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OVERVIEW OF 2014 ENERGY-FOCUSED FIELD STUDIES IN SUSITNA BASIN, SOUTH-CENTRAL ALASKA, AND PRELIMINARY RESULTS

by
Robert J. Gillis, editor

Geologists (background) examining subvertical Cenozoic strata on Lake Creek in west-central Susitna basin. This outcrop hosts a poorly-sorted cobble-boulder conglomerate interval; rapid sedimentary facies and provenance changes suggest deposition in a tectonically active basin.

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OVERVIEW OF 2014 ENERGY-FOCUSED FIELD STUDIES IN SUSITNA BASIN, SOUTH-CENTRAL ALASKA, AND PRELIMINARY RESULTS

R.J. Gillis[1], Editor

INTRODUCTION

The Susitna basin is a poorly-studied Cenozoic terrestrial sedimentary basin expressed as a vast, approximately 13,000 km^2 lowland that is adjoined at its southern edge with the better-studied and petroliferous Cook Inlet basin. Cook Inlet basin is the largest commercially-producing gas basin in the state and the principal supplier of energy to south-central Alaska. Cook Inlet gas is biogenic and likely sourced from abundant interstratified Miocene–Pliocene-age coal seams (Claypool and others, 1980; Magoon, 1994) that, along with the overlying sandbodies, can also serve as a reservoir for the gas. Susitna basin stratigraphy resembles the coal-bearing intervals of Cook Inlet basin, and may also be a potential resource for microbial gas. Although the basin was recently included with Cook Inlet in an assessment of identified, undiscovered conventional and coalbed gas by the U.S. Geological Survey (Stanley and others, 2011), it is structurally distinct from Cook Inlet basin and has been only lightly explored. Therefore, uncertainties persist about whether a Cook Inlet model for biogenic gas is valid for the Susitna basin. However, exploration interest exists in the basin, as a new exploration well near its southern end is currently in the permitting process.

Recent studies leveraging high-density gravity data (Saltus and others, 2012, 2014) and well control, sparse proprietary seismic reflection, and aeromagnetic data (Stanley and others, 2013, 2014; Shah and others, 2014) have improved what is known about the age, stratigraphy, and structural configuration of the basin. However, detailed outcrop studies are still needed and remain important for understanding the stratigraphic architecture, depositional systems, reservoir and seal quality, gas potential of interstratified coal, and structural kinematics of the basin.

To begin filling this gap in data, the Alaska Division of Geological & Geophysical Surveys (DGGS) initiated reconnaissance-level stratigraphic field studies in Susitna basin in summer 2011 (Gillis and others, 2013) to develop a baseline geologic framework and lay the groundwork for future geologic investigations. DGGS continued field studies in 2014 aimed at better defining the stratigraphy, structural geology, and energy potential of the basin (fig. 1-1). Field studies focused mainly on the stratigraphic framework, sediment provenance, and reservoir quality of Cenozoic outcrops discontinuously exposed around the western and northern periphery of the basin, along with selected exposures of underlying Cretaceous bedrock. Samples for coal quality and high-pressure methane adsorption were collected and analyzed from nearly every major accessible coal seam exposed in the basin to quantify their attributes as a primary energy resource in addition to their ability to sequester methane. Additional research included preliminary structural kinematic analyses of fault slip data collected from bedrock outcrops near the western margin of the basin and companion thermochronologic sampling to help link periods of rock uplift with deformation and basin deposition. An overview and preliminary results of these studies are included as individual short interpretive reports in this volume. Main points from each report are summarized below.

CENOZOIC AND MESOZOIC STRATIGRAPHY: LePain and others, 2015

Stratigraphic sections were measured in Cenozoic strata at three locations on the northwest and west sides of the basin at Fairview Mountain and Johnson Creek. Strata mapped as Tyonek(?) Formation (Reed and Nelson, 1980) are coal-bearing and interpreted to have been deposited in mixed-load, low- to moderate-sinuosity streams. Sterling(?) Formation strata at Johnson Creek record deposition in moderate-gradient, low- to moderate-sinuosity gravelly streams. Sandstones at all of the study locations are quartzo-feldspathic, weakly cemented, and likely to have good reservoir potential if not buried too deeply. Common interbedded argillaceous mudrocks likely represent effective seal facies.

Mesozoic Kahiltna assemblage strata were examined at five locations in the Peters Hills, Dutch Hills, and Yenlo Hills. Strata in the Peters and Dutch hills are dominated by argillite with common interstratified fine-grain sandstone beds with rare thick, amalgamated sandstone beds interpreted as low- and high-density turbidites, respectively. Strata in the Yenlo Hills are more sand-prone, mostly massive, and interpreted as reflecting deposition in high-density, non-turbulent flows. Mesozoic strata in all examined locations appear to have poor reservoir potential.

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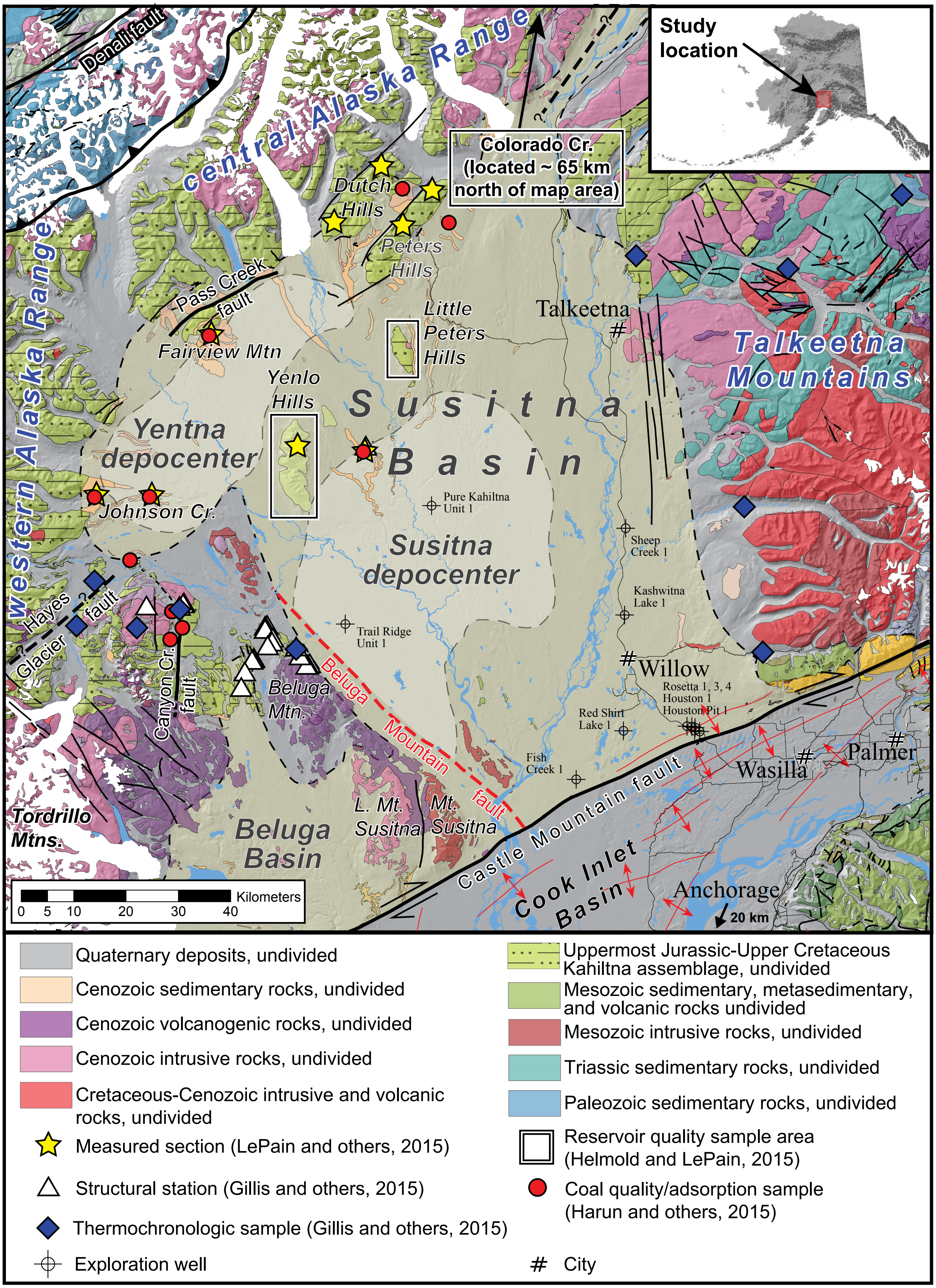

Figure 1. Generalized geologic map of the Susitna basin and its margins, including parts of the western and central Alaska Range, and Talkeetna Mountains. Thick black lines represent mapped surface faults (dashed where approximately located). Thin solid black lines represent lineaments or hypothesized faults (Wilson and others, 2009). Thin dashed lines represent approximate outline of Susitna basin (Meyer, 2005). Figure adapted from Wilson and others, 2009; Solie and Layer, 1993; and Stanley and others, 2014.

RESERVOIR QUALITY OF MESOZOIC STRATIGRAPHY: Helmold, 2015

Seventeen thin-section samples were collected in 2011 for petrographic analysis from Kahiltna assemblage strata at Little Peters Hills and the Colorado Creek area, and the graywacke of Yenlo Hills. Additional field examinations from the same and additional sites were conducted in 2014 and the results will be presented in future reports. Sandstones from Little Peters Hills and the Colorado Creek area strata are mostly quartzo-feldspathic with framework grains consisting mainly of chert with lesser mono- and poly-crystalline quartz. Accessory grains include plutonic and volcanic fragments, feldspar, and mica. Their overall reservoir quality is poor, with porosities less than 12 percent and permeabilities less than 1 millidarcy (md). Sandstones from Yenlo Hills are largely feldspatholithic with framework grains consisting mainly of plagioclase and volcanic lithic fragments that are highly susceptible to alteration. Accessory grains include sedimentary and plutonic rock fragments, mica, and feldspar. Reservoir quality is very poor, with porosities less than 1 percent and permeabilities less than 0.0001 md.

RECONNAISSANCE COAL STUDY: Harun and others, 2015

Twenty-two coal samples were collected from 11 localities and submitted for coal quality, high-pressure methane adsorption (HPMA), Rock-Eval pyrolysis, and vitrinite reflectance analyses to assess their potential as a primary energy source, a potential methane gas source, their organic carbon content and type, and thermal maturity. Coal cleats were also measured at eight locations to lay the groundwork for understanding the coal's fracture porosity and principal orientations. Coal ranks range from lignite A to subbituminous A. Coal cleat orientations varied, but face cleats tend to cluster into two main orientations, northwest-striking and northeast-striking. HPMA, Rock-Eval, and vitrinite reflectance results are pending, and will be presented in future reports.

RECONNAISSANCE STRUCTURAL KINEMATIC ANALYSIS: Gillis and others, 2015

One-hundred-four fault measurements from four areas in the Susitna basin and at its western margin yielded 39 unidirectional slip indicators that were analyzed to assess spatial and temporal patterns of fault slip at the basin margin. Regionally distributed fault orientations formed three sets: northwest striking (set A), east–northeast striking (set B), and north–northwest striking (set C). Set A faults commonly slip sinistrally and in a reverse sense. Set B faults exhibit variable senses of slip, but are commonly sinistral and transtensional. Set C faults also have variable senses of slip, but are commonly dextral and transtensional. Set A and C faults cut all other orientations, and set A faults cut set C faults. Analyzed together, the kinematic data tentatively record two nearly orthogonal directions of principal shortening representing two separate phases of deformation. The first phase was driven by northeast-directed principal shortening resulting in southeast-to-east extension. Phase two was driven by northwest-directed principal shortening resulting in northwest transpression and perhaps reactivation of earlier transtensional faults.

CLOSING REMARKS

The brief reports included in this volume present preliminary results and tentative interpretations from 2014 and earlier Susitna basin field studies by DGGS, which focus on its geologic development and energy potential. These field summaries will be followed by more substantial reports addressing the stratigraphy, reservoir quality, coal quality, hydrocarbon potential, basin structure, and basin uplift history as pending data are returned and interpreted in the coming months.

ACKNOWLEDGMENTS

These reports benefited from a thorough review by Marwan Wartes. Preliminary figure drafting by D. Mauel (DGGS). Helicopter support in the field was provided by Pathfinder Aviation, with thanks to Melissa Elerick, Mike Fell, and pilot Merlin (Spanky) Handley. Charter air services were provided by Regal Air and Hesperus Air Service, LLC, with thanks to Rob Jones, Jr., and Letta Stokes. Hesperus Air Services also provided remote fuel supplies. Meals and lodging were provided by the Skwentna Roadhouse, with thanks to proprietors Cindi Herman and Mark Torkelson. Funding for this project was provided by the State of Alaska through capital improvement projects.

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CHAPTER 2

RECONNAISSANCE STRATIGRAPHIC STUDIES IN THE SUSITNA BASIN, ALASKA, DURING THE 2014 FIELD SEASON

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INTRODUCTION

The Susitna basin is a poorly-understood Cenozoic successor basin immediately north of Cook Inlet in south-central Alaska (Kirschner, 1994). The basin is bounded by the Castle Mountain fault and Cook Inlet basin on the south, the Talkeetna Mountains on the east, the Alaska Range on the north, and the Alaska–Aleutian Range on the west (fig. 2-1). The Cenozoic fill of the basin includes coal-bearing nonmarine rocks that are partly correlative with Paleogene strata in the Matanuska Valley and Paleogene and Neogene formations in Cook Inlet (Stanley and others, 2013, 2014). Mesozoic sedimentary rocks are present in widely-scattered uplifts in and around the margins of the basin; these rocks differ significantly from Mesozoic rocks in the forearc basin to the south. Mesozoic strata in the Susitna region were likely part of a remnant ocean basin that preceded the nonmarine Cenozoic basin (Trop and Ridgway, 2007). The presence of coal-bearing strata similar to units that are proven source rocks for microbial gas in Cook Inlet (Claypool and others, 1980) suggests the possibility of a similar system in the Susitna basin (Decker and others, 2012). In 2011 the Alaska Division of Geological & Geophysical Surveys (DGGS) and Alaska Division of Oil and Gas, in collaboration with the U.S. Geological Survey, initiated a study of the gas potential of the Susitna basin (Gillis and others, 2013). This report presents a preliminary summary of the results from 14 days of helicopter-supported field work completed in the basin in August 2014. The goals of this work were to continue the reconnaissance stratigraphic work begun in 2011 aimed at understanding reservoir and seal potential of Tertiary strata, characterize the gas source potential of coals, and examine Mesozoic strata for source and reservoir potential.

COAL-BEARING TERTIARY STRATA

Three stratigraphic sections were measured in the Tertiary fill of the basin to better understand fluvial styles and sand-body geometries, and to collect samples of sandstone for reservoir quality analysis and coal for high-pressure methane adsorption testing and organic geochemistry. Coal seams sampled as part of this work are discussed by Harun and others (2015). One section is at Fairview Mountain in the northwestern corner of the basin and two are along Johnson Creek on the basin's west side (fig. 2-1, locations 1–3). These sections are in the northern half of the basin where Reed and Nelson (1980) applied Cook Inlet stratigraphic nomenclature, with minor modifications, to the Tertiary stratigraphy. They mapped the Tyonek(?) Formation, assigned a Miocene age, and divided it into two mappable members: a sandstone member and a conglomerate member. They also mapped the Sterling(?) Formation and assigned a Pliocene age. The measured section at Fairview Mountain is in the conglomerate member of the Tyonek(?) Formation and is 79 m thick, and the sections on Johnson Creek include one each in the sandstone member of the Tyonek(?) and the Sterling(?) Formations, which are 27 m and 35 m thick, respectively. Finally, we briefly discuss an outcrop of moderately to steeply dipping sandstone and pebble-cobble-boulder conglomerate that was measured in 2011 and revisited in 2014 to collect additional samples for isotopic age dating (fig. 2-1, location 4).

The measured section in the conglomerate member of the Tyonek(?) Formation at Fairview Mountain includes at least two complete fluvial cycles, at least one incomplete fluvial cycle, and multiple seams of lignitic coal in a thick mudstone package (fig. 2-2a). The lower complete fluvial cycle includes more than 9 m of pebble conglomerate and lenses and interbeds of coarse- to very-coarse-grained sandstone. The top of the cycle consists of a 0.5-m-thick bed of sandstone with a prominent fining-upward grain size trend (medium lower to fine lower). A prominent erosion surface at the base of this cycle truncates steeply dipping beds of cross-bedded, fine- to coarse-grained sandstone (fig. 2-2b). It is unclear whether these dipping beds belong to this fluvial cycle or to an underlying cycle. The upper complete fluvial cycle is approximately 15 m thick and includes a 4-m-thick stepped, coarsening-upward succession (erosion surfaces separating beds of successively coarser-grained material) at its base. Otherwise this cycle is similar to the lower cycle. Sandstones throughout are quartzo-feldspathic and weakly cemented. These cycles are separated by a 53-m-thick mudstone package comprising many thin (30 cm or less) beds of fine-grained sandstone, a few thicker, fining-upward bedsets of fine-grained sandstone-siltstone (up to 2.2 m thick), and at least seven lignitic coal seams from 10 to 90 cm thick. Siltstones are typically argillaceous, and a few thin beds of faintly-laminated claystone are present. The upper 3.5 m of the measured section consists of interbedded pebble and cobble conglomerate that is part of a thicker, coarse-grained fluvial succession that is inaccessible due to

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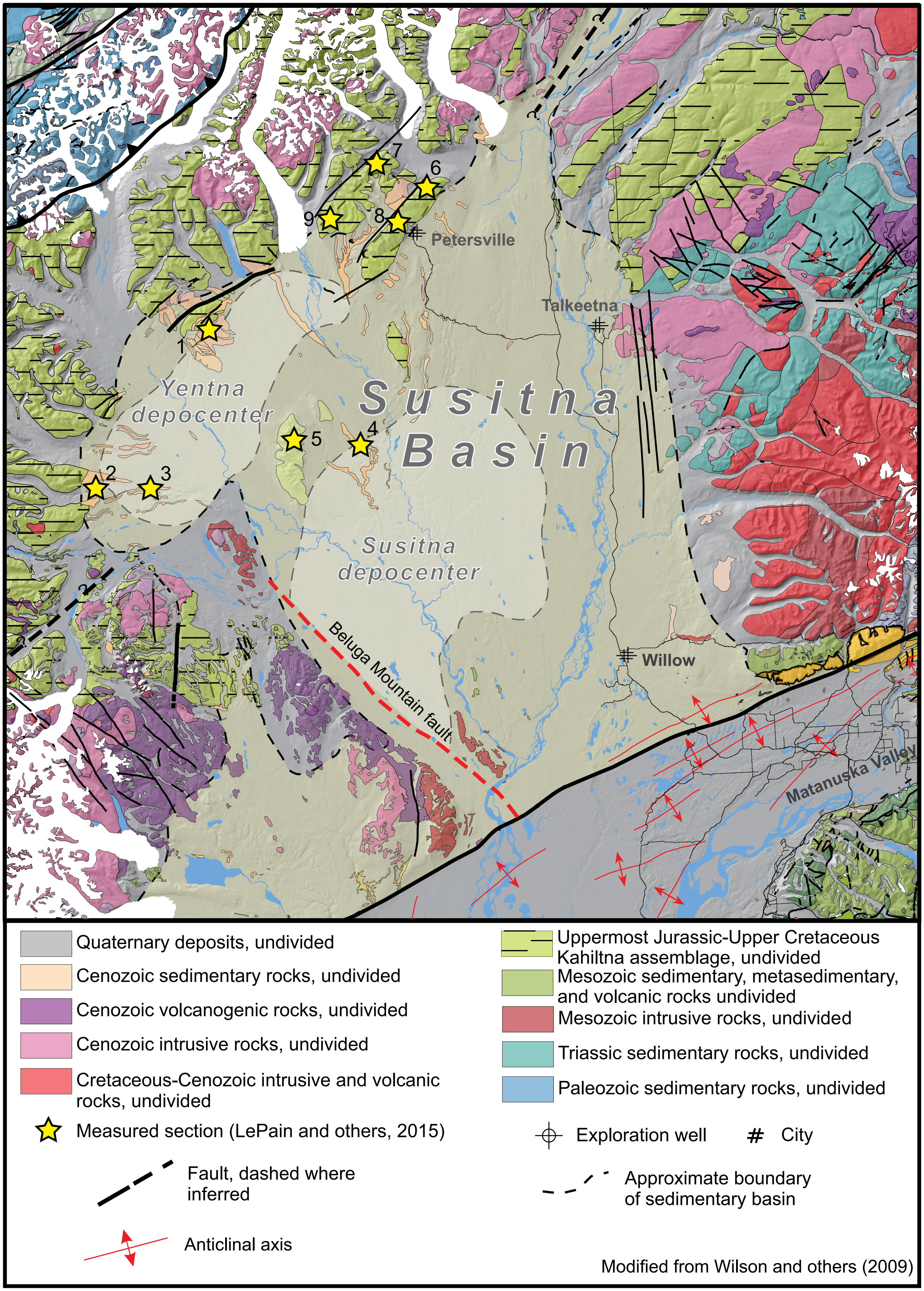
Petersville
Talkeetna
Yentna depocenter
Susitna Basin
Susitna depocenter
Beluga Mountain fault
Willow
Matanuska Valley
1
2
3
4
5
6
7
8
9
Quaternary deposits, undivided
Cenozoic sedimentary rocks, undivided
Cenozoic volcanogenic rocks, undivided
Cenozoic intrusive rocks, undivided
Cretaceous-Cenozoic intrusive and volcanic rocks, undivided
Measured section (LePain and others, 2015)
Fault, dashed where inferred
Anticlinal axis
Uppermost Jurassic-Upper Cretaceous Kahiltna assemblage, undivided
Mesozoic sedimentary, metasedimentary, and volcanic rocks undivided
Mesozoic intrusive rocks, undivided
Triassic sedimentary rocks, undivided
Paleozoic sedimentary rocks, undivided
Exploration well
City
Approximate boundary of sedimentary basin
Modified from Wilson and others (2009)

steep topography. This part of the section may represent the base of the Sterling(?) Formation (fig. 2-2a). This section is interpreted as the product of mixed-load, low- to moderate-sinuosity streams that likely included braided and meandering reaches (Miall, 2006). Flows were routinely able to move cobble- and pebble-sized material as bedload, indicating that stream gradients were moderate. Active channel tracts were flanked by poorly drained flood basins that included topogenous mires (McCabe, 1984). The steeply dipping strata at the base of the section are interpreted as a slump block or the limb of a soft-sediment fold, but a tectonic origin is also possible.

The measured section in the sandstone member of the Tyonek(?) Formation along Johnson Creek includes a lower, fine-grained succession 13 m thick overlain by 14 m of sandstone and pebbly sandstone (fig. 2-2c). The lower, fine-grained succession includes four lignitic coal seams from 0.1 to 1.4 m thick and two fining-upward successions 2.5 to 4.2 m thick. The fining-upward successions begin with a pebble lag overlain by ripple cross-laminated sandstone that includes abundant carbonaceous material draping foresets and minor scour surfaces, and terminate in siltstone or interlaminated siltstone and fine-grained sandstone. The upper, sandstone succession consists of trough cross-bedded, medium- to very-coarse-grained sandstone and numerous pebble lags up to 10 cm thick (fig. 2-2d). Pebble- and granule-sized clasts also line scour pits associated with trough cross-beds; clasts in this size range are commonly dispersed in sandstone beds. Sandstones are quartzo-feldspathic and largely uncemented. This section is interpreted as the product of mixed-load, moderate-sinuosity streams. Stream gradients were moderate and flows were commonly able to move pebble- and granule-sized material as bedload. Active channel tracts were flanked by poorly drained flood basins where peat accumulated in topogenous mires (McCabe, 1984). The two fining-upward successions near the base of the lower, fine-grained unit are interpreted as minor crevasse channel-fills.

The measured section in the Sterling(?) Formation along Johnson Creek is 38 m thick and includes a lower, 9-m-thick, poorly exposed, fine-grained interval and an upper, 29-m-thick, coarse-grained interval (fig. 2-2e). More coarse-grained material is exposed above the 38 m level but is inaccessible. The lower interval includes a chocolate-brown sandstone with black grains that is possibly volcanogenic. The upper, coarse-grained interval consists of clast-supported pebble conglomerate with subordinate pebbly sandstone. Bed boundaries are difficult to identify in the conglomeratic part where sandstone is lacking, as much of it likely comprises amalgamated beds. Low-angle foresets and large trough cross-beds are abundant in the pebbly sandstones and conglomerates (fig. 2-2f). Sandstones are quartzo-feldspathic and weakly cemented. The Sterling(?) Formation at this location dips moderately toward the west and is truncated by a horizontal erosion surface that separates it from horizontal beds of Quaternary(?) pebble and cobble conglomerate. The succession documented in this measured section records deposition in moderate-gradient, low- to moderate-sinuosity, gravelly streams characterized by relatively deep channels into which gravelly barforms migrated, and within which moderate- to large-scale, three-dimensional, gravelly dunes migrated downstream.

An outcrop along Lake Creek east of the Yenlo Hills, mapped by Reed and Nelson (1980) as the sandstone member of the Tyonek(?) Formation, stands out in sharp contrast to all other exposures of Tertiary strata in the basin studied by our group. Bedding dips steeply toward the west. The lower half of the exposure consists of interbedded pebble conglomerate, fine- to coarse-grained sandstone, and coal-bearing argillaceous mudstone consistent with Reed and Nelson's sandstone member; the upper half of the exposure consists of a thick succession of amalgamated clast-supported, cobble and boulder conglomerates with minor lenses of coarse- to very-coarse-grained pebbly sandstone. The contact between the two successions is sharp (fig. 2-2g). Clasts in the upper half of the exposure include a subequal amount of mafic/intermediate volcanics and granitoids, and minor lithic sandstone, argillite, and vein quartz. A small population of latest Miocene to Pliocene age detrital zircons place constraints on the maximum age of this succession (Bob Gillis, DGGS, unpublished data), which is likely younger than the Tyonek Formation in Cook Inlet basin. The lower, finer-grained succession is the product of dilute stream flow in a moderate- to high-sinuosity fluvial system, whereas the upper, conglomeratic succession records a steep alluvial gradient and consists of facies typically present in alluvial fan systems. Facies strongly suggest a nearby source for the cobble and boulder conglomerates, but mafic volcanic and granitoid clasts do not resemble lithologies recognized in nearby exposures of Mesozoic strata, such as the Yenlo Hills. More work is needed to understand the significance of this location.

Figure 2-1 (left). Generalized bedrock geology of the Susitna basin, showing locations discussed in this report. Numbered yellow stars mark locations of : 1. Conglomerate member of the Tyonek(?) Formation, Fairview Mountain; 2. Sandstone member of the Tyonek(?) Formation, Johnson Creek; 3. Sterling(?) Formation, Johnson Creek; 4. Sandstone member of the Tyonek(?) Formation, Lake Creek; 5. Graywacke of Yenlo Hills; 6. Kahiltna assemblage, northern Peters Hills; 7. Kahiltna assemblage, northern Dutch Hills; 8. Kahiltna assemblage, central Peters Hills; 9. Kahiltna assemblage, southern Dutch Hills. Black lines show faults. Red lines show anticlinal fold axes and red arrows show dip direction of fold limbs.

MESOZOIC ROCKS

Mesozoic sedimentary rocks of the Kahiltna assemblage were examined at five locations (fig. 2-1) in the Peters Hills (locations 6 and 8), Dutch Hills (locations 7 and 9), and Yenlo Hills (location 5). These rocks likely represent the foundation upon which much of the Cenozoic basin developed. Rocks at the latter location have been mapped as the graywacke of Yenlo Hills by Wilson and others (2012) and detrital zircon data suggest they are slightly older than the Kahiltna assemblage to the north (Hults and others, 2013). In the Peters and Dutch Hills argillite appears to be the dominant lithology in the Kahiltna, but the unit commonly includes thin-bedded, fine-grained sandstones and locally envelops multi-meter-thick packages of amalgamated thick-bedded, fine- to medium-grained sandstone (fig. 2-2h). Many of the thin-bedded sandstones appear massive or display subtle normal grading, but plane-parallel (horizontal) lamination is locally prominent. Most of the thick-bedded sandstone (bed thickness greater than a few decimeters) appears massive and some includes dark gray to black mudstone (argillite) rip-up clasts up to 10 cm long. An exposure in the southern Dutch Hills includes small, poorly preserved and carbonized plant fragments, and sole marks, including poorly developed (equivocal?) flute casts that demonstrate bedding at that location is overturned toward the north (fig. 2-1, location 9). Sandstones are lithic-rich, tightly cemented, and lack visible porosity. Features observed in thin- and thick-bedded sandstones are commonly attributed to low- and high-density turbidites, respectively (Lowe, 1982; Talling and others, 2012). Given the isolation of the exposures examined, it is not possible to place them with confidence in a depositional profile, but the features observed are consistent with deposition in base-of-slope or basin-floor positions. Sandstone is abundant in the Yenlo Hills outcrop visited (fig. 2-1, location 5) and most had massive textures, consistent with deposition from high-density, non-turbulent flows.

DISCUSSION

The quartzo-feldspathic composition of sandstones documented in Tertiary exposures is likely to have good reservoir potential in the subsurface if not too deeply buried. Common interbedded argillaceous mudrocks indicate that effective seal facies are present in the basin. Characteristics of Mesozoic strata examined in outcrop suggest they have poor reservoir potential (Helmold and LePain, 2015). More detailed reports summarizing our stratigraphic work, including analytical data on reservoir quality, coal quality and gas holding capacity of coals, and source rock potential of coals will be released in 2015.

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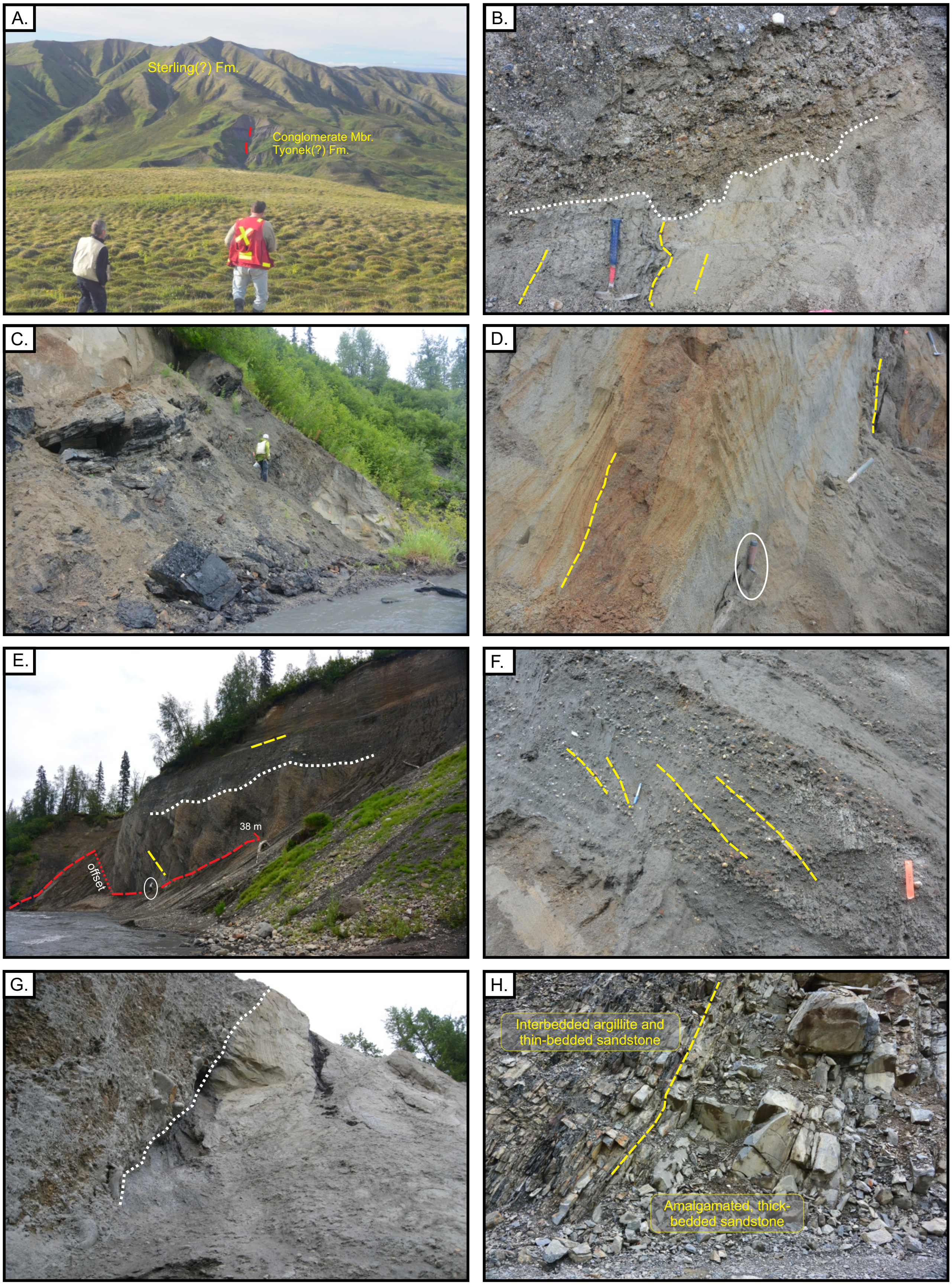
Figure 2-2 (right). Selected photographs showing outcrops discussed in this report. **A.** View toward the east, across the saddle at the head of Cottonwood Creek, showing the coal-bearing conglomerate member of the Tyonek(?) Formation and overlying conglomerates of the Sterling(?) Formation at Fairview Mountain (location 1, fig. 2-1). Red dashed line shows location of measured stratigraphic section. **B.** Close-up view showing the erosional truncation of moderately dipping mudstone and sandstone at the base of a pebble conglomerate succession, conglomerate member, Tyonek(?) Formation, Fairview Mountain. White dotted line shows the contact between pebble conglomerate and sandstone; yellow dashed lines show bedding in sandstone **C.** Overbank mudstones, sandstones, and coal overlain by pebbly sandstone, sandstone member, Tyonek(?) Formation, Johnson Creek (location 2, fig. 2-1). View toward the southwest. **D.** Close-up view of pebbly sandstone succession, showing trough cross-bedding and pebble lags in the sandstone member, Tyonek(?) Formation, Johnson Creek. Yellow dashed line at right marks the base of a pebble lag and the yellow dashed line at left shows contact between sets of trough cross-bedding. Exposed part of trowel is 20 cm long. **E.** View toward the southeast, showing pebble and cobble conglomerates in the Sterling(?) Formation along Johnson Creek (location 3, fig. 2-1). Dashed red line shows approximate line of measured section. Interbedded mudstone, sandstone, and lignitic coal are visible near creek level at the left edge of the photograph. Top of measured section is marked by 38 m measurement. Nearly flat-lying unconformity surface (dotted white line) separates the Sterling(?) Formation from overlying Quaternary gravels. The yellow dashed lines show the orientation of bedding. Geologist in white oval for scale. **F.** Close-up view showing low-angle foreset stratification (yellow dashed lines) in pebbly sandstone in the Sterling(?) Formation along Johnson Creek. Red surveyor's flag is located 13 m above the base of our measured stratigraphic section. **G.** View toward the north showing the erosional contact (dotted white line) between the lower, sandstone–mudstone succession and upper, cobble–boulder conglomerate succession on Lake Creek (location 4, fig. 2-1). The sandstone bed immediately below the contact is approximately 5 m thick. **H.** View toward the north, showing the contact (yellow dashed line) between amalgamated, thick-bedded sandstones and interbedded argillites and thin-bedded sandstones in Kahiltna assemblage (location 8, fig. 2-1). See text for discussion and preliminary interpretation.


A.
Sterling(?) Fm.
Conglomerate Mbr.
Tyonek(?) Fm.
B.
C.
D.
E.
38 m
offset
F.
G.
H.
Interbedded argillite and thin-bedded sandstone
Amalgamated, thick-bedded sandstone

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CHAPTER 3

PETROLOGY AND RESERVOIR QUALITY OF SANDSTONES FROM THE KAHILTNA ASSEMBLAGE AND YENLO HILLS GRAYWACKE: INITIAL IMPRESSIONS

Kenneth P. Helmold[1] and David L. LePain[2]

INTRODUCTION

The Division of Geological & Geophysical Surveys (DGGS) and Division of Oil & Gas (DOG) are currently conducting a study of the hydrocarbon potential of Alaska's frontier basins, including the natural gas potential of the greater Susitna basin (LePain and others, 2011). The Tertiary stratigraphic section of Susitna basin includes some of the same coal-bearing units that are prolific gas reservoirs in neighboring Cook Inlet basin and has large structures that could act as hydrocarbon traps. The present-day Susitna basin is a Cenozoic feature, but very little is known regarding the pre-Cenozoic stratigraphy beneath the basin. Based on regional studies to date, the Cretaceous strata surrounding the basin appear very different than in Cook Inlet basin (Hampton and others, 2007; Kalbas and others, 2007). As part of this project, two days were spent during the 2011 field season examining Susitna basin outcrops (at reconnaissance scale) of the Kahiltna assemblage and Yenlo Hills graywacke. Several samples from Yenlo Hills, Little Peters Hills, and Colorado Creek drainage were collected for petrographic analysis (fig. 3-1). During the 2014 field season, three additional days were spent revisiting the 2011 locations plus additional outcrops of the Kahiltna assemblage and Yenlo Hills graywacke. This report summarizes initial impressions of the petrology and reservoir quality of these units and incorporates modal analyses of thin sections from 17 of the samples collected in 2011 (table 3-1).

KAHILTNA ASSEMBLAGE

Based on modal analyses of six outcrop samples, Kahiltna sandstones in the Susitna basin area are largely quartzolithic with an average modal composition of $Q_{t83}F_4L_{13}$, $Q_{m6}F_4L_{t90}$, $Q_{m77}P_{18}K_5$, $Q_{p88}L_{vm1}L_{sm11}$ (figs. 3-2 and 3-4) and a plagioclase/feldspar (P/F) ratio of 0.56 (see table 3-2 for explanation of grain parameters). The average grain size is 0.32 mm (lower

Table 3-1. Samples of sandstones collected during the 2011 Susitna basin field season that are included in this report.

Sample Number	General Location	Specific Location	Latitude	Longitude	Unit
11DJM035A	Susitna basin	Little Peters Hills	N 62.31761	W 150.84175	Kahiltna assemblage
11DJM036B	Susitna basin	Little Peters Hills	N 62.30777	W 150.84300	Kahiltna assemblage
11DL008A	Susitna basin	Colorado Creek	N 63.30653	W 149.72969	Kahiltna assemblage
11DL008C	Susitna basin	Colorado Creek	N 63.30715	W 149.72787	Kahiltna assemblage
11DL008D	Susitna basin	Colorado Creek	N 63.30741	W 149.72209	Kahiltna assemblage
11DL008E	Susitna basin	Colorado Creek	N 63.30880	W 149.72160	Kahiltna assemblage
11DL001A	Susitna basin	Yenlo Hills	N 62.07430	W 151.25990	Yenlo Hills graywacke
11DL001B	Susitna basin	Yenlo Hills	N 62.07430	W 151.25990	Yenlo Hills graywacke
11DJM015A	Susitna basin	Yenlo Hills	N 62.13672	W 151.24072	Yenlo Hills graywacke
11DJM022A	Susitna basin	Yenlo Hills	N 62.13464	W 151.23534	Yenlo Hills graywacke
11DJM029A	Susitna basin	Yenlo Hills	N 62.14265	W 151.23117	Yenlo Hills graywacke
11DJM041B	Susitna basin	Yenlo Hills	N 62.12816	W 151.26662	Yenlo Hills graywacke
11DJM043B	Susitna basin	Yenlo Hills	N 62.12530	W 151.25369	Yenlo Hills graywacke
11DJM045B	Susitna basin	Yenlo Hills	N 62.12339	W 151.24704	Yenlo Hills graywacke
11DJM047B	Susitna basin	Yenlo Hills	N 62.11818	W 151.23755	Yenlo Hills graywacke
11DJM049B	Susitna basin	Yenlo Hills	N 62.11288	W 151.21432	Yenlo Hills graywacke
11DJM050B	Susitna basin	Yenlo Hills	N 62.13498	W 151.28378	Yenlo Hills graywacke

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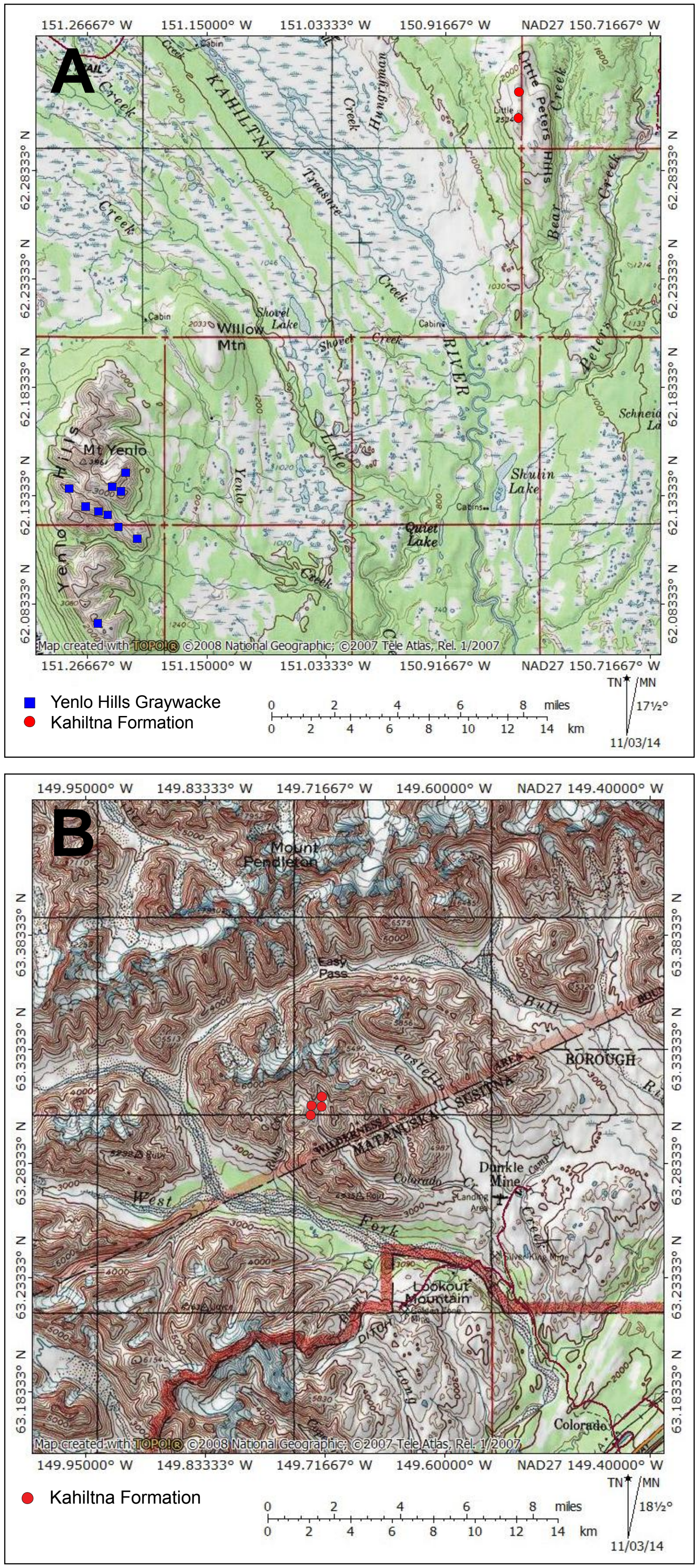
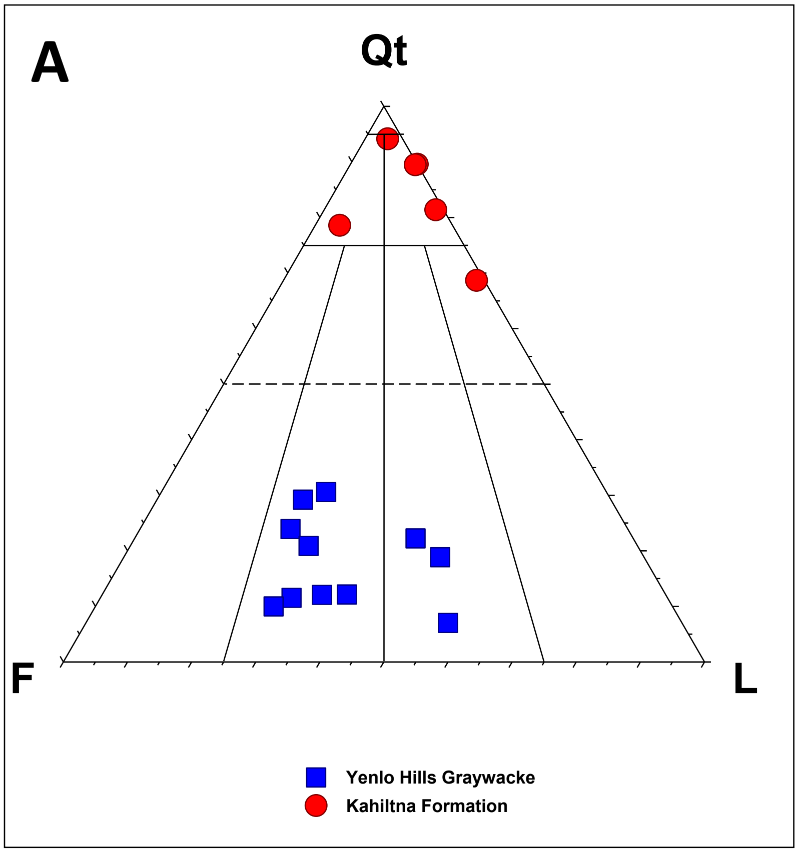
Figure 3-1. **A.** Topographic map, showing locations of Yenlo Hills graywacke samples collected from Yenlo Hills, and Kahiltna sandstones collected from Little Peters Hills. **B.** Topographic map, showing locations of Kahiltna sandstones collected from the Colorado Creek drainage northwest of Lookout Mountain.





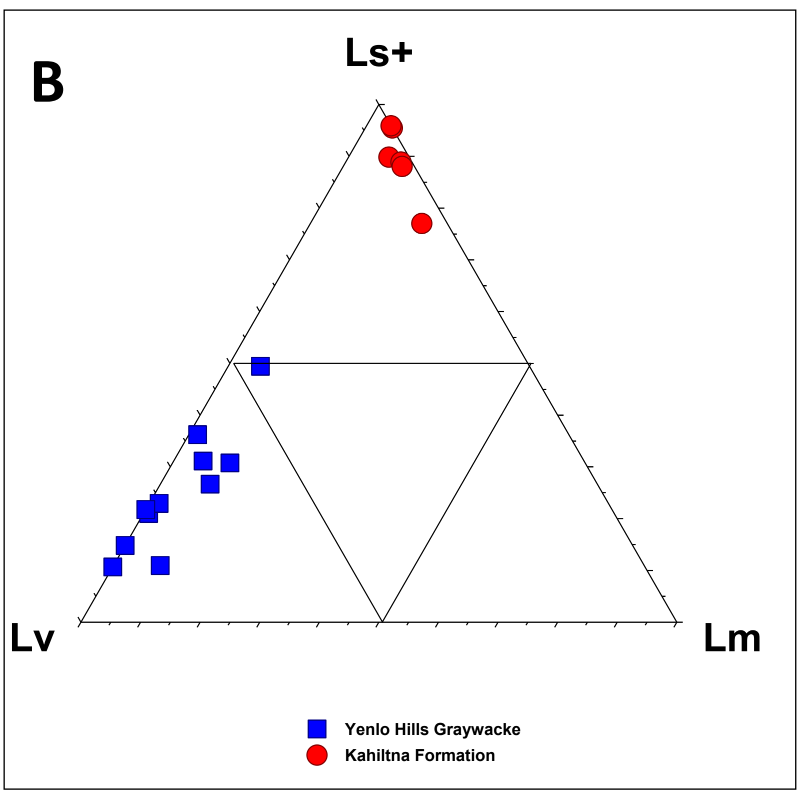


Figure 3-2. **A.** Ternary diagram of total quartz (Qt)–Feldspar (F)–Lithic grains (L), showing the composition of the entire population of grains. The Kahiltna sandstones are more quartzose (chert plotted with quartz) compared to the Yenlo Hills graywackes, which contain abundant plagioclase and VRFs. **B.** Ternary diagram of Sedimentary lithic grains including chert (Ls^+)–Volcanic lithic grains (Lv)–Metamorphic lithic grains (Lm), showing the composition of just the polycrystalline grains. The Kahiltna sandstones are enriched in sedimentary detritus (including chert) compared to the Yenlo Hills graywacke, which contain significant volcanic material.

Table 3-2. Classification of Grain Parameters

A. Quartzose grains

Qm = Monocrystalline quartz
Qp = Polycrystalline quartz (including chert)
Qt = Total quartzose grains (Qm + Qp)

B. Feldspar grains

P = Plagioclase
K = Potassium feldspar
F = Total feldspar grains (P + K)

C. Lithic grains

Ls^+ = Sedimentary rock fragments (including chert)
Lv = Volcanic rock fragments
Lm = Metamorphic rock fragments
Lp = Plutonic rock fragments
Lsm = Sedimentary and metasedimentary rock fragments
Lvm = Volcanic and metavolcanic rock fragments
L = Lithic grains (Ls^+ + Lv + Lm + Lp)
Lt = Total lithic grains (L + Qp)

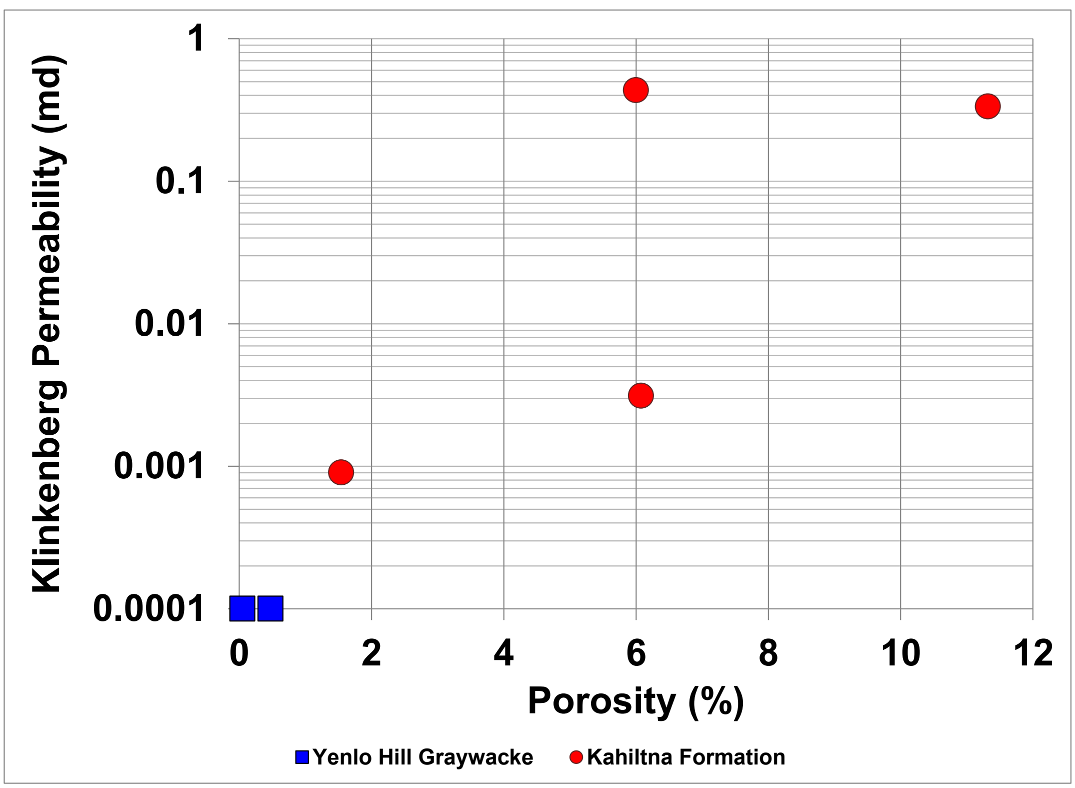


Figure 3-3. Porosity–permeability cross plot. Based on a limited dataset, the reservoir quality of the Kahiltna sandstones is fairly poor (porosity [φ] <12%, permeability [k] < 1 md) while that of the Yenlo Hills graywacke is very poor (φ <1%, k < 0.0001 md).

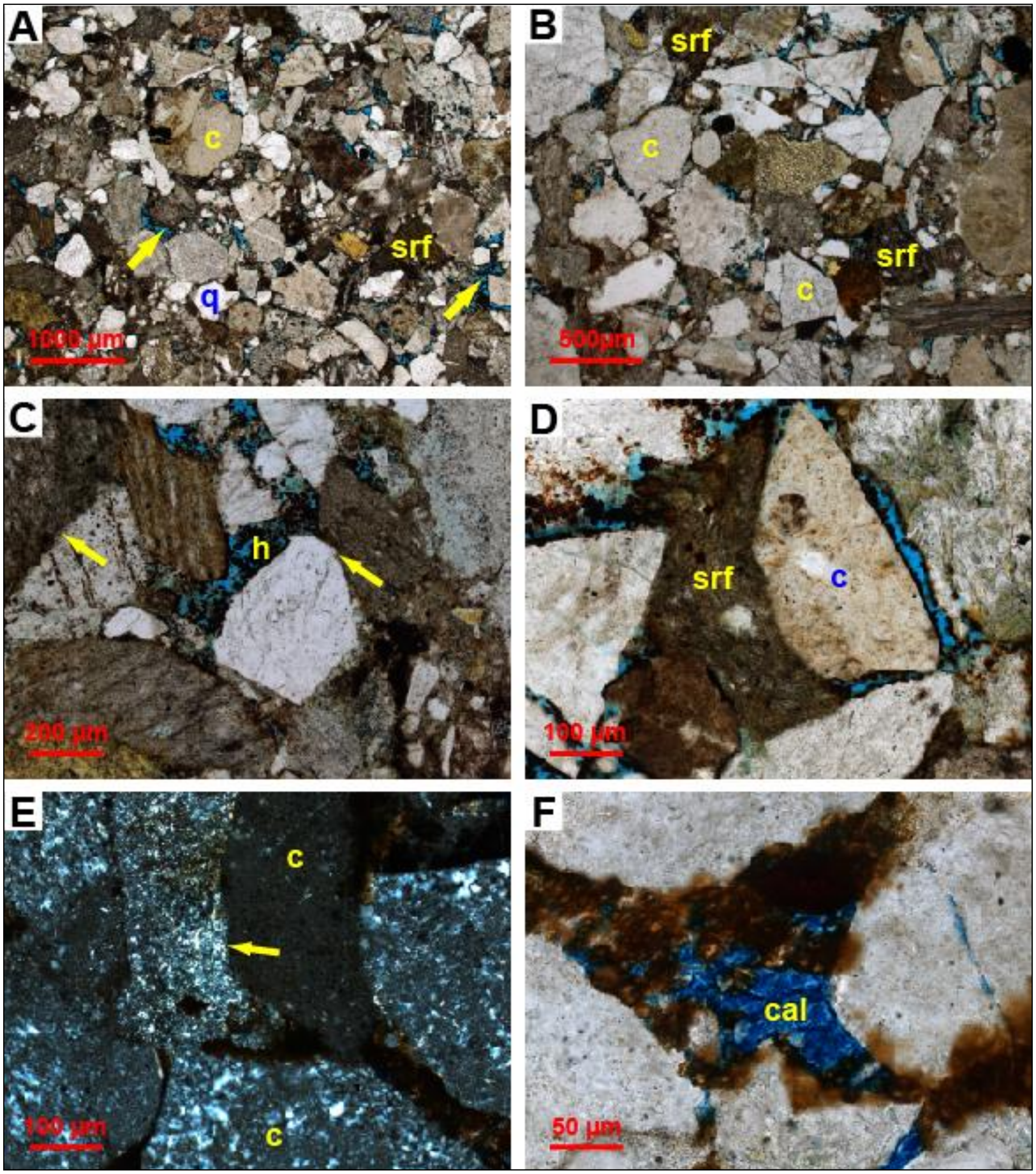


Figure 3-4. Photomicrographs of Kahiltna sandstones. **A.** Medium-grained (upper), moderately sorted sandstone consisting largely of quartz (q), chert (c), and argillaceous sedimentary rock fragments (srf). Minor remnant intergranular pores (arrows) are scattered throughout the rock. Sample 11DL008A; plane-polarized light. **B.** Chert (c) and argillaceous sedimentary rock fragments (srf) comprise the majority of the rock framework. Primary intergranular porosity is almost completely occluded by compaction and ductile grain deformation. Sample 11DL008A; plane-polarized light. **C.** Long and concavo–convex grain contacts (arrows) are evidence of significant compaction. Residual intergranular pores are lined and partially occluded by authigenic iron oxide cement (hematite?) (h). Sample 11DL008A; plane-polarized light. **D.** Mudstone rock fragment (srf) that has been ductilely deformed between more mechanically resistant chert grains (c). Sample 11DL008A; plane-polarized light. **E.** Several chert grains with typical “salt and pepper” extinction showing evidence of chemical compaction (arrows). Sample 11DL008A; crossed polarizers. **F.** Ferroan-calcite cement (cal) occluding remnant intergranular pore. Sample 11DL008C; plane-polarized light.

medium) with an average Folk sorting (Folk, 1974) of 1.19 (poor). The rock framework predominantly consists of chert (range 22–82 percent, average 55 percent; figs. 3-4B–3-4F) with lesser amounts of quartz (both polycrystalline [Q_p] and monocrystalline [Q_m]; range 6–59 percent, average 27 percent; fig. 3-4A). The average Q_p/Q ratio is 0.75, indicating the bulk of quartz is polycrystalline in character; the actual amount of monocrystalline quartz is fairly low, averaging only 6 percent (range 1–14 percent). Additional minor components include metamorphic rock fragments (average 6 percent), sedimentary rock fragments (average 4 percent), and plagioclase (average 3 percent). Accessory grains include plutonic and volcanic rock fragments, K-feldspar, and micas. The high ratio of chert to monocrystalline quartz and the presence of sedimentary and metamorphic rock fragments (mainly phyllite and schist) suggests the rocks were most likely derived from a recycled orogen provenance (Hampton and others, 2007; Kalbas and others, 2007; Hults and others, 2013). Although all the analyzed samples have a fairly similar detrital composition, differences were noted in their degree of deformation. Samples from the Colorado Creek area (fig. 3-1B) have a sedimentary texture little affected by metamorphism. In contrast, those from Little Peters Hills (fig. 3-1A) show a penetrative deformation most likely related to regional metamorphism.

Overall reservoir quality of the Kahiltna sandstones is generally poor with porosities less than 12 percent and permeabilities less than 1 millidarcy (md). (fig. 3-3). Primary depositional porosity has been reduced mainly by mechanical compaction, as indicated by a fairly low average intergranular volume (IGV) of 14 percent. Remnant primary intergranular porosity is evident in some samples (figs. 3-4C, D) while in others it has been occluded by late-stage ferroan calcite cement (fig. 3-4F). Many of the intergranular pores are lined by small crystals (<10 μm) of authigenic iron-oxide, probably hematite, of uncertain origin (figs. 3-4C, D, F). They may be replacing or masking early-formed, authigenic, pore-lining ferruginous clays, such as chlorite or mixed-layer chlorite/smectite, and may be solely a product of outcrop weathering. The presence of concavo–convex contacts between chert grains (fig. 3-4E) suggests that chemical compaction (pressure solution) likely contributed to porosity destruction, particularly in samples from Colorado Creek that have seen minimal regional metamorphism.

YENLO HILLS GRAYWACKE

Based on modal analyses of 11 outcrop samples, Yenlo Hills graywacke in Susitna basin are largely feldspatholithic with an average modal composition of $Q_{t18}F_{48}L_{34}$, $Q_{m8}F_{47}L_{t45}$, $Q_{m14}P_{84}K_2$, $Q_{p24}L_{vm66}L_{sm10}$ (figs. 3-2 and 3-5) and a P/F ratio of 0.98. The average grain size is 0.10 mm (upper very-fine) with an average Folk sorting of 2.60 (very poor; figs. 3-5A, B). The rock framework predominantly consists of plagioclase (range 26–48 percent, average 38 percent; figs. 3-5B, C) and volcanic rock fragments (VRFs; range 15–42 percent, average 23 percent; figs. 3-5B, D). Additional components include monocrystalline quartz (average 6 percent), polycrystalline quartz (average 3 percent), chert (average 6 percent), and heavy minerals (average 8 percent). Accessory grains include sedimentary and plutonic rock fragments, micas, and K-feldspar. Conspicuous among the sedimentary rock fragments are grains of detrital carbonate composed of 5–20 μm-sized calcite crystals (fig. 3-5E); little micrite was seen in the few samples analyzed. Matrix consisting largely of detrital clay is a significant component in most samples (range 5–39 percent, average 19 percent) and effectively occludes remnant intergranular pores. It is suspected that much of this clay has been recrystallized, resulting in a mixture of detrital and regenerated clays (fig. 3-5F). The prevalence of plagioclase and VRFs, along with the dearth of K-feldspar, suggests the sandstones were derived from an undissected volcanic arc terrane. The most likely provenance is volcanic flows, ignimbrites, and tuffs of the Jurassic magmatic arc (Reed and Lanphere, 1973; Reed and Nelson, 1980; Hults and others, 2013; Karl and others, 2013; Karl and others, 2015).

The labile nature of the detrital mineralogy results in a rock framework that is highly susceptible to diagenetic alteration. In general, plagioclase is chemically unstable in the diagenetic environment, while VRFs are both chemically and mechanically unstable. Notably, authigenic cements are not a major component of the graywackes; the bulk of porosity loss is the result of mechanical compaction and clay matrix. Plagioclase is typically altered to albite and sericite but no obvious zeolites were observed, possibly because the extensive matrix limited isochemical diagenesis. Based on two analyzed samples, reservoir quality of the Yenlo Hills graywacke is very poor, with porosities less than 1 percent and permeabilities less than 0.0001 md (fig. 3-3).

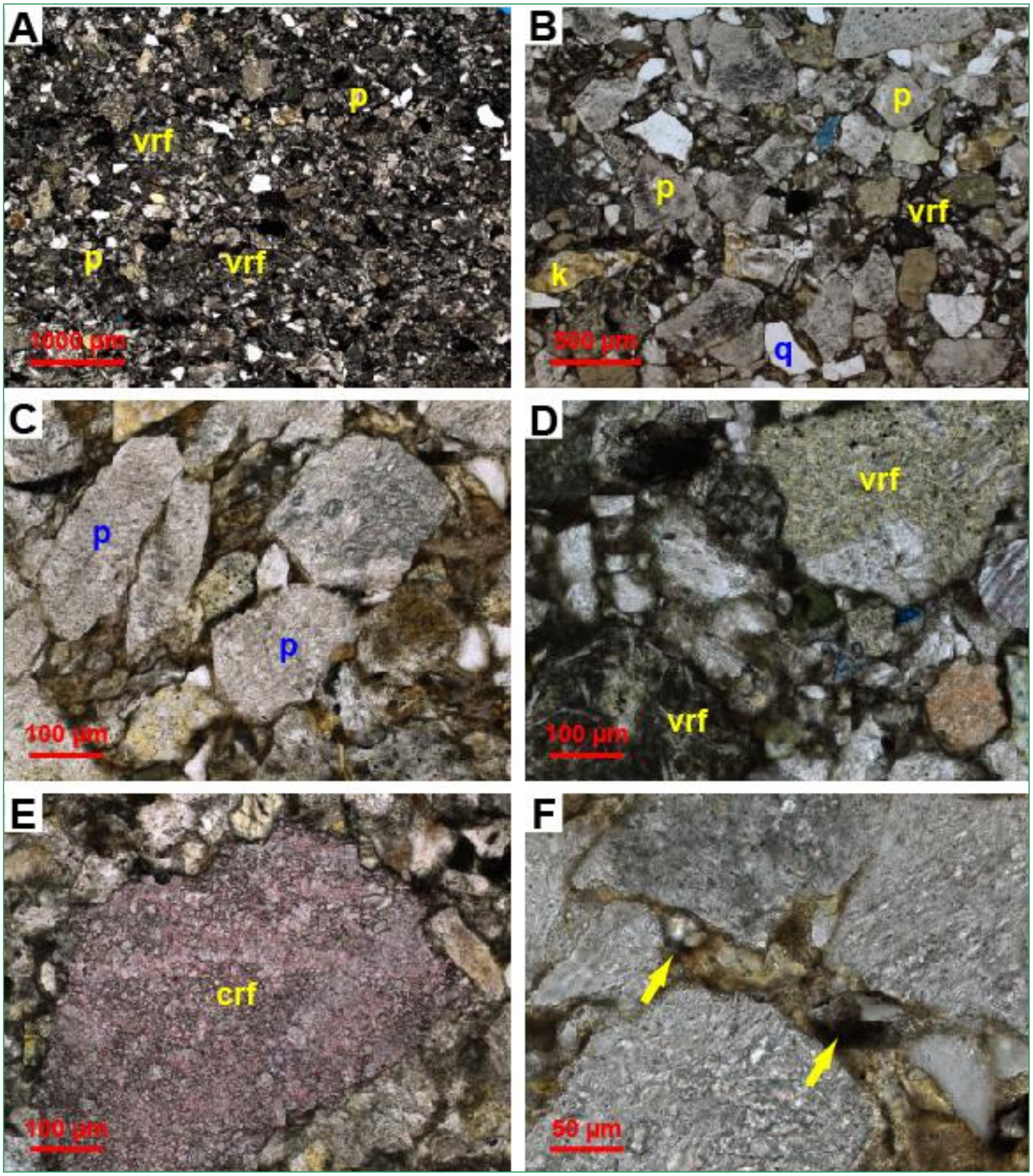


Figure 3-5. Photomicrographs of Yenlo Hills graywacke. **A.** Fine-grained (upper), moderately-sorted sandstone consisting largely of plagioclase (p) and volcanic rock fragments (vrf). The primary pore system has been almost completely destroyed by substantial mechanical compaction. Sample 11DL001A; plane-polarized light. **B.** Sandstone consisting largely of subhedral to euhedral plagioclase (p), with minor quartz (q), K-feldspar (k), and volcanic rock fragments (vrf). Porosity reduction has been accomplished mainly by compaction. Sample 11DJM022A; plane-polarized light. **C.** The brownish color and murky nature of the plagioclase (p) indicates it has been highly altered, mainly through albitization and sericitization. Sample 11DJM015A; plane-polarized light. **D.** Intermediate to mafic volcanic rock fragments (vrf) consisting largely of plagioclase microlites. Sample 11DJM029A; plane-polarized light. E. Oversized carbonate rock fragments (crf, pink stain) are a minor, but conspicuous, component of many of the sandstones. Sample 11DL001B; plane-polarized light. **F.** A combination of detrital matrix and authigenic/recrystallized clay filling intergranular pores between altered plagioclase. Sample 11DJM015A; plane-polarized light.

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CHAPTER 4

RECONNAISSANCE COAL STUDY IN THE SUSITNA BASIN, 2014

Nina T. Harun[1], David L. LePain[1], Rebekah M. Tsigonis[1], Kenneth P. Helmold[2], and Richard G. Stanley[3]

INTRODUCTION

The Alaska Division of Geological & Geophysical Surveys (DGGS) conducted fieldwork during the summer of 2014 in the Susitna basin as part of an ongoing evaluation of the hydrocarbon potential of frontier basins, particularly those near the Railbelt region (for example, Decker and others, 2013; Gillis and others, 2013). Topical studies associated with this recent work include sedimentary facies analysis (LePain and others, 2015) and structural geology investigations (Gillis and others, 2015). The Susitna basin contains coal-bearing Paleogene and Neogene strata correlative with formations that host oil and gas in Cook Inlet basin to its south. Isotopic signatures of natural gas reservoired in the Miocene/Pliocene Sterling and Miocene Beluga Formations suggest a biogenic origin for Cook Inlet gas (Claypool and others, 1980). To assess the biogenic gas potential of the Susitna basin, it is important to obtain information from its coal-bearing units.

Characteristics of coal, such as maturity/rank and cleat development are key parameters influencing viability of a biogenic gas system (Laubach and others, 1998). In an early study of the Susitna basin (Beluga–Yentna region), Barnes (1966) identified, analyzed, and recognized potentially valuable subbituminous coal resources at Fairview Mountain, Canyon Creek, and Johnson Creek. Merritt (1990), in a sedimentological study to evaluate surface coal mining potential of the Tertiary rocks of the Susitna basin (Susitna lowland), concluded that the basin contained several billion tons of mineable reserves. This preliminary report offers a brief summary of new information on coals in the Susitna Basin acquired during associated stratigraphic studies (see LePain and others, 2015).

FIELD OBSERVATIONS AND SAMPLING

In this study, coal from the Miocene Tyonek(?) and Pliocene Sterling(?) Formations (Reed and Nelson, 1980) were examined and collected in the western and northern portions of the Susitna Basin (fig. 4-1). Twenty-two coal samples were collected from 11 localities for coal quality, high-pressure methane adsorption (HPMA), vitrinite reflectance, and Rock-Eval pyrolysis to aid in the determination of gas potential in the basin (fig. 4-1).

The Susitna basin study area contains lignite to subbituminous coal beds ranging from 10 cm to 3 m thick in the Tyonek(?) and Sterling(?) Formations. Coal rank (subbituminous versus lignite) was difficult to ascertain in the field. In several locations subbituminous coal was similar in field appearance to lignite coal. Lignite coal is brownish-black in color with a dull luster and includes abundant plant debris, whereas subbituminous coal is brown to black with a dull to vitreous luster. Sixteen coal samples were analyzed for proximate and ultimate analyses by Geochemical Testing Laboratories (table 4-1)

The best-exposed coal beds are at Fairview Mountain (sample 14DL007), in the northern portion of the basin (fig. 4-2b). Seven coal beds were identified in the Tyonek(?) Formation that ranged in thickness from 10 cm to 1 m. Six of these coal beds are contained in five major (minimum 1 m thick) coal intervals that also contain interbedded carbonaceous mudstone. The lowest coal in the section (at 23 m) is subbituminous A, whereas the upper coal (at 70 m) is subbituminous B. Coal beds elsewhere in the study area, as in this section, are often interbedded with or overlain by carbonaceous mudstone.

To understand basin-wide hydrocarbon and water flow patterns, it is important to understand coal cleat development in the coal beds. Coal cleats are opening-mode fractures in coal beds that control effective porosity and permeability within the coal bed (Laubach and others, 1998). Upon depressuring of the reservoir through removal of water, adsorbed methane in the coal matrix migrates into the cleats. Cleats, as a natural fracture network, define permeability conduits that therefore control coal bed methane production with dewatering of the coal (Laubach and others, 1998). Coal beds from eight localities were described in detail, including coal cleat measurements and orientations. Where present, coal face and butt cleats were measured and described (fig 4-2a). Twenty-two cleat orientations and 27 cleat length, frequency, and aperture width measurements were recorded (fig 4-1, table 4-1).

PRELIMINARY RESULTS

Although coal rank was difficult to ascertain in the field, our coal quality proximate and ultimate analyses indicate that Tyonek(?) and Sterling (?) Formation coal sampled from Susitna basin localities range from subbituminous A to lignite A

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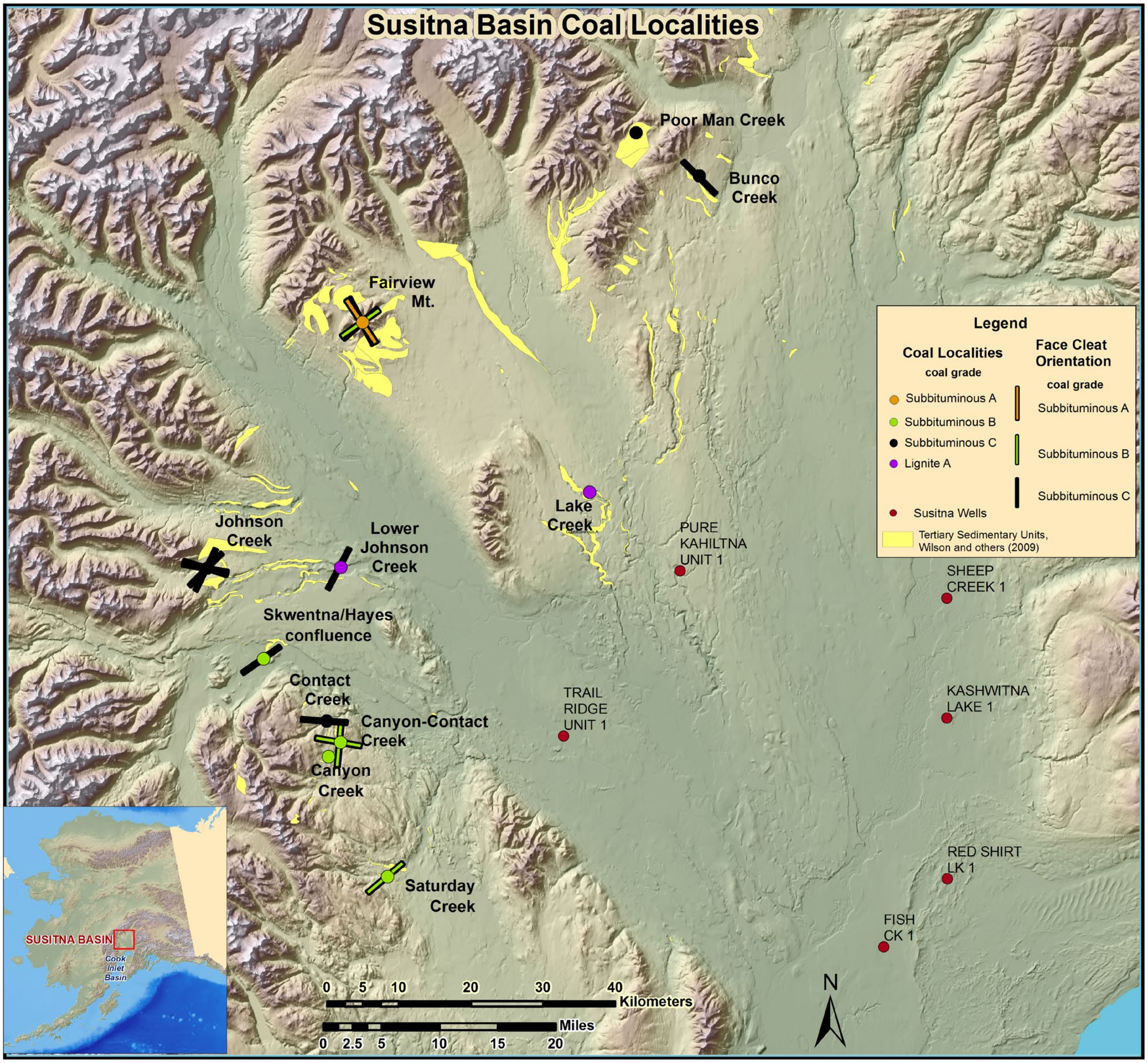

Figure 4-1. Map of study area showing localities and face cleat orientations color coded by coal rank.

(figure 4-1; table 4-1). In several locations subbituminous coal was similar in field appearance to lignite coal. Lignite coal is brownish-black in color with a dull luster and includes abundant plant debris, whereas subbituminous coal is brown to black with a dull to vitreous luster.

The best exposed coal beds are at Fairview Mountain in the northern portion of the study area (fig. 4-2b). The lower (23 m) and upper (70 m) coal beds at Fairview Mountain are ranked subbituminous A and subbituminous B, respectively. Coal collected from Saturday Creek (14DL008a), the tributary of Canyon Creek (14A09a), the Skwentna/Hayes confluence (14DL010a), and Canyon/Contact Creek (14NH100a) are subbituminous B grade coal (fig 4-2a). One of the best exposures was at Canyon Creek, where a 2-m-thick subbituminous B coal bed was well exposed at the creek bottom.

Subbituminous C coal beds were sampled from the Tyonek(?) Formation throughout the study area at Contact Creek (11DL005), Lake Creek (lowest coal bed; 11DL009), Bunco Creek (11DL011), Johnson Creek (14DL011), and Poorman Creek (14DL012) sections. At Johnson Creek (14DL011) subbituminous C beds contain alternating discontinuous vitreous layers (1 cm thick) with fissile coal layers (2–3 cm thick).

Coals from Sterling(?) Formation exposed at Lake Creek and lower Johnson Creek in the western portion of the basin, were ranked lignite A. These coal beds were characterized by an abundance of woody material.

Table 4-1. Table of coal quality data.

Sample	Location	Formation	Latitude	Longitude	COAL ANALYSIS						Apparent rank
					Total Moisture	Fixed Carbon	Volatile matter	BTU	Ash	Sulfur	
11DL005-5.6a1	Contact Creek		61.87	-151.71	21.62	34.44	39.07	8,728	4.87	0.16	*Subbituminous C*
11DL005-5.6a2	Contact Creek		61.87	-151.71	23.02	32.99	37.14	8,342	6.85	0.18	*Subbituminous C*
11DL009.20.15a	Lake Creek	Sterling?	62.14	-150.99	18.84	18.10	31.60	5,533	31.46	0.30	*Subbituminous C*
11DL009-36.1a	Lake Creek	Sterling	62.14	-150.99	17.37	17.60	29.42	4,973	35.61	0.49	*Lignite A*
11DL011.10a	Bunco Creek	Tyonek	62.53	-150.65	15.56	13.86	18.60	3,855	51.98	0.26	*Subbituminous C*
11DL011-25.5a	Bunco Creek	Tyonek	62.53	-150.65	16.71	17.52	29.55	5,358	36.22	0.23	*Subbituminous C*
14A09a	Tributary off of Canyon Creek	Tyonek?	61.83	-151.71	17.84	31.24	32.38	7,807	18.54	0.44	*Subbituminous B*
14DL007-23.1a	Fairview Moun-tain	Tyonek	62.36	-151.58	17.89	36.98	38.81	9,421	6.32	0.32	*Subbituminous A*
14DL007-70.1a	Fairview Moun-tain	Tyonek	62.36	-151.58	20.19	29.50	34.62	7,535	15.69	0.22	*Subbituminous B*
14DL008a	Saturday Creek		61.68	-151.56	15.08	25.58	29.82	6,599	29.52	0.34	*Subbituminous B*
14DL010a	Skwentna/Hayes confluence	Tyonek	61.95	-151.87	15.55	32.71	43.41	8,787	8.33	0.22	*Subbituminous B*
14DL011-1.4a	Johnson Creek	Tyonek	62.07	-152.01	18.64	26.05	32.51	7,034	22.80	0.38	*Subbituminous C*
14DL011-12.75a	Johnson Creek	Tyonek	62.07	-152.01	19.83	31.54	36.16	8,060	12.47	0.33	*Subbituminous C*
14DL012b	Poor Man Creek	Sterling	62.59	-150.82	17.18	22.73	29.02	6,073	31.07	0.34	*Subbituminous C*
14DL014-2.0a	Lower Johnson Creek	Sterling	62.06	-151.66	26.61	18.20	30.20	5,123	24.99	0.41	*Lignite A*
14NH100a	Canyon/Contact Creek	Tyonek	61.85	-151.67	19.58	39.76	36.37	9,412	4.29	0.24	*Subbituminous B*

Figure 4-2a. Coal cleats in the Tyonek(?) Formation at Contact Creek.

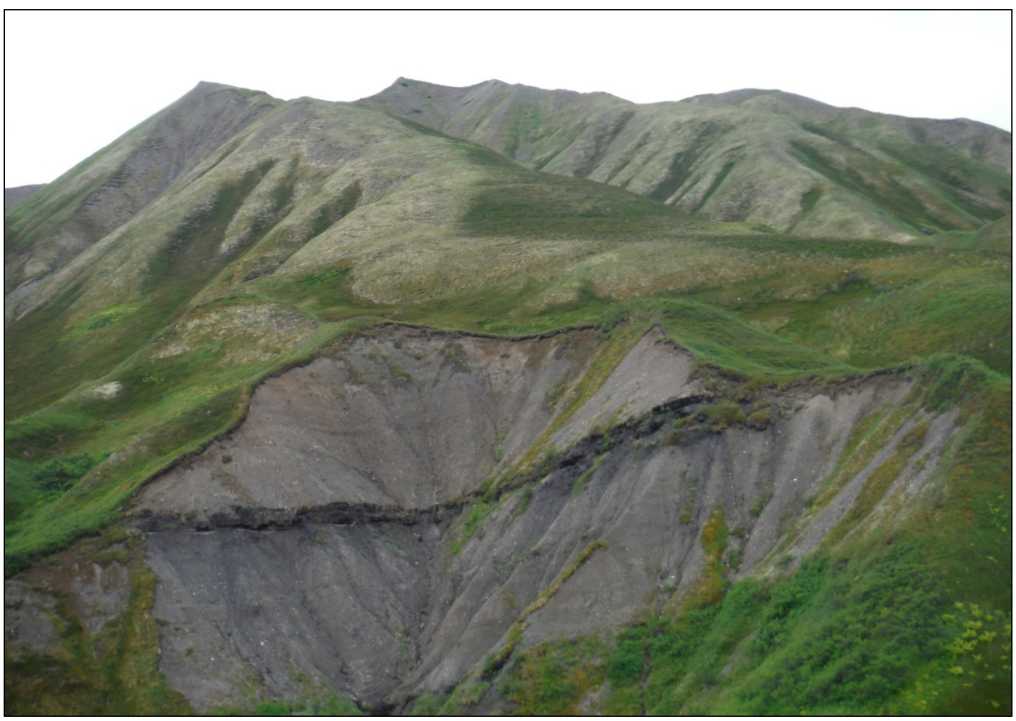

Figure 4-2b. Coal bed in Tyonek(?) Formation at Fairview Mountain.

Cleat development, orientations and densities were variable in the study area (fig 4-1, fig. 4-3). In general, face cleats strike to the northwest and southwest. Cleat orientations (face and butt) are consistently orthogonal to one another. Cleat dip orientations are high-angle, ranging from 55 to 90 degrees.

Cleat orientations show a marked change from Fairview Mountain to the north to the localities to the south (Johnson Creek, Lower Johnson Creek, Skwentna/Hayes confluence, Contact Creek, Canyon-Contact Creek and Saturday Creek). (fig. 4-1, fig. 4-3) Face cleat orientations can show two distinct orientations within a given section. To the south of Fairview Mt. face

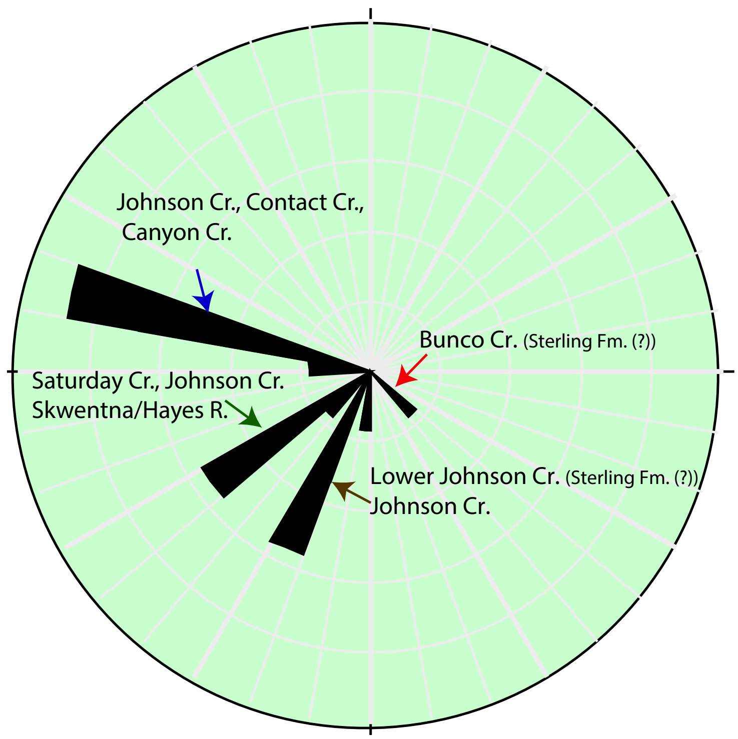

Figure 4-3a. Rose diagram of coal face cleat orientations at all localities excluding Fairview Mountain. Orientations are from the Tyonek(?) Formation, except where noted. N=12.

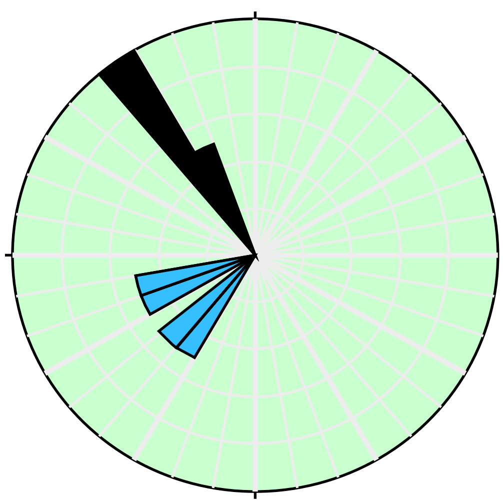

Figure 4-3b. Rose diagram of coal cleat orientations at Fairview Mountain in the Tyonek(?) Formation. Subbituminous A - 23 m; face cleats – black; butt cleats – blue; N=8.

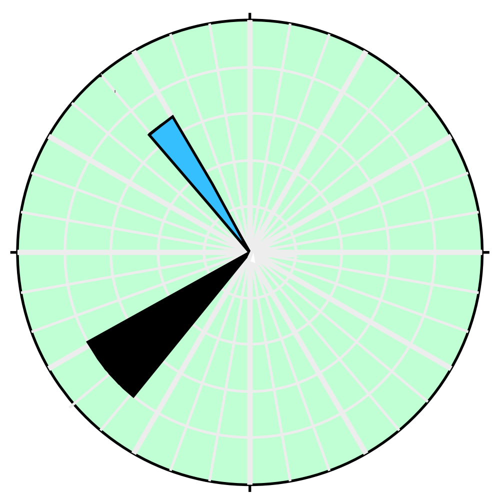

Figure 4-3c. Rose diagram of coal cleat orientations at Fairview Mountain in the Tyonek(?) Formation. Subbituminous B - 70 m; face cleats – black; butt cleats – blue; N=4.

cleat orientations vary but in general are orientated to the west-northwest (274° to 287° azimuth) or to the southwest (225° to 235° azimuth) and (206° to 208° azimuth) (fig. 4-3a). At Fairview Mountain, face and butt cleats are oriented to the northwest (316° to 332° azimuth) and southwest (224° to 237° azimuth). At Fairview Mt. face and cleat orientations switch from the bottom of the section (23 m) to the top coal bed (70 m) (fig. 4-3b, fig. 4-3c). The variations in cleat orientations from the north to the south of the study area may reflect deferring tectonic stress directions in these areas.

In general, cleat development variability could be a function of diagenetic and/or tectonic processes (Laubach and others, 1998). Additionally, the quality of exposure plays an important role in cleat recognition. Lower rank coal, lignite A, seems to contain fewer well recognized cleats in the study area.

Cleat height, frequency and aperture vary throughout the study area but are generally consistent within outcrops. Face cleat height varies from 70 cm to 1 m and butt cleat height varies from 30 to 70 cm. Cleat frequency, measured across the face of the outcrop vary from 4 to 16 face cleats per meter, 9 to 20 butt cleats per meter and 40 to 150 tertiary cleats per meter. Cleat apertures range from closed to 7.5 mm, with averages less than 3 mm. Only small tertiary cleats were filled. No fill material was observed in face or butt cleats.

SUMMARY

As part of the 2014 DGGS Susitna basin study, coal beds in 11 localities of the Tyonek(?) and Sterling(?) Formations were examined and sampled. Preliminary coal-quality analyses of these samples indicate that the older unit (Tyonek[?]) coals range from subbituminous A to subbituminous B in rank and the younger strata (Sterling[?]) coals are lignite A in rank. Cleat development was variable, although face cleats trend to the northwest or southwest. This coal data, along with pending high-pressure methane adsorption (HPMA), vitrinite reflectance, and Rock-Eval pyrolysis data, will offer new constraints on the viability of a coal-related biogenic gas system in the Susitna basin.

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CHAPTER 5

PRELIMINARY RESULTS OF RECONNAISSANCE STRUCTURAL STUDIES OF THE WESTERN SUSITNA BASIN, SOUTH-CENTRAL ALASKA

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INTRODUCTION

The Susitna basin of south-central Alaska is an actively subsiding depocenter expressed as a broad, ~13,000 km^2 lowland. The basin is bordered by the central and western segments of the Alaska Range to the north and west, respectively, and by the Talkeetna Mountains to the east (fig. 5-1). Dense vegetation cover in the lower foothills and the extremely rugged and heavily glaciated topography at higher elevations has made it difficult to identify and characterize major range-front structures. Few structural field studies have been undertaken in the basin (for example, Bier, 2010) and therefore little is known about fault systems separating the high-relief areas defining the periphery of the basin from its Paleocene to modern depocenter (Stanley and others, 2013). Much of what has been inferred about the structural configuration and deformation history of the Susitna basin is based chiefly on interpretation of geophysical data, including gravity (Hackett, 1977; Meyer and Boggess, 2003; Meyer, 2005; Saltus and others, 2012, 2014), aeromagnetics (Stanley and others, 2013; 2014; Saltus and others, 2012, 2014; Shah and others, 2014), and a few 2D seismic reflection lines (Haeussler and others, 2000; Stanley and others, 2014; Shah and others, 2014).

The Alaska Division of Geological & Geophysical Surveys (DGGS) conducted reconnaissance-level structural studies and thermochronologic sampling in summers 2010, 2012, and 2014 to better understand the deformation and exhumation history of the Susitna basin margin. Structural studies were focused in the eastern foothills of the western Alaska Range (fig. 5-1) where an abrupt, linear boundary on the southwest side of the basin strikes to the northwest (fig. 5-2a). Rock outcrops in this area are generally isolated, difficult to access, and small (fig. 5-2b). More continuous exposures occur along some drainages that are incised into the surrounding bedrock, but swift currents and near-vertical banks often make collecting structural data from these outcrops challenging (fig. 5-3). Preliminary results from small sets of unidirectional fault slip data collected from Lake Creek, Beluga Mountain, Talachulitna River, and Canyon Creek (fig. 5-1) are presented below and tentatively suggest at least two episodes of deformation resulting from northwest–southeast extension followed by northwest–southeast shortening.

New low-temperature thermochronologic sampling in this region ties together published apatite fission-track and (U-Th)/He results from the Tordrillo Mountains to the west (Haeussler and others, 2008) with unpublished data acquired by DGGS at Beluga Mountain to the east (Gillis and others, 2013a, 2013b, 2014); this work helps constrain the timing and location of uplift and denudation across structures at the western margin of the basin (fig. 5-1). Similarly, results from detrital apatite fission-track and detrital zircon samples of modern sediment collected from every major drainage sourced from the Talkeetna Mountains (fig. 5-1) will help constrain uplift and exhumation over a broad region of the eastern basin margin. These results will be combined with a similar suite of samples analyzed by DGGS in 2012 from major rivers draining the western and central Alaska Range (Gillis and others, 2013a, 2013b, 2014) to characterize the ages of principal source lithologies currently contributing sediment to the Susitna basin and to document spatial patterns of exhumation over time along the entire periphery of the basin. Further discussion of these data will be presented in a future report.

GEOLOGIC SETTING

The Susitna basin is a poorly understood modern, terrestrial, successor basin that is physiographically connected to the better-studied Cook Inlet forearc basin directly to the south (fig. 5-1). The Susitna basin is filled by late Paleocene and middle Miocene to younger nonmarine strata separated by a basinwide unconformity (Stanley and others, 2013, 2014). Although subsidence appears to have initiated in the Susitna and Cook Inlet basins contemporaneously during Paleocene time (for example, Swenson, 2003; Stanley and others, 2013), the Susitna basin is structurally separated from Cook Inlet basin by the Castle Mountain and Beluga Mountain faults (fig. 5-1), rendering similar yet distinct subsidence histories (Stanley and others, 2013). Clastic detritus in the Susitna basin overlies uppermost Jurassic to Upper Cretaceous marine Kahiltna assemblage strata, which were deformed and exhumed during diachronous collision and suturing of the Wrangellia composite terrane from mostly Early to Late Cretaceous time (Hampton and others, 2010). This tectonic event imposed a northeast-striking structural fabric on the region, which is broadly followed by the northern and southern margins of the basin. The deepest part of the Susitna basin (Susitna depocenter, fig. 5-1) is deformed by north-striking reverse faults and

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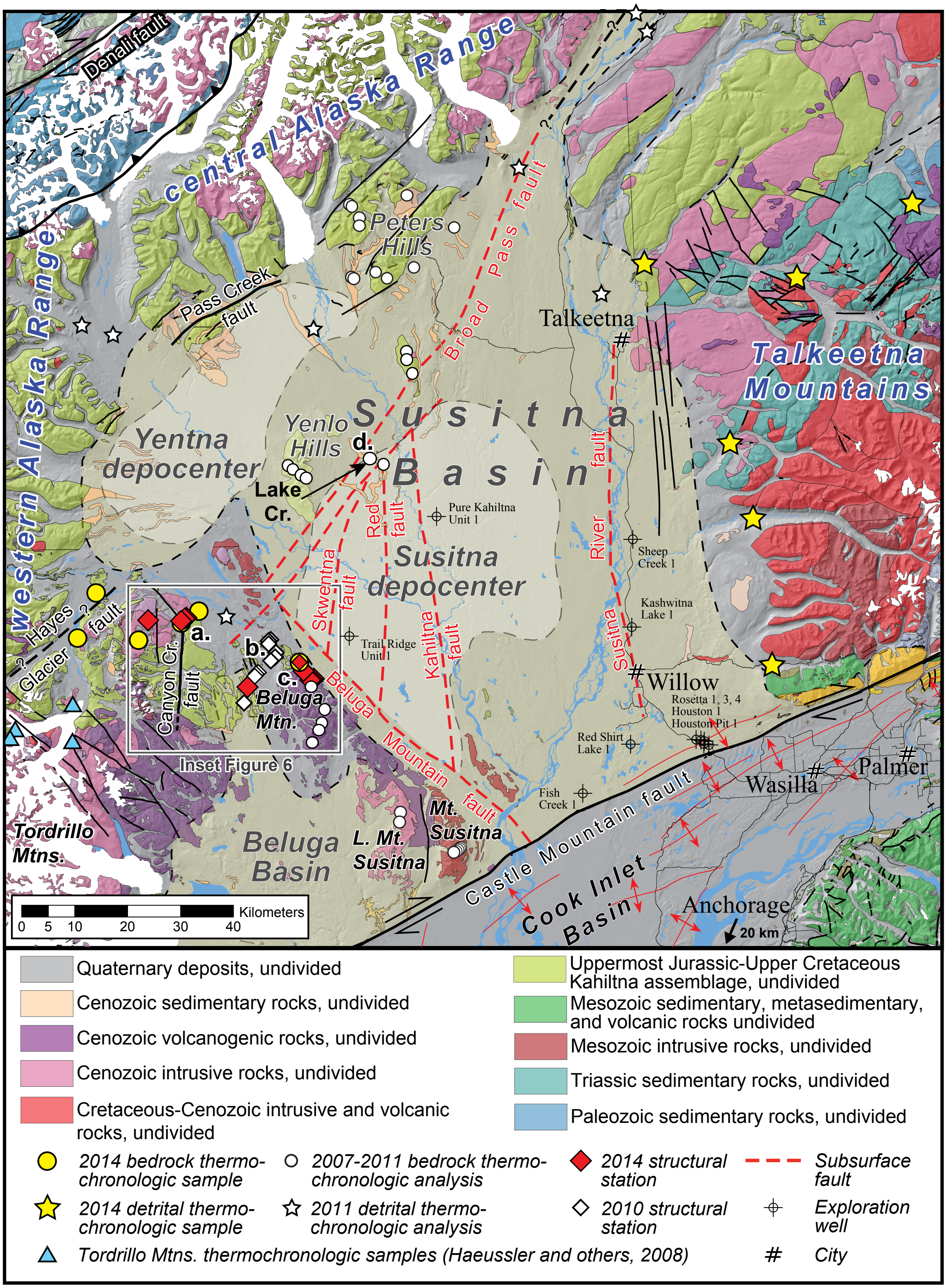

Figure 5-1. Generalized geologic map of Susitna basin and its margins, including parts of the western Alaska Range to the west, central Alaska Range to the north, and Talkeetna Mountains to the east. Bold lower-case black letters mark general locations along (a) Canyon Creek, (b) Talachulitna River, (c) northeast front of Beluga Mountain, and (d) Lake Creek, where structural data were collected and are keyed to stereonets in figure 5-4. Thick black lines represent major, named, or substantiated faults (dashed where approximately located). Red dashed faults constrained by geophysical data (Hackett, 1977; Saltus, and others, 2012, 2014).Thin solid black lines represent lineaments or hypothesized faults (Wilson and others, 2009). Thin dashed lines represent approximate outline of Susitna basin (Meyer, 2005). Adapted from Wilson and others, 2009; Solie and Layer, 1993; and Stanley and others, 2014.

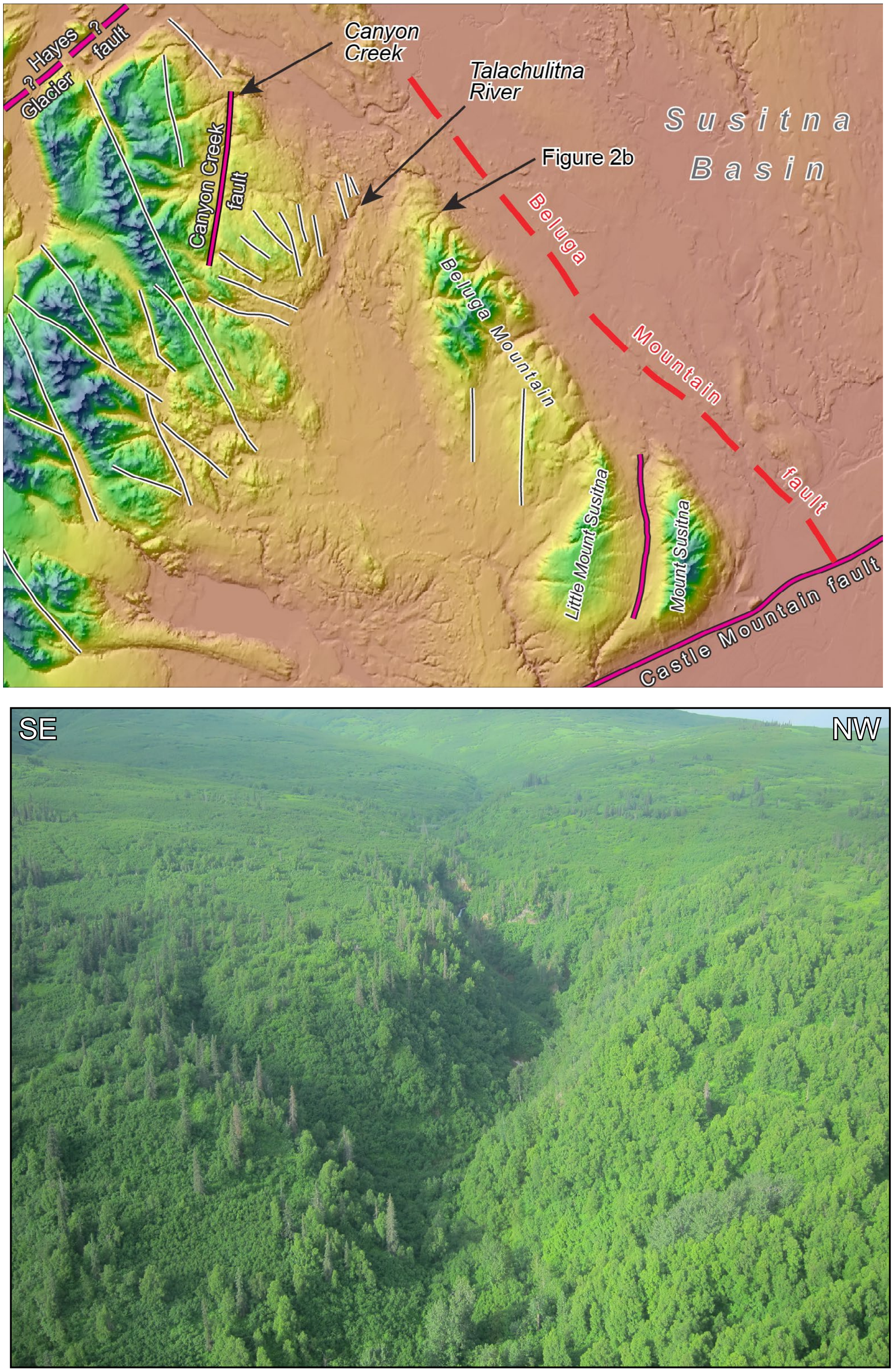

Figure 5-2. (a) Color digital elevation model of the western margin of Susitna basin, highlighting its linear character and potential structures controlling its deformation (refer to text for discussion). Red dashed fault (Beluga Mountain fault) constrained by geophysical data (Hackett, 1977; Saltus, and others, 2012, 2014). Thick magenta and black lines represent previously mapped faults (Barnes, 1966; Reed and Nelson, 1980; Solie and Layer, 1993; and Wilson and others, 2009). Thin solid black and white lines represent lineaments interpreted from the DEM. Geographic labels discussed in text. (b) View of the northeastern slope of Beluga Mountain, which faces Susitna basin. Poor bedrock exposures along the flank of the mountain and difficult access to outcrops hinder the collection of geologic data and an understanding of the structural style and history of the western basin margin.

Figure 5-3. View looking north along the Talachulitna River. The most extensive rock outcrops at the western Susitna basin margin occur in bedrock gorges where creek and river incisions have exposed tall vertical rock faces.

associated folds that cut across the Kahiltna structural trend (Stanley and others, 2014; Shah and others, 2014), but parallel the eastern boundary of the basin defined by the Talkeetna Mountain front (fig. 5-1). The western margin of the basin is defined by the northwest-striking Beluga Mountain front, which is likely controlled by the inferred Beluga Mountain fault (figs. 5-1 and 5-2; Hackett, 1977). The Beluga Mountain fault has been interpreted variably as a southwest-dipping, high-angle reverse fault (Hackett, 1977), a northeast-dipping normal fault (Ehm, 1983; Kirschner, 1988, 1994), and most recently as a southwest-dipping, low-angle thrust fault (Saltus and others, 2012, 2014).

PRELIMINARY RESULTS

Orientation and slip data from 104 fault planes at four locations in the Susitna basin and at its western periphery yield 39 unidirectional slip vectors (for example slip lineations with associated fault surface asperities such as secondary shear-fracture steps or fibrous crystal growth, tensile vein fill, riedel shears, or offset lithologic markers) used for a preliminary kinematic analysis of the faults deforming the basin margin (fig. 5-4). Fault data were collected from lithologies with wide-ranging ages and compositions (Barnes, 1966; Wilson and others, 2012). These rocks include Lower to Upper Cretaceous metapsammite and metapelite of the Kahiltna assemblage that underlie the basin and compose part of the proximal basin margin at Beluga Mountain and the Talachulitna River; middle Paleocene felsic intrusive rocks that intrude Kahiltna strata at Canyon Creek; middle to late Paleocene (DGGS unpublished age data) volcaniclastic strata at Beluga Mountain that overlie Kahiltna; and Oligo-Miocene to Pliocene(?) (DGGS unpublished age data) fluvial strata exposed along Lake Creek in the Susitna basin (fig. 5-1). Fault orientations common to most locations are divided into three principal sets (figs. 5-4 and 5-5): a northwest-striking set with mainly sinistral transpressional kinematics (set A), an east–northeast-striking set with chiefly normal/transtensional kinematics (set B), and a third north–northwest-striking set with mostly normal/transtensional kinematics (set C).

Patterns of faulting appear to be controlled more strongly by location than by the age or lithology of the deformed rocks. General observations regarding the distribution of faults and their kinematics include (1) an east-to-west transition from mostly north-striking faults (set C) in the basin (Lake Creek) and at its margin (Beluga Mountain) to more common or dominant east–northeast-striking faults (set B) observed only at the basin margin (Beluga Mountain and Talachulitna River), to

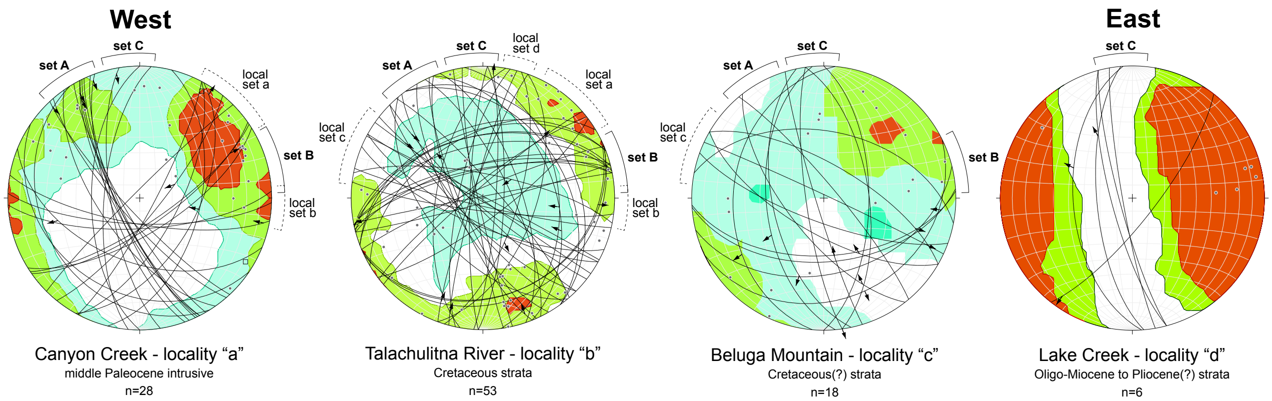

Figure 5-4. Equal area projection stereonets from four locations (see figs. 5-1 and 5-6), showing planes (black arcs), poles to planes (gray dots), and slip vectors (arrows off of planes). Colored shading represents density contours of poles to planes with higher values represented in red, intermediate values in green, and lower values in light blue. Regional fault sets (for example, "set A") are labeled in bold, denoted by upper-case letters, and qualitatively enveloped by solid brackets. Fault sets unique to a certain location(s) (for example, "local set a") are denoted by with lower-case letters and qualitatively enveloped by dashed brackets. See bold lower-case letters on figs. 5-1 and 5-6 for general data locations.

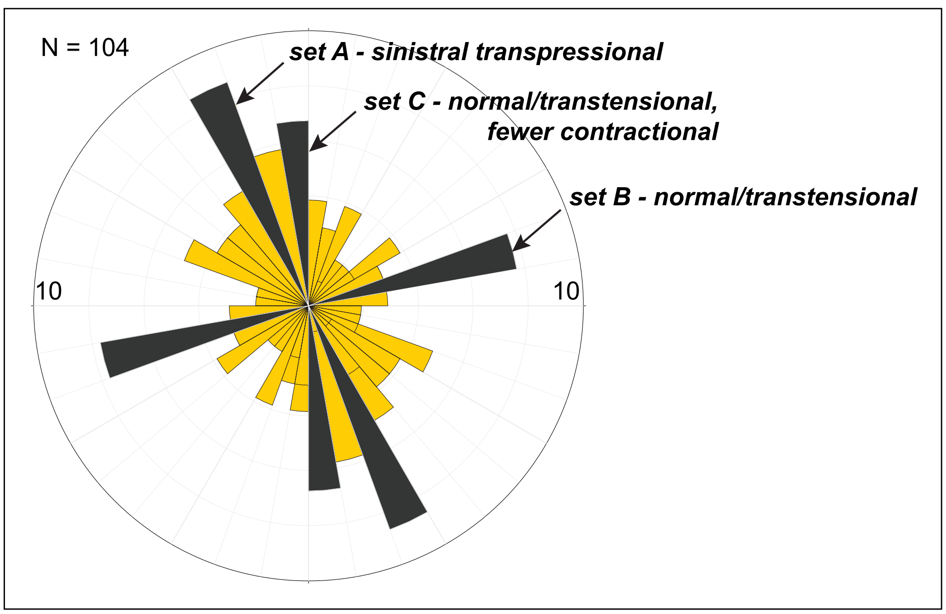

Figure 5-5. Rose diagram of the distribution of all fault strike directions measured for this study. Dark gray wedges highlight the three regional fault sets (see text for discussion and figure 5-6 for data plotted by specific location).

mostly northwest-striking faults (set A) more distal to the margin (Canyon Creek) (figs. 5-5 and 5-6); and (2) faults within the basin (Lake Creek) and at its margin (Beluga Mountain and Talachulitna River) tend to contain a proportionally larger number of extensional or transtensional faults in contrast to more prevalent transpressional faults more distal to the margin (Canyon Creek) (fig. 5-4).

DISCUSSION

The fault orientations measured from outcrops in this study (fig. 5-6) are compatible with the distribution of lineaments and faults mapped in the subsurface of the Susitna basin (for example, Stanley and others, 2014) and at the surface to the west of the basin (for example, Wilson and others, 2012). Northwest-striking lineaments and speculatively mapped faults become increasingly prevalent to the west of the Susitna basin margin (as defined by the Beluga Mountain front; figs. 5-1 and 5-2a), whereas north-striking structures, such as the Skwentna, Red, Kahiltna, and Susitna River faults (Stanley and

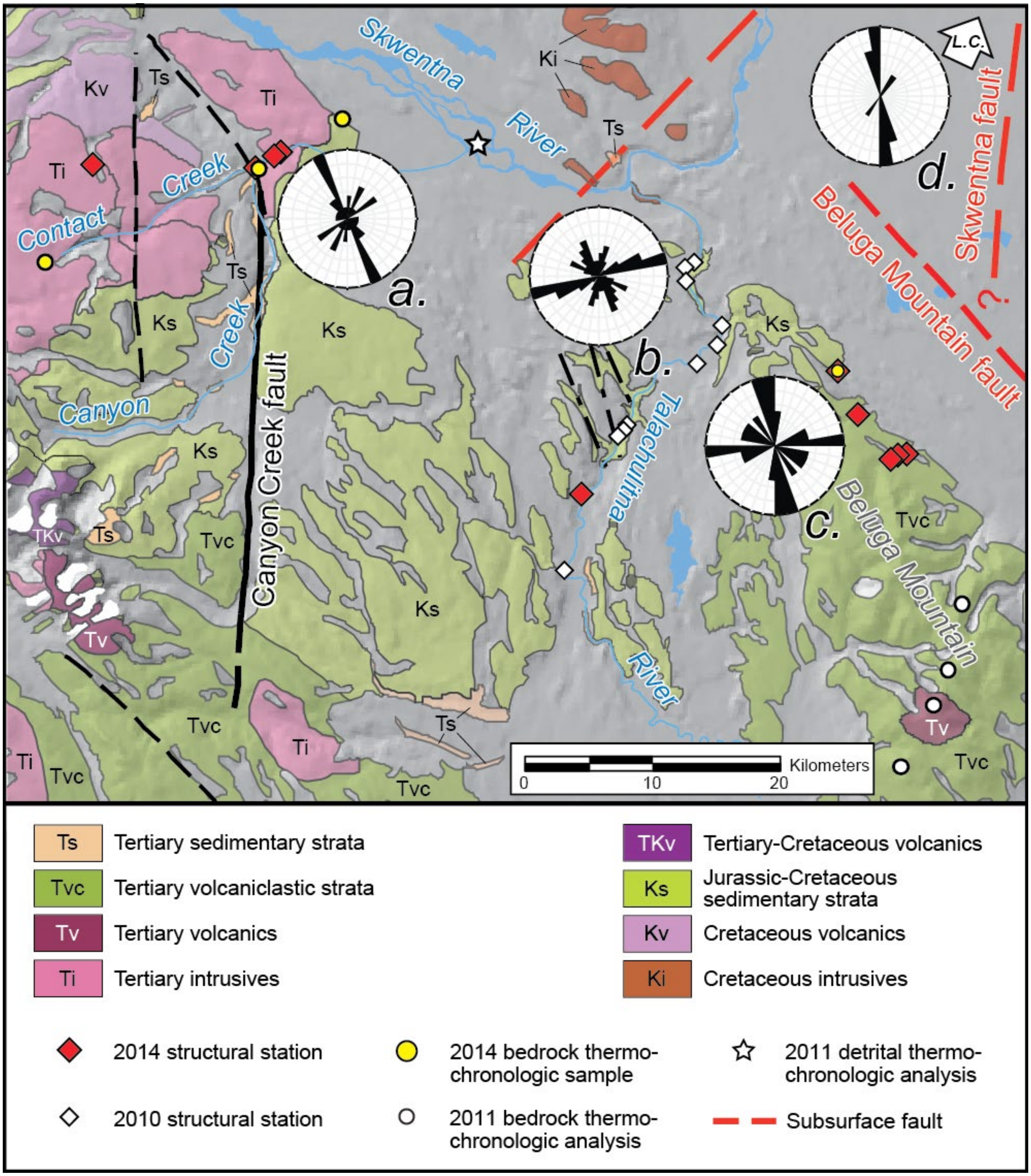

Figure 5-6. Larger-scale geologic map (see location on fig. 5-1 outlined in white and black) showing rose diagrams of fault strike directions for each of four locations where fault data was collected. Lower-case letters are keyed to stereonets in figure 5-4. White arrow points in the direction of Lake Creek (L.C.), located off of the map to the northeast. Thick black line represents fault mapped by Barnes (1966) and Wilson and others (2009). Thin dashed lines represent major lineaments or speculative faults from Wilson (2009). Thin dashed-dotted lines near the Talachulitna River represent lineaments interpreted from aerial photos. Thick red dashed faults constrained by geophysical data (Hackett, 1977; Saltus, and others, 2012, 2014). Adapted from Wilson and others, 2009; Solie and Layer, 1993; and Stanley and others, 2014.

others, 2013, 2014), the Canyon Creek fault (Barnes, 1966), and an unnamed fault separating Mt. Susitna from Little Mt. Susitna (Wilson and others, 2012) are restricted to the Susitna basin and a region to the west within about 25 km of the basin margin (figs. 5-1 and 5-6).

Preliminary kinematic analysis of all of the unidirectional fault data (n=39) and outcrop cross-cutting relationships suggests at least two episodes of deformation, indicating nearly orthogonal northeast-directed (D1) and northwest-directed (D2) principal shortening. D1 is interpreted to have resulted in southeast- to possibly east-directed extension defined by dextral transtension on set C faults (fig. 5-7), and sinistral transtension on set B faults. All but one fault of this kinematic subset (n=14) deform Mesozoic and Paleocene strata near the basin margin or Cenozoic strata filling the Susitna basin. D2 (n=25) is manifested as sinistral transpression on set A faults (fig. 5-8), which are best expressed farthest from the basin margin at Canyon Creek (figs. 5-4 and 5-6). Field observations of small fault cross-cutting relationships indicate that set C and set A faults cut faults of all other orientations. Yet where cross-cutting relationships between set C and set A faults are observed, set A (northwest-striking) faults cut set C (north-striking) faults, indicating that sinistral transpression on northwest-striking faults postdates apparent earlier transtension focused near the basin margin. This relationship holds true at the map scale, as the northwest-striking Beluga Mountain fault appears to truncate all north-striking faults (fig. 5-1). However, steeply-dipping north-striking faults mapped in the subsurface of Susitna basin using seismic reflection and aeromagnetic data exhibit reverse throw, inferred to be Miocene and younger contraction (Stanley and others, 2014). Therefore, if the limited kinematic data from north-striking faults presented in this study are indicative of regional dextral transtension or extension, then the basin reverse faults could have reactivated earlier transtensional faults, possibly contemporaneously with northwest shortening.

Shah and others (2014) also infer northwest- and northeast-directed shortening events along with an additional east-directed event, using the same data as Stanley and others (2014). However, the sequence for which they interpret the events to have occurred differs from that presented in this report. This discrepancy hinges on the different kinematic models considered. The interpretation by Shah and others (2014) implies dip-slip motion on major faults and fold growth orthogonal to the shortening direction, which requires three different episodes of deformation. Our interpretation based on fault kinematic data requires oblique slip on faults that allows for fold growth to occur obliquely to fault orientations, strain partitioning across faults, and only requires two deformation events.

Although the fault data are in general agreement with field observations and map-scale features, they do little to support a recent inference that the Beluga Mountain fault is a thrust. All of the locations from which fault data were collected for

Figure 5-7. Photo of weathered east-striking fault surface on the bank of the Talachulitna River. Secondary shear steps and faint striae (grooves) indicate dextral-normal slip.

Figure 5-8. Photo of northwest-striking anastomosing faults on Canyon Creek (arrows indicate approximate trend across outcrop). Secondary shear steps and striae (grooves) on fault surfaces at this location indicate principally sinistral to sinistral-reverse slip.

the current study, except along Lake Creek, ostensibly lie in the proximal hanging-wall of this major northwest-striking, southwest-dipping structure inferred from gravity data (Saltus and others, 2012, 2014). In this recent interpretation, the Beluga Mountain fault is hypothesized to thrust uppermost Jurassic to Upper Cretaceous basement and Cretaceous–Paleocene arc rocks northeastward several tens of kilometers over Paleocene and younger Susitna basin strata, making it one of the largest faults in terms of slip magnitude known in the forearc region. However, northwest-striking, low-angle contractional faults are nearly absent in the data (n=2) presented here, implying that their contribution to regional deformation along the western margin of the basin is minimal. The fact that only 10 percent of our fault data of any orientation have dip magnitudes less than 45 degrees suggests that high-magnitude contraction in this region is probably rare. However, a major limitation to our fault dataset is the low number of surfaces and kinematic measurements collected from only a few locations, especially at Beluga Mountain and Lake Creek. Therefore the small structural dataset presented here certainly over- or under-represents some structural relationships.

CONCLUSION

This reconnaissance structural study of the Susitna basin is the first of its kind to be conducted from the basin's western periphery and provides preliminary insights into a multi-phase structural history. Kinematic analyses of fault slip data and outcrop cross-cutting relationships suggest at least two episodes of deformation requiring different principal shortening directions. D1 is tentatively interpreted as transtensional, resulting in southeastward or eastward extension along northward-striking faults. D2 appears to have been transpressional, accommodating sinistral contraction along northwest-striking faults that cross-cut all other fault orientations. North-striking structures in the Susitna basin subsurface that deform middle Miocene and younger strata could have originated as extensional faults during middle Paleocene basin subsidence that were later reactivated as reverse faults during D2 (contemporaneous with shallow, obliquely-oriented fold growth in the basin [for example, Shah and others, 2014]). The geometry and slip history of the Beluga Mountain fault remains cryptic. The outcrop structural data does not support high-magnitude contraction in the region, as inferred from a recent high-density gravity survey that suggested several tens of kilometers of northeastward structural thrust shortening along the Beluga Mountain fault. Regardless, additional structural data would substantially enhance understanding of the tectonic evolution of the area and further constrain permissible interpretations of geophysical data in the Susitna basin.

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