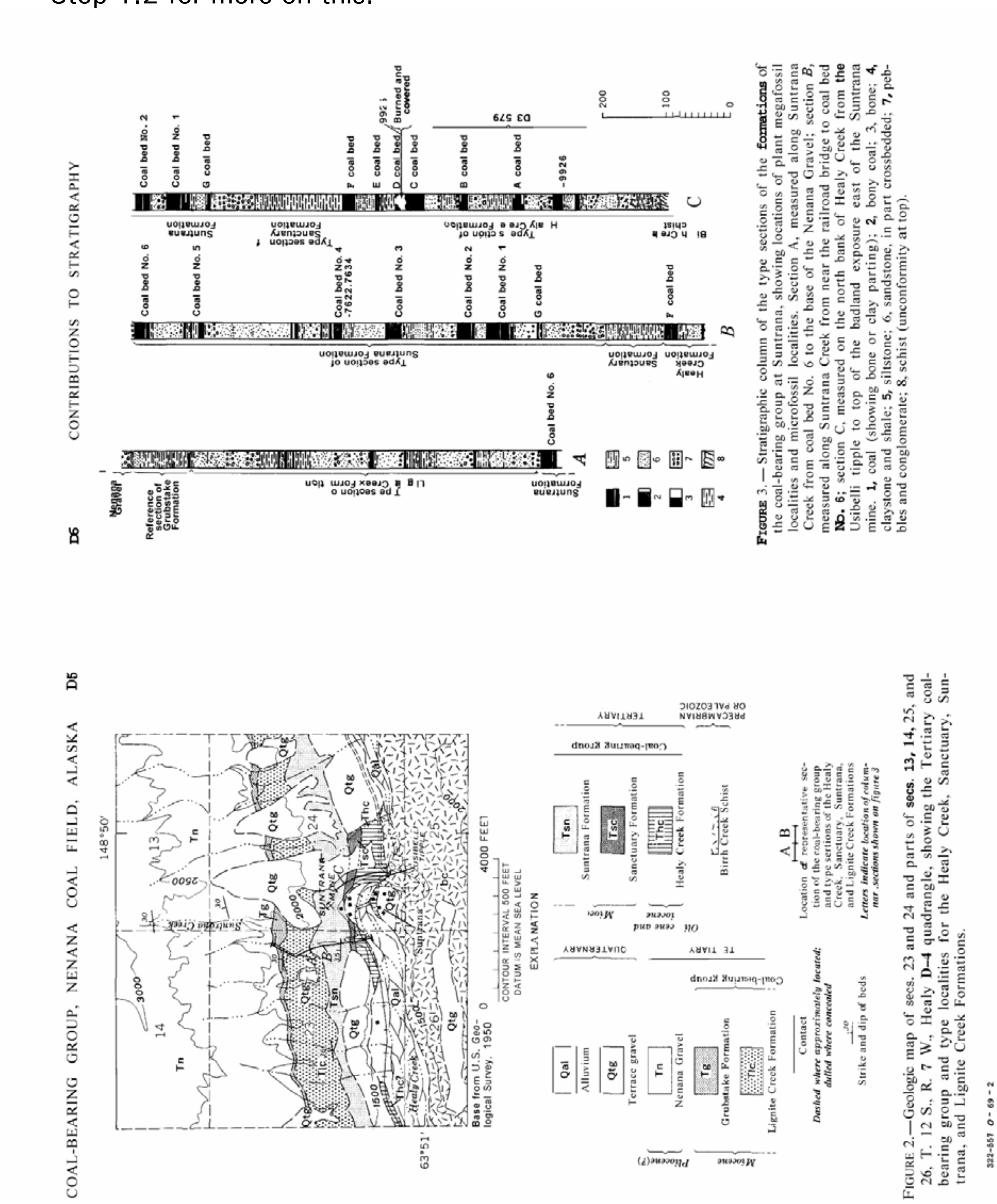

Figure 8. Geologic map of the Suntrana area and stratigraphic column of the Usibelli Group (Wahrhaftig, et al., 1969).

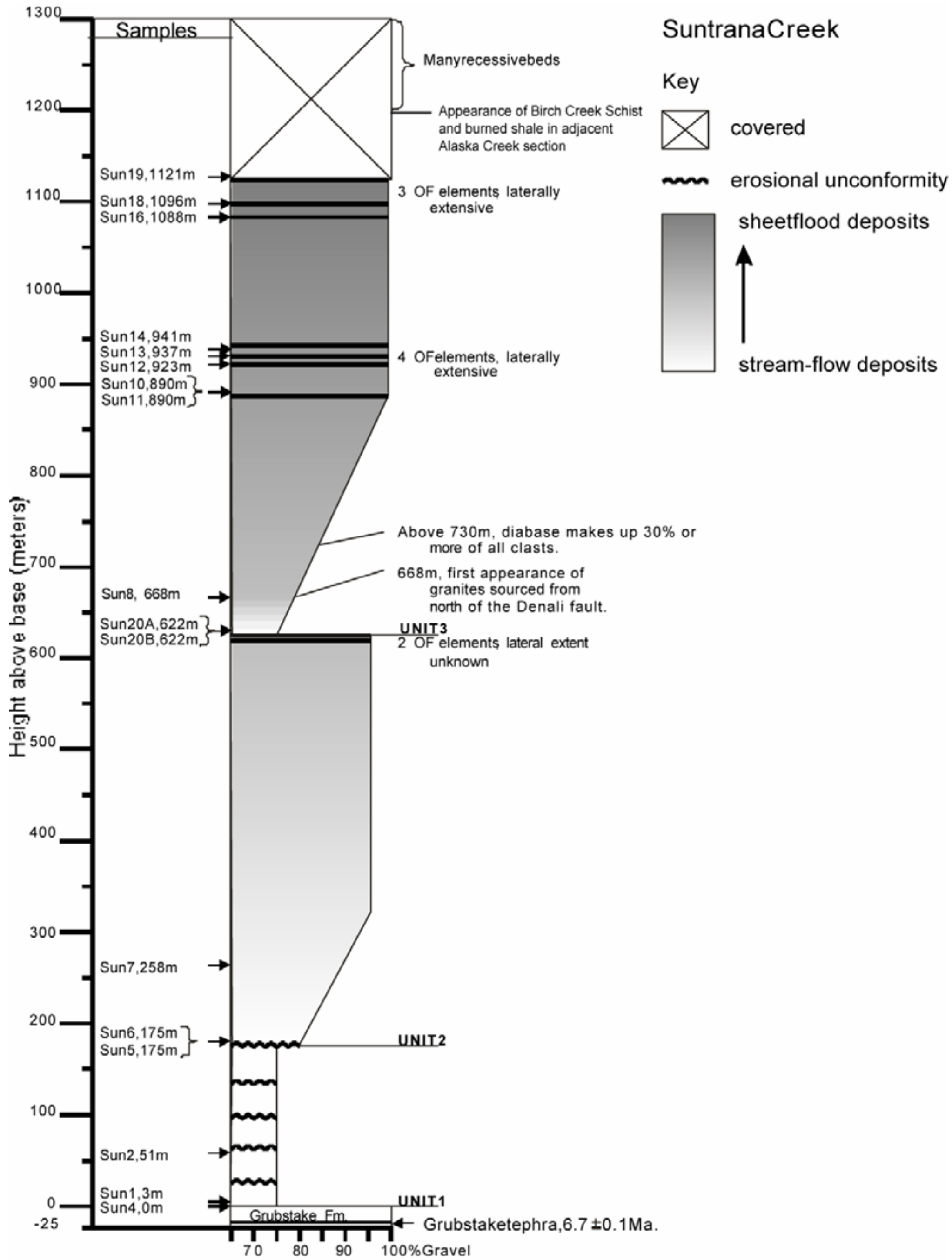

Figure 9. Stratigraphic column of the Nenana Gravel at Suntrana. Modified from Thoms (2000). OF = Overbank Flood deposits. Regarding the annotation at 730 m about the change in the amount of diabase: diabase is a common sill rock throughout the Alaska Range, but makes up nearly 50% of exposures near the present day terminus of the Yanert Glacier in the eastern Alaska Range.

Sample	*Height above base (m)*	*Age (My)*	*Provenance (south of Denali fault or within the Cantwell basin)*
SUN4-CLAST	0	53 +/-0.25	south of Denali fault
SUN1-SAND	3	42 +/-0.19	south of Denali fault
SUN2-SAND	51	55 +/-0.23	south of Denali fault
SUN5-SAND	175	52 +/-0.64	south of Denali fault
SUN6-CLAST	175	59 +/-0.31	south of Denali fault
SUN7-CLAST	258	51 +/-0.29	south of Denali fault
SUN20A-CLAST	622	55 +/-0.42	south of Denali fault
SUN20B-CLAST	622	69 +/-0.52	south of Denali fault
SUN8-CLAST	668	37 +/-0.16	Cantwell basin
SUN10-SAND	890	55 +/-0.50	south of Denali fault
SUN11-CLAST	890	33 +/-0.15	Cantwell basin
SUN12-SAND	923	56 +/-0.26	south of Denali fault
SUN13-CLAST	937	30 +/-0.31	Cantwell basin
SUN13-SAND	937	39 +/-0.36	Cantwell basin
SUN14-SAND	941	51 +/-0.76	south of Denali fault
SUN14-SAND#2	941	54 +/-0.24	south of Denali fault
SUN 16-SAND	1088	33 +/-0.17	Cantwell basin
SUN18-CLAST	1096	68 +/-0.37	south of Denali fault
SUN18-CLAST#2	1096	54 +/-0.35	south of Denali fault
SUN19-CLAST	1121	26 +/-0.21	Cantwell basin

Table 2. Results and interpretation of $^{40}Ar/^{39}Ar$ dating of feldspars from the Suntrana section. (Thoms, 2000). Granitic bodies south of the Suntrana section generally fall into two age brackets. Plutons south of the Denali fault are generally between 57 and 60 Ma whereas plutons from within the Cantwell Basin (north of the Denali fault to the Hines Creek fault are generally between 36 and 40 Ma.

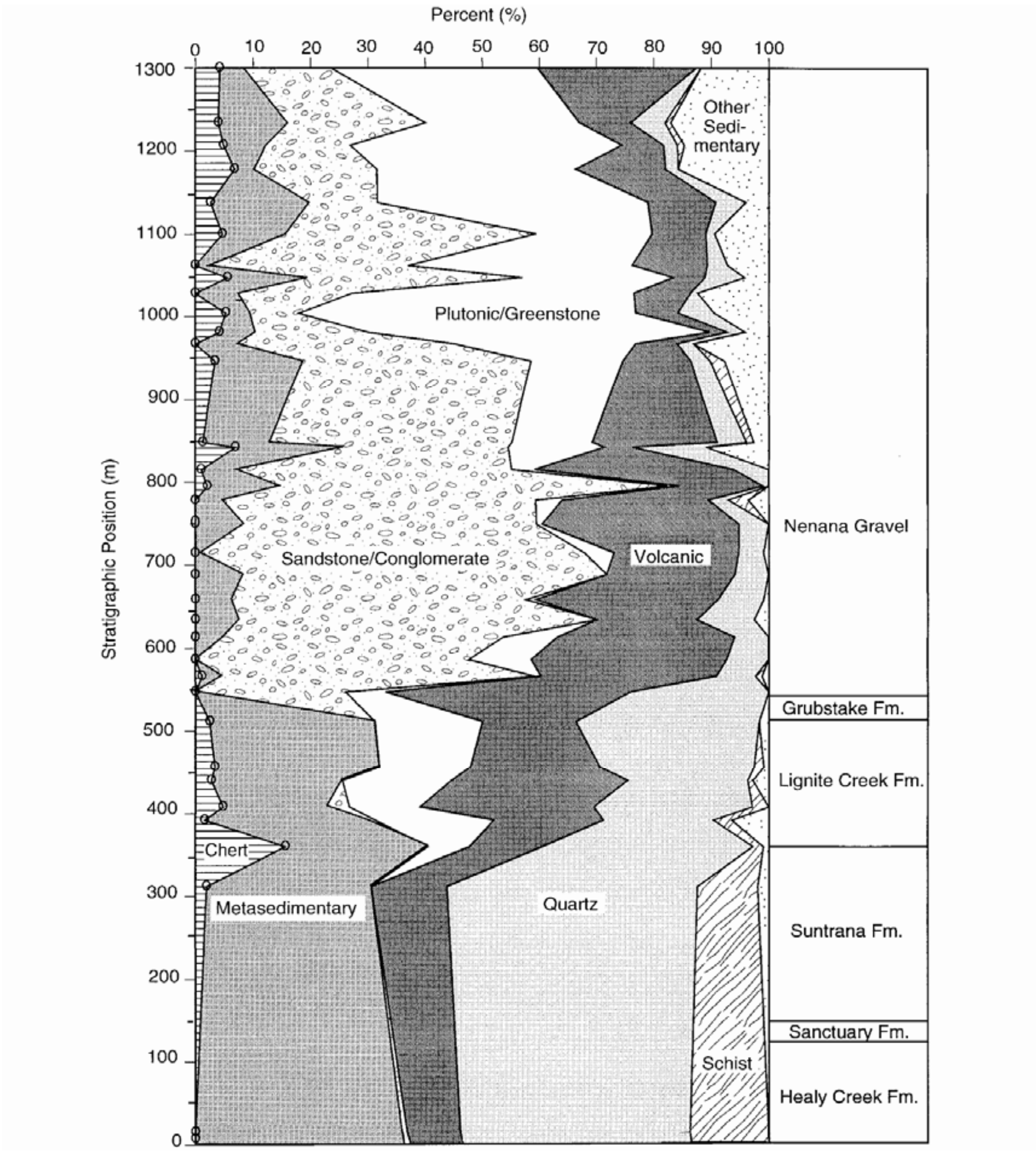

Figure 10. Conglomerate clast composition of the Usibelli Group and Nenana Gravel (Ridgway et al., 1999). Circle on the left side of the figure mark the stratigraphic position of the 36 clast counts used to construct this diagram. Total clasts couted = 3420.

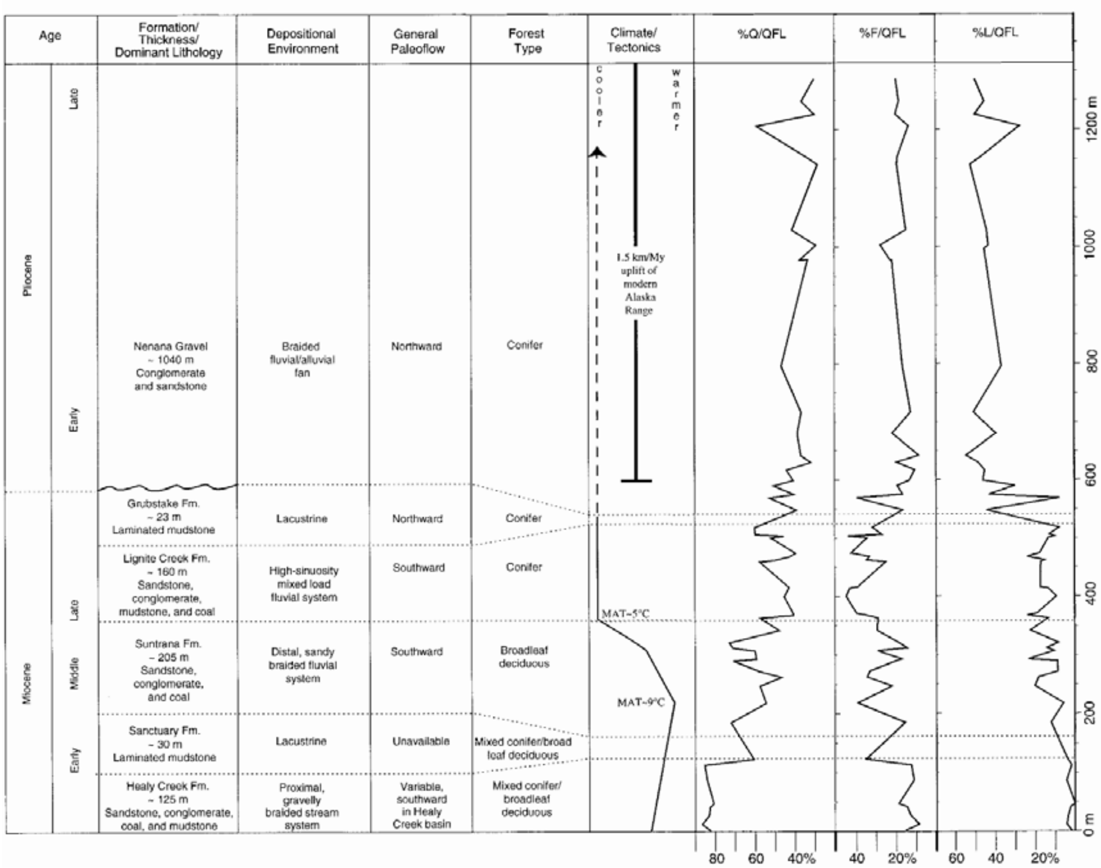

Figure 11. Summary diagram for the Usibelli Group and the Nenana Gravel (Ridgway et al., 1999)

Stop 1.2 Healy Creek overlook (Sean Bemis)

Directions:
From Suntrana Creek head west and take the first right on an unmarked road. Follow this road for approximately 1.2 miles to a pullout on the left side with a wooden fence surrounding it. There is one section of this road that may prove too rough for low clearance vehicles. Arrange to ride with someone else at the base of the road if you are worried about your car.

The Sugar Loaf Mountain Enigma:
Looking southwest from the lookout you will see Sugar Loaf Mountain, a prominent light gray-colored ridge that stands out in strong contrast to the dull brown of the remainder of the Mount Healy anticline. Sugar Loaf consists of rhyolite that has been intruded by andesite and overlies the Birch Creek Schist (Wahrhaftig, 1970a; Albanese, 1980). Wahrhaftig (1970a) also mapped a small exposure of the Healy Creek Formation underneath the rhyolite, which he interpreted as a viscous plug dome. This interpretation appears to suggest that the rhyolite was extruded essentially onto the present land surface (cross-section B-B', Wahrhaftig, 1970a). Albanese (1980) provided the first ages for the Sugar Loaf, using the K-Ar dating method to constrain the age of the rhyolite between 32-34 Ma. Triplehorn et al. (2000) point out that this clearly would be too long for the preservation of a volcanic edifice. They also suggest that the sediments underneath Sugar Loaf belong to the Early Miocene 'upper' Healy Creek Formation, as this is the portion of the formation that is exposed at its nearest location at Suntrana Creek, about 8 km away. Therefore, Triplehorn and others (2000) suggest several possible scenarios to explain this dilemma:

1) If the age assignment by Albanese (1980) is somehow wrong, and the cross-sectional interpretation by Wahrhaftig (1970) is correct, then that would suggest a very young age for Sugar Loaf. Nearly the entire thickness of Tertiary sediments (~1600m) that exist at Suntrana Creek, just 10 km north, would be removed during uplift of the Mount Healy anticline, with the eruption of Sugar Loaf trapping the small patch of the Healy Creek Formation. However, there is no reason to be suspect of the ages of Albanese (1980), and further, unpublished Ar-Ar ages (Bemis, personal communication) on biotite grains in the rhyolite and hornblende grains in the andesite appear to confirm the published ages.

2) Therefore, if we assume that the 32-34 Ma age assignment is correct, then Sugar Loaf certainly did not erupt onto the present land surface. But if it did erupt onto the land surface at some point, then it calls into question the assignment of the sediments underneath Sugar Loaf to the 'upper' Healy Creek Formation. The 'lower' Healy Creek Formation is assigned to the Early Oligocene, which would correspond with the age of Sugar Loaf. Triplehorn et al. (2000) are suspicious of this assignment because the nearest exposures of the Healy Creek Formation (8 km north) are clearly the upper member. However, Wahrhaftig et al. (1969) mention a locality ~13 km northeast of Sugar Loaf

where there are exposures of the Healy Creek Formation that they suggest are much older. So, given that the Healy Creek Formation was deposited on a surface of moderate relief (Wahrhaftig et al., 1969), perhaps the lower member was preserved in localized depressions. However, in this scenario, for Sugar Loaf to be preserved, it would have to be preserved beneath rapidly accumulated sediments.

3) A third possibility is perhaps Sugar Loaf was intruded into the relatively unconsolidated Usibelli Group sediments, acting somewhat as a sill by intruding into the Usibelli Group/schist unconformity.

Stop 1.3 Healy fault trench (Sean Bemis)

Directions:
From the Healy Creek overlook, drive back out the Parks Highway, turn left (south) and drive 1.7 miles to an unmarked road on the east side of the highway directly across from Otto Lake road on the west (Fig. 12).

Overview:
To access the Healy fault, we will follow a road that used to lead into the town of Healy when it was just a small train depot on the Nenana River.The road leaves the Parks Highway on moraine deposits from the Healy glaciation, and then drops through a gully down to the uppermost terrace from the Riley Creek glaciation. The road crosses at least 3 prominent terrace levels that the road will cross.

Thorson (1979) first recognized the Healy fault while working as part of the Northern Alaska Range Early Man project. He noted that the older terraces were offset a greater amount across the fault, suggesting multiple faulting events. He also found exposures of the fault in a gully at its eastern end near the Nenana River with evidence indicating it was a S-dipping normal fault. However, Bemis (2004) reinterpreted the fault as a N-dipping reverse fault, due to a 3-point problem presented by an offset in the riser of the topographically higher Healy moraine and the trace of the fault. Also, he notes the trend of the fault scarp corresponds exactly with the strike of N-dipping bedding in the underlying Usibelli Group, and suggests the Healy fault is a flexural-slip fault.

Access the trench following instructions in the road log. The fault scarp forms a prominent E-W trending step in the topography that beavers have used as a wall for construction of their dams.The trench was opened on August 20th, 2005, will be backfilled after the field trip visit to this stop. It exposes stratigraphic evidence for at least 2 reverse faulting events, with additional events likely due to the size of the scarp relative to the magnitude of offset in the observed events.

Old Healy Road log

0 Intersection of Otto Lake Road and the Parks highway. Turn left

onto the unlabeled gravel road. See Figure 12.

0.3 Stay right at cemetery sign.

0.6 Edge of Healy moraine deposits. The hill on the left offers a view of the lower Riley Creek terraces.

1.0 Access trail to Healy fault trench. Follow the ATV track south to where it merges with another trail, turn left. Take the first right that leads out to an open, drained beaver pond. Turn right and the trench is a short distance back to the west along the forested fault scarp.

1.2 Edge of upper Riley Creek terrace.

1.6 Powerline clearing with Healy fault scarp a short distance to the right.

1.8 Fork in the road, turn right.

2.1 Healy fault scarp with stream flowing along base of scarp.

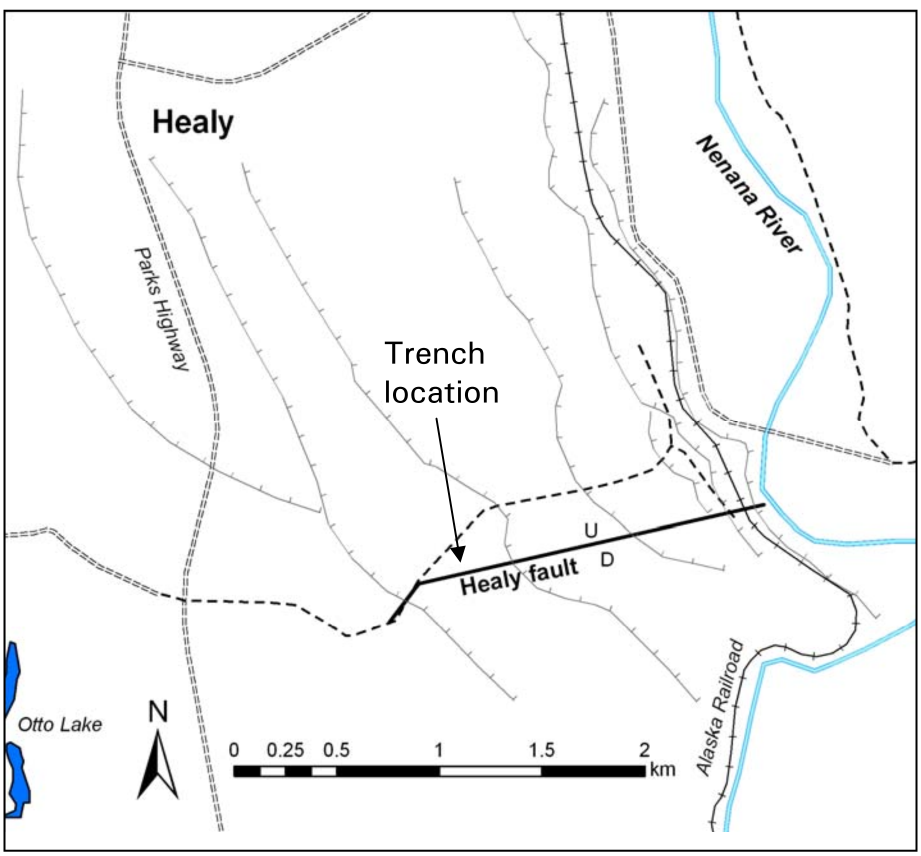

Figure 12. Map of Healy fault location. Double-dashed lines are paved roads and single-dashed lines are gravel roads. Gray lines with hachures delineate terrace risers.

DAY 2

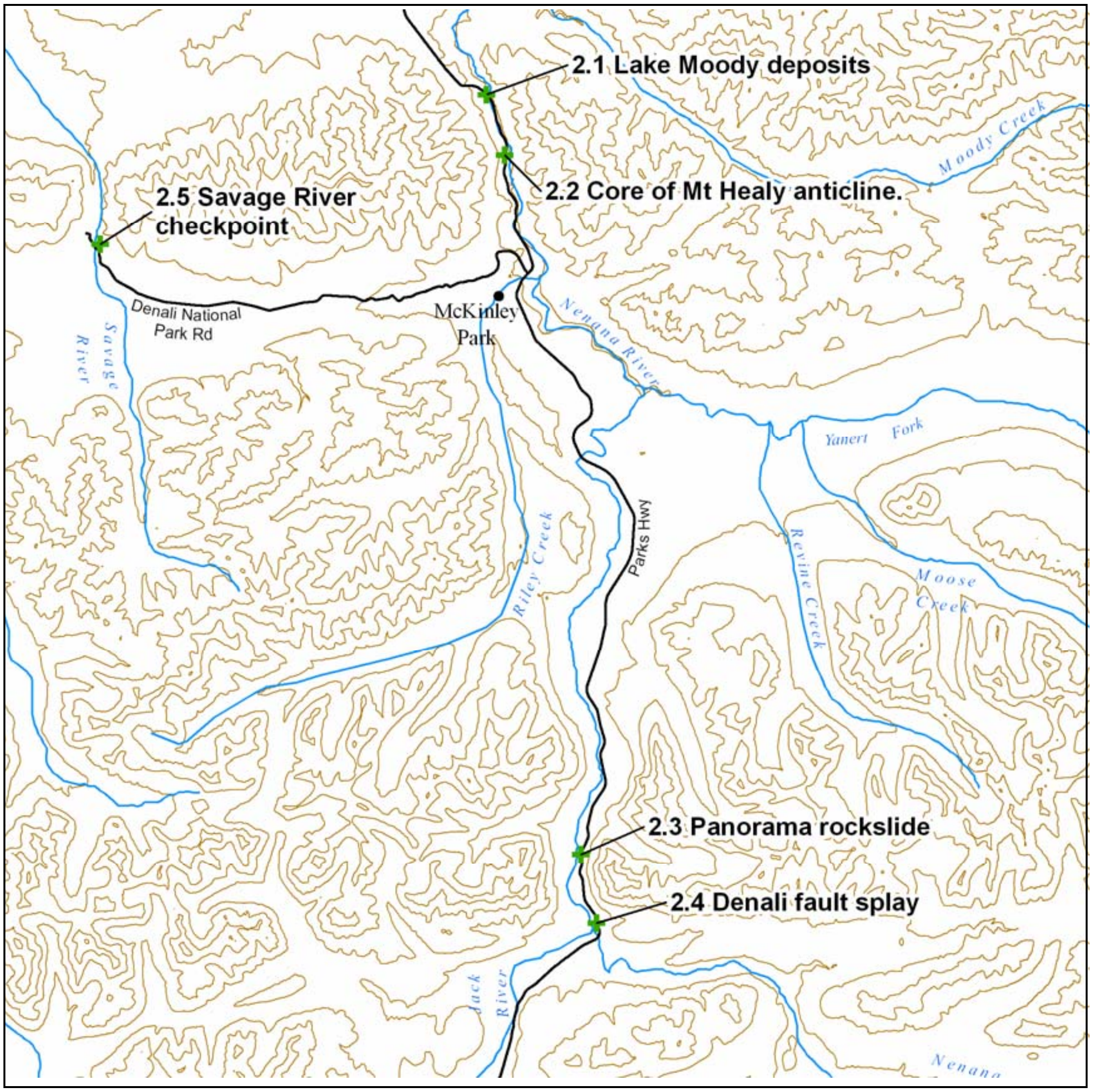

Figure 13. Map of stops on Day 2.

Day 2 road log

Drive south from FOP Headquarters and zero your odometer at the intersection of Healy Road and the Parks Highway.

0.0 Healy Road intersection.

On the skyline to the east, note the long ramp on the northern side of the Mt. Healy anticline. This is an exhumed remnant of the pre-Usibelli Group unconformity. (0.5mi. from Otto Lake Rd)

5.1 Bison Gulch. Incised alluvial fan.

5.2 Lake Moody sediments. The deposits are exposed in a freshly plowed (Aug. '05) roadcut, exposing silt overlain by clay with several possible soft sediment deformation features. Discussion of Glacial Lake Moody is in Stop 2.1.

6.0 Pullout immediately south of Nenana Gorge bridge. Stop 2.1.

Stop 2.1 Glacial Lake Moody (Sean Bemis)

Overview:
Lake Moody and Healy glaciation (summarized from Wahrhaftig (1958)):
Just south of Healy, the Parks Highway ascends onto the terminal moraine of the Healy glaciation (Table 1). The outermost extent of these deposits is defined by 6 or 7 parallel arcuate ridges, and to the south of these are numerous kettles and large conglomerate boulders. The highway follows the moraine deposits for a short distance, and then traverses across portions of alluvial cones that built out from the small tributary drainages to the west. Bison Gulch exposes a cross-section into one of these alluvial cones. On the north side of the bridge over the Nenana River, just south of Bison Gulch, is an exposure of fine-grained lacustrine clays. These clays were deposited into what Wahrhaftig (1958) referred to as Glacial Lake Moody, a lake formed by the damming of the Nenana River behind the Healy glaciation terminal moraine. This lake was gradually filled with lacustrine clays and by small deltas that formed in the same manner of the tributary drainages that created the alluvial cones near Bison Gulch. One of these deltas can be seen from the pullout south of Dragonfly Creek by looking across the canyon to Sheep Creek and the steeply dipping foreset beds exposed above the railroad tracks on the north side of the creek. These sediments filled the valley carved out by the Healy glaciers, and the deltas and alluvial cones formed from the longer drainages to the west forced the Nenana River against the eastern wall of the canyon. Thus, when the Nenana River began to incise, it cut a bedrock gorge into this eastern wall, rather than reoccupying the valley that was filled by Lake Moody.

Stop 2.2 Core of Mt. Healy anticline (Evan Thoms)

Directions:
At 7.8 miles south from the intersection of Healy Road and the Parks Highway is a paved pullout on the west side of the road opposite a large exposure of schist.

Overview
Because we have been focusing on deformation of the Pleistocene landscape, it is easy to forget the effects of orogeny on the underlying bedrock. At this stop we have an opportunity to explore the relatively unweathered interior of the Mt Healy anticline and look for evidence within the Birch Creek Schist for recent tectonism. Immediately evident is the tight folding throughout the exposure. The hinges of these folds trend predominantly roughly east-west, presumably reflecting north-south compression during the Late Cretaceous orogeny.

Also obvious are a number of low-angle south-dipping faults cutting through the exposure. During the brief reconnaissance visit I made to this stop before the field trip, I could not identify any offset markers to get a sense of displacement. The dips of the faults and the fact that we know these rocks have most recently been undergoing compression suggest that these are north vergent reverse faults. Were they formed in the Late Cenozoic to accommodate growth of the Mt. Healy anticline or are they older?

Road log, continued

11.7 Highway crosses the Park Road fault, a north dipping back thrust.

11.8 Northernmost extent, roughly, of the youngest glaciation in the Nenana River valley, the Riley glaciation, dated at 17-25 Ka. During this advance, ice from the Yanert glacier (up the Yanert Fork valley to the SE) merged with ice flowing north off a large ice sheet that covered Broad Pass and the headwaters of the Nenana River. This is also, roughly, the southernmost extent of glacial Lake Moody.

13.2 Highway crosses the Hines Creek fault, a major terrane boundary. Significant dextral slip ended at least by 95 Ma, the age of an un-faulted pluton that truncates the fault (Wahrhaftig et al., 1975). But Trop and Ridgway (1997) have evidence from the Lower Cantwell Fm that suggest that at least a segment of the fault was active as recently as 70 – 80 Ma.

~15.5 The Yanert Fork merges with the Nenana River about 2 miles east of here. Based on paleocurrent indicators and clast lithologies, during most of Nenana Gravel time, the ancient Yanert Fork was probably the principal drainage carrying sediments into the central Nenana Gravel basin.

18.4 Northernmost extent of a proglacial lake that preceded the Carlo advance of the Riley glaciation.

30.3 Pullout on west side. Park for Stop 2.3 and walk ¼ mile down the highway to a slight curve in the road to the left and boulders visible through the brush to the right.

Stop 2.3 Panorama rockfall (Jim Begét)

Directions:
The safest parking for this stop is at a pullout about ¼ mile north of where we will walk into the brush to get a good view of the boulders. If the road is not busy and you have a small car, you can park on the shoulder.

Overview:
The 2002 Denali Fault earthquake triggered many large rockfalls and some huge rockfall avalanches from mountains adjacent to the fault trace. Many of these fell on glaciers, and are unlikely to be preserved in the geologic record. A prehistoric giant rockfall avalanche from the west face of Panorama Peak covers approximately 10 square kilometers, and may have been generated by an earthquake on the nearby Denali Fault. The rockfall can be distinguished from Pleistocene glacier deposits in the same area as it contains huge blocks of fractured rock derived from Panorama Peak set in matrix consisting exclusively of the same lithology. The surface of the rockfall is hummocky, and most of it lies across the river from the highway. Unpublished studies of the rockfall by Beget and his students indicate the rockfall is about 500 years old. This is consistent with other data suggesting the most recent major earthquake on the portion of the Denali Fault lying west of the 2002 rupture also occurred about 500 years ago.

Stop 2.4 Denali fault splay and 2002 earthquake (Jim Begét, Evan Thoms, Patty Burns, Gary Carver)

Directions: At 32.5 miles south of the intersection of Healy Road and the Parks Highway, park in a paved pullout on the west side of the highway.

Overview:
Splay of Denali fault
A splay of the Denali Fault is exposed in the road cut opposite the pullout. Pleistocene glacial till is juxtaposed against bedrock in the roadcut. There is no surface relief on the fault splay, suggesting it has not been active in Holocene time, but it probably continues to the east between Panorama Mountain and a large unnamed bedrock hill.

2002 earthquake and damaged trees
After the 2002 Denali Fault earthquake a number of damaged trees were found near where the fault crosses the Richardson Highway (Carver et. Al, 2003). Evidence for damage included concentric cracks around the bases of trees from strong ground shaking, trees that had been tilted or knocked over, and trees that had been split but not toppled. Some of the trees carried scars from previous damage. Annual ring counts from damaged trees indicate that the previous event was the 1912 Ms 7.2-7.4 Delta earthquake that had an epicenter within 60-90km of the Delta River. Data and observations from the 1912 event suggest that the rupture propagated toward the west. Anyone want to core some trees?

2002 earthquake and recent paleoseismic research

For the past three seasons, researchers have been investigating the paleoseimology of the Denali fault. Here are two recent abstracts that document some of the work:

Abstract from Haeussler et al., 2004:

The 3 November 2002 Denali fault, Alaska, earthquake resulted in 341 km of surface rupture on the Susitna Glacier, Denali, and Totschunda faults. The rupture proceeded from west to east and began with a 48-km-long break on the previously unknown Susitna Glacier thrust fault. Slip on this thrust averaged about 4 m (Crone et al., 2004). Next came the principal surface break, along 226 km of the Denali fault, with average right-lateral offsets of 4.5-5.1 m and a maximum offset of 8.8 m near its eastern end. The Denali fault trace is commonly left stepping and north side up. About 99 km of the fault ruptured through glacier ice, where the trace orientation was commonly influenced by local ice fabric. Finally, slip transferred southeastward onto the Totschunda fault and continued for another 66 km where dextral offsets average 1.6-1.8 m. The transition from the Denali fault to the Totschunda fault occurs over a complex 25-km-long transfer zone of right-slip and normal fault traces. Three methods of calculating average surface slip all yield a moment magnitude of M_w 7.8, in very good agreement with the seismologically determined magnitude of M 7.9. A comparison of strong-motion inversions for moment release with our slip distribution shows they have a similar pattern. The locations of the two largest pulses of moment release correlate with the locations of increasing steps in the average values of observed slip. This suggests that slip-distribution data can be used to infer moment release along other active fault traces.

Abstract from Matmon et al., 2004:

Preliminary results of in-situ cosmogenic ^{10}Be analysis from boulders (n = 16) and sediment (n = 4) collected from one terminal and two lateral moraines offset by the Totchunda and Denali Faults, respectively, suggest ages that range from 12.2 ± 1.3 to 16.7 ± 1.8 ky. The offset moraines have broad crests with relatively few large boulders (> 1 meter in diameter) protruding above the surface. Most of the boulders are composed of quartz pegmatites, granite, and gneiss. Two of the sampled moraines, which are offset approximately 150 meters, are located along the part of the Denali Fault that ruptured in November 2002. During sampling, we avoided boulders that were clearly pushed to the surface by permafrost and fault activity. The sediment samples consisted of hundreds of small (approximately 1 cm) clasts from the surface in the area between the sampled boulders. On one moraine the sediment samples (n = 2) yielded an average age of 11.9 ± 1.3 ky, identical to the boulders (n = 7; 12.2 ± 1.3 ky). On the second moraine the sediment samples (n = 2) yielded an average age of 11.6 ± 1.2 ky, slightly younger than the boulders (n = 5; 14.1 ± 1.5 ky) although similar within 1 sigma. We interpret this difference being the result of mixing of surface and depth material by bioturbation and freeze-thaw cycles. The four boulders that were sampled from the terminal moraine, offset approximately 100 m, yielded an average age of 16.7 ± 1.8 ky. All of the cosmogenic ages were corrected for snow cover of 1 meter over 8 months and boulder surface erosion (1 mm/ky). Age calculation based on cosmogenic analysis are moderately sensitive to the modeled snow cover, but are relatively insensitive to the modeled erosion rate as long as these values are within the accepted range for this region (1-3 mm/ky). Because these moraines were derived from very small drainage basins (1-5 km^2), we assume that cosmogenic nuclide inheritance is low. Therefore, ages were not corrected for possible pre-deposition cosmogenic nuclide inheritance. Preliminary ages of the offset moraines imply an average slip rate since the late Pleistocene of 9 to 13 mm/yr on the Denali Fault and 6 mm/yr on the Totchunda Fault. This difference in rates is expected because slip along the Denali Fault is partitioned between the Denali and Totchunda Faults east of the Little Tok River. These rates are consistent with short term paleoseismic rates for the past approximately 1000 years.

Denali Park road

Directions:
Drive north approximately 20 miles to the Denali Park National Park entrance and follow signs to the park road or Savage River checkpoint. You can drive to the checkpoint with no fee (about 15 miles).

Cantwell Basin overview (Evan Thoms):
As you drive into the park, consider the history of the Cantwell Basin as it raises some interesting questions concerning the recent deformation on which we are focusing. Trop and Ridgway (1997) interpret the Cantwell basin as having formed as a piggy-back (or thrust top) basin in the northern part of the suture zone associated with the Late Cretaceous accretionary event (see Geologic Setting). The basin was filled by the Cantwell Formation, which has two distinct units: a lower, mostly sedimentary unit consisting of fluvial, lacustrine, and marginal marine deposits deposited between 85 and 67 Ma and an upper, mostly volcanic, unit deposited between 60 and 54 Ma (Cole et al., 1999). Sedimentological data from the lower Cantwell Formation suggest that a large upland of Birch Creek Schist was positioned closely to the north basin margin (Trop and Ridgway, 1997), as in the present day. But in order to deposit Usibelli Group sediments within the Cantwell basin and Nenana Gravel sediments north of the basin, the anticline could not have existed as a major barrier to stream flow. If the schist found within the lower Cantwell is indeed from the ancient Mt. Healy anticline, the only plausible explanation is that the relief of the anticline was reduced by erosion and then rejuvenated in the Late Cenozoic. A similar argument can be made for the mountains to the south of the Cantwell basin based on a distinctive limestone that appears in both the lower Cantwell and some Nenana Gravel sections both within and slightly north of the Cantwell basin.

The upper Cantwell Formation is remarkable in that paleocurrent measurements suggest the presence of a volcanic center not far to the southeast. These deposits could be the erupted products related to the emplacement of plutons in the heart of the Alaska Range.

Stop 2.5 Savage River Checkpoint (Sean Bemis)

Overview:
This is the end of open road access for Denali National Park. On the drive in, we were following a long, linear ridge of the "Birch Creek Schist" to our right and the Hines Creek fault somewhere to our left. The fault forms the southern boundary of the metamorphic basement that underlies the northern foothills. Since we left the park headquarters and the Nenana River, we have been following essentially east-west oriented drainages until again we find a north-flowing stream at the Savage River. As the park road continues to the west, it crosses the Sanctuary, Teklanika, and Toklat River, all of which have relatively parallel NNW-trending courses. In order to flow north, these streams have to cross 2 large east-west trending ridges, clearly indicating the youth of these ridges relative to these major streams (Fig. 14).

Approximately 1.5 km downstream from the bridge over the Savage River there is a prominent bedrock knickpoint. This is accessible by walking down the maintained trail on either side of the river to the small footbridge, then hiking along the edge of the stream (either side of the river will get you there) until you reach a small waterfall. Below the waterfall you will notice that the banks of the river are steep and rocky.Compare this to the streambanks you walked along downstream to the waterfall, much of it bouldery, but appearing to have had time for hillslope processes to act.

This knickpoint in the stream profile (Fig. 15) occurs along the axis of the Mount Healy anticline (Thoms, 2000; Bemis, 2004), and Bemis (2004) points out that a similar knickpoint occurs on 3 other streams that flow across this structure to the west. Two likely explanations for this knickpoint are the lithology change to metamorphic rocks in the Mount Healy anticline from Tertiary sedimentary rocks in the downstream reaches, or recent uplift of the anticline. Bemis and Wallace (in revision) argue the knickpoint is due to tectonic activity of the Mount Healy anticline since 2 of these streams, the Sushana and the Teklanika, cross the Stampede anticline, which is cored by similar metamorphic rocks, and neither shows a knickpoint at this structure (Fig. 15).

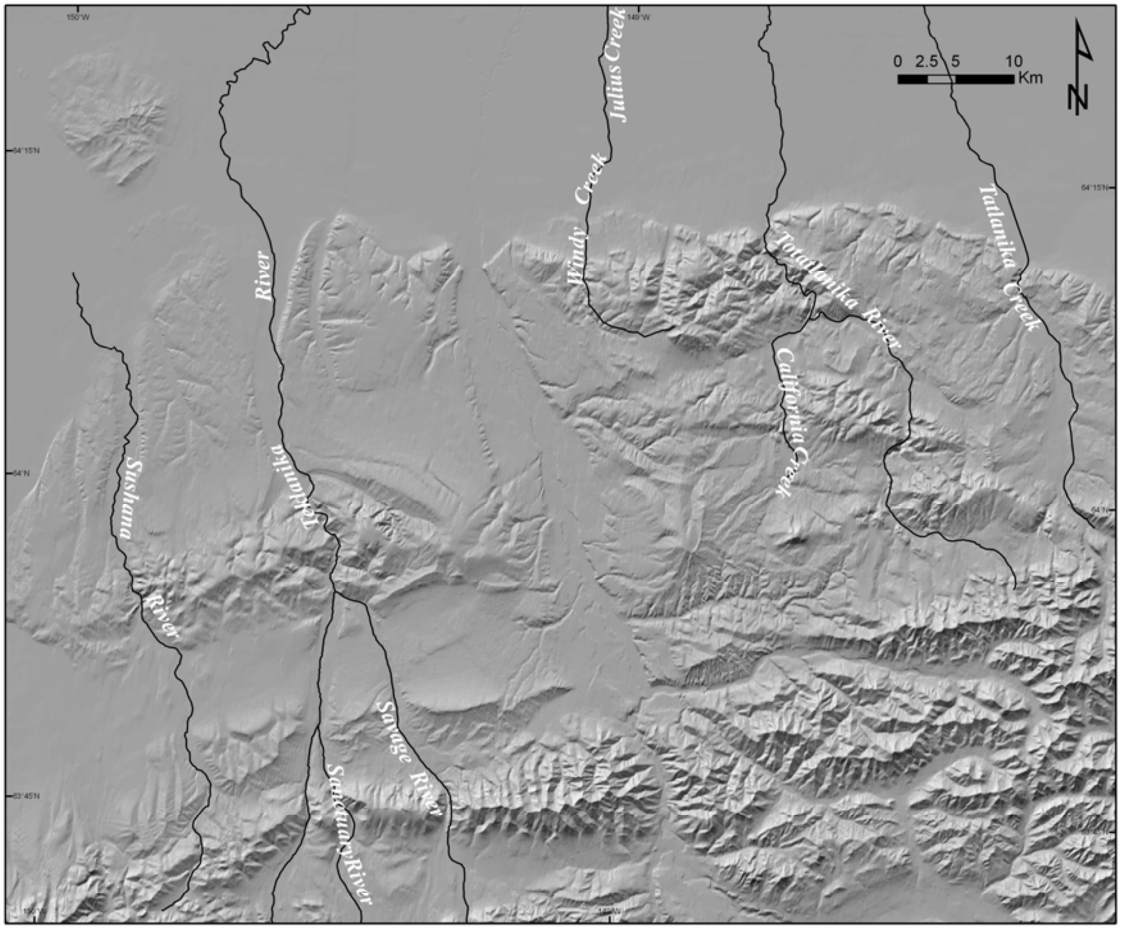

Figure 14. Map of streams used by Bemis (2004) for long profile analysis. Steams east of the Nenana River are not discussed in the text but profile plots are shown in Fig. 15.

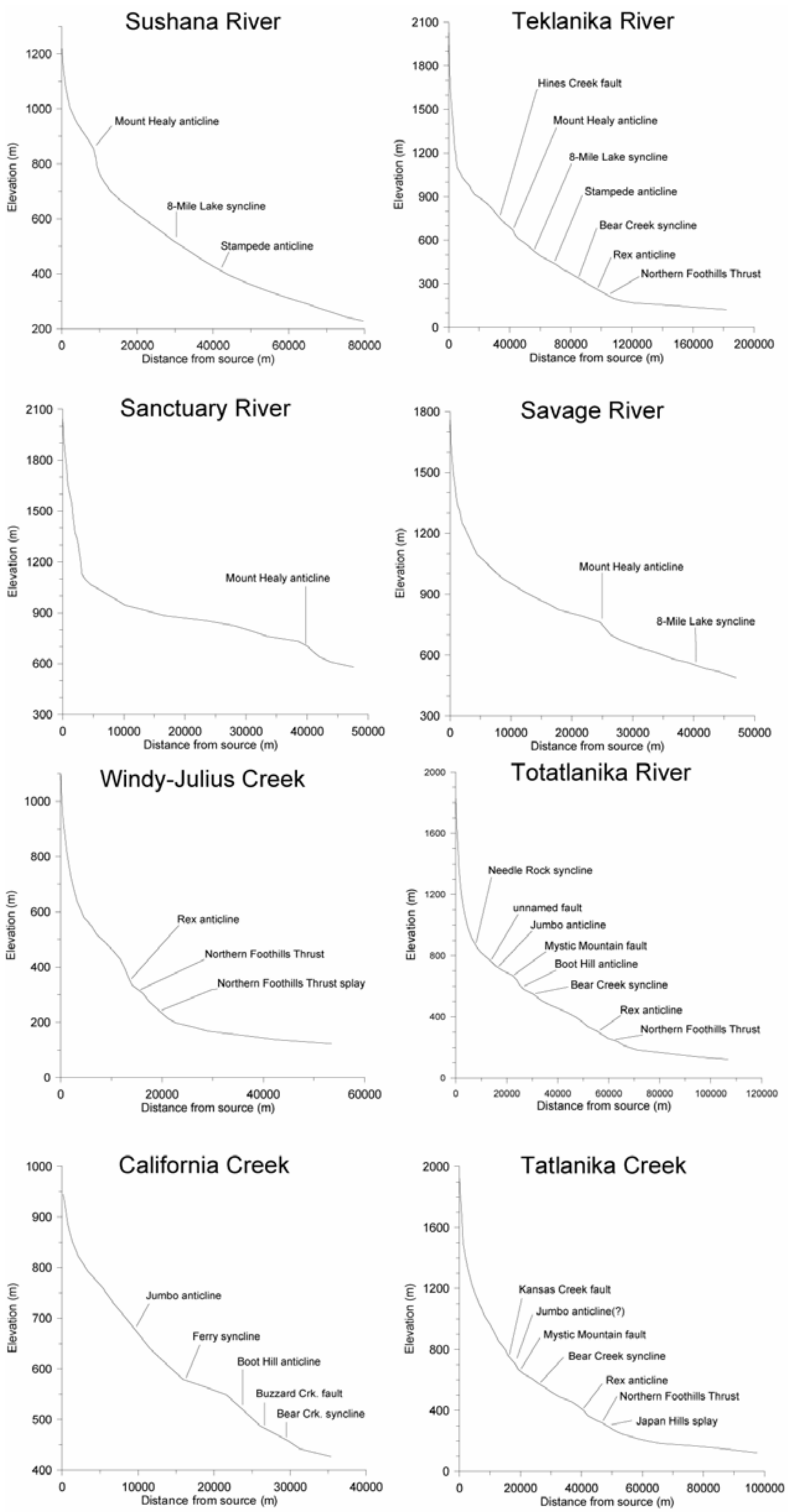

Figure 15. Long profiles of streams analyzed by Bemis (2004). The lower four graphs are for streams east of the Nenana River, which are not discussed in the text.

DAY 3

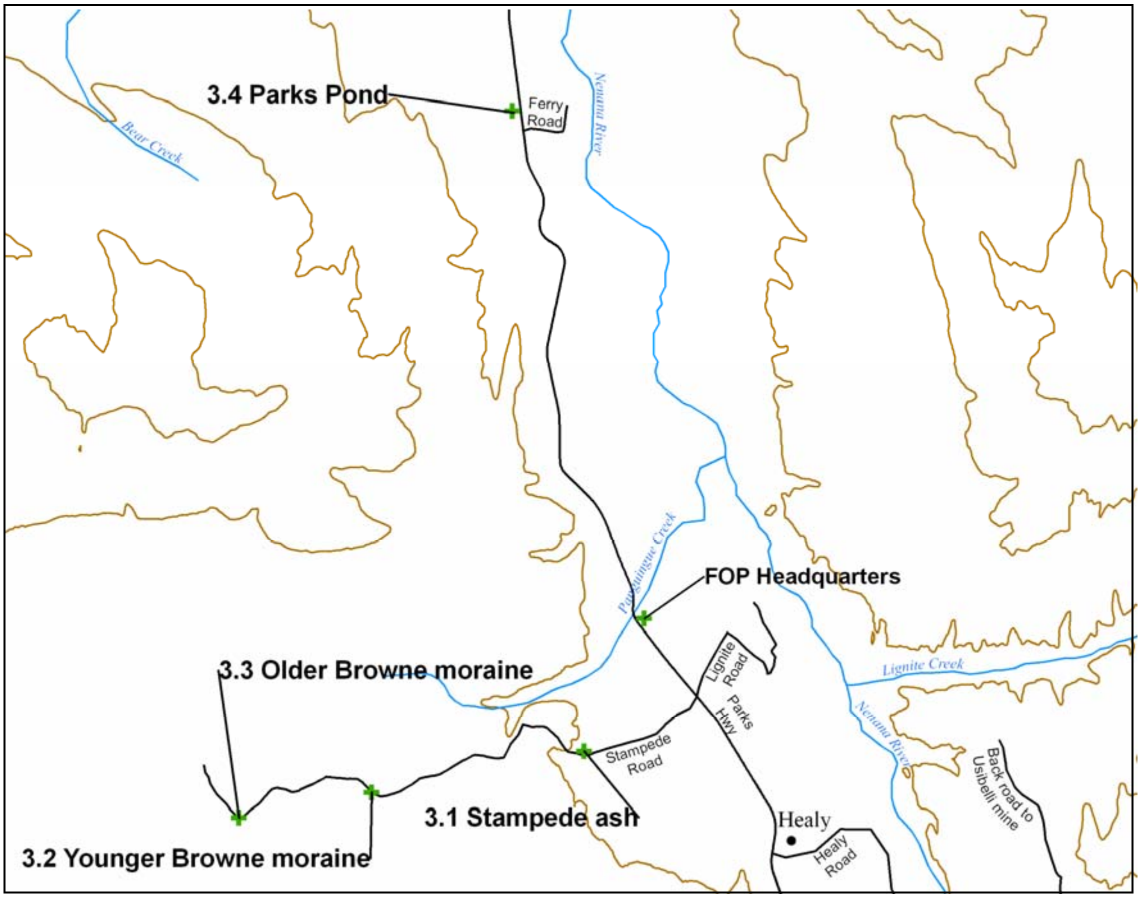

Figure 16. Map of stops on Day 3 in the Nenana valley.

Day 3 road log

Mileages on Day 3 are base on the intersection of the Stampede Road and the Parks Highway. Turn left (south) out of the Panguinue Creek gravel pit and drive 1.2 miles to the Stampede Road. Turn right (west) and zero your odometer.

Stampede road (Sean Bemis)

This road was originally built to access the Stampede Mine, which was an active antimony mine between 1935 and 1970. The road is currently maintained for the first ~8 miles (13 km) and then degrades rapidly into a very rough off-road vehicle track with several difficult stream crossings. Approximately 30 miles out this road, next to the Sushana River, is an old bus made famous by Jon Krakauer in his book Into the Wild.

The road ascends from late Pleistocene stream terraces into mid-late Pleistocene moraine deposits, and then reaches its high point on early-mid Pleistocene moraines. For this stretch, the road also follows the axis of a syncline that is clearly defined by the folded upper surface of the Nenana Gravel.

At the intersection of Parks Highway and Stampede road, the highway is on alluvium shed onto the highest Riley Creek terraces and the Stampede Road heads west into a gap eroded into a terrace correlated with the ~70 ka Healy glaciation. Bemis (2004) interprets the Healy Creek fault, a north-dipping reverse fault, to trace through this gap, due to the 8-10 m offset of the terrace tread and the alignment with the previously mapped trace of the fault to the east.

Stop 3.1 Stampede Ash (Jim Begét)

Directions:
At mile 1.7 pull off at a gravel pit

Overview:
Beget and Keskinen (1991) defined the Stampede Tephra here and discuss its deformation within a push moraine, placing a constraining age on the Lignite Creek glaciation. Recent work in this area is being done by Dylan Ward and Bob Anderson of the University of Colorado, Boulder who will be using cosmogenic isotopes to date glacial terraces in the Nenana valley.

Stop 3.2 Younger Browne moraine (Sean Bemis)

Directions:
Drive west on the Stampede Roade 5.2 miles. You should be at the top of a small rise in the road.

Overview:
This is the crest of the first of 2 moraines that Wahrhaftig (1958, 1970b) correlated with the early to mid-Pleistocene Browne glaciation. Looking north, you can see how this subdued ridge and the next ridge to the west bounds Eight-Mile Lake. Furthermore, north-south drainage is restricted by the folding of the Eight-Mile Lake syncline, thereby trapping the lake at the pass between the Nenana River and Savage River drainages.

Looking east, you can see the Usibelli Coal Mine, Jumbo Dome (a 2.8 Ma intrusion), several terraces across the Nenana River (one which shows subtle folding, just south of the mine), and Sugarloaf Mtn (I think..). The large ridge forming the skyline to the south is composed of the 'Birch Creek Schist' a perhaps improper, but widely used, name for the metasedimentary rocks (Precambrian – Paleozoic protolith, Bundtzen and Turner (1979)) that are the lowest unit recognized in the foothills north of the Hines Creek fault. This ridge forms the crest of the Mount Healy anticline (Thoms (2000)), the southernmost fold of the northern foothills fold-and-thrust belt. The intervening ridge is composed of the Nenana Gravel, and folding of the southern limb of the Eight-Mile Lake syncline has tilted this unit up to 45° N. Also note that as you follow this ridge from its highest point along to the east that there is an abrupt step down in elevation of the ridge that aligns with the south projection of the moraines that we are standing on. This feature demonstrates that folding of the

Mount Healy anticline and Eight-Mile Lake syncline began prior to the Browne glaciation.

Stop 3.3 Older Browne moraine (Sean Bemis)

Directions:
At 7.2 miles pull off beside a cabin.

Overview:
This is the crest of the outer Browne moraine. Again, you can see how the roughly N-S orientation of these moraines within the E-W trending fold has trapped Eight-Mile Lake. Looking west, you can see the continuation of the Eight-Mile Lake syncline, defined by the N-dipping Nenana Gravel on the south and the Stampede anticline on the north. Flowing to the north across these structures are the Savage and Teklanika Rivers. Clearly these drainages were established with initial uplift of the northern foothills, and the terraces along the river show continuing deformation. There are a couple of important surfaces visible from here. The smooth surface on the highest region of the Stampede anticline is an exhumed unconformity surface where the Tertiary sedimentary rocks have been eroded off the metamorphic basement. Also, visually defining the Eight-Mile Lake syncline is the upper surface of the Nenana Gravel. Immediately west, notice how the drainage from the ridge to the south limb of the fold flows north, and then is abruptly diverted to the west by a large step in topography. Bemis (2004) interprets this topographic step as the westward continuation of the Healy Creek fault. Finally, about 0.75 km south along this moraine is a large granitic glacial erratic.

Stop 3.4 Parks Pond (Evan Thoms)

Directions:
After returning to the intersection of Stampede Road and the Parks Highway, zero your odometer and head north. At mile 9.7 there is a pullout on the east side of the highway just before Rock Creek Road. Park here or in the pullout to Parks Pond 0.2 mile to the north on the west side.

Overview:
We will look at two exposures here. The southern exposure is directly across the highway from the southern pullout and the northern exposure makes up the western wall of the Parks Pond pullout. The Parks Pond exposure, in particular, has puzzled Alaskan geologists for years. Wahrhaftig mapped it as distal Nenana Gravel overlain by outwash from the Healy glaciation. Others believe the deposits are wholly Pleistocene. Thorson (1986) described a lodgement till within the lower part of (presumably) this exposure and took it to as evidence for a glacial advance during Nenana Gravel time. The southern exposure is of thinly bedded silts and sands overlain by, clearly, glacial outwash. Where this section fits into the history of the Nenana valley is not clear.

Don Triplehorn at UAF has recently suggested that some soft sediment deformation features observed in Alaska Range Neogene sediments may be tectonic in origin. He has described clastic dikes from the Parks Pond exposure (Fig. 16) and convoluted bedding from within the southern exposure (Fig. 16) and suggest that they may have resulted from earthquake-induced shaking. However, there are many processes that may also produce these features including sudden loading (perhaps at this exposure from the overlying debris flows), natural slumping, or even from being overridden and loaded by glaciers. One objective of this stop is to solicit suggestions from visitors who have seen earthquake liquefaction features elsewhere to comment on the origin of the structures exposed here.

Figure 16. Clastic dike from the Parks Pond exposure. Photo by D. Triplehorn

Figure 17. Convoluted bedding and flame structures from the exposure south of Parks Pond. Photo by D. Triplehorn.

Stop 3.5 Tanana River overlook (Evan Thoms)

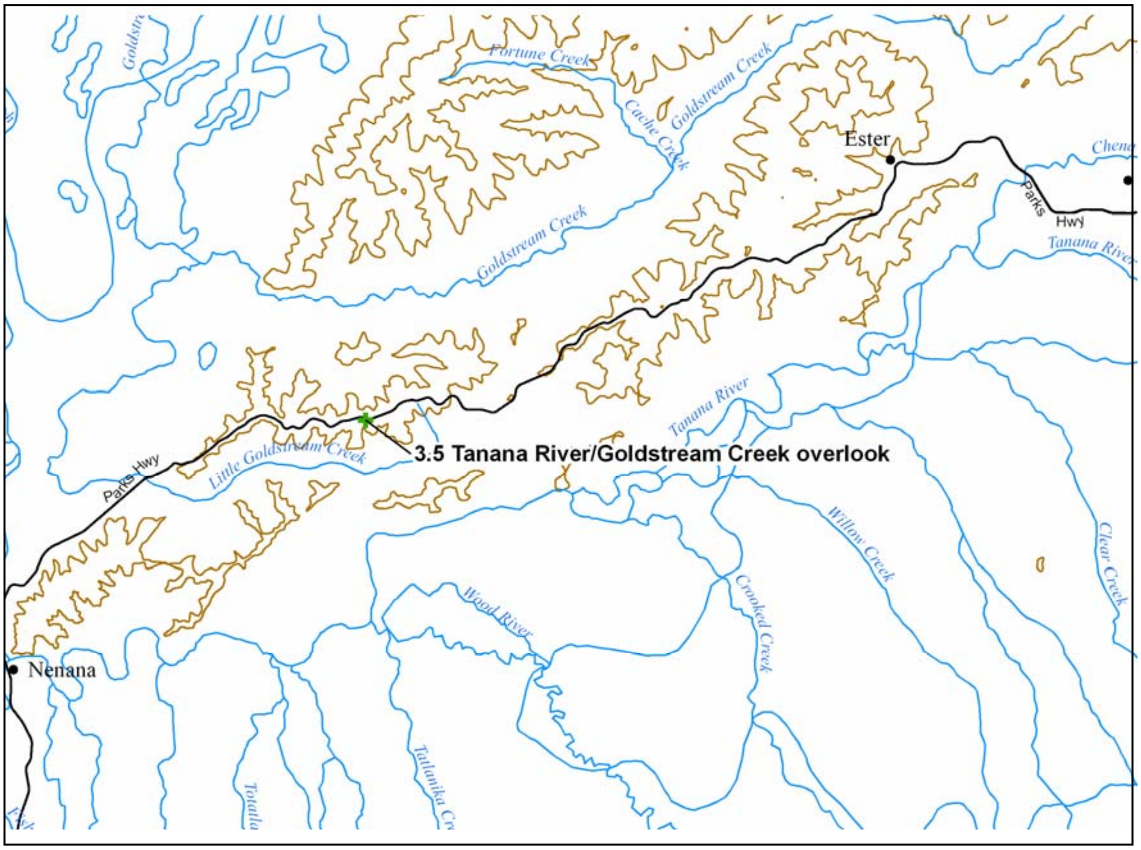

Figure 17. Map of last stop on Day 3 (roughly located)

Directions:
To be announced on the field trip.

Overview
Mark Lesh, Ken Ridgway, and J. White wrote this abstract for the 2001 GSA meeting in Boston:

Geomorphologic, stratigraphic, seismological, and palynological data indicate that the Neogene foreland basin of the Alaska Range is an actively deforming landscape and has been since the Miocene. The strata of the Neogene foreland basin consist of the Miocene Usibelli Group (approximately 600 m thick), the Pliocene Nenana Gravel (approximately 1000 m thick), and unnamed Quaternary deposits. Evidence of active deformation is derived from digital topographic data and Landsat 7 imagery that document the interaction between fluvial systems and basement-cored folds in the foreland basin. For example, in the distal part of the foreland basin, the Goldstream anticline is a plunging anticline whose western nose is buried by modern deposits of the foreland basin. The abrupt deflection of the Tanana River around the nose of this anticline and the documentation of several wind gaps along the western end of the anticline suggest that the Tanana River has had to abandon its channel several times due to recent uplift along this fold. In the proximal part of the foreland basin, similar relationships can be shown between the McKinley River and the Kantishna Hills anticline. Seismicity data from both the Goldstream and Kantishna Hills anticlines also document active deformation. Evidence for Miocene and Pliocene deformation in the foreland basin comes from stratigraphic data. Documentation of abrupt changes in paleodrainage, local lacustrine deposits, regional changes in stratigraphy, and recycled palynomorphs indicate deformation coeval with sedimentation. Reconstruction of Miocene depositional systems indicates that the foreland basin was filled axially by a west-southwestward prograding deltaic system. The Pliocene foreland basin was characterized by northward prograding, transverse braided streams systems.

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