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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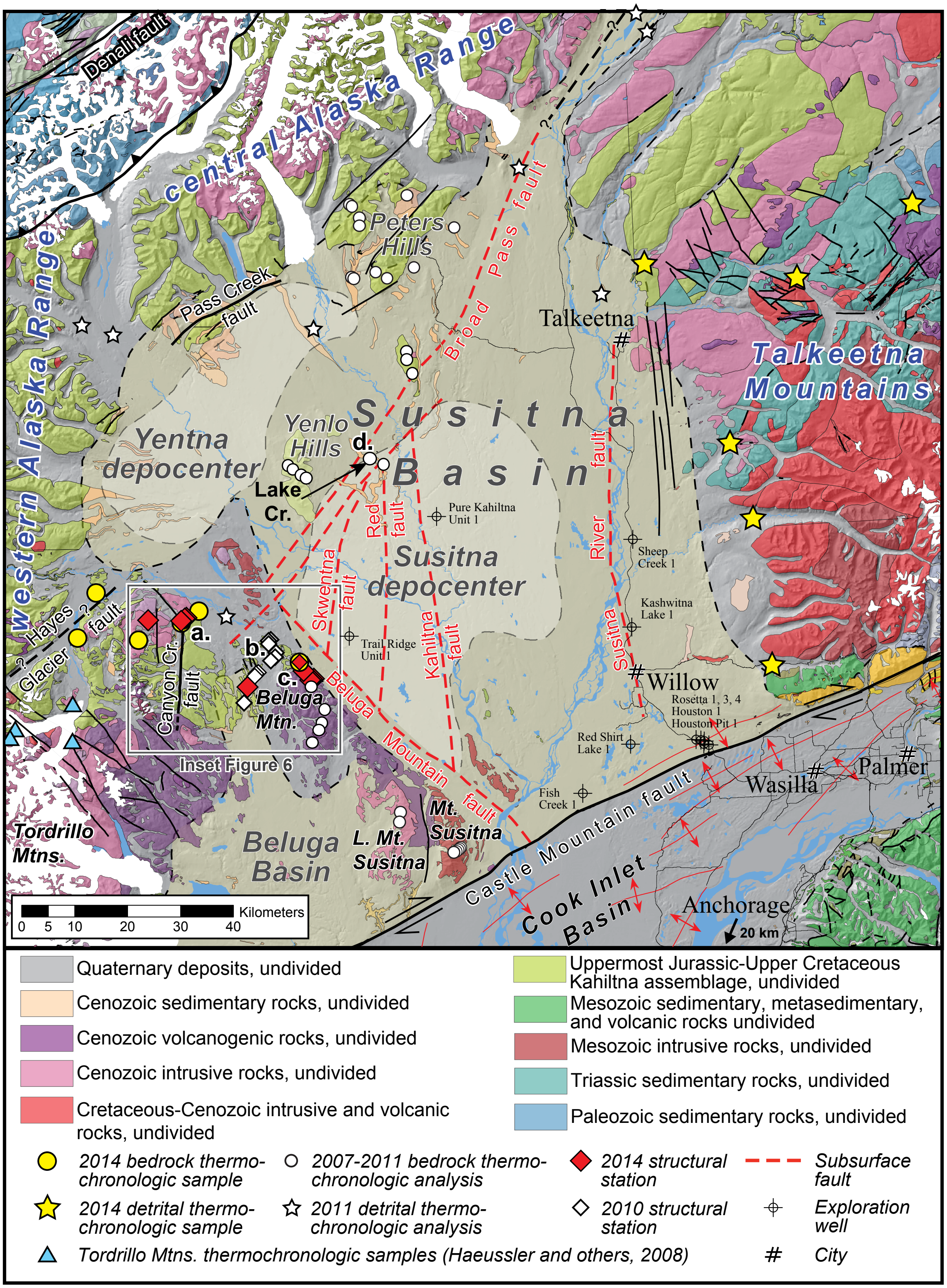

Figure 5-1. Generalized geologic map of Susitna basin and its margins, including parts of the western Alaska Range to the west, central Alaska Range to the north, and Talkeetna Mountains to the east. Bold lower-case black letters mark general locations along (a) Canyon Creek, (b) Talachulitna River, (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.

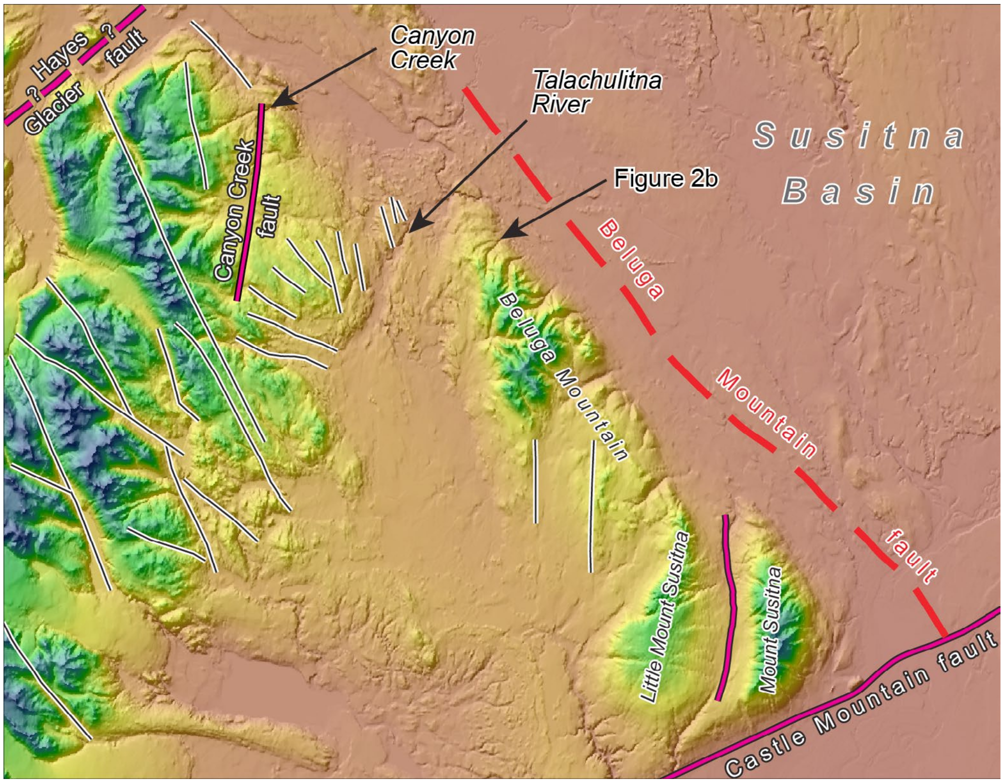

Figure 5-2. (a) Color digital elevation model of the western margin of Susitna basin, highlighting its linear character and potential structures controlling its deformation (refer to text for discussion). Red dashed fault (Beluga Mountain fault) constrained by geophysical data (Hackett, 1977; Saltus, 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

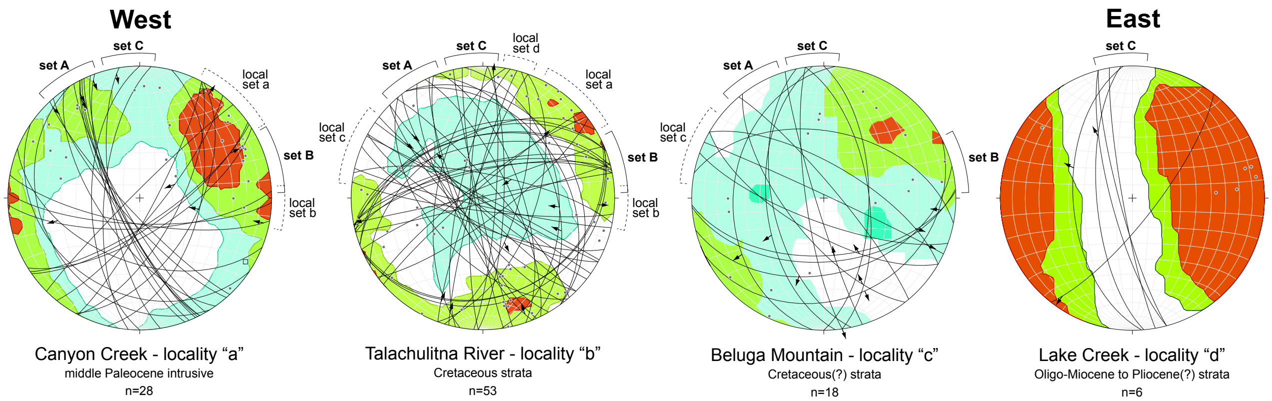

Figure 5-4. Equal area projection stereonets from four locations (see figs. 5-1 and 5-6), showing planes (black arcs), poles to planes (gray dots), and slip vectors (arrows off of planes). Colored shading represents density contours of poles to planes with higher values represented in red, intermediate 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.

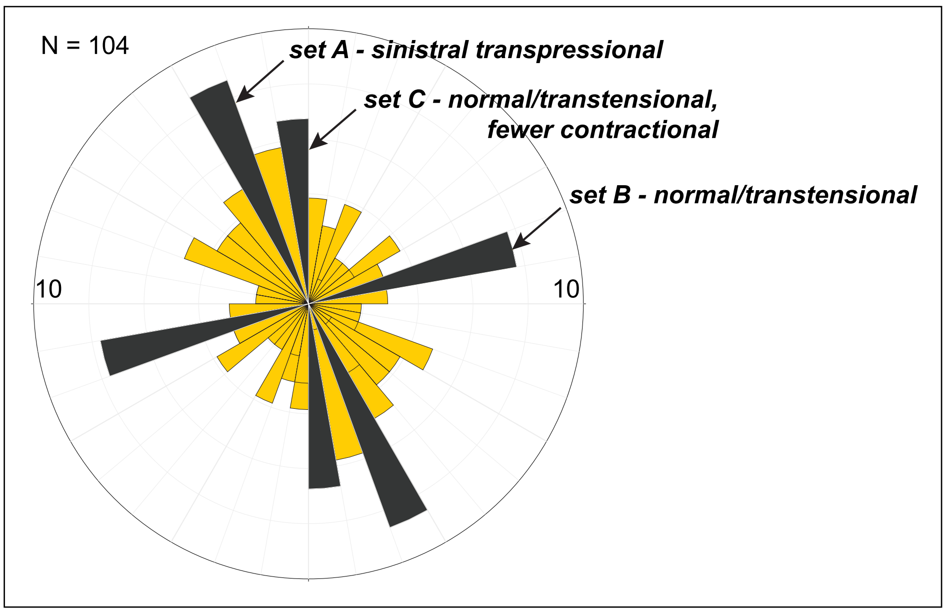

Figure 5-5. Rose diagram of the distribution of all fault strike directions measured for this study. Dark gray wedges highlight the three regional fault sets (see text for discussion and figure 5-6 for data plotted by specific location).

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

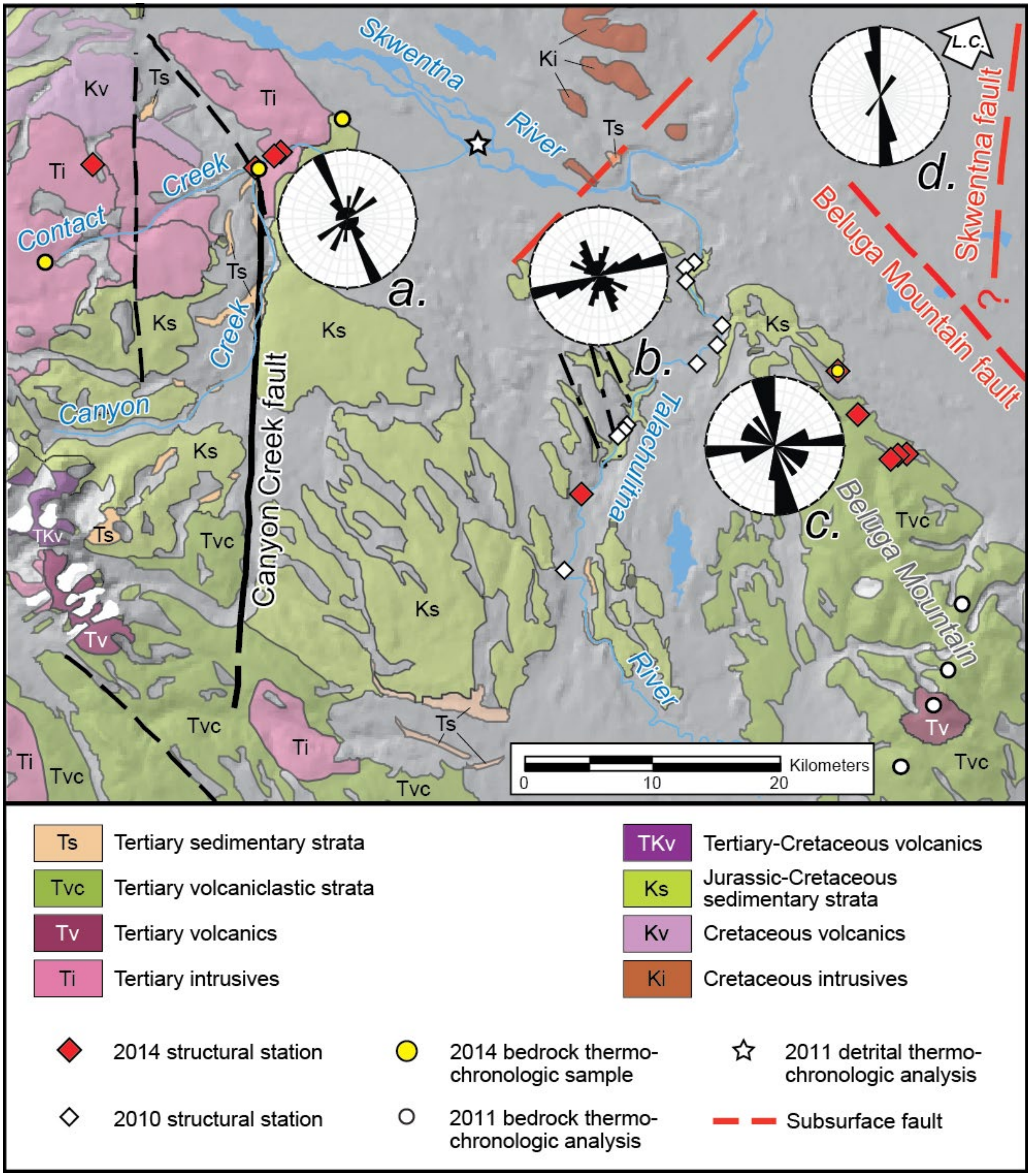

Figure 5-6. Larger-scale geologic map (see location on fig. 5-1 outlined in white and black) showing rose diagrams of fault strike directions for each of four locations where fault data was collected. Lower-case letters are keyed to stereonets in figure 5-4. White arrow points in the direction of Lake 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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