Engineering/Fault Zone Crossing Design Glennallen to Palmer Spur Line

FINAL REPORT

October 2005

URS
2700 Gambell Street, Suite 200
Anchorage, Alaska 99503

Table of Contents

Figures

Tables

Appendices

Executive Summary

URS was retained by the Alaska Natural Gas Development Authority (ANGDA) to conduct a geologic study and conceptual engineering design of fault crossings along the proposed natural gas spur line from Glennallen to Palmer, Alaska. The spur line route crosses a number of faults that comprise the eastern portion of the Castle Mountain fault, also known as the Castle Mountain-Caribou fault system. Although previous investigations and aerial photographs contain little to no clear evidence of Holocene faulting in the study area, two recent earthquakes have been attributed to the Castle Mountain fault in the Sutton area, and Holocene surface breakage has been well documented along the western portion of the fault in the Houston area.

The proposed spur line route crosses potentially active faults at five locations in the Chitna and Boulder Creek valleys between about MP 84 and MP 103: the Caribou fault (two separate crossings), two splays of the Caribou fault, and the Castle Mountain fault. A total of approximately 3.6 miles of the proposed route crosses mapped fault zones, and the total length of the route that falls within fault-related zones of uncertainty is 6.6 miles. Some crossings are relatively long due to the sub-parallel orientation of the faults and pipeline in several areas. Each crossing was staked in the field, and GPS coordinates, photographs, and surface soil samples were collected. The results of the field reconnaissance are summarized in Table 1, which provides mileposts at each crossing, zones of uncertainty, the likelihood of Holocene activity on each fault, fault orientation and sense of movement, and ground conditions.

Maximum displacement estimates and orthogonal components were calculated using several different approaches. A maximum magnitude 7.0 earthquake was conservatively used in these preliminary estimates based on studies of the western Castle Mountain fault, although the maximum earthquake on shorter splays of the eastern Castle Mountain-Caribou fault system may be less. Based on previous field studies, the fault crossings should exhibit dominantly vertical offset; however, the sense of movement during recent earthquakes to the west indicates that the fault system may respond more purely laterally. Based on these contradictions and other unknowns, maximum displacement was conservatively estimated to be 7 feet for both vertical and horizontal (right lateral) components at each fault crossing. The vertical sense is north-side-up at three of the crossings, and south-side-up at two crossings.

Considering the location, safety issues, and possible sensitive environment of the pipeline alignment, the preliminary design displacement is recommended as two-thirds of the maximum fault displacement, or approximately 5 feet for both vertical and horizontal components. Based on studies of the western Castle Mountain fault, a 700-year return period was conservatively used for the fault crossings; as this value lies within typical pipeline performance goal ranges, no additional design adjustments were applied. Both above ground and buried fault crossing designs are technically and economically feasible. However, considering safety concerns, the buried mode of crossing design is recommended for the fault crossings for this pipeline. With a double layer geomembrane liner and proper thickness design of the pipeline, this type of construction can accommodate both vertical and lateral directions safely.

Recommendations are provided for methodologies to further evaluate crossing length, maximum displacement, and return period at each fault crossing prior to final design. Based on the results of these investigations, the design permanent displacement and crossing length could be significantly reduced, and/or some faults could be eliminated from requiring special design.

1.0 Introduction and Setting

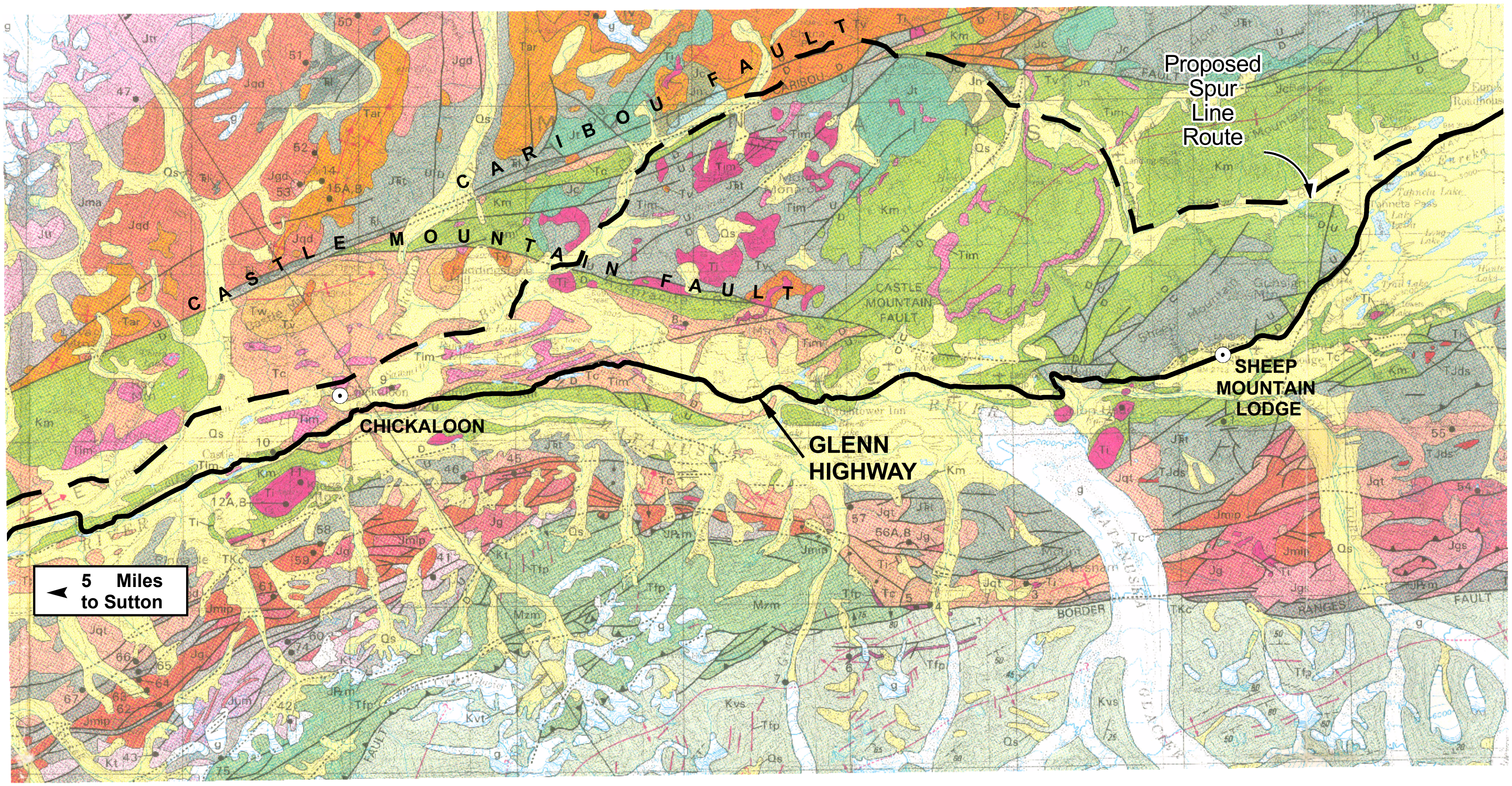
Presented in this report are the results of a geologic study and preliminary engineering design of fault crossings along the Alaska Natural Gas Development Authority's (ANGDA's) proposed natural gas spur line from Glennallen to Palmer, Alaska. The study was conducted in support of ANGDA's continuing work to bring Alaska North Slope gas to southcentral Alaska by 2009, and in response to ANGDA's Request for Proposal (RFP) 06-0411 dated July 11, 2005.

The proposed spur line is located in a tectonically active area of south-central Alaska, which features many large linear surface fault systems. The Castle Mountain fault system is one of the longest of these structures in the Matanuska-Susitna Valley and Cook Inlet basin. It is roughly 120 miles long, extending from the southwestern Susitna lowlands, where it may be contiguous with the Lake Clark fault, to the Talkeetna Mountains in the east. The Castle Mountain fault system consists of two parts. The western part, referred to as the Susitna segment, is known for its clear evidence of Holocene surface breakage, while the eastern Talkeetna segment has shown historic seismicity, but little evidence of surface breakage (Haeussler, et al., 2002; Lahr et al., 1986).

The Talkeetna segment of the Castle Mountain fault splits into two main faults in the vicinity of Castle Mountain near Chickaloon River (Figure 1). The northern fault, called the Caribou fault, continues along the same east-northeasterly trend as the western part of the Castle Mountain fault, while the southeastern branch becomes a shorter splay, but retains the name Castle Mountain fault. Subsidiary faults include a series of sub-parallel splays that branch off the Caribou fault, and several northeast-trending faults mapped in the wedge between the Caribou and Castle Mountain faults, including the East Boulder Creek and Hicks Creek faults. Collectively, the complex interconnected faults in this area are referred to as the Castle Mountain-Caribou fault system.

The proposed spur line crosses several splays of the Castle Mountain-Caribou fault system (Figure 1). West of Boulder Creek valley, the pipeline route is parallel to, but remains south of, the Castle Mountain fault. Thus, while the Castle Mountain, as well as buried plate boundary faults, could cause ground shaking effects on the pipeline during earthquakes, the pipeline is not expected to suffer significant lateral displacement during earthquakes in these areas. Thus, the focus of this study was on the potential for surface fault rupture at pipeline crossings within and east of the Boulder Creek drainage.

M:\Projects\2005\26219736 - ANGDA\mxd\Figure1 - Location Map.mxd



N

0 5 10

Miles

Source: Winkler (1992)

ALASKA NATURAL GAS DEVELOPMENT AUTHORITY
ENGINEERING/FAULT ZONE CROSSING DESIGN

PROJECT LOCATION AND GEOLOGIC MAP

GLENNALLEN TO PALMER SPUR LINE

URS

JOB NO:	26219736	DRAWN:	PLB
DATE:	9/05	FILE:	SEE PATH

FIGURE 1

2.0 Scope and Methodology

The scope of the study was based on ANGDA's RFP 06-0411 of July 11, 2005; URS Corporation's (URS') Technical and Cost Proposals dated July 27, 2005; and a kick-off meeting held between ANGDA and URS on August 2, 2005. The objective of the study was to evaluate the presence and nature of potentially active fault crossings along the proposed spur line route, and to develop a preliminary design approach and criteria for the pipeline crossings. As the study was intended to be preliminary in nature, final design will be based on soil investigations conducted during a later engineering and design phase of the project. Tasks included in the scope of work and completed during this study are described in the following subsections.

2.1 Data Review and Field Planning

- Published documents and maps on the eastern Castle Mountain fault system were obtained from the Alaska Resources Library & Information Services (ARLIS), U.S. Geological Survey, ANGDA, and the internet; and reviewed for information on the location, nature, and recency of faulting.

- High altitude infrared stereo aerial photographs of the study area, as well as color stereo aerial photographs of the pipeline alignment were obtained from ANDGA and Aeromap (1978; 2004), and reviewed in detail to identify potential evidence of surface faulting, such as lineaments and other geomorphic features.

- Geologists from the U.S. Geological Survey (USGS) and academia were contacted for specific knowledge of previous investigations, recency and style of faulting, and potential displacement along the Castle Mountain-Caribou fault system.

- Field planning included preparation of field forms to standardize data collected at each fault crossing, plotting the location of potentially active faults on pipeline alignment base maps provided by ANGDA, arranging logistics and equipment for the field effort, and preparation of a project-specific URS Safety Work Plan.

The results of the data review conducted under Task 1 are presented in Sections 3.1 through 3.3. References cited are provided in Section 5.0.

2.2 Field Work

Based on the results of the review of geologic information and stereo aerial photographs under Task 1, the field effort focused on the following spur line route locations (from east to west):

- The east crossing of the Caribou fault along Chitna Creek, just west of Chitina-Caribou Creek confluence;

- Crossing of a northeastern splay of the Caribou fault along an unnamed tributary to Chitna Creek located southeast of Chitna Pass;

- The west crossing of the Caribou fault along the Boulder Creek drainage southwest of Chitina Pass;
- Crossing of a southwestern splay of the Caribou fault in the Boulder Creek drainage; and
- The eastern Castle Mountain fault crossing just north of Anthracite Ridge.

Field locations were accessed by helicopter on September 1, 2005 by a two-person team including a URS senior geologist and soil scientist. The field team was flown by JayHawk Air from Merrill Field in Anchorage, Alaska. Weather in the study area was mostly overcast with intermittent rain and a relatively low ceiling. Efforts at each fault crossing location included:

- Location of fault crossings in the field based on previous mapping investigations and aerial photo evidence;
- Observations of surficial geomorphic features from the air and ground;
- Review of bedrock types and exposures in the immediate vicinity of each crossing, and collection of strike and dip data if accessible;
- Collection of soil samples from a shallow hand-dug pit; and documentation of soil types, layering, and thicknesses;
- Field staking and collection of GPS and photographic documentation at each crossing; and
- Revisions of previously mapped fault locations as necessary based on field evidence.

The location of faults and fault crossings are provided on strip maps of the pipeline route in Appendix A. The results of the field effort were recorded on field forms provided in Appendix B. Selected photographs collected during the field effort are provided in Appendix C.

2.3 Data Analysis and Design Approach

This task included the following:

- Assessment of the evidence for recency of surface fault rupture at each crossing based on field results and literature review;
- Evaluation of the orientation, dip, and sense of movement at each potentially active fault crossing;
- Analysis of maximum vertical and lateral displacement of each potentially active fault based on previous studies, published empirical relationships of fault length and earthquake magnitude, and overall slip rate on the Castle Mountain-Caribou fault system;

- Development of a preliminary design recommendation and approach as to whether the fault(s) can be crossed below- or above-ground; and

- Typical drawings of potential construction types at the fault crossings.

The results of Task 3 are presented in Sections 3.5 through 3.7, Table 1, and Figure 2. Recommendations for additional methods to further refine surface fault rupture data prior to final design are provided in Section 4.0.

3.0 Results

3.1 Previous Investigations

Map sources used for this study were derived from a number of published and unpublished investigations. Grantz (1961a, 1961b) completed geologic maps in the eastern part of the study area that feature fault splay details in the vicinity of the Caribou and Squaw Creek drainages. Detterman, et al. (1976) completed maps focused on identifying the recency of faulting along the Talkeetna segment of the Castle Mountain fault, including the Boulder, East Boulder, Chitna, and Hicks Creek drainages. Csejtey, et al. (1978) extended previous mapping coverage of the Caribou fault splays northeast of the study area. Fuchs (1980) remapped much of the study area previously covered by Detterman, et al. (1976), and provided alternative fault trace locations and age interpretations of the Caribou fault splays crossing Boulder Creek valley. In 1995, Haeussler (2005a) examined stream terraces along several drainages of the eastern Castle Mountain fault, including the Boulder Creek valley, for surficial evidence of faulting. Labay and Haeussler (2001) digitized faults in the study area based largely on previous work by Detterman, et al. (1976).

Related work reviewed during this study included fault investigations of the western segment of the Castle Mountain fault by Haeussler (1998) and Haeussler et al. (2002) and several large scale geologic and fault maps (e.g., Magoon, et al., 1996; Plafker, et al., 1993). These maps, such as that proved in Figure 1 (Winkler, 1992), are mostly generalized compilations of previous work conducted at a more detailed scale, and were not used to identify specific fault crossing locations.

3.2 Geologic Units

The various fault breaks within the Castle Mountain-Caribou fault system offset Jurassic and Cretaceous sedimentary and volcanic rocks, as well as Tertiary volcanic and intrusive igneous rocks. Names and brief descriptions of bedrock types at each fault crossing location are listed on the field forms in Appendix B. These include the following (from oldest to youngest):

- Lower Jurassic Talkeetna Formation: andesitic flows with associated volcanic breccia and tuff with interbedded sandstone and siltsone;
- Upper Jurassic Chitna Formation: shale and siltstone;
- Cretaceous Matanuska Formation: shale and siltstone with interbedded sandstone;
- Tertiary (Paleocene) Chickaloon Formation: coal-bearing sandstone, sitstone, claystone, and conglomerate;
- Tertiary (Paleocene-Eocene) Wishbone Formation: conglomerate with interbedded sandstone, siltstone, and claystone;
- Mid-Tertiary basalt flows and associated pyroclastic rocks; and

- Mid-Tertiary granitic and basaltic stocks and sills that locally intrude other bedrock (Detterman, et al., 1976; Grantz, 1961a; Winkler, 1992).

The Caribou fault generally juxtaposes Tertiary basalts to the north against older Talkeetna or Matanuska Formation rocks to the south for much of its length, although there are many local variations along smaller fault splays. The Castle Mountain fault places the Talkeetna and Matanuska Formations, against both Tertiary sedimentary/volcanic rocks and the Matanuska Formation, the latter forming Anthracite Ridge.

Quaternary deposits mapped in the vicinity of the fault crossings include landslide deposits, morainal material, and undifferentiated glacial and alluvial deposits (Detterman, et al., 1976; Grantz, 1961a). Detterman, et al. (1976) have assigned relative approximate ages to some landslides and moraines in the study area, mostly indicated as more than or less than 8,000 years old. Brief descriptions of surficial units and soil types encountered in the field at each fault crossing are listed in Table 1 and Appendix B, and described in Section 3.4.

3.3 Recency of Faulting

3.3.1 Western Castle Mountain Fault

Plafker et al. (1993) summarize ages of activity along the Castle Mountain fault system based on a compilation of sources. They indicate Holocene displacement (less than 11,000 years old) for the western segment of the Castle Mountain fault, which is born out by more recent studies (Haeussler, 1998; Haeussler et al., 2002) indicating dates of 730 to 610 years ago for the latest surface breakage on the fault, and an average recurrence interval of about 700 years. The surface expression of the fault has scarps typically 3 to 5 feet high and up to 11 feet high. A magnitude 7.0 earthquake in 1933 may be attributable to the western segment of the Castle Mountain fault, but its depth and focal mechanism are uncertain (Lahr et al., 1986).

3.3.2 Eastern Castle Mountain Fault (West of Caribou Fault Juncture)

The portion of the eastern Castle Mountain fault west of its bifurcation with the Caribou fault is classified as “historic” on the basis of recent earthquakes, but does not exhibit clear evidence of surface rupture. There have been two recorded earthquakes on the Castle Mountain fault zone in this area. A magnitude 5.7 (body-wave magnitude, m_b) earthquake occurred in 1984 in the Sutton area, and a magnitude 4.6 (local magnitude, M_L) earthquake occurred in 1996 about 4 miles east of the 1984 earthquake. Focal mechanisms for these earthquakes indicated right-lateral slip on a steeply north-dipping fault plane, and their 8- to 12-mile depths are consistent with the lack of observed surface breakage in this area (Bunds, 2001; Haeussler, 2005a; Lahr et al., 1986).

3.3.3 Eastern Castle Mountain Fault (Southeast of Caribou Fault Juncture)

The age of the Castle Mountain fault southeast of its split with the Caribou fault is designated as “suspicious” but unknown by Plakfer, et al. (1993). The fault surface expression is characterized by a series of saddles and notches, linear gullies, aligned stream canyons, and varying amounts of dextral offset of several drainages (Detterman, et al., 1976). As the amount of offset is not systematic, it could be caused by erosion along sheared rock weaknesses, rather than lateral displacement. Detterman et al. (1976) indicates that there is no conclusive evidence of fault movement since deposition of 8,000-year-old glacial deposits, except for one possible scarp near the head of Pinochle Creek. Haeussler (2005a) examined stream terraces in Boulder Creek valley at the location of the Castle Mountain fault, and found no evidence of surface faulting.

Fuchs (1980) suggests that structural style of the triangular fault block between the Castle Mountain and Caribou faults is one of a tilting up on the north side of the Castle Mountain fault, and rotation around the pivot point located at the juncture of the two faults. This fault block rotation occurred throughout most of the Tertiary, and reactivation of the Caribou fault post-dates the rotation. Total overall displacement on the Castle Mountain-Caribou fault system east of the pivot point is estimated to be on the order of 12 miles right lateral, of which about 8.7 miles is attributable to the Caribou fault and about 3.3 miles to the Castle Mountain fault (Fuchs, 1980).

The mapped location of the Castle Mountain fault along the west side of Boulder Creek valley varies approximately 900 feet between the Detterman et al. (1976) and Fuchs (1980) interpretations. Aerial photographs reviewed for this study (Aeromap, 2004) indicate possible faint lineaments in alluvial fan material located an additional 500 feet south of both previous interpretations, including a possible vegetation/tree alignment that lines up with an alluvial fan ridge and bedrock notches to the west. The fan lineament could be explained by depositional processes, and the vegetation by underlying fault-related groundwater ponding. Although these features are indistinct and do not necessarily indicate Holocene offset, the trace of the Castle Mountain fault and pipeline crossing were conservatively widened to include them.

The eastern end of the Castle Mountain fault splays into a number of northeast-trending faults in the vicinity of Sheep Mountain. Aerial photographs reviewed for this area (Aeromap, 1978; 2004) show these bedrock faults disappearing beneath the Quaternary alluvial and glacial deposits of Squaw Creek valley. As they exhibit no surface expression across the Quaternary deposits, they were not considered potentially active for the purposes of this study

3.3.4 Caribou Fault

The Caribou fault and its subsidiary splays form the northeast-trending extension of the eastern Castle Mountain fault. The Caribou fault zone has been characterized as late Pleistocene in age by Plafker et al. (1993), indicating displacement of 500,000 to 11,000 year old deposits. Detterman et al. (1976) mapped possible offsets of late Pleistocene to early Holocene moraines along a southern parallel splay of the Caribou fault as evidence of its activity, although cautioned that alternative explanations of gravity sliding could also explain the offsets. Other fault evidence mapped by Detterman et al. (1976) along the Caribou fault, such as aligned streams and ponds, notches in bedrock ridges, and linear gullies, could be due to preferential erosion along weakened rock within the fault zone, and are not necessarily an indication of recent activity. Detterman et al. (1976) also note several deflected stream drainages in the area (Boulder Creek is one example), but they do not show systematic offsets suggestive of Holocene lateral movement, and could also be explained by zones of weakness along the faults.

Fuchs (1980) mapped the presence of two short north-trending strike slip faults that cut the Caribou fault about 1 mile west of Boulder Creek valley. Fuchs proposes a "meat-slicer" effect to explain a process of alternating activation between the Caribou fault and the cross faults, and suggests that the cross faults are preserved because more recent activity on the Caribou fault zone was shifted to its southern splay. Fuchs (1980) speculates that the southern splay is the best candidate for an active fault in the area, and that it functions to bypass the most complicated segment of the Caribou fault where the cross faults lock up a portion of the fault zone. The southern splay, located about ¾ mile south of the main fault where it enters Boulder Creek valley from the west, is referred to herein as the Caribou fault-southwest splay to distinguish it from other splays to the northeast. (It was originally named the Boulder Creek fault by Fuchs, but this nomenclature was not adopted in later references.) Detterman et al. (1976) originally mapped the Caribou fault-southwest splay as two fault breaks located about 500 feet apart in the east slope of Boulder Creek valley. Later mapping by Fuchs (1980), however, suggests that the southern of the two breaks is Mesozoic in age; thus only the northern of the two was considered to be potentially active for the purposes of this study. The eastern end of the Caribou fault-southwest splay rejoins the main Caribou fault near the northerly bend in Boulder Creek valley.

Aerial photographs reviewed for this study (Aeromap, 1978; 2004) indicate possible faint lineaments at several previously unmapped locations along the east-northeast trending portion of Boulder Creek valley: in two unnamed south-flowing drainages in the northwest corner of the valley that may connect with bedrock notches to the northwest, in alluvial fans along the north side of the valley, and in a large fan lobe at the east end of the valley. Field observations from the air proved most of these to be explainable by alluvial erosive processes. Even if fault-related, they do not necessarily imply Holocene offset, but may be related to underlying rock weakness along the fault zone. However, their possible alignment with bedrock notches and the overall trace of the Caribou fault zone, lead to conservatively widening the overall Caribou fault zone and its pipeline crossing length. It is possible that if fault-related, the lineaments could represent a northern splay that functions similar to Fuchs (1980) interpretation of the southwest splay, that is, to bypass the "locked up" cross-faulted portion of the Caribou fault to the west.

Two other splays of the Caribou fault are crossed by the proposed pipeline route: an east-trending splay north of the main fault that extends through Chitna Pass, and a northeast-trending splay that crosses a south-flowing tributary to Chitna Creek (referred to herein as the Caribou fault-northeast splay). The fault extending through Chitna Pass is intruded at its east end by a Tertiary granitic stock (Detterman et al., 1976), and as such, was not considered potentially active for the purposes of this study. The northeast splay has been characterized as late Pleistocene in age by Plafker et al. (1993).

East of the Chitna-Caribou Creek confluence, the Caribou fault splits into numerous east- and northeast-trending splays, and disappears beneath Quaternary deposits of the Copper River basin (Csejtey, et al., 1978). The southernmost of these splay faults, as mapped in the subsurface by Grantz (1961b) on the basis of aeromagnetic data, extends to within 2 miles north of the proposed pipeline route northeast of Eureka Roadhouse near MP 55, but does not cross it. Aerial photographs reviewed for this area (Aeromap, 1978) did not reveal clear evidence of surface fault rupture in this area.

3.3.5 East Boulder Creek Fault

The East Boulder Creek fault has been characterized as late Pleistocene in age, indicating displacement of 500,000 to 11,000 year old deposits (Plafker et al., 1993). Detterman et al. (1976) mapped a possible offset of undifferentiated Pleistocene or Holocene moraine the East Boulder Creek fault as evidence of its activity. Later work by Fuchs (1980) suggests the East Boulder Creek fault is non-existent. The supposed juncture of the East Boulder Creek fault with the Caribou fault comes within 500 feet of the proposed pipeline route near Milepost (MP) 86, but does not cross it.

3.3.6 Hicks Creek Fault

The age of the Hicks Creek fault is designated as "suspicious" but unknown by Plakfer, et al. (1993). Detterman et al. (1976) mapped the Hicks Creek fault on the basis of stream alignments and benches, but note no offsets of late Pleistocene and early Holocene landslides that cross the fault. Its northern terminus with the Caribou fault appears highly questionable as mapped by Grantz (1961a), and it may be cut by an older west-trending splay of the Caribou fault south of the main Caribou fault. Aerial photographs reviewed for this area (Aeromap, 1978, 2004) did not reveal clear evidence of surface fault rupture of Quaternary deposits covering this area. Based on its uncertainty and lack of evidence for surface breakage on published maps and aerial photographs, it was not considered potentially active for the purposes of this study.

3.3.7 Summary of Fault Activity

Based on previous mapping studies, aerial photograph review, and field observations, the likelihood of Holocene activity for each fault crossed by the proposed pipeline route was given a rating of low, moderate, and/or high (Table1). The likelihood of activity on western Castle Mountain fault and the eastern Castle Mountain fault west of the Caribou fault juncture, although not crossed by the pipeline route, would both be considered high. The East Boulder Creek and Hicks Creek faults were both considered to have a low likelihood of activity and were not further evaluated in this study. Ratings for the remaining fault crossings range from low-to-moderate for the Caribou fault-northeast splay and southeast Castle Mountain fault, to moderate-to-high for the Caribou fault-southwest splay. Due to the number of uncertainties, all faults in Table 1, including those with low to moderate ratings, were conservatively assumed to be active for the purposes of preliminary design.

3.4 Conditions at Pipeline Crossings of Potentially Active Faults

The field effort focused on locations where the proposed spur route crosses faults that may be potentially active, as described in Section 3.3. The locations of the faults are shown on strip maps of pertinent sections of the pipeline route in Appendix A. Strike and dip, and the sense of movement on each fault, are listed in Table 1. Notes collected during the field effort were recorded on the field forms provided in Appendix B. Selected photographs taken during the field effort are provided in Appendix C.

3.4.1 Sources of Uncertainty

Although the fault crossings were staked in the field at discrete locations, several sources of uncertainty are associated with the location of each crossing. The highly complex structural geology of the area has yielded multiple interpretations of faulting at certain crossings. Field mapping to resolve these differences was beyond the scope of this project. Where varying interpretations appeared to have equal validity, the width of certain fault zones was expanded to include multiple interpretations. An additional source of uncertainty comes from concealment beneath surficial deposits in the absence of clear surface rupture.

Other sources of uncertainty include field resolution of the GPS unit, as well as locating faults in the field where concealed. Fault crossing locations were identified based on prior aerial photograph mapping, pre-programmed GPS coordinates, and observations of mostly distant bedrock exposures. GPS coordinates as obtained from field maps, and as staked in the field, are provided on the field forms in Appendix C.

Mileposts numbers for each fault crossing as mapped are provided in Table 1, along with an approximate zone of uncertainty to accommodate the above factors. Uncertainty was judged to range from roughly 200 feet to 500 feet perpendicular to strike at each fault. In cases where faults extend sub-parallel to the pipeline route (e.g., the east crossing of the Caribou fault), this uncertainty may add more than a mile to the length of pipeline that could require special design consideration. A total of approximately 3.6 miles of the proposed spur route crosses mapped fault zones, and the total length of the route that falls within fault-related zones of uncertainty is 6.6 miles.

3.4.2 Caribou Fault - East Crossing, MP 84.7-84.85

The proposed spur line route approaches the eastern crossing of the Caribou fault from the southeast at an initial angle of about 14 degrees, then bends westward where it is roughly coincident with the trace of the fault for about 1,000 feet (Appendix A, Drawing 014). The fault crossing was staked in the field at the approximate midpoint of the coincident part. At the west end of the crossing, the pipeline and fault diverge at about a 12-degree angle. The pipeline then bends westward again, where it is runs parallel to and north of the Caribou fault for about 1-1/2 miles. Observations of the fault zone from the air indicated the presence of multiple fault blocks within a possibly larger fault zone, particularly on the north side of the mapped trace of the fault in Chitna Creek canyon. Based on these observations, the fault-pipeline parallel segment in Sections 28 and 29 were considered to lie within an approximate 500-foot zone of uncertainty for this fault (Table 1). The terminus of the speculative East Boulder Creek fault (Section 3.3.5) at the Caribou fault lies within this zone near MP 86.15.

The staked location of the crossing was positioned on a small bench just downslope of the main bench on the south side of Chitna Creek, which is roughly defined by the 3,200-foot contour. No evidence of surface faulting was observed at the crossing in the field. Several notches and saddles were observed on the aerial photographs (Aeromap, 2004) along sharp bends in Chitna Creek; these are roughly coincident with the mapped trace of the fault or within the zone of uncertainty, and appear to be related to bedrock faulting and not necessarily rupture of surficial deposits. A short lineament near the pipeline crossing at MP 84.8-84.9 is more likely related to downslope movement than faulting.

Surface soils at the staked location consist of wet sticky clay with occasional cobbles, likely a glacial till-type soil deposit. Observations of soil exposures on the north side of Chitna Creek indicate this deposit may be on the order of 50 feet thick on top of bedrock. Numerous slides and slumps were observed along the Chitna Creek banks in this area, and the staked location of the crossing may be located on one such feature.

Table 1 Fault Crossing Summary

Fault Name	Fault Crossing (MP)		Likelihood of Holocene Activity[2]	Sense of Movement[3]	Fault Strike	Fault Dip	Pipeline Trend	Pipeline Angle of Approach	Surficial Unit	Soil Type (USCS)	References
	Mapped Pipeline Crossing	Zone of Uncertainty[1]									
Caribou Fault-East Crossing	84.7-84.85[4]	84.3-86.3	M	R(U-S/ U-N[5]), RLSS	089-101°/ 089°[5]	75 °N-90° / 55°N[5]	101-115°	0-14°	Glacial till	Silty clay with cobbles (CL)	Csejtey et al. (1978); Detterman, et al. (1976); Grantz (1961a)
Caribou Fault - Northeast Splay	86.6	86.55-86.65	L-M	R(U-N), RLSS	072°	70-80°N	135°	63°	Landslide deposit	Silt with gravel (ML)	Csejtey et al. (1978); Detterman, et al. (1976)
Caribou Fault West Crossing	93.5-96.5[6]	93.4-96.8	L-H	R(U-N), RLSS	070-072°	75-85°N	041-074°	0-31°	Alluvial fan, alluvial terrace, modern alluvium	Silty sandy gravel (GM) to sandy gravel and cobbles (GP).	Detterman, et al. (1976); Fuchs (1980); Labay and Haeussler (2001); aerial photo evidence – this study
Caribou Fault Southwest Splay	97.25	97.1-97.5	M-H	R(U-S), RLSS	066°	58°S - near-vertical	029°	37°	Alluvial fan	Sandy gravel with silt (GP)	Detterman, et al. (1976); Fuchs (1980)
Castle Mountain Fault	102.0-102.4[7]	101.8-102.5	L-M	R(U-N), RLSS	090-102°	Near-vertical, steep to north	041-074°	0-23°	Pond deposits, modern alluvium	Organic silt/silt (OL/ML) to sandy gravel (GP)	Detterman, et al. (1976); Fuchs (1980); Labay and Haeussler (2001); aerial photo evidence – this study

Notes:
1. Ranges from +/- 200' to +/- 500' perpendicular to fault strike, depending on variation between authors and amount of concealment beneath surficial deposits.
2. L = low; M = moderate; H = high
3. R = reverse; U-N = up to north; U-S = up to south; RLSS = right lateral strike-slip
4. Staked in field at approximate mid-point.
5. Main Caribou fault listed first / east-trending splay listed second.
6. Staked at both ends of crossing zone.
7. Staked approximately 350' south of east end of crossing (MP 102.0), due to beaver pond covering actual east end location.

MP = milepost
USCS = Unified Soil Classification System

3.4.3 Caribou Fault - Northeast Splay, MP 86.6

The proposed spur line route crosses the northeast splay of the Caribou fault at about a 63-degree angle (Appendix A, Drawing 14). The staked location of the crossing was situated on the east side of a Pleistocene landslide deposit mapped by Detterman et al. (1976) near a break in slope. The aerial photographs indicate the break in slope is likely related to the end of a slide lobe, rather than surface faulting. Surface soils at the staked fault crossing consist of slightly gravelly silt, likely derived from landslide parent material.

The landslide deposit lies in a relatively narrow canyon containing a south-flowing tributary to Chitna Creek. Bedrock exposures observed on the west side of the canyon contain the probable fault trace, as well as steeply dipping beds of the Chickaloon and Matanuska Formations (Appendix C, Photograph 3). Bedrock exposed at the base of the slope in the upper part of the east side of the canyon consisted of light green sandstone or andesitic volcaniclastic rock, likely part of the Talkeetna Formation mapped on the north side of the fault by Detterman et al. (1976). The fault and bedrock to the south were obscured by colluvium on the east side of the canyon. The dip of bedrock in both exposures is roughly 70 to 80 degrees north. The zone of uncertainty applied to the location of the fault at this crossing was considered to be about 200 feet due to the relatively well constrained fault location on the west canyon wall.

3.4.4 Caribou Fault - West Crossing, MP 93.5-96.5

The spur line route approaches the western crossing of the Caribou fault from the northeast at an initial angle of about 25 to 30 degrees (Appendix A, Drawing 15), then bends towards the west-northwest and follows the fault zone for about 3 miles (Drawing 16). At the west end of the crossing, the pipeline route diverges from the fault zone at an angle of about 15 degrees, then bends away from it towards the south.

This 3-mile-long fault crossing was staked in the field at the approximate east and west endpoints (Photographs 4 through 9). There was no evidence of surface rupture at either location or along the pipeline route in between. Faint lineaments on aerial photographs and observations made from the air of this fault zone, described in Section 3.3.4, did not yield conclusive evidence of surface rupture. Because much of the interpretive variation surrounding this fault zone was incorporated into widening the mapped trace itself, the additional zone of uncertainty applied to this fault zone was minimal, about 200 feet perpendicular to strike at both ends (Table 1).

The staked location of the east end of the crossing was positioned on a lower alluvial fan or alluvial terrace deposit with relatively dense vegetation, while the west end is located on modern alluvium in the valley bottom. Surface soils at the east end consist of silty sandy gravel and cobbles beneath a thin vegetative mat, and at the west end of sandy gravel and cobbles with no surface vegetation and little or no fines. The pipeline route crosses similar soils types in between the two endpoints.

3.4.5 Caribou Fault - Southwest Splay, MP 97.25

The spur line approaches the southwest splay of the Caribou fault (also referred to as the Boulder Creek fault by Fuchs (1980)), at an angle of about 37 degrees (Appendix A, Drawing

16). The fault is fairly well defined in bedrock northeast of the crossing. Possible offsets of 8,000-year old moraines located about 2-1/2 to 4 miles northeast of the crossing, were mapped by Detterman et al. (1976) along this fault, and could be seen on the aerial photographs reviewed for this study (Aeromap, 1978; 2004), although it is unclear if gravity slumping could be the cause of the offsets.

The mapped trace of the fault in bedrock southwest of Boulder Creek valley is more complex and controversial. The fault trace in this area on Drawing 16, represents the Detterman et al. (1976) interpretation with approximate modifications from Fuchs' (1980) map. As Fuchs' map is only available at a greatly reduced scale, the fault trace west of Boulder Creek is considered very approximate. The fault is near-vertical northeast of the crossing, and becomes a lower angle, almost thrust-type fault (about 58 degrees dip to south) west of Boulder Creek. Due to the uncertainty of the fault location as it crosses Boulder Creek, a 500-foot zone of uncertainty was applied to the width of the fault at the pipeline crossing.

No evidence of surface faulting was observed on the aerial photographs in Boulder Creek valley Quaternary deposits, and no evidence was found in the densely vegetated alluvial fan deposits at the crossing (Appendix C, Photograph 11). Surface soils at this crossing consist of slightly silty, coarse sandy gravel.

3.4.6 Castle Mountain Fault, MP 102.0-102.4

The spur line route approaches the Castle Mountain fault from the east-northeast at an angle of about 15 degrees, runs coincident with fault for about 2,000 feet, then bends away from the fault at about a 23-degree angle (Appendix A, Drawing 17). Faint lineaments seen on the aerial photographs (Aeromap, 2004) along the west side of Boulder Creek valley, described in Section 3.3.3, do not provide conclusive evidence of surface rupture. No evidence of surface rupture of Quaternary deposits was observed in the field.

The trace of the fault was slightly different on the Detterman et al. (1976) and Fuchs (1980) maps. East of Boulder Creek, these differences do not affect the location of the pipeline fault crossing; thus, the more detailed Detterman et al. (1976) map was used. As described in Section 3.3.3, interpretations vary as much as 1,300 feet near the west side of Boulder Creek valley. Because these affect the width of the crossing zone at the proposed spur line location, the fault zone was widened to accommodate the different interpretations. The additional zone of uncertainty applied to this crossing was roughly 200 to 300 feet perpendicular to strike (Table 1).

Because widening of the fault crossing was decided upon after the field visit, this crossing was staked only at its east end. The east end stake is located in the field about 350 feet south of the actual east end crossing point, due to the actual location being in a beaver pond (Appendix C, Photograph 14). Soil conditions at the staked location consist of sandy gravel of a Holocene gravel bar. Soil conditions beneath the beaver pond are presumed to contain organic-rich silt or other fine-grained material. Based on the aerial photographs, wetlands ground conditions appear to extend westward throughout most the 2,000-foot fault crossing, except at the approximate midpoint of the crossing where gravelly alluvium may be encountered.

3.5 Sense of Movement

The overall sense of movement on the Castle Mountain-Caribou fault system is an oblique combination of right lateral strike-slip and high angle reverse faulting, upthrown to the north. Trench studies of the western segment of the Castle Mount fault indicate Holocene displacement dominated by north-dipping thrust and reverse faults (Haeussler et al., 2002), while focal mechanisms on the two recent earthquakes near Sutton indicate mostly right lateral strike-slip movement.

An understanding of principal stress provides a view of how faults might displace in the event of an earthquake. Based on a study of slickenside orientations from a number of localities along the Castle Mountain-Caribou fault system, Bunds (2001) indicates that principal stress acting on the system is mostly compressive, driven by relative motion between the Pacific and North American plates, which is directed at an average angle of about 80 degrees towards the strike of the main fault. Bunds (2001) also suggests, however, that because most of the fault is mechanically weak due to clay-rich gouge and elevated pore pressure, it slips laterally in response to the small component of right-lateral obliqueness in the stress regime. At specific locations within the study area, measured principal stress is even more purely compressive along the Caribou fault (85 degrees to fault strike), but more oblique along the Castle Mountain fault southeast if its split with the Caribou fault (about 30 degrees to strike). Bunds (2001) study provides specific details as to sense of past movements within the study area, but adds uncertainty to the predicted direction of future displacement.

The sense of movement of each potentially active fault crossed by the proposed spur line route is listed in Table 1. All faults within the study area were presumed to have a right-lateral strike slip component, as they are part of a larger right-lateral system, and because of the recent earthquake evidence (Section 3.3.2). Geologic evidence of right lateral displacement is supported in the literature, however, for only the main Caribou fault and the Castle Mountain fault, but not the Caribou fault splays. Most faults in the study area are reverse north-side-up. The Caribou fault-southwest splay is upthrown to the south. Although both senses of vertical displacement have been mapped in the vicinity of the Caribou fault-east crossing, south-side-up appears to be the dominant one.

3.6 Maximum Displacement

Based on trench studies of the western Castle Mountain fault, Haeussler et al. (2002) suggest that the fault may be capable of a magnitude 6-7 earthquake in the near future. Although the maximum earthquake on one of the shorter fault splays of the eastern Castle Mountain-Caribou fault system is likely to be less due to partitioning of strain among multiple splays, for the purpose of this preliminary study, calculations of maximum displacement were conservatively based on applying a magnitude 7.0 earthquake to all of the potentially active faults in the study area. A magnitude 7.0 earthquake is capable of considerable damage and partial collapse of buildings within many miles of the epicenter (U.S. Geological Survey, 2004).

Maximum displacement can be estimated using several different approaches, such as the use of empirical relationships between magnitude and displacement (Wells and Coppersmith, 1994; Honegger and Nyman, 2004). Wells and Coppersmith (1994) relationships predict about 6 to 7 feet of maximum displacement for a magnitude 7.0 earthquake. Maximum displacement can also be estimated using rupture length relationships. Haeussler (2005b) suggests that contiguous rupture of the entire Castle Mountain fault is unlikely, and that the system should be viewed as separate west and east segments. If the segment from about Sutton to the Chitna Creek area were to slip during one earthquake (a length of about 40 miles), about 10 feet of maximum displacement is predicted by the Wells and Coppersmith (1994) relationship. A more likely scenario is that rupture length would reflect the length of splays in the study area. Fault lengths from the Caribou-Castle Mountain fault juncture to Caribou or Pinochle Creeks (about 20 to 25 miles on either fault), yield about 4 to 6 feet of maximum displacement.

Haeussler (2005b) preliminarily suggests that slip rate on the western segment of the Castle Mountain fault may be on the order of 2 to 3 mm/year (0.08 to 0.1 inches/year) based on possible piercing points that are still under investigation. Assuming an approximate 700-year recurrence interval for significant earthquakes (Haeussler et al., 2002), this yields roughly 5 to 6 feet of maximum displacement in the event of significant earthquake.

Orthogonal components of maximum displacement were calculated for several different fault rupture scenarios using principal stress angles of Bunds (2001) (Section 3.5), and assuming a maximum displacement of 6 to 7 feet. For example, an earthquake responding to more compressive stress along the Caribou fault breaks down to about 6 feet of vertical displacement, about ½ foot lateral displacement, and about 2 feet transverse horizontal displacement perpendicular to strike. An earthquake responding to oblique stress at a 30-degree angle along the Castle Mountain fault would have the following displacement components: about 6 feet vertical, 2 feet lateral, and 1-1/2 feet transverse horizontal. A purely strike-slip earthquake similar to the sense of the 1984 Sutton earthquake would result in all 7 feet being displaced laterally.

Based on the character of the faults examined in the field by Bunds (2001), the potentially active faults that cross the pipeline route should exhibit dominantly vertical offset; however, the sense of movement during recent earthquakes to the west indicates that the fault system may respond more purely laterally due to mechanical weaknesses and high pore pressure (Bunds, 2001) (Section 3.5). For these reasons, and for the purpose of preliminary design, it is conservatively estimated that both the vertical and horizontal components of displacement be 7 feet at each fault crossing. The vertical sense of offset is assumed to up to the north at the Castle Mountain fault crossing, Caribou fault-west crossing, and Caribou fault-northeast splay. The vertical sense is assumed to be up to the south on the Caribou fault-southwest splay and at the Caribou fault-east crossing.

3.7 Preliminary Design Criteria and Approach

3.7.1 Design Fault Displacement

Design fault displacements are determined from the estimated fault displacements based on considerations for the performance requirements of the pipeline and the consequences for loss of pipeline pressure integrity. Adjustments are made to the estimated fault displacements to account for the consequences of loss of pipeline pressure integrity and for faults of lower likelihood of occurrence than the pipeline performance criteria.

The pipeline alignment is primarily through less populated areas, however, the most of the pipeline alignment particularly at the locations of fault crossings are considered environmentally sensitive. Based on the Pipeline Research Council International (PRCI) Guidelines (Honegger and Nyman, 2004), the design fault displacement for this gas pipeline is recommended as two-thirds of the mean maximum fault displacement.

Faults are considered active when there is recorded movement within the last 11,000 years, which may present a mean annual probability of exceedance as low as $9.1x10^{-5}$. On the other hand, the typical pipeline performance goal for experiencing loss of pressure integrity from a seismic event is given by 500- to 1000-year average return period, which corresponds to a mean annual probability of exceedance of $1x10^{-3}$ to $2x10^{-3}$. The PRCI guidelines also have provisions to further adjust the design fault displacement in order to account for the possibility of significantly lower average annual probability for the fault displacement compared to the specified performance goal of the pipeline. A return period of about 700 years has been suggested for the western Castle Mountain fault (Haeussler et al., 2002) (Section 3.3.1). Individual faults within the eastern Castle Mountain-Caribou fault system may have return periods greater than 700 years, which could possibly be substantiated through additional studies (Section 4.0). With a longer return period for fault movement, the design permanent displacement could be significantly reduced. This may result in a permanent displacement close to the allowable settlement design criteria and the fault could be eliminated from requiring special crossing design. Based on the unknowns present in the fault system in the study area, the 700-year return period is conservatively applied for the purpose of preliminary design, which lies within the pipeline performance goal range; thus, no additional adjustments are recommended at this time.

The estimated maximum permanent horizontal and vertical displacements are discussed in Section 3.6. Based on this, and the application of the two-thirds design adjustment described above, the preliminary design permanent displacement is estimated to be 5 feet for both vertical and horizontal (right lateral) components at each fault crossing. The sense of vertical offset at each crossing is summarized in Section 3.6 and Table 1.

For comparison purposes, design displacements for the Trans-Alaska Pipeline System (TAPS) at the Denali fault crossing are 20 feet horizontal (right lateral) and 5 feet vertical for an 8.5-magnitude earthquake with a 300-year return period (Hall et al., 2003). Thus, the preliminary design displacement being considered for the Castle Mountain-Caribou fault system is about one-fourth that of the Denali fault horizontal displacement, about the same as the Denali fault vertical displacement, and about half the Denali fault frequency (i.e., about twice the return period).

3.7.2 Fault Crossing Design Approach

The fault crossings may be designed using any of the following approaches:

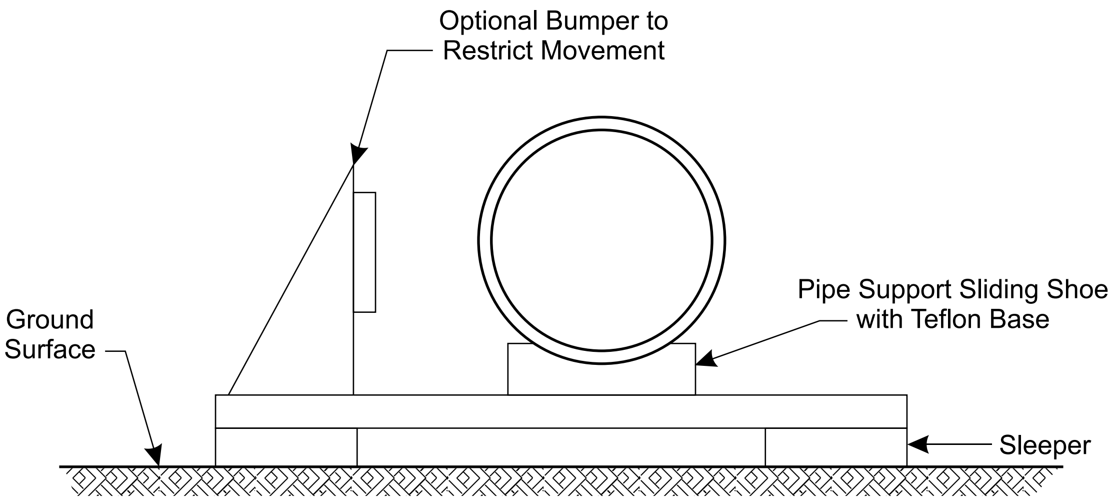
- Placing the pipeline on aboveground sliding supports.
- Placing the pipeline in an aboveground berm constructed of low-strength soil.

- Placing the pipeline in an oversized ditch surrounded by low-strength crushable material or loose granular fill.

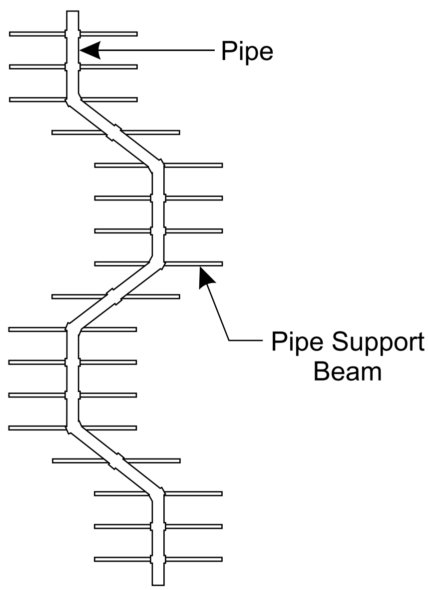
The aboveground sliding support design is effective where displacements are large and dominantly horizontal, and if located in remote areas where vandalism is not a concern. The TAPS fault crossing at the Denali fault was constructed on aboveground sliding support shoes and performed well in the Denali earthquake of 2002 (Cluff, et al., 2003). In order to accommodate large thermal and permanent ground displacement the pipeline is laid in a zigzag alignment and attached to pipe support shoes with teflon base. The support shoes are free to slide on structural steel members along and transverse to the pipeline. A typical plan and section of this concept is shown on Figure 2. Where soil cover is required to provide protection from third party damage, an earth berm can be used in lieu of burial. However with increasing security and wildlife concerns, locating the pipeline aboveground has become less desirable.

Burying the pipeline within a shallow trench lined with double layers of smooth geomembrane liner and filled with loose granular backfill, as shown on Figure 3, is most desirable for the reasons outlined above. The trench walls typically would be sloped at an angle of about 30 to 45 degrees to allow horizontal and/or vertical permanent ground displacement, or about 60 degrees to allow for primarily vertical ground displacements. The backfill would consist of a loose well-graded granular material with an angle of internal friction less than 35 degrees. The backfill material should be well graded, rounded, less than 1-inch in diameter and obtained from a natural fluvial deposit. Angular material should be prohibited from use in the backfill to reduce the likelihood of settlement and compaction. The backfill should be placed to a relative density as close to 66 percent or less if achievable (Honegger and Nyman, 2004). The fill should be protected from compaction activities and monitored on a periodic basis to ensure it retains the loose state. The two layers of smooth geomembrane liner create a low-friction failure surface during both frozen and thawed soil conditions. This type of construction can accommodate vertical and lateral directions safely, provided that the thickness of the pipeline at the crossing is designed considering the design displacement and the length of the special fault crossing. For a horizontal relative ground displacement, backfill will fail along weak liner failure surface, as shown on Figure 3. For vertical ground displacements, an upward breakout would occur within the loose granular backfill or along the weak liner.

The pipeline design should consider the design permanent ground displacement at the fault crossings and ensure that the stress and strain values in the pipeline are within allowable limits based on the performance criteria established for the pipeline.



Section
Not to Scale



Plan
Not to Scale

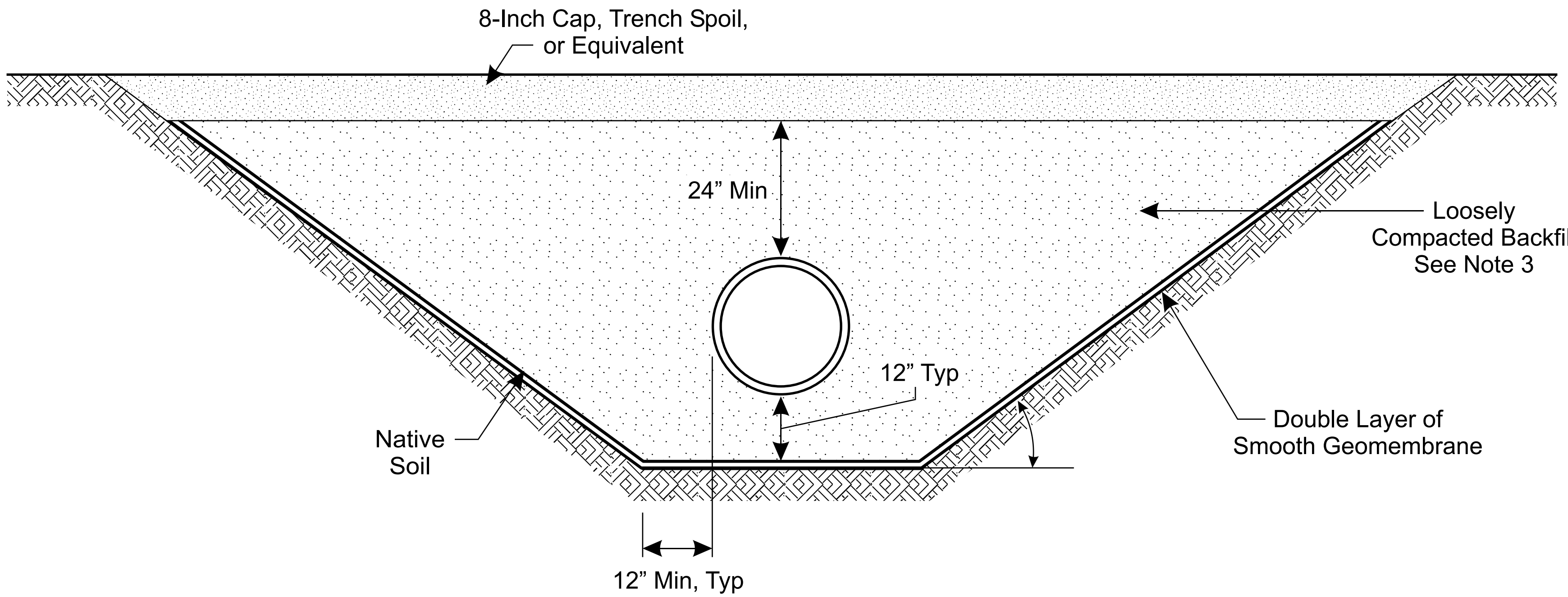
Figure 2

Typical Aboveground Fault Crossing

Job No. 26219736

URS

Glennallen to Palmer Spur Line
Engineering/Fault Zone Crossing Design
ANGDA, Anchorage, Alaska



NOTES

1. = 30° to 45° for horizontal or vertical ground displacement

   = ~60° for vertical ground displacement

2. Angle of internal friction of soil backfill < 35°

3. Relative density of compacted backfill less than 66%, if achievable

Figure 3

Typical Section of Buried Fault Crossing

Job No. 26219736

URS

Glennallen to Palmer Spur Line
Engineering/Fault Zone Crossing Design
ANGDA, Anchorage, Alaska

4.0 Recommendations

The following are recommended for conceptual design of fault crossings for the Spur Line between Palmer and Glennallen:

- Based on the unknowns presented by the complex geology of the study area, as well as contradictions between field evidence of faulting and recent earthquakes, mean maximum displacement at each fault crossing is conservatively estimated to be 7 feet for both vertical and horizontal components.

- Considering the location and possible sensitive environment of the pipeline alignment, the design displacement is recommended as two-thirds of the mean maximum fault displacement, or approximately 5 feet for both vertical and horizontal components.

- Both above ground and buried fault crossing designs are technically and economically feasible. However, considering the safety concerns, the buried mode of crossing design with a double layer geomembrane liner is recommended for the fault crossings for this pipeline.

The following methods are recommended for further investigation to refine the estimation of recency of activity, fault crossing length, maximum displacement, and return period at each fault crossing prior to final design:

- Light Detecting and Ranging (LIDAR) aerial reconnaissance should be flown over the study area to detect potential evidence of surface rupture that may not have been captured by previous aerial photograph surveys. LIDAR technology offers an accurate method to map detailed elevation information of bare earth without the obscuring influence of vegetation. The study area should be flown in late spring or fall to avoid the most heavily vegetated months. Detailed review of the LIDAR data would focus on Quaternary deposits on the sides of valleys near the pipeline fault crossings and for some distance along strike away from the fault crossings. LIDAR coverage should extend from approximately the Castle Mountain-Caribou fault split near the Chickaloon River, along the Caribou fault to about Sheep Creek, and along the Castle Mountain fault to about Caribou Creek.

- Organic material from basal soil horizons collected during this study where present should be submitted for radiocarbon age dating.

- In the event of clear or suspicious evidence of surface faulting or lineaments through Quaternary deposits, detailed ground-checking should be conducted at all such locations along the faults to assess whether lineaments are fault-related and the relative age of surficial material. Samples of the basal soil horizons at these locations should be collected and analyzed radiocarbon age using AMS (accelerator mass spectrometry) dating techniques.

- Detailed geologic mapping of selected bedrock areas should be conducted in the vicinity of the fault crossings where fault zones and/or zones of uncertainty are wide, to resolve variations by previous authors, and to potentially reduce fault zone widths and the lengths of pipeline needing special design consideration. To this end, an attempt should be made to recover the original detailed scale geologic maps completed by Fuchs (1980) at the University of Utah.

Following collection of the above data, the recency of activity and estimated return period on each fault should be reassessed. A recommendation should be made as to which fault zones are unlikely to be active or have long return periods not requiring special design, and/or whether trenching is warranted to resolve this issue at certain faults.

- If trenching at or near fault crossings is recommended, trenches should be dug to the depth of the water table across the zone of concern. Detailed logging of trenches should include information on microstratigraphic units, paleosols, potential fault-related deformation features, liquefaction features, and volcanic ash layers. Haeussler et al. (2002) provides an indication of the types of features that may be anticipated and the level of logging detail that should be conducted. Organic material associated with disturbed zones or layers should be collected and analyzed for radiocarbon age using AMS dating techniques.

- The seismic hazard of permanent ground displacement is addressed in this report and the above recommendations. Other seismic hazards such as liquefaction, lateral spreading, settlements, landslides, and wave propagation (ground shaking) are also present at the fault crossing locations. These hazards should be investigated by conducting detailed geotechnical investigations at the pipeline crossings.

5.0 References

AeroMap U.S. 1978. High altitude infrared aerial photographs, Chickaloon-Chitna Pass-Eureka Roadhouse area, Alaska. Roll 02670, Frames 8116-8125, 8239-8242, 8250-8259. Approx. Scale 1" = 5,000'. August.

Aeromap, U.S. 2004. Color stereo aerial photographs, ANGDA spur line. Frames 5-2 to 5-10, 6-5 to 6-7, 7-1 to 7-5, and 8-5 to 8-8. Approx. Scale 1" = 2,000'. October.

Bunds, M.P. 2001. Fault Strength and Transpressional Tectonics Along the Castle Mountain Strike-Slip Fault, Southern Alaska. Geological Society of America Bull. v.113, no. 7. July.

Cluff, L.S., G. Plafker, and D.B. Slemmons. 2003. Is There an Urgency to Restore the Pipeline's Denali Fault Displacement Capacity? Position Paper prepared for Alyeska Pipeline Service Company, Anchorage, Alaska.

Csejtey, Jr., B., W.H. Nelson, D.L. Jones, N.J. Silberling, R.M. Dean, M.S. Morris, M.A. Lanphere, J.G. Smith, and M.L. Silberman. 1978. Reconnaissance Geologic Map and Geochronology, Talkeetna Mountains Quadrangle, Northern Part of Anchorage Quadrangle, and Southwest Corner of Healy Quadrangle, Alaska. U.S. Geological Survey Open-File Report 78-558-A. Scale 1:250,000.

Detterman, R.L. 1976. Geology and Surface Features Along Part of the Talkeetna Segment of the Castle Mountain - Caribou Fault System, Alaska. U.S. Geological Survey Misc. Field Studies Map MF-738. Scale 1:63,360.

Fuchs, W.A. 1980. Tertiary Tectonic History of the Castle Mountain - Caribou Fault System in the Talkeetna Mountains, Alaska. Ph.D. dissertation, University of Utah. June. 152 p.

Grantz, A. 1961a. Geologic Map and Cross Sections of the Anchorage (D-2) Quadrangle and Northeasternmost Part of the Anchorage (D-3) Quadrangle, Alaska. U.S. Geological Survey Misc. Geologic Investigations Map I-342. Scale 1:48,000.

Grantz, A. 1961b. Geologic Map of the North Two-Thirds of Anchorage (D-1) Quadrangle, Alaska. U.S. Geological Survey Misc. Geologic Investigations Map I-343. Scale 1:48,000.

Haeussler, P.J. 1998. Surficial Geologic Map Along the Castle Mountain Fault Between Houston and Hatcher Pass Road, Alaska. U.S. Geological Survey Open-File Report OF 98-480.

Haeussler, P.J. 2005a. Paleoseismicity of the Castle Mountain Fault System. Unpubl. notes on investigations undertaken in 1994 and 1995. http://erp-web.er.usgs.gov/reports/annsum/vol37/pn/haeussle.htm. Accessed July 5.

Haeussler, P.J., U.S. Geological Survey, Anchorage, Alaska. 2005b. Verbal communication, re: recency of faulting and previous studies on Castle Mountain-Caribou fault system; overall slip rate, maximum displacement, and maximum credible earthquake on Castle Mountain fault; persistence of surficial evidence and investigative methods.

Haeussler, P.J., T.C. Best, and C.F. Waythomas. 2002. Paleoseismology at High Latitudes: Seismic Disturbance of Upper Quaternary Deposits Along the Castle Mountain Fault near Houston, Alaska. Geological Society of America Bull. v 114, no. 10, p. 1296-1310. October.

Haeussler, P.J., R.L. Bruhn, and T.L. Pratt. 2000. Geological Society of America Bull. v 112, no. 9, p. 1414-1429. September.

Haeussler, P.J. and R.W. Saltus. 2004. 26 km of Offset on the Lake Clark Fault Since Late Eocene Time. Studies by the U.S. Geological Survey, 2004; U.S. Geological Survey Professional Paper 1709-A. 4 p.

Hall, W.J., D.J. Nyman, E.R. Johnson, and J.D. Norton. 2003. Performance of the Trans-Alaska Pipeline in the November 3, 2002 Denali Fault Earthquake. Proceedings of the Sixth U.S. Conference and Workshop on Lifeline Earthquake Engineering, ASCE Technical Council on Lifeline Earthquake Engineering, Long Beach, CA, August 2003. 13 p.

Honegger, D.G. and D.J. Nyman. 2004. Guidelines for the Seismic Design and Assessment of Natural Gas and Liquid Hydrocarbon Pipelines. Pipeline Research Council International, Inc. (PRCI), Catalog No. L51927. October 1.

Labay, K. and P.J. Haeussler. 2001. GIS Coverages of the Castle Mountain Fault, South Central Alaska. U.S. Geological Survey Open-File Report 01-504.

Lahr, J.C., R.A. Page, C.D. Stephens, and K.A. Fogleman. 1986. Sutton, Alaska, Earthquake of 1984: Evidence for Activity on the Talkeetna Segment of the Castle Mountain Fault System. Bull. of the Seismological Society of America, v. 76, no. 4, p. 967-983. August.

Lubick, N. 2002. Geophenomena: Alaska Rumbles. Geotimes, December 2002. American Geological Institute. www.geotimes.org/dec02/geophen.html.

Michael Baker Jr., Inc. 2005. Glennallen to Palmer Spur Line, Engineering Report. Prepared for: Alaska Natural Gas Development Authority, Anchorage, Alaska. March.

Michael Baker, Jr., Inc.2005. Transport of North Slope Natural Gas to Tidewater. Prepared for the Alaska Natural Gas Development Authority, Anchorage, Alaska.

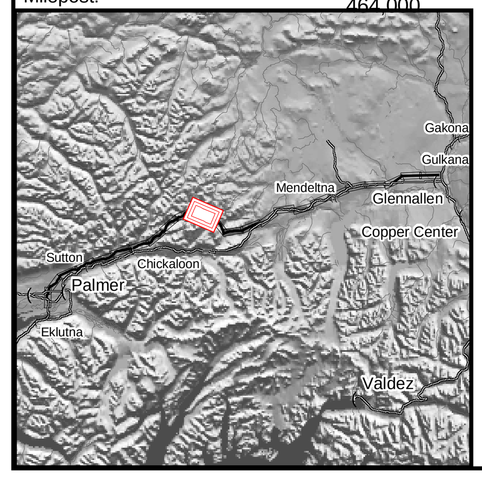
Plafker, G., Gilpin, L.M. and Lahr, J.C., 1993, Neotectonic Map of Alaska (Plate 12), *in* Geology of Alaska, Volume G-1, Geology of North America, Geology Society of America, scale 1:2,500,000.

U.S. Geological Survey (USGS), Earthquake Hazards Program. 2004. Magnitude/Intensity Comparison. http://wwwneic.cr.usgs.gov/neis/general/mag_vs_int.html. Last modified June 1.

Wells, D.L. and Coppersmith, K.J. 1994. New Empirical Relationships Among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement. Bull. of the Seismological Society of America, v. 84, no.4., p. 974-1002.

Appendix A

Route Maps with Potentially Active Faults



- Pipeline Route
- Road
- Secondary Road
- Trail
- Landing Strip
- Existing Pipeline
- Railroad
- Crossin Block Valves
- Material Site
- Concern Wetland
- Wetland
- Private (200)
- Native Corporation (2NC)
- State (300)
- State: MHT (3MH)
- State: UA (3UA)
- Borough (400)
- Mile Posts
- Fault
- Fault, concealed or approximate
- Fault Zone

REV	DATE	REVISIONS	BY	CHECKED BY	PROJ. MANAGER	CUST. APPROVAL
2	6/08/05	Revised Township/Range Annotation	BJB	VLR	VLR	ODO
1	4/28/05	Replaced USGS quads with Aerial Photography	BJB	VLR	VLR	ODO
0	3/31/05	Issued for Final Application	IWM	VLR	VLR	ODO

ALASKAN NATURAL GAS DEVELOPMENT AUTHORITY

URS

Basemap : Michael Baker Jr., Inc (2005)

ALASKA NATURAL GAS PIPELINE AUTHORITY

POTENTIALLY ACTIVE FAULTS

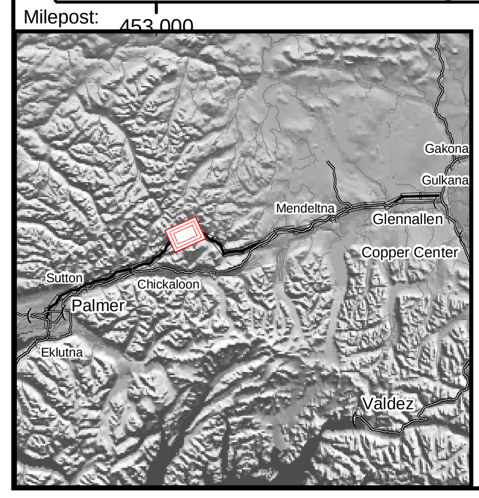
M.P. 80.89 to M.P. 87.22

GLENNALLEN TO PALMER SPUR LINE

0 500 1,000 2,000 3,000 4,000 Feet

26219736-014

REV.: A



Legend	
Pipeline Route	Material Site
Road	Concern Wetland
Secondary Road	Wetland
Trail	Private (200)
Landing Strip	Native Corporation (2NC)
Existing Pipeline	State (300)
Railroad	State: MHT (3MH)
Crossin Block Valves	State: UA (3UA)
	Borough (400)
Mile Posts	Fault
	Fault, concealed or approximate
	Fault Zone

REV	DATE	REVISIONS	BY	CHECKED BY	PROJ. MANAGER	CUST. APPROVAL
2	6/08/05	Revised Township/Range Annotation	BJB	VLR	VLR	ODO
1	4/28/05	Replaced USGS quads with Aerial Photography	BJB	VLR	VLR	ODO
0	3/31/05	Issued for Final Application	IWM	VLR	VLR	ODO

ALASKAN NATURAL GAS DEVELOPMENT AUTHORITY

URS

Basemap : Michael Baker Jr., Inc (2005)

ALASKA NATURAL GAS PIPELINE AUTHORITY

POTENTIALLY ACTIVE FAULTS

M.P. 87.22 to M.P. 93.72

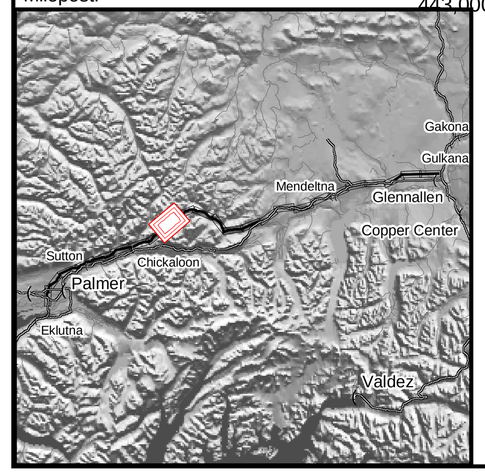
GLENNALLEN TO PALMER SPUR LINE

0 500 1,000 2,000 3,000 4,000 Feet

26219736-015

REV.: A

UTM Zone 6, NAD 83, meters



Legend

- Pipeline Route
- Road
- Secondary Road
- Trail
- Landing Strip
- Existing Pipeline
- Railroad
- Crossin Block Valves
- Material Site
- Concern Wetland
- Wetland
- Private (200)
- Native Corporation (2NC)
- State (300)
- State: MHT (3MH)
- State: UA (3UA)
- Borough (400)
- Mile Posts
- Fault
- Fault, concealed or approximate
- Fault Zone

REV	DATE	REVISIONS	BY	CHECKED BY	PROJ. MANAGER	CUST. APPROVAL
2	6/08/05	Revised Township/Range Annotation	BJB	VLR	VLR	ODO
1	4/28/05	Replaced USGS quads with Aerial Photography	BJB	VLR	VLR	ODO
0	3/31/05	Issued for Final Application	IWM	VLR	VLR	ODO

ALASKAN NATURAL GAS DEVELOPMENT AUTHORITY

URS

Basemap : Michael Baker Jr., Inc (2005)

ALASKA NATURAL GAS PIPELINE AUTHORITY

POTENTIALLY ACTIVE FAULTS

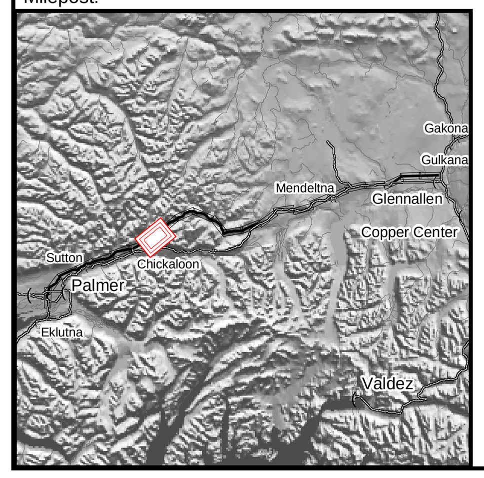
M.P. 93.72 to M.P. 100.07

GLENNALLEN TO PALMER SPUR LINE

0 500 1,000 2,000 3,000 4,000 Feet

26219736-016

REV.: A



Milepost:

Legend		
Pipeline Route	Material Site	Mile Posts
Road	Concern Wetland	
Secondary Road	Wetland	
Trail	Private (200)	
Landing Strip	Native Corporation (2NC)	Fault
Existing Pipeline	State (300)	Fault, concealed or approximate
Railroad	State: MHT (3MH)	Fault Zone
Crossin Block Valves	State: UA (3UA)	
	Borough (400)	

REV	DATE	REVISIONS	BY	CHECKED BY	PROJ. MANAGER	CUST. APPROVAL
2	6/08/05	Revised Township/Range Annotation	BJB	VLR	VLR	ODO
1	4/28/05	Replaced USGS quads with Aerial Photography	BJB	VLR	VLR	ODO
0	3/31/05	Issued for Final Application	IWM	VLR	VLR	ODO

ALASKAN NATURAL GAS DEVELOPMENT AUTHORITY

URS

Basemap : Michael Baker Jr., Inc (2005)

ALASKA NATURAL GAS PIPELINE AUTHORITY

POTENTIALLY ACTIVE FAULTS

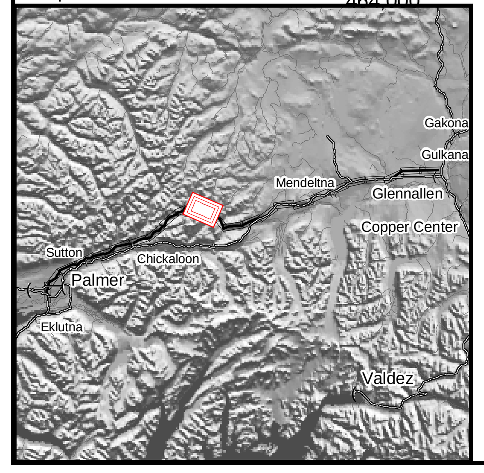
M.P. 100.07 to M.P. 106.57

GLENNALLEN TO PALMER SPUR LINE

0 500 1,000 2,000 3,000 4,000 Feet

26219736-017

REV.: A



Pipeline Route
Road
Secondary Road
Trail
Landing Strip
Existing Pipeline
Railroad
Crossin Block Valves

Material Site
Concern Wetland
Wetland
Private (200)
Native Corporation (2NC)
State (300)
State: MHT (3MH)
State: UA (3UA)
Borough (400)

Mile Posts

Fault
Fault, concealed or approximate
Fault Zone

REV	DATE	REVISIONS	BY	CHECKED BY	PROJ. MANAGER	CUST. APPROVAL
2	6/08/05	Revised Township/Range Annotation	BJB	VLR	VLR	ODO
1	4/28/05	Replaced USGS quads with Aerial Photography	BJB	VLR	VLR	ODO
0	3/31/05	Issued for Final Application	IWM	VLR	VLR	ODO

ALASKAN NATURAL GAS DEVELOPMENT AUTHORITY

URS

Basemap : Michael Baker Jr., Inc (2005)

ALASKA NATURAL GAS PIPELINE AUTHORITY

POTENTIALLY ACTIVE FAULTS

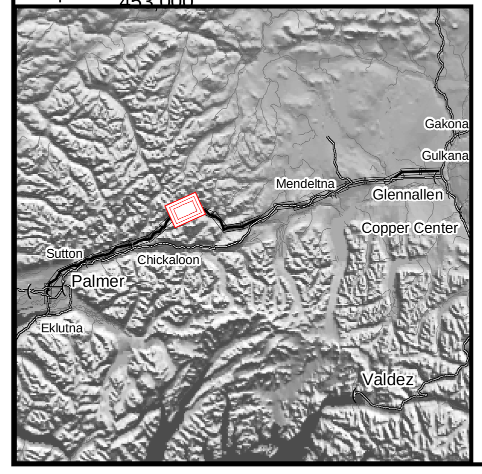
M.P. 80.89 to M.P. 87.22

GLENNALLEN TO PALMER SPUR LINE

0 500 1,000 2,000 3,000 4,000 Feet

26219736-014

REV.: A



Legend	
Pipeline Route	Material Site
Road	Concern Wetland
Secondary Road	Wetland
Trail	Private (200)
Landing Strip	Native Corporation (2NC)
Existing Pipeline	State (300)
Railroad	State: MHT (3MH)
Crossin Block Valves	State: UA (3UA)
	Borough (400)

Mile Posts

Fault

Fault, concealed or approximate

Fault Zone

REV	DATE	REVISIONS	BY	CHECKED BY	PROJ. MANAGER	CUST. APPROVAL
2	6/08/05	Revised Township/Range Annotation	BJB	VLR	VLR	ODO
1	4/28/05	Replaced USGS quads with Aerial Photography	BJB	VLR	VLR	ODO
0	3/31/05	Issued for Final Application	IWM	VLR	VLR	ODO

ALASKAN NATURAL GAS DEVELOPMENT AUTHORITY

URS

Basemap : Michael Baker Jr., Inc (2005)

ALASKA NATURAL GAS PIPELINE AUTHORITY

POTENTIALLY ACTIVE FAULTS

M.P. 87.22 to M.P. 93.72

GLENNALLEN TO PALMER SPUR LINE

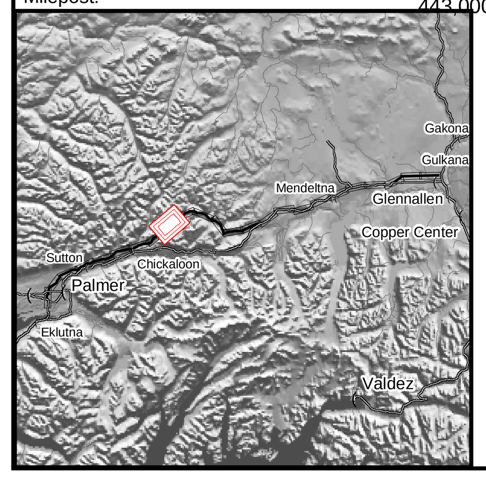
0 500 1,000 2,000 3,000 4,000 Feet

26219736-015

REV.: A

UTM Zone 6, NAD 83, meters

Milepost:



Legend:

- Pipeline Route
- Road
- Secondary Road
- Trail
- Landing Strip
- Existing Pipeline
- Railroad
- Crossin Block Valves
- Material Site
- Concern Wetland
- Wetland
- Private (200)
- Native Corporation (2NC)
- State (300)
- State: MHT (3MH)
- State: UA (3UA)
- Borough (400)
- Mile Posts
- Fault
- Fault, concealed or approximate
- Fault Zone

REV	DATE	REVISIONS	BY	CHECKED BY	PROJ. MANAGER	CUST. APPROVAL
2	6/08/05	Revised Township/Range Annotation	BJB	VLR	VLR	ODO
1	4/28/05	Replaced USGS quads with Aerial Photography	BJB	VLR	VLR	ODO
0	3/31/05	Issued for Final Application	IWM	VLR	VLR	ODO

ALASKAN NATURAL GAS DEVELOPMENT AUTHORITY

URS

Basemap : Michael Baker Jr., Inc (2005)

ALASKA NATURAL GAS PIPELINE AUTHORITY

POTENTIALLY ACTIVE FAULTS

M.P. 93.72 to M.P. 100.07

GLENNALLEN TO PALMER SPUR LINE

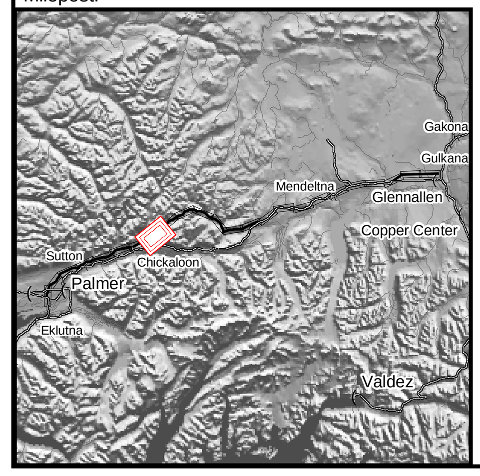
0 500 1,000 2,000 3,000 4,000 Feet

26219736-016

REV.: A

Milepost:

436,000 435,000 434,000 433,000 432,000 431,000 430,000 429,000



Legend	
Pipeline Route	Material Site
Road	Concern Wetland
Secondary Road	Wetland
Trail	Private (200)
Landing Strip	Native Corporation (2NC)
Existing Pipeline	State (300)
Railroad	State: MHT (3MH)
Crossin Block Valves	State: UA (3UA)
	Borough (400)

Mile Posts

Fault

Fault, concealed or approximate

Fault Zone

REV	DATE	REVISIONS	BY	CHECKED BY	PROJ. MANAGER	CUST. APPROVAL
2	6/08/05	Revised Township/Range Annotation	BJB	VLR	VLR	ODO
1	4/28/05	Replaced USGS quads with Aerial Photography	BJB	VLR	VLR	ODO
0	3/31/05	Issued for Final Application	IWM	VLR	VLR	ODO

ALASKAN NATURAL GAS DEVELOPMENT AUTHORITY

URS

Basemap : Michael Baker Jr., Inc (2005)

ALASKA NATURAL GAS PIPELINE AUTHORITY

POTENTIALLY ACTIVE FAULTS

M.P. 100.07 to M.P. 106.57

GLENNALLEN TO PALMER SPUR LINE

0 500 1,000 2,000 3,000 4,000 Feet

26219736-017

REV.: A

Appendix B

Field Report Forms

ANGDA FAULT CROSSING FIELD FORM

URS Job No.: 26219736 Study Area: Glenallen to Palmer Spur Line Date: 9/1/05 Field Crew: NJD/JCD

Fault Name: Caribou Fault - East Crossing (CF-E) Site (1)
1235

Location Information

Strip Map No.: 014

Approximate MP at Crossing: 84.7 - 84.85

Stereo Aerial Photo Nos. 8252, 8253 (infrared)

Geologic Map Reference(s): Detterman et al. (1976), Grantz (1961)

GPS Coordinates:

From Map: Lat/Long: 61°58.173N, 147°48.243W

UTM Zone 6, NAD 83: —

As Staked: WGS 84 - Lat/Long: N61°58.145 W147°48.323

UTM Zone 6, NAD 83: —

Landing Zone: Bench south of Chitna Creek: E. end of xsg just below SSW-trending ridge across bench
Actual (E) SE of So. end

Field Checklist

Mapped: ✓

Staked: ✓ *

GPS: ✓

Photos: ✓

Soil Samples: ✓

* stake located at approx midpt. of E-W overlap between 2 ends of fault xsg.

Fault Information

Strike at Crossing (from map): 089° (splay) - 89-101° (CF)

Fault Type/Sense of Offset*: CF R(U-south), RLSS; splay R(U-north)

Dip (from map): Splay 55°N, CF - 75°N - 90°

Pipeline Orientation (Strike): 101° - 115° (bends at E. end Flt xsg)

Field Evidence of Strike and Dip: Not at stake

Angle Between Fault Strike and Pipeline 10-14°, 0° where coincident

Field Evidence of Fault Exposure (sketch on back no): Km bedrock exposed in ridge to N + N. bank of Chitna Creek may be dipping steeply to north

Aerial Photo Evidence of Recent Movement: None on bench at xsg.

Field Evidence of Recent Movement: No, CF splay to NE appears to coincide w/ So. end Qls at Caribou C. where there is break in slope, but could be

Additional Information: depositional feature

Soil/Rock Information

Surface Geologic Unit at Crossing (from map): bedrock on map - see below. Probable thick section of glacial till over bedrock.

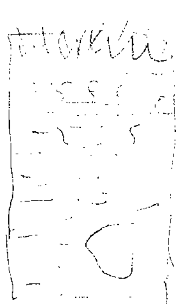
Nearest Bedrock Location: at crossing

Nearest Bedrock Units (from map): Km to north, Tv between splay + CF to east, Jc to south
Km = Mat. Fm sh, z, intbdd ss, local cgl. Tv = basalt flows + intbdd tuff Jc = Chinitna Fm sh, z, intbdd gywke + ls concretns

Bedrock Description (field, if nearby): none encountered near stake.

Soil Sample Location: at stake

Soil Column:

Sketch	Depth	Description	Sample No.(s)
	0-4"	Vegetative mat	
	4-6"	Dark brn-black organic silty clay, sticky, ~50% roots	CF-E1
	6"-8"	V. sticky silty clay, light to dark brown, <25% roots	CF-E2
	8"-2'+	Lt brown silty clay, very sticky, wet, occasional large cobbles. Probably glacial till deposit. Looking north across Chitna Ck, similar brown surficial deposit appears ~50' thick on top of Km bedrock.	CF-E3

Photographs

Photos Taken (No./Description):

Field Photo Nos:	Rept. Photo Nos:
24-26 CF-E (1)	1

*R = reverse (U = up side); RLSS = right lateral strike slip; T =thrust

ANGDA FAULT CROSSING FIELD FORM

URS Job No.: 26219736 Study Area: Glenallen to Palmer Spur Line Date: 9/1/05 Field Crew: NDD/JCD

Fault Name: Caribou Fault - Northeast splay (CF-NE) Site (2)
weather overcast, drizzling, low ceiling 1135

Location Information

Strip Map No.: 014
Approximate MP at Crossing: 86.46
Stereo Aerial Photo Nos. 8252, 8253 (infrared)
Geologic Map Reference(s): Detterman et al. (1976)
GPS Coordinates:
From Map: Lat/Long: 61°58.412N, 147°51.516'W } was 84
UTM Zone 6, NAD 83:
As Staked: Lat/Long: 61°58.415'N, 147°51.506'W
UTM Zone 6, NAD 83:

Intended Landing Zone: Qls bench between 2 small NNW-trending tribs to Chitna Creek, Xsg is just W. of E. tributary.
Actual LZ about 600' no. of stake on Qls ridge.

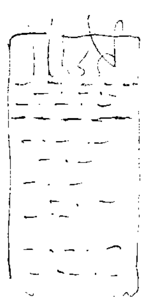
Field Checklist
Mapped: ✓
Staked: ✓
GPS: ✓
Photos: ✓
Soil Samples: ✓

Fault Information

Strike at Crossing (from map): 072°
Fault Type/Sense of Offset*: R(U-north)
Dip (from map): steep to north?
Pipeline Orientation (Strike): 135°
Field Evidence of Strike and Dip: yes, on W side of W. trib
Angle Between Fault Strike and Pipeline 63°
Field Evidence of Fault Exposure (sketch on back yes): dip ≈ 70-80°N. in FZ exposure. S+D N. of fault N70W, 73°N is fault-‖.
See below* + over.
Aerial Photo Evidence of Recent Movement: No
Field Evidence of Recent Movement: Possible increased slope in Qls deposit along fault.
Additional Information:
See sketch over

Soil/Rock Information

Surface Geologic Unit at Crossing (from map): Qls[1] = Pleistocene landslide deposit > 8000 yrs bp
Nearest Bedrock Location: bottom or E. side of E. tributary
Nearest Bedrock Units (from map): Jtk to north Tc to south
Jtk = Talk. Fm andes. flows agg, tuff intbdd w/ ss + z, local grnst. alt Tc = Chickaloon Fm ss, z, clyst, cgl, coal
Bedrock Description (field, if nearby): lt. greenish-gray hard ss (or andesitic tuffaceous ss?) in bed of E. trib. S+D N70W, 73°N. Weathers to orangish-brown. Sample CF-NE3 located NE of stake prob. in Jtk. *Lose bedrock exposure to so. beneath colluv. which appears to cover CF-NE
Soil Sample Location: at stake
Soil Column:

Sketch	Depth	Description	Sample No.(s)
	0-6"	Veg. material, mostly roots	
	6-8"	Dark brown to black silt/silt loam with occ. gvl	CFNE-1 @ 8"
	8"-2'+	Light brown silt with ~10% small gravels.	CFNE-2 @ 1.5'
			CFNE-3 bedrock sample see over

Photographs

Photos Taken (No./Description):

Field Photo Nos.	Description	Rept. Photo Nos.
19-21	CF-NE	2-3
22-23	possible fault evidence SW of (2)	

*R = reverse (U = up side); RLSS = right lateral strike slip; T =thrust

ANGDA FAULT CROSSING FIELD FORM

URS Job No.: 26219736 Study Area: Glenallen to Palmer Spur Line Date: 9/1/05 Field Crew: NJD/JCD

Fault Name: Caribou Fault – West Crossing / East end (CF-WE) Site ③

0935

Location Information

Strip Map No.: 016

Approximate MP at Crossing: 93.5

Stereo Aerial Photo Nos. 8119, 8120 (infrared)

Geologic Map Reference(s): Detterman et al. (1976), Fuchs (1980)

GPS Coordinates:

From Map: Lat/Long: –

UTM Zone 6, NAD 83: –

As Staked: Lat/Long: 61° 56.575 N, 148° 02.249 W ← WGS 84

UTM Zone 6, NAD 83: –

Landing Zone: W. side of Qag tributary to Bldr creek about 300' south of confluence.

Field Checklist

Mapped: ✓

Staked: ✓

GPS: ✓

Photos: ✓

Soil Samples: ✓

Fault Information

Strike at Crossing (from map): ~072°

Dip (from map): Steep to north ?

Field Evidence of Strike and Dip: Not near crossing

Field Evidence of Fault Exposure (sketch on back ___): none

Fault Type/Sense of Offset*: R (U-north), RLSS

Pipeline Orientation (Strike): 041°

Angle Between Fault Strike and Pipeline 31°

Aerial Photo Evidence of Recent Movement: Possible lineaments in Pleist–Holo Qag north side of Bldr Ck valley

Field Evidence of Recent Movement: No Apparent lineament in glacial lobe NE of confluence appear erosional stream related

Additional Information: East end of CF-W xsg extended approx 700' north of previous authors interpretation on the basis of poss. lineaments on air photos.

Ground conditions: sl. hummocky low brush covered stream terrace

Soil/Rock Information

Surface Geologic Unit at Crossing (from map): Qag = Pleist-Holo glac-fluv. deposits. Fault may offset ≤8000 yr bp moraine lobe to E.

Nearest Bedrock Location: 1½ miles to east along strike

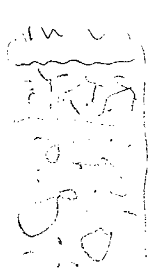
Nearest Bedrock Units (from map): Tv to north side of fault; Jtk south side

Tv = basalt + assoc. volc. Jtk = Talk. Fm andesitic flows + assoc. volc intbdd w/ ss #7

Bedrock Description (field, if nearby): Not in vicinity of xsg.

Soil Sample Location: Right at stake

Soil Column:

Sketch	Depth	Description	Sample No.(s)
	0-½"	Organic mat	
	½-2½"	Brn-dk brn cse sndy Z to silty sand with abundant rootlets + some grvl	CF-WE1
	2½"+	Silty sandy grvl to cobbles, alluvium–alluvial fan material	CF-WE2

Photographs

Photos Taken (No./Description):

Field Photo Nos.	Description	Rept. Photo Nos.
1-5	Area upstream of ③	4-6
6	LZ near ③	
7-8	CF-WE	
9-12	CF-WE LZ	

*R = reverse (U = up side); RLSS = right lateral strike slip; T =thrust

ANGDA FAULT CROSSING FIELD FORM

URS Job No.: 26219736 Study Area: Glenallen to Palmer Spur Line Date: 9/1/05 Field Crew: NJD/JCD

Fault Name: Caribou Fault – West Crossing / West End (CF-WW) Site (4)

1035

Location Information

Strip Map No.: 016

Approximate MP at Crossing: 96.5

Stereo Aerial Photo Nos. 8118, 8119 (infrared)

Geologic Map Reference(s): Detterman et al (1976), Fuchs (1980), Labay + Haessler (2001)

GPS Coordinates:

From Map: Lat/Long: 61°55.423'N, 148°06.845'W

UTM Zone 6, NAD 83: –

As Staked: WGS 84 Lat/Long: N 61°35.375, 148°06.782 W

UTM Zone 6, NAD 83: –

Landing Zone: SE side of Bldr Creek, right in Holo. alluvium. ~100' SE of main channel + ~100' S. of small bend to E. Staked ~ equidistant betw main channel + older terrace to so.

Field Checklist

Mapped: ✓

Staked: ✓

GPS: ✓

Photos: ✓

Soil Samples: ✓

Fault Information

Strike at Crossing (from map): 070°

Dip (from map): 75-85 N

Field Evidence of Strike and Dip: no bdrk/FZ near stake

Field Evidence of Fault Exposure (sketch on back no): see bedrock description below

Fault Type/Sense of Offset*: R (U-north), RLSS

Pipeline Orientation (Strike): 059°

Angle Between Fault Strike and Pipeline 11° (becomes sub-ll to ea

Aerial Photo Evidence of Recent Movement: possibly on north side of Fault zone

Field Evidence of Recent Movement: No

Additional Information: Nose is location of fault per Detterman (76);

Soil/Rock Information

Surface Geologic Unit at Crossing (from map): Qag = Pleist-Holo glac-fluv deposits, gravel bar — Staked on Holo. part

Nearest Bedrock Location: 3/4 mi to W. along strike of fault

Nearest Bedrock Units (from map): Jtk to North, Km to south. Jtk = Talk Fm And. flows + assoc tuff, agg intbdd w/ ss + z. Km = Mat. Fm. sh + z w/ intbdd ss + cg.

Bedrock Description (field, if nearby): As viewed from stake, Km appears to form cliff on south side of nose, Jtk more eroded slope to north, with notch in betw.

Soil Sample Location: at stake

Soil Column:

Sketch	Depth	Description	Sample No.(s)
	0-3"+	Mixed grey + brown sandy gravel and cobbles w/ occ. small bldr. (no organic mat) Modern streambed alluvium	CF-WW 1

Photographs

Photos Taken (No./Description): Field Photo Nos.

Field Photo Nos.	Description	Rept. Photo No.
13-16	CF-WW	7-9
17	Possible lineaments north side of Boulder Ck betw. (3) + (4)	
18	LZ @ CF-WW	

*R = reverse (U = up side); RLSS = right lateral strike slip; T = thrust

ANGDA FAULT CROSSING FIELD FORM

URS Job No.: 26219736 Study Area: Glenallen to Palmer Spur Line Date: 9/1/05 Field Crew: NJB/JLD

Fault Name: Caribou Fault - Southwest splay (CF-SW) Site (5)
(Also called Boulder Creek Fault by Fuchs (1980)) 1420

Location Information

Strip Map No.: 016

Approximate MP at Crossing: 97.25

Stereo Aerial Photo Nos. 8118, 8119 (infrared)

Geologic Map Reference(s): Detterman et al. (1976), Fuchs (1980)

GPS Coordinates:

From Map: Lat/Long: 61°54.899N, 148°07.675'W
UTM Zone 6, NAD 83: —

As Staked: Lat/Long: N61°54.901, W148°07.673 (WGS 84)
UTM Zone 6, NAD 83: —

Landing Zone: E. edge of Qag Bldr Ck valley bottom near base of bedrock slope/NE corner nose. ~200' so. of drainage

Field Checklist

Mapped: ✓
Staked: ✓
GPS: ✓
Photos: ✓
Soil Samples: ✓

Fault Information

Strike at Crossing (from map): 066°

Dip (from map): 58°S – near-vertical (Fuchs 80)

Field Evidence of Strike and Dip: —

Fault Type/Sense of Offset*: R(U-south), RLSS

Pipeline Orientation (Strike): 029°

Angle Between Fault Strike and Pipeline 37°

Field Evidence of Fault Exposure (sketch on back no): looking ENE upslope from xsg, obvious bedrock change from dk gray Km to north, and Jtk to south, but no Q surficial dep. on top.

Aerial Photo Evidence of Recent Movement: None in Q deposits

Field Evidence of Recent Movement: None

Additional Information:

Soil/Rock Information

Surface Geologic Unit at Crossing (from map): Qag = Pl.-Holo. glac-fluv. deposits

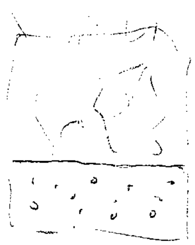
Nearest Bedrock Location: Just E of xsg in slope

Nearest Bedrock Units (from map): Km to north. Jtk to south.
Km = Mat. Fm sh + z w/ intbdd ss + cgl Jtk = Talk Fm. andes. flows, agg, tuffs.

Bedrock Description (field, if nearby): Too far upslope past dense alder thickets. Qag/Km (alluv fan/bedrock) contact is probably further upslope than mapped by Detterman (76).

Soil Sample Location: At stake.

Soil Column:



Sketch	Depth	Description	Sample No.(s)
	0-8"	Thick vegetative mat sl. silty, dark brown	CF-SW 1 (collected at base of veg mat 8")
	8" - 12"+	Lt. brown coarse sandy gravel with minor silt. Alluvial fan material	CF-SW 2

Photographs

Photos Taken (No./Description): Field Photo Nos. 27-32 CF-SW (5) Rept. Photo Nos. 10-11

*R = reverse (U = up side); RLSS = right lateral strike slip; T =thrust

ANGDA FAULT CROSSING FIELD FORM

URS Job No.: 26219736 Study Area: Glenallen to Palmer Spur Line Date: 9/1/05 Field Crew: NJD/JCD

Fault Name: Castle Mountain Fault (CMF) Site (6)
Weather - rain - drizzle 1605

Location Information

Strip Map No.: 017

Approximate MP at Crossing: 102 - 102.4

Stereo Aerial Photo Nos. 8118 - 8119 (infrared)

Geologic Map Reference(s): Detterman (1976), Fuchs (1980)

GPS Coordinates:

From Map: Lat/Long: 61°51.819 N 148°12.703 ← E. end of fault xsg

UTM Zone 6, NAD 83: — } both WGS84

As Staked: Lat/Long: N 61°51.763 W 148°12.729 } → ~350' south of (E. end of) fault xsg
350' S. of Flt Xsg ~100'

UTM Zone 6, NAD 83:

Intended Landing Zone: North bank of Boulder Creek Holo. drainage near SW. end of confluence of 2 wetlands/tribs
Brush looks thick - maybe LZ in BC alluv + walk 100' N. of bank.

Field Checklist

Mapped: ✓

Staked: ✓ 350' so. of xsg due to location in middle of beaver pond

GPS: ✓

Photos: ✓

Soil Samples: ✓

Fault Information

Strike at Crossing (from map): 90 - 102°

Dip (from map): steep to north to near-vertical

Field Evidence of Strike and Dip: No

Fault Type/Sense of Offset*: R (u - north), RLSS

Pipeline Orientation (Strike): 087° - 093° - 069° } N-S transition

Angle Between Fault Strike and Pipeline 15° - 0 - 23°

Field Evidence of Fault Exposure (sketch on back No): Bedrock exposed at sharp bend in river - E. side near Fault. JTk, Km + Tif units exposed high on ridges looking E down Fault

Aerial Photo Evidence of Recent Movement: None in Qag high on ridges too

Field Evidence of Recent Movement: None

Additional Information:

Soil/Rock Information

Surface Geologic Unit at Crossing (from map): Qag = ~~Pleist~~-Holo ~~glac.~~ - fluv. dep./gravel bar

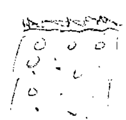
Nearest Bedrock Location: 1/2 E along Fault strike at E. side of Qag valley bottom

Nearest Bedrock Units (from map): JTk to north Tc/Tif to south
JTk = Talk Fm. andes flows + assoc. Tc = Chickaloon Fm sed. sequence w/coal Tif = granitic stock

Bedrock Description (field, if nearby): Closest loc. is on opposite side of Boulder Creek - too high to cross. W. nose of Anthracite Ridge

Soil Sample Location: at stake 350' South of Flt Xsg.

Soil Column:

Sketch	Depth	Description	Sample No.(s)
	0-1"	Vegetative mat	
	1" - 6"+	Lt. brn - lt. gray sandy gravel. Holocene alluvium / gravel bar.	CMF-1 350' So. of crossing. Crossing itself is in pond/wetlands - probably dominantly organic silt.

Photographs

Photos Taken (No./Description): Field Photo Nos. 33-36 CMF (6) 350' south of actual pt. due to beaver pond. } Rept. Photo Nos. 12-14

*R = reverse (U = up side); RLSS = right lateral strike slip; T =thrust

Appendix C

Photographs

Photograph 1. Caribou Fault – East Crossing, MP 84.7-84.85: Chitna Creek is to right; fault follows bench on left (south) side of creek. Pipeline route coincides with fault for about 1,000 feet at this crossing, then crosses to north side of creek in center-right of photograph. Northeast splay of Caribou fault (MP 86.6) is in mountainside in center background.

Photograph 2: Caribou Fault – Northeast Splay, MP 86.6: Looking southeast down pipeline route towards Chitna Creek valley from fault crossing. Fault trends sub-parallel to Chitna Creek valley into hillslope at left.

Photograph 3. Caribou Fault - Northeast Splay, MP 86.6: Looking southwest from fault crossing across at possible fault trace, noted by difference in bedrock type on either side of the gully in center of photograph. Fault and bedrock to left both dip steeply to north.

Photograph 4. Caribou Fault – East End of West Crossing, MP 96.5: Aerial view above crossing point looking upstream through upper Boulder Creek valley. Fault crossing is in alluvial fan/terrace material similar to right side of photograph. Pipeline route crosses photograph from right to left, trending north away from fault.

Photograph 5. Caribou Fault – East End of West Crossing, MP 96.5: Looking west, pipeline route runs along left side of photograph. East end of this 3-mile-long fault crossing is in trees beyond helicopter to left.

Photograph 6. Caribou Fault – West Crossing, MP 93.5-96.5: Aerial view near east end of crossing looking west down Boulder Creek valley. Pipeline route extends down left side of valley and lies within Caribou fault zone for about 3 miles. Fault zone gradually crosses Boulder Creek to right and trends into hill in center background.

Photograph 7. Caribou Fault – West End of West Crossing, MP 96.5: Looking northwest across Boulder Creek valley toward possible fault race in hillslope.

Photograph 8. Near Caribou Fault – West End of West Crossing, MP 96.5: Aerial view looking northwest across Boulder Creek valley. Fault interpretations vary between nose of slope at left (same as Photograph 7), to a line trending between base of slope at right and ridge notches in left-center. Area in between designated as Caribou fault zone.

Photograph 9. Caribou Fault – West End of West Crossing, MP 96.5: Looking north across Boulder Creek valley from west end of fault crossing in modern alluvium. Fault zone may extend to base of slopes on north side of valley.

Photograph 10. Caribou Fault – Southwest Splay, MP 97.325: Looking south, fault extends across Boulder Creek valley and curves to right up tributary canyon in center background.

Photograph 11. Caribou Fault – Southwest Splay, MP 97.25: Pipeline route crosses fault in densely vegetated alluvial fan material.

Photograph 12. Castle Mountain Fault, MP102.0: Looking northeast across north side of Boulder Creek valley, east end of crossing is approximately 350 feet north of staked location in beaver pond, just beyond beaver house in left-center.

Photograph 13. Castle Mountain Fault, MP 102.0: Looking east across Boulder Creek valley from east end of fault crossing. Fault crosses north slope of Anthracite Ridge in center background.

Photograph 14. Castle Mountain Fault, MP102.0-102.4: Looking west from near east end of fault crossing, which is to right in wetlands/drunken spruce forest. Pipeline route coincides with fault zone for about 2,000 feet, then bends to southwest across left side of photograph. Fault zone continues into center-left background across south-dipping slopes.