PRELIMINARY DESCRIPTION AND INTERPRETATION OF THE DOONE CREEK FAULT AND ASSOCIATED STRUCTURES: THE POTENTIAL OFFSET AND NORTHEASTWARD CONTINUATION OF THE BRUIN BAY FAULT SYSTEM IN THE SOUTH-CENTRAL TALKEETNA MOUNTAINS, ALASKA

Robert J. Gillis, Jeffrey M. Trop, and Leo Kuyl

Preliminary Interpretive Report 2024-1

This publication is PRELIMINARY in nature and meant to allow rapid release of field observations or initial interpretations of geology or analytical data. It has undergone limited peer review but does not necessarily conform to DGGS editorial standards. Interpretations or conclusions contained in this publication are subject to change.

2024
STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

STATE OF ALASKA
Mike Dunleavy, Governor

DEPARTMENT OF NATURAL RESOURCES
John Boyle, Commissioner

DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS
Melanie Werdon, State Geologist & Director

Publications produced by the Division of Geological & Geophysical Surveys are available to download from the DGGS website (dggs.alaska.gov). Publications on hard-copy or digital media can be examined or purchased in the Fairbanks office:

Alaska Division of Geological & Geophysical Surveys (DGGS)
3354 College Road | Fairbanks, Alaska 99709-3707
Phone: 907.451.5010 | Fax 907.451.5050
dggspubs@alaska.gov | dggs.alaska.gov

DGGS publications are also available at:

Alaska State Library, Historical
Collections & Talking Book Center
395 Whittier Street
Juneau, Alaska 99801

Alaska Resource Library and
Information Services (ARLIS)
3150 C Street, Suite 100
Anchorage, Alaska 99503

Suggested citation:
Gillis, R.J., Trop, J.M., and Kuyl, Leo, 2024, Preliminary description and interpretation of the Doone Creek fault and associated structures: The potential offset and northeastward continuation of the Bruin Bay fault system in the south-central Talkeetna Mountains, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2024-1, 18 p. https://doi.org/10.14509/31108

PRELIMINARY DESCRIPTION AND INTERPRETATION OF THE DOONE CREEK FAULT AND ASSOCIATED STRUCTURES: THE POTENTIAL OFFSET AND NORTHEASTWARD CONTINUATION OF THE BRUIN BAY FAULT SYSTEM IN THE SOUTH-CENTRAL TALKEETNA MOUNTAINS, ALASKA

Robert J. Gillis[1], Jeffrey M. Trop[2], and Leo Kuyl[2]

ABSTRACT

Recent 1:25,000-scale geologic mapping of a small (~129.5 km^2) area between the Kings and Chickaloon rivers in the Talkeetna Mountains has identified a previously unrecognized fault that places Late Jurassic plutonic rocks of the Talkeetna arc against genetically related Late Triassic?–Middle Jurassic volcanic deposits of the Talkeetna Formation (Jtk). Referred herein as the Doone Creek fault (DCF), it offsets an erosional surface upon which late Paleocene to early Eocene Arkose Ridge Formation (Tar) is deposited. The south–southwest-striking DCF and an adjacent southwest-trending, subvertical brittle shear zone (the intra-Jtk shear zone, or ITSZ) that is restricted to Jtk wrap westward into the dextral-reverse slip Castle Mountain fault (CMF) to the south. The relationship implies that they either formed as splays to the CMF or were truncated by the CMF and rotated about a vertical axis due to slip coupling at the fault interface. Preliminary kinematic data from the DCF suggest that an early phase of sinistral strike slip preceded reverse motion. The DCF, ITSZ, and other unnamed and unstudied faults confined between the Kings and Chickaloon rivers constitute a discontinuous array of fault segments that deform the Jurassic arc–forearc basin transition similar to the sinistral transpressional Bruin Bay fault system (BBFS) to the southwest. The BBFS forms the structural boundary of the Talkeetna arc for nearly 500 km from the upper Alaska Peninsula to upper Cook Inlet where it projects obliquely into the CMF from the south–southwest. Thus, the DCF may constitute part of the northeastward continuation of the BBFS that was truncated and translated dextrally by the CMF.

INTRODUCTION

The study area in the Talkeetna Mountains is situated at the boundary between volcanic deposits of the Late Triassic?–Middle Jurassic Talkeetna magmatic arc complex and its exhumed plutonic batholith (fig. 1A). In the southern region of the study area, the Talkeetna arc is truncated against the Castle Mountain fault (CMF)—a discontinuously exposed system of faults that extend for nearly 250 km from west of the Nelchina River in the Matanuska Valley to Lone Ridge west of the Beluga River in the northwestern Cook Inlet basin (Grantz, 1965; Detterman and others, 1976; Fuchs, 1980; 2019; Gillis and others, 2017) (figs. 1A and B). Slip on the CMF was chiefly right lateral since perhaps Late Cretaceous until late Oligocene or early Miocene (Grantz, 1965), although middle Eocene appears to have been a period of heightened activity (Little, 1990; Gillis and others 2022). Dextral transpression may have been the dominant slip mode after the early Miocene, resulting in an estimated 1.5 to nearly 5 km of throw in the Matanuska Valley region (Grantz, 1965; Detterman and others, 1976; Fuchs, 1980; Bruhn and Pavlis, 1981; Terhune and others, 2019). The CMF is locally tectonically active and produced a 5.7 magnitude (M_b) earthquake centered near the town of Sutton in 1984 (Lahr and others, 1986) and deforms Quaternary glacial and fluvial deposits across the southern Susitna lowlands (Detterman and others, 1974; Haeussler and others, 2002; Koehler and others, 2012).

---

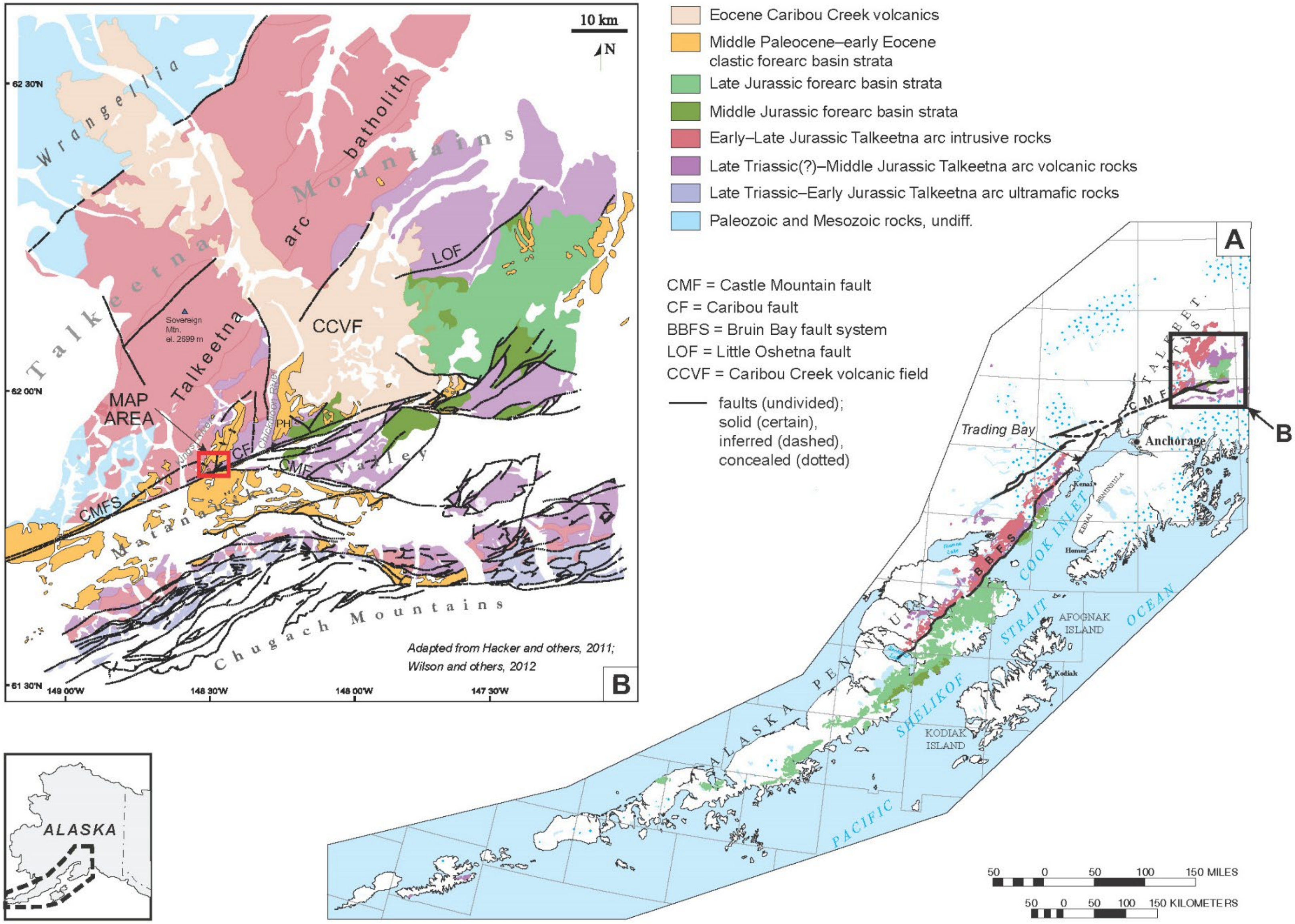
[1] Division of Geological & Geophysical Surveys, 3354 College Road, Fairbanks, AK 99709

[2] Department of Geology and Environmental Geosciences, Bucknell University, Lewisburg, PA 17837

The Talkeetna arc reappears across the CMF to the west-southwest in the upper Cook Inlet region and continues southwestward for nearly 500 km along the Cook Inlet to the upper Alaska Peninsula (fig 1B), constraining 110–130 km of dextral separation across the fault (Hackett, 1976; Trop and others, 2005). Along the Cook Inlet segment of the Talkeetna arc, the batholith is exhumed against the forearc basin and locally against its volcanic edifice by the Bruin Bay fault system (BBFS)—a well-expressed regional structure that exploits the mechanical contrast between strong plutonic rocks carried in its hanging-wall from weaker sedimentary and volcanic footwall lithologies (Detterman and Hartsock, 1966; Magoon and others, 1976; Detterman and Reed, 1980; Betka and others, 2017). Whereas most major fault systems in southern and Interior Alaska, such as the CMF, record large magnitudes of right lateral slip, the BBFS is a rare example of a map-scale left lateral fault in the region. Fault slip kinematic data collected for the BBFS record two distinct phases of deformation consisting of an earlier sinistral and contractional episode perhaps initiating in the Paleogene followed by a post-Paleogene phase that favored dextral reactivation and extension (Decker and others, 2008; Betka and others, 2017).

All the principal elements of the Talkeetna arc–forearc complex are recognized to the southwest and northeast of the CMF in the Cook Inlet region and Talkeetna Mountains, respectively, except for a major fault system analogous to the BBFS that separates the arc–forearc boundary in the Talkeetna Mountains (fig. 1B). The nascent state of geologic mapping in the area may be a factor in its apparent absence. For example, much of the arc–forearc boundary has only been mapped at 1:250,000-scale (e.g., Csejtey and others, 1978). Trop and others (2005) proposed that a fault segment in the eastern Talkeetna Mountains (Little Oshetna fault), which places Jurassic Talkeetna Formation volcanic rocks (Jtk) against Jurassic forearc basin clastic lithologies, may represent the northeastward continuation of the BBFS (fig. 1B). However, the fault's limited exposed length and relative isolation in the eastern Talkeetna Mountains complicate establishing a concrete correlation. Other candidate structures closer to the CMF include unstudied fault segments mapped between the Kings and Chickaloon rivers by Csejtey and others (1978) that locally place Jurassic plutonic and volcanic rocks against Paleogene forearc basin strata (Arkose Ridge Formation). However, resolving their role in deforming the arc–forearc transition will require new, detailed bedrock geologic mapping. In a continuing effort to understand the evolution of the CMF and BBFS and their roles in Matanuska and Cook Inlet forearc basin subsidence, staff from the Alaska Division of Geological & Geophysical Surveys (DGGS) and Bucknell University spent four days in June of 2022 conducting reconnaissance field mapping in the southern Talkeetna Mountains while collecting structural and stratigraphic information (fig. 2). This publication discusses structural observations and preliminary findings and includes field station location data, available at https://doi.org/10.14509/31108. For a summary of preliminary stratigraphic observations and results, see Kuyl and others (2023).

Figure 1 (next page). A. Map of southcentral Alaska highlighting regional faults and distribution of Jurassic Talkeetna arc intrusive rocks that comprise much of the Talkeetna Mountains and western margin of the Cook Inlet forearc basin. Note the approximately 130 km right lateral separation of the Talkeetna arc by the Castle Mountain fault (CMF). **B.** Generalized geologic map of the Talkeetna Mountains (black box in fig. A) highlighting the northeast trend of Talkeetna arc plutonic rocks through the central region of the range. Unstudied north and northeast structures concentrated at the southwest margin of the Jurassic batholith suggest a mechanical contrast between stronger intrusive rocks to the northwest (pale red) and weaker volcanic rocks to the southeast (green) that either controls the deposition or preservation of Paleogene sedimentary and volcanic lithologies, or both. Map area for this study encompassed within the solid red box. Late Cretaceous forearc basin strata omitted to highlight the distribution of Paleogene lithologies with respect to the Talkeetna arc–forearc complex.



Adapted from Hacker and others, 2011; Wilson and others, 2012

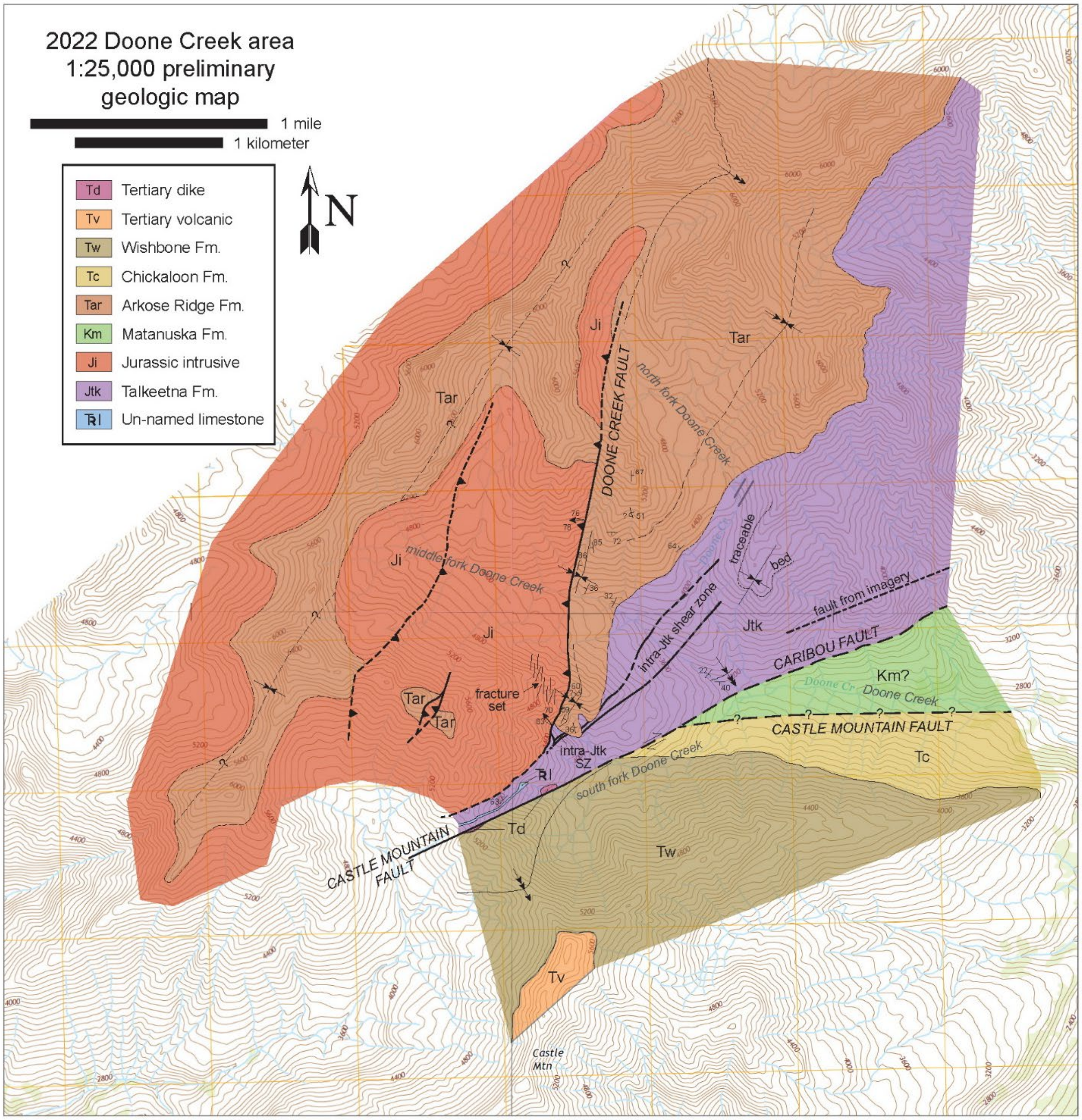


Figure 2. Preliminary 1:25,000 scale geologic map of the Doone Creek area, southcentral Talkeetna Mountains. The map area encompasses the junction between the Castle Mountain and Caribou faults that cut obliquely across the Jurassic Talkeetna arc. The area also contains the newly identified Doone Creek fault and an intra-formational brittle fault zone that deform Talkeetna arc lithologies subparallel to the arc boundary. The DCF and other north and northeast-trending faults and folds represent an unstudied family of structures that may be correlative to similar features that bound the southeastern margin of the Talkeetna arc in the Cook Inlet area to the southwest.

PRELIMINARY OBSERVATIONS AND RESULTS

Geologic mapping at a scale of 1:25,000 of the Doone Creek region northeast of Castle Mountain (fig. 2) resulted in the discovery of a previously unidentified fault that branches off the CMF, referred to here as the Doone Creek fault (DCF), along with a wide, unmapped, subvertical brittle shear zone in the Talkeetna Formation (intra-Talkeetna shear zone, or ITSZ). The DCF is a south–southwest-striking steeply west–northwest-dipping reverse fault that locally defines the structural boundary between intrusive and extrusive lithologies of the Talkeetna magmatic arc. Thus, the DCF and related structures in the Talkeetna Mountains might represent elements associated with the BBFS that have been offset right-laterally by the CMF.

CASTLE MOUNTAIN FAULT

The CMF in the study area is a subvertical to steeply north–northwest-dipping fault that elevates Late Triassic?–Middle Jurassic arc volcanic rocks and Upper Cretaceous Matanuska Formation (Km) forearc basin strata to its north–northwest against middle Paleocene to early Eocene clastic forearc basin lithologies of the Chickaloon (Tc) and Wishbone (Tw) Formations to the south-southeast (fig. 2). The fault contact is not well exposed, although only a few meters of Quaternary cover separate sub-vertical Jtk and associated marble of the upthrown block from steeply southeast-dipping Tw of the downthrown block in the saddle northwest of Castle Mountain. A single fault plane measured within a thin marble body deformed in the fault zone produced a strike of 247°, sub-parallel to the regional trend of the CMF, and subvertical northwest dip of 89°. Shallowly southwestward plunging mullions (8°) and steeply southeastward dipping shaley cleavage at the subsidiary fault interface suggest dextral transpression along the fault plane, consistent with previous studies of the fault system (e.g., Detterman and others, 1976; Fuchs, 1980; Bruhn and Pavlis, 1981; Fuchs, 2019). A striking feature southeast of the fault is a large asymmetrical syncline with a moderate to steeply northwest-dipping axial plane deforming Tw in the downthrown block (figs. 2 and 3A). The syncline axis in the downthrown block of the CMF is 0.5 km distant from the fault contact, indicating dextral slip was accompanied by a major component west-side-up offset. The CMF splays to the east into the Castle Mountain and Caribou fault strands at a branch point located in the south fork near its confluence with the middle fork of Doone Creek (fig. 2). Although the branch point is concealed, the CMF is well exposed near Puddingstone Hill outside of the study area (PH, fig. 1B) to the east-northeast where it strikes 268° with a steep north dip of 82°. Surfaces measured on the principal fault plane (n=3) near Puddingstone Hill preserve moderately plunging striae (37–52°) and ornamentation indicating oblique right slip. A conspicuous feature at this location is an isoclinally folded dike several meters thick that intrudes the length of the fault exposure and constrains northwest-side-up displacement. Although additional fault slip surface measurements are required to produce a robust kinematic dataset for the CMF in this area, the few presented here are consistent with a small, published kinematic dataset from the CMF zone to the west–southwest (n=13; Bruhn and Pavlis, 1981). These new data along with outcrop-scale relations support previous interpretations of bulk dextral reverse slip on the CMF.

DOONE CREEK FAULT

The DCF is a reverse-slip structure that is mappable for at least 2.5 km from the CMF north–northeastward and is well exposed at two locations in the south and middle forks of Doone Creek (fig. 2). Kinematic indicators at both sites suggest that dip-slip motion was preceded by an earlier episode of strike slip. At the location in the south fork of Doone Creek near the CMF (figs. 3A and B), the DCF strikes ~212° and places Middle–Late Jurassic plutonic rocks (Ji) in its upthrown block to the northwest against Late Triassic? –Middle Jurassic mafic volcanic rocks (Jtk) in its downthrown block to the southeast along a steeply northwest-dipping (83°) plane. Approximately 100 m to the northeast, the DCF places Ji against middle Paleocene–early Eocene sedimentary rocks (Arkose Ridge Formation [Tar]) that are deposited on top of Jtk. The fault plane at this location is expressed as a small, uniform 5 m by 1 m surface with a locally preserved 0.5- to 1-cm-thick cemented cataclastic core. Numerous secondary shear fractures and weak, steeply plunging striae ornament the weathered Ji fault surface a few centimeters distal to the core (fig. 3C). Closely spaced decimeter-scale subvertical fractures emanate to the south from the fault core into Jtk at a shallow (31–37°) counterclockwise angle about a vertical axis (fig. 3C). Granitic rock proximal to the fault has a dense, steeply southeast-dipping brittle fabric that produces fresh, weakly rounded weathered surfaces that suggests micro-fracturing via distributed shear. In upthrown Ji distal to the DCF, widely spaced subvertical fractures 10's of meters long trend northward at a shallow angle to the fault (12–29°) and produce thin, weathered triangular fins several hundred meters into the granitoid body (labeled in fig. 2). Upthrown and downthrown block fractures that trend away from the fault surface to the north and south, respectively, have relative orientations to the DCF that are broadly consistent with synthetic Riedel (R) shears in a sinistral strike-slip system. Slip lineations on the surfaces of subsidiary faults in the downthrown block exhibit shallow rakes (<15°) and sinistral kinematics that are consistent with their interpretation as R shears. However, weak, steeply plunging slip lineations (83° rake) and well-developed secondary shear fractures on the main DCF surfaces (fig. 3C) indicate the most recent slip sense was northwest-side up reverse, which is supported by nearby Tar footwall strata that dip steeply away from the DCF and shallow distally in an apparent display of reverse drag folding. Unrotating the footwall subsidiary fault orientations by restoring the overlying Tar strata to horizontal does not significantly modify the shallow plunges, shallow orientations to the principal DCF plane, or change their sinistral sense of slip.

The DCF sweeps westward into parallelism with the CMF to the southwest near Castle Mountain (figs. 2 and 3A). To the northeast, it rotates about a vertical axis to a north orientation that cuts at a shallow angle to the regional trend of the Jurassic arc (figs. 1 and 2). In an ancillary drainage to the middle fork of Doone Creek, the DCF strikes 189° and west–northwest side up separation places the Jurassic batholith against Tar along a steep (76°) west-dipping plane (fig. 4A). The fault is intruded along its entire exposed length by an intermediate to mafic dike several meters thick of probable Paleogene age (Thi?) that forms a remarkably planar yet weathered overhanging surface up to 2 m wide (figs. 4A and B). A 1–2 m-wide zone of dark, recessively weathered, chippy Tar siltstone separates heavily fractured and blocky weathering hanging-wall Thi? from steeply west–northwest-dipping, weakly structurally dismembered Tar sandstone beds (fig. 4A and 4B). Nearby systematic shear fractures that extend for several meters into the granitic hanging-wall at a high acute angle to the DCF in map view are ornamented by shallowly plunging lineations and secondary shear fractures that indicate dextral slip consistent with antithetic Riedel (R') shears in a sinistral-slip system. However, apparent overturning of Tar strata against the DCF is consistent with footwall coupling during reverse slip and kinematic indicators preserved on the fault surface confirm reverse motion. For instance, steeply plunging mullions and weak slip lineations produce rakes that commonly vary between 67 and 86° and numerous secondary shear fracture intersections with the fault surface demonstrate reverse-dextral motion. At higher elevations to the north–northeast, hanging-wall Tar occupies ridgelines and peaks above a gently south-southeast-dipping Ji erosional surface (fig. 4A and 4C). In the footwall, Tar is unconformable with down dropped Jtk. Vertical separation of the unconformity across the fault varies from about 320 to 465 m, placing limits to the amount of throw along the fault. Preliminary evaluation of the reconnaissance kinematic dataset and map-scale geologic relations suggests that an early episode of sinistral strike slip along the DCF, perhaps prior to erosional beveling, was later overprinted by reverse, west–northwest-side-up motion during or after Tar deposition (fig. 5).

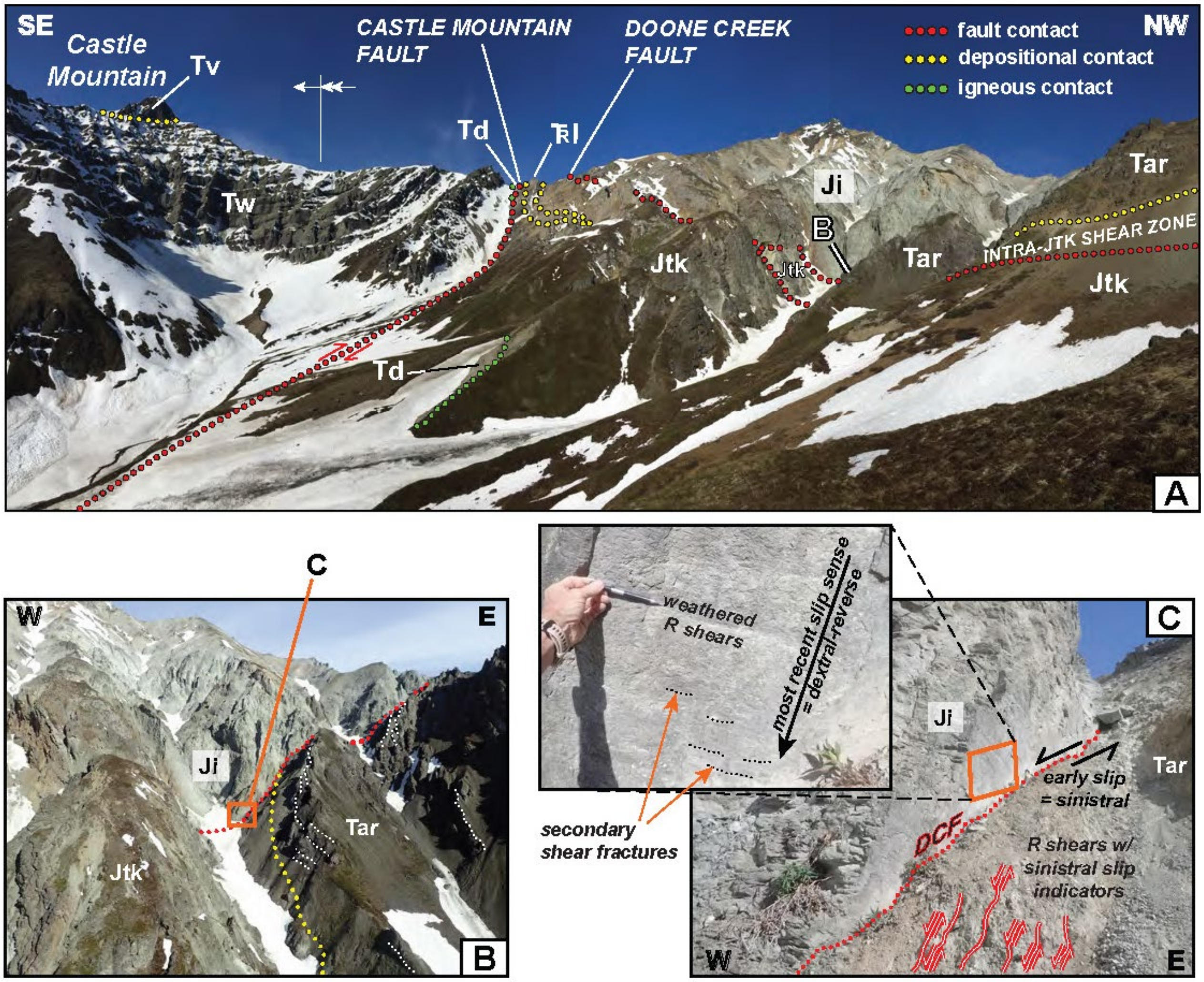


Figure 3. A. Panoramic view looking up the south fork of Doone Creek at the Castle Mountain and Doone Creek faults (CMF and DCF) and intra-Talkeetna Formation (Jtk) brittle shear zone (ITSZ). Paleogene Wishbone Formation (Tw) capped by Eocene volcanic rocks (Tv) is folded into an asymmetrical footwall syncline against the CMF, highlighting its component of reverse slip. The DCF and ITSZ wrap into parallelism with the CMF and may be truncated by it. Arkose Ridge Formation (Tar) appears to locally overlay the ITSZ in the south fork, suggesting the shear zone predates Tar deposition. Examples of a felsic dike (Td) on both sides of the CMF appear to be separated dextrally as mapped by Fuchs (2019), but the contacts are concealed making fault truncation unclear. TRl = undated limestone and marble intercalated with Jtk believed to be correlative to the Upper Triassic Kamishak Formation in the lower Cook Inlet and Chitistone Limestone in the Wrangell Mountains (Winkler, 1992). "B" refers to location of fig. 3B. **B.** Well-exposed example of the Doone Creek fault in the south fork of Doone Creek that places the Talkeetna arc batholith (Ji) against Jtk and Paleogene Arkose Ridge forearc basin strata (Tar). Tar footwall strata dip moderately away from the fault contact and are locally overturned against it, consistent with reverse fault displacement. "C" refers to location of fig. 3C. **C.** A weathered slip surface at the fault contact constrains most recent motion as reverse dip slip, however well-developed footwall synthetic Riedel shears suggest an earlier history of sinistral strike slip.

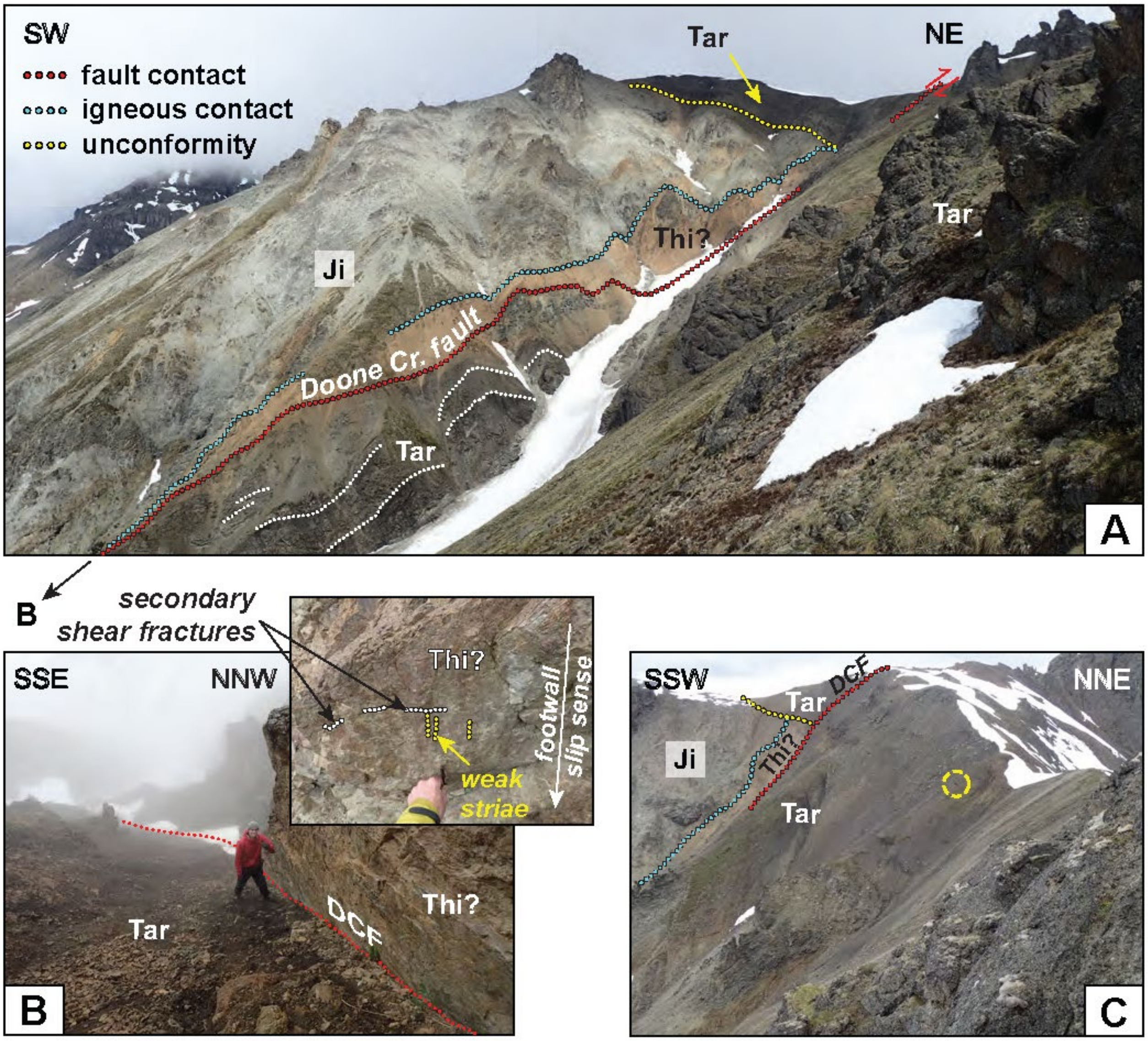


Figure 4. A. Doone Creek fault exposure in the middle fork of Doone Creek where Jurassic plutonic rocks (Ji) are faulted against Paleogene Arkose Ridge Formation (Tar) forearc basin strata in a reverse sense. Tar strata are subvertical in the proximal footwall of the fault (dotted white lines), consistent with drag folding during reverse slip. An undated mafic dike of likely Paleocene age (Thi of Wilson and others, 2012; Tim of Winkler, 1992) intrudes the fault plane, but is too thin to appear on the map. **B.** A large slickenside along the entire length of the dike at the DCF interface is ornamented by numerous subvertical lineations and mullions, indicating DCF slip continued after dike emplacement. Fault plane kinematics ornamenting Thi? (not mapped) constrain most recent slip as reverse (B), but nearby hanging-wall antithetic Riedel shears (not pictured) suggest an earlier phase of sinistral strike slip. **C.** The crosscutting relationship between Thi? and Tar is uncertain, but preliminary observations suggest that Tar rests unconformably over Thi?. If so, then Tar deposition postdated dike emplacement but predated, or was synchronous with DCF slip. Geologists for scale (encompassed in yellow dashed circle).

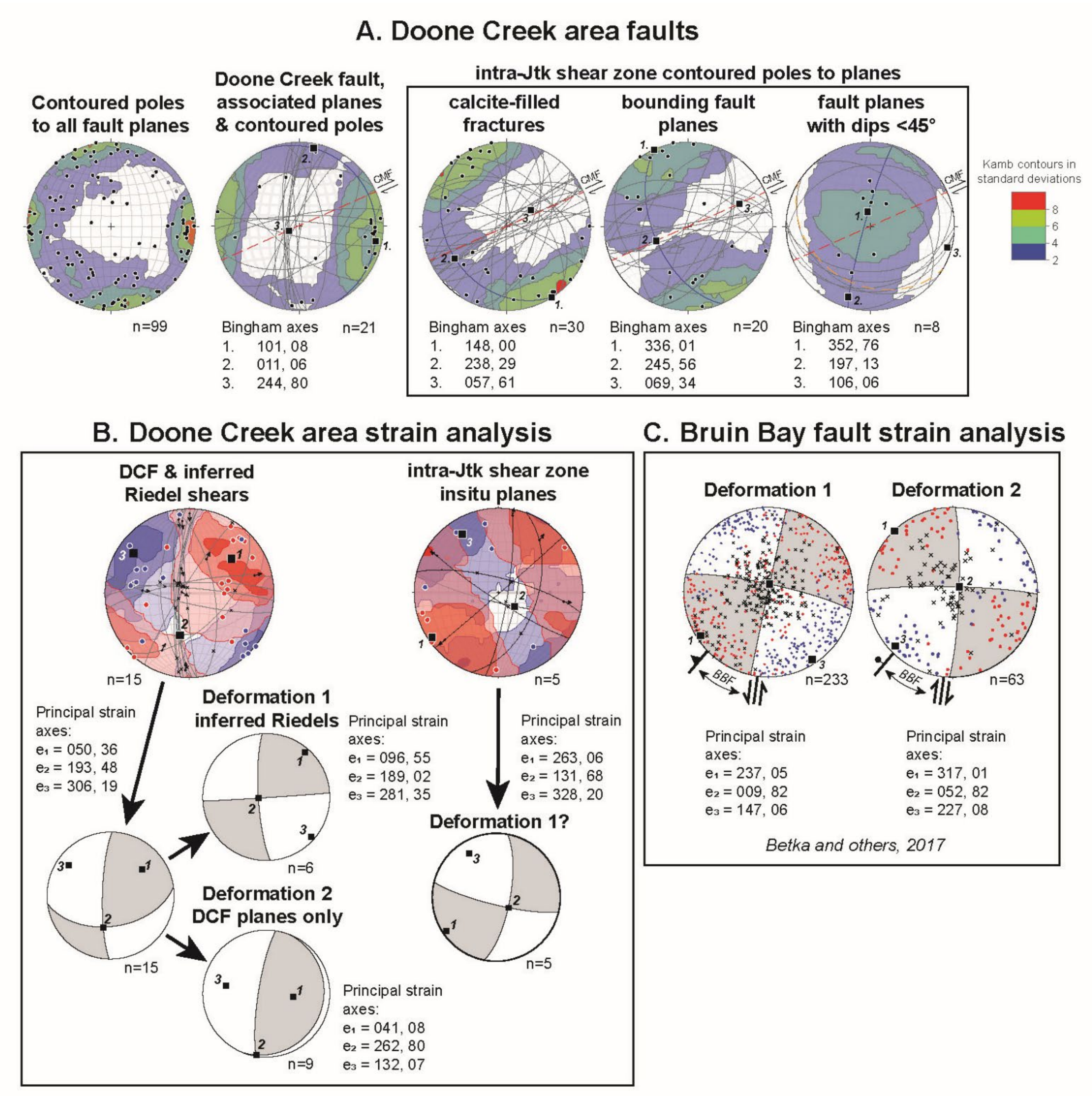


Figure 5. Caption on next page.

Figure 5 (previous page). A. Stereographic representation of Doone Creek area faults plotting Kamb contoured poles to all measured fault planes (black dots), Doone Creek fault (DCF) and associated Riedel shears, and subsets of faults and fractures measured within the intra-Jtk shear zone (ITSZ). Strike orientation of the Castle Mountain fault (CMF) shown as dashed red line for reference. **B.** Strain analysis of the DCF and ITSZ with contoured strain axes. Red dots represent the maximum elongation axis calculated for individual faults. Blue dots represent orthogonal maximum shortening axes. Red and blue fields are Kamb contours of the elongation and shortening axes. Note that maximum elongation axes that plot in fields that favor maximum shortening axes, and vice versa, suggest potential strain incompatibility within the dataset, possibly reflecting multiple deformations. Black arrows indicate the slip vector of individual planes. The numbered squares are the orientations of the Bingham strain axes calculated for the data set (1 = maximum elongation axis, 2 = intermediate strain axis, 3 = maximum shortening axis). Note that the DCF fault set can be divided into dip-slip and strike-slip subsets based chiefly on field relations at the fault contact and are inferred to record two distinct deformations that result in significantly different maximum elongation and intermediate strain axes orientations and fault plane solutions. **C.** Strain analysis of the Bruin Bay fault system (BBFS) along the Cook Inlet basin (Betka and others, 2017). Uncontoured strain axes colors and Bingham orientations the same as in B. Based on slip compatibility/incompatibility, Betka and others (2017) inferred two deformations recorded by BBFS faults. Deformation #1 is characterized by northeast and southwest elongation and northwest and southeast contraction (C) that is practically identical to Doone Creek area deformation #1 orientations (B), whereas deformation #2 axes differ between the two faults systems (B and C), perhaps suggesting earlier deformation in a common stress field and later deformation under different states of stress. Stereonet analysis plots by Stereonet 11 (Allmendinger and others, 2012; Cardozo and Allmendinger, 2013). Kinematic analysis and plots by FaultKin 10 (Marrett and Allmendinger, 1990; Allmendinger and others, 2012).

INTRA-TALKEETNA FORMATION SHEAR ZONE (ITSZ)

A previously unmapped subvertical brittle shear zone (ITSZ) restricted to the downthrown Jtk block of the DCF trends northeastward from the south fork of Doone Creek across the middle fork into the north fork and beyond the study area boundary. It merges with (or is truncated by) the DCF at its southwestern limit in the south fork where it parallels the CMF (fig. 2). The ITSZ deviates from the CMF orientation to a more northeastward trend approaching the middle fork and varies in width from 10's of meters near its intersection with the DCF to approximately 200 m in middle fork outcrops (fig. 6A). The shear zone weathers a distinctive pale green owing to a dense network of subvertical calcite-filled fractures commonly 1 mm to 1 cm thick which obliterates all volcanic textures and bedding (fig. 6B). The calcite-filled fractures are often mutually cross-cutting and vary in strike, but most commonly trend northeast at approximately 60° azimuth (fig. 5A). Orientations of steep outcrop-scale faults that separate relatively coherent rock from zones of intense distributed brittle shear are more variable, but also favor northeast trends (fig. 5A). The ITSZ slip sense is uncertain due mainly to poor preservation of slip surfaces in the highly deformed domains and on their boundary faults. However, the few surfaces that preserved kinematic indicators (n=5) suggest sinistral strike slip on northeast-trending planes (fig. 5B). Shallow-dipping faults are rare but commonly trend east–west and infrequently cut steep faults that bound zones of distributed shear (fig. 5A). The apparent southwestward narrowing of the ITSZ is due in part to Quaternary cover that obscures portions of the zone, but also to Tar that is locally deposited over the shear zone in the south fork of Doone Creek and perhaps tectonic removal by the DCF where it converges with the CMF.

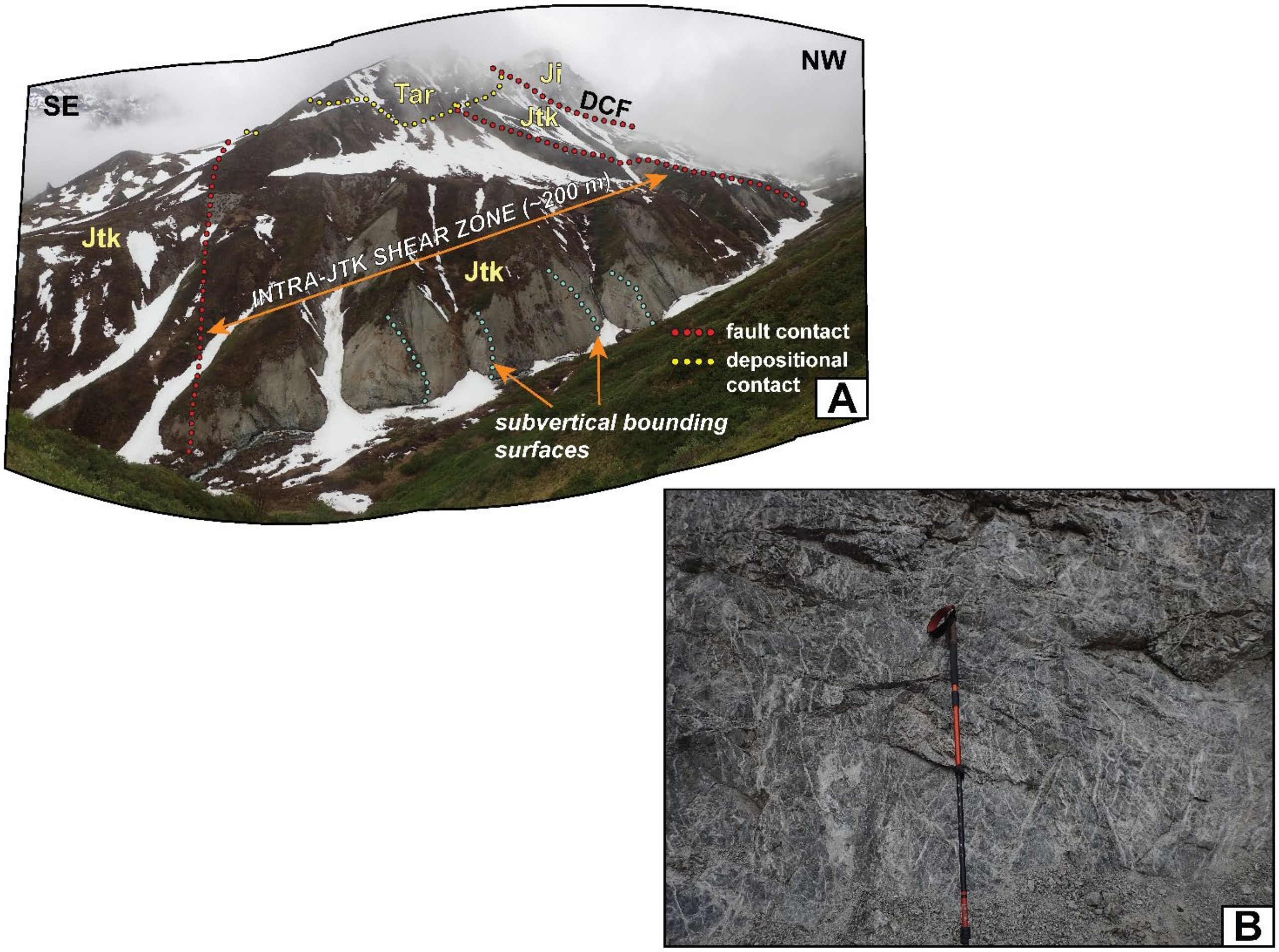


Figure 6. A. View looking southwest of the intra-Talkeetna Formation (Jtk) shear zone (ITSZ) in the middle fork of Doone Creek. The approximately 200-m-wide zone contains pervasively deformed bands of volcanic rocks several meters to 10s of meters wide separated by less deformed intervals commonly bounded by northeast-trending subvertical planes (fig. 5A). **B.** The intensely deformed bands consist of dense, high-angle mutually cross cutting calcite veins typically 1-mm to1-cm thick that produce a wide variety of strike orientations but most commonly trend to the northeast (fig. 5A). The dense calcite veins (B) concentrated between the subvertical bounding surfaces render a characteristic pale green hue to highly deformed outcrops that differentiate them from less deformed Jtk exposed elsewhere in the map area (A). Paleogene Arkose Ridge Formation (Tar) depositionally overlays parts of the shear zone in the middle fork (A), provisionally suggesting that most motion along the zone predates Tar deposition in the area.

STUDY AREA FOLDS

Anticlines and synclines that deform Cenozoic strata constitute the majority of mappable folds in the area (fig. 2). Potential folding of Talkeetna volcanic and volcaniclastic successions is difficult to ascertain due to their weak to absent stratification and ubiquitous fracturing, however map relations tentatively suggest that the unconformity beneath Cenozoic strata northwest of the CMF is also folded. Except for footwall synclines mapped directly against the DCF and partial exposure of a gentle roll-over anticline in the proximal upthrown block of the CMF in Jtk, most folds in the study area were identified and mapped from vantage points on adjacent ridges and extended beyond sight lines using satellite imagery. All folds in the study area belong to one of two families—

northeast- to east-trending folds associated with slip on the CMF (figs. 2 and 3A), and north- and north–northeast-trending folds associated with the DCF and adjacent unmapped north–northeast-trending faults (fig. 2), respectively. Paleocene Tw strata define a well-expressed mountain-scale footwall syncline against the CMF at Castle Mountain, where its backlimb is folded sub-vertically against the fault plane and its shallow northwest-dipping forelimb constrain a moderately northwest-dipping axial surface. Most Cenozoic folds in the study area trend northeast at a shallow angle to the DCF and constitute an understudied structural domain whose orientation approximates the Jurassic batholith margin. Displacement on the DCF decays north–northeastward into a 1 km wavelength, southeast vergent, open anticline-syncline pair with steep west–northwestward dipping axial planes (fig. 2). The northwest dip of the syncline forelimb is likely controlled by an unmapped fault(s) in Jtk to the east. A northwest-directed reverse fault mapped across a ridge southwest of the middle fork of Doone Creek may fold Tar into a syncline preserved as a thin ribbon along a ridgeline at the creek's headwaters (e.g., Winkler, 1992) (fig. 2).

TIMING OF DEFORMATION IN THE DOONE CREEK AREA

Geologic relations suggest that faulting and folding in the Doone Creek area are mainly Cenozoic, although there may have been an earlier episode of deformation in Jtk recorded as overprinted shear indicators along the DCF and Tar that locally drapes the ITSZ. Deformed Holocene deposits along the CMF approximately 75 km to the southwest of the study area in the southeastern Susitna lowlands (e.g., Koehler and others, 2012), and a 5.7 M_b earthquake centered on the CMF near the town of Sutton in 1984 (Lahr and others, 1986) approximately 25 km southwest of the study area indicate the fault remains locally active. Detterman and others (1976) highlighted features along the CMF between the Kings and Chickaloon rivers that potentially record recent dextral offset including a possible scarp, offset stream, and most notably, a 2-km deflection of the Chickaloon River they attribute to dextral slip. However, no deformed Quaternary to modern surface deposits were observed along the CMF trace in the south fork of Doone Creek during this study or detailed mapping by Fuchs (2019). Therefore, the most recent motion in this area is only constrained to late Paleocene–Eocene based on truncated and folded Tc and Tw in the downthrown block of the CMF (Trop and others, 2003). Similarly, the earliest reverse motion on the DCF leading to vertical separation of a study area-wide unconformity and east–southeast-directed shortening is constrained by the age of Tar at ca. 60–55 Ma (Idleman and others, 2011; Sunderlin and others, 2014), although it is feasible that sinistral strike slip along the fault occurred prior to development of the unconformity. The apparent absence of offset alluvial aprons or stream deposits in the middle fork of Doone Creek across which the DCF projects suggests that DCF activity ceased prior to the Quaternary. Deformation along the ITSZ is less well constrained, however Tar is locally deposited on top of the shear zone, suggesting that much of its slip was complete by approximately 60–55 Ma. Additionally, the DCF appears to truncate the ITSZ where they converge near Castle Mountain, implying that the shear zone may be a Mesozoic feature and not kinematically linked to CMF or DCF slip during the Cenozoic.

SUMMARY

Geologic mapping, cross-cutting relations, and fault kinematic data define three major structural domains in the Doone Creek area between the Kings and Chickaloon rivers that record two or more deformational events. Domain one is defined by sub-vertical east–northeast- and east-trending dextral-reverse structures characterized by the CMF, the prominent CMF footwall syncline, and its subtle hanging-wall anticline. Domain two includes the sub-vertical north–northeast-trending Doone Creek reverse fault, its associated anticline and syncline, smaller reverse faults to the west that offset the Arkose Ridge unconformity, and a potential subparallel syncline to the northeast. Domain three is represented by the sub-vertical ITSZ that strikes northeast sub-parallel to the CMF but swings to a trend intermediate to the CMF and DCF to the northeast. Domain one cuts obliquely across the Jurassic arc at a high angle, elevating the dominantly crystalline rocks of the arc complex against Late Cretaceous and Paleogene forearc basin strata. Domain two is aligned sub-parallel to the margin of Jurassic arc and largely elevates the arc plutonic rocks against their volcanic edifice and the Paleogene forearc basin. Deformation of domain one and two may be partially or largely coeval, as both cut similar age rocks. However, along strike to the southwest, domain one deformation appears to post-date domain two activity. Domain three deformation appears to be mainly Mesozoic but may have continued into early Eocene. A potential fourth, poorly expressed domain is defined by broadly east–west-trending low-angle faults mainly confined within the ITSZ. It is important to note that Fuchs (2019) also recognized localized zones of intensely deformed Jtk in the middle fork of Doone Creek but attributed them to low-angle thrusting, rather than subvertical shear. Our observations are that all low-angle faults are relatively minor features that appear to post-date vertical shear.

We provisionally propose that the newly identified Doone Creek structures represent previously unmapped examples of the distal, lower-slip, northern reaches of the BBFS exposed along the Cook Inlet to the southwest (fig. 1A). Like the DCF and associated structures, the southwest- to south–southwest-striking BBFS separates mainly Jurassic arc granitoids from Jtk arc volcanic rocks and the Jurassic forearc basin (Magoon and others, 1976; fig. 1A). The arc–forearc complex and BBFS continue for nearly 500 km from the upper Alaska Peninsula northeastward to upper Cook Inlet, where they are inferred to have been truncated and offset right laterally as much as 130 km since the Late Jurassic based on the apparent separation of the entire arc–forearc system across the CMF (fig. 1A) (Grantz, 1965; Detterman and others, 1976; Hackett, 1976; Trop and others, 2005; Gillis and others, 2022).

Although the small reconnaissance kinematic dataset collected for the DCF may warrant future modification of the fault's slip history as additional data are collected, preliminary results suggest that the DCF and the BBFS each record an early phase of sinistral strike slip on south–southwest-striking planes during northwest shortening (e.g., Betka and others, 2017) (fig. 5). Elsewhere in southern Alaska, sinistral slip faults are rare. Both fault systems were subsequently reactivated by a second, but different, deformation (e.g., Betka and others, 2017) with shortening and extension axes orientations that differ between the systems, implying that their slip histories diverged after phase I deformation (fig. 5). Since both the DCF and the ITSZ wrap into parallelism with the CMF, they either formed prior to (then were subsequently cut by) the CMF or the fault systems were co-genetic. If the former scenario occurred, then the divergent slip histories between the DCF and BBFS could mark the point at which their states of stress became decoupled.

Finally, geologic map relations suggests that vertical and horizontal displacement along the BBFS decreases northeastward. Vertical separation on the BBFS decreases from approximately 5 km across its main strand in lower Cook Inlet to an estimated 1 km or less in the Trading Bay area of upper Cook Inlet (fig 1B) (Detterman and Hartsock, 1966; Shellenbaum and others, 2010). Likewise, estimates of lateral offset vary from 19 to 65 km in lower Cook Inlet (Detterman and Hartsock, 1966; Detterman and Reed, 1980) to negligible offset near Trading Bay based on coarsely mapped contacts cut by the BBFS (Magoon and others, 1976; Gregersen and Shellenbaum, 2016) implying a net loss of vertical and lateral slip approaching the CMF. Much of the Talkeetna Mountains lacks detailed geologic mapping, however unnamed and unstudied fault segments mapped between the Kings and Chickaloon rivers at 1:250,000 scale by Csejtey and others (1978) (fig 1B) define a 4.5-km-wide zone of northeast- and north–northeast-trending structures that include the DCF. The elevation of the Tar unconformity estimated from reconnaissance geologic mapping (Kortyna and others, 2013) and satellite imagery across the width of the zone suggests 850 m or more of net down-to-east–southeast separation. Thus, the magnitude of structural relief appears to be commensurate with the estimated value across the BBFS in upper Cook Inlet near its point of truncation by the CMF but distributed over several strands in the Talkeetna Mountains—a characteristic commonly observed near fault and fault system termini (e.g., McGrath and Davison, 1995). However, resolving the nature and significance of faults that deform the Jurassic arc–forearc margin in the Talkeetna Mountains will require additional detailed geologic mapping and a more robust kinematic dataset.

ACKNOWLEDGMENTS

We thank Eric and Corrie Feige for generously allowing us access to their property for helicopter deployment to the field location. Soloy Helicopters deployed and demobilized our camp near Castle Mountain. This project was funded by State of Alaska In-State Gas Phase 2 and 3 Capital Improvement Projects and Geological Society of America Northeastern Section student grant (to Leo Kuyl). A technical review by Travis Naibert improved the clarity of the paper.

REFERENCES

Allmendinger, R.W., Cardozo, Nestor, and Fisher, D.M., 2012, Structural Geology Algorithms: Vectors and Tensors in Structural Geology: Cambridge University Press, 32 Avenue of the Americas, New York, NY 10013, USA, pp. 289.

Betka, P.M., Gillis, R.J., and Benowitz, J.A., 2017, Cenozoic sinistral transpression and polyphase slip within the Bruin Bay fault system, Iniskin–Tuxedni region, Cook Inlet, Alaska: Geosphere, v. 13, no. 6, p. 1–28. https://doi.org/10.1130/GES01464.1

Bruhn, R.L., and Pavlis, T.L., 1981, Late Cenozoic deformation in the Matanuska Valley, Alaska: Three-dimensional strain in a forearc region: Geological Society of America Bulletin, v. 92, p. 282–293. https://doi.org/10.1130/0016-7606(1981)92<282:LCDITM>2.0.CO;2

Cardozo, Nestor, and Allmendinger, R.W., 2013, Spherical projections with OSXStereonet: Computers & Geosciences, v. 51, p. 193–205. https://doi.org/10.1016/j.cageo.2012.07.021

Csejtey, Bela, Jr., Nelson, W.H., Jones, D.L., Silberling, N.J., Dean, R.M., Morris, M.S., Lanphere, M.A., Smith, J.G., and Silberman, M.L., 1978, Reconnaissance geologic map and geochronology, Talkeetna Mountains Quadrangle, northern part of Anchorage Quadrangle, and southwest corner of Healy Quadrangle, Alaska: U.S. Geological Survey Open-File Report 78-558-A, 60 p., 1 sheet, scale 1:250,000.

Decker, P.L., Reifenstuhl, A.E., and Gillis, R.J., 2008, Structural linkage of major tectonic elements in the Ugashik-Becharof Lakes region, northeastern Alaska Peninsula, *in* Reifenstuhl, R.R., and Decker, P.L., eds., Bristol Bay-Alaska Peninsula region, overview of 2004-2007 geologic research: Alaska Division of Geological & Geophysical Surveys Report of Investigation 2008-1F, p. 85–103, 1 sheet. https://doi.org/10.14509/17946.

Detterman, R.L., and Hartsock J.K., 1966, Geology of the Iniskin–Tuxedni Peninsula region, Alaska: U.S. Geological Survey Professional Paper 512, 78 p., 7 plates.

Detterman, R.L., Plafker, George, Hudson, Travis, Tysdal, R.G., Pavoni, Nazario, and Weber, F.R., 1974, Surface geology and Holocene breaks along the Susitna segment of the Castle Mountain Fault, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map 618, 1 sheet, scale 1:24,000.

Detterman, R.L., Plafker, George, Tysdal, R.G., and Hudson, Travis, 1976, Geology and surface features along part of the Talkeetna segment of the Castle Mountain-Caribou fault system, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map 738, 1 sheet, scale 1:63,360.

Detterman, R.L., and Reed, B.L., 1980, Stratigraphy, structure, and economic geology of the Iliamna Quadrangle, Alaska: U.S. Geological Survey Bulletin 1368-B, 86 p., scale 1:250,000, 1 plate.

Fuchs, W.A., 1980, Tertiary tectonic history of the Castle Mountain-Caribou fault system in the Talkeetna Mountains, Alaska: University of Utah, Salt Lake City, Ph.D. dissertation, 162 p., illustrated. (some color), maps.

———2019, Geologic map of the Castle Mountain–Caribou fault system, Talkeetna Mountains, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2017-2, 57 p., 2 sheets, scale 1:24,000. https://doi.org/10.14509/29715

Gillis, R.J., LePain, D.L., Herriott, T.M., Wartes, M.A., Decker, P.L., Shellenbaum, D.P., Benowitz, J.A., and O'Sullivan, P.B., 2017, Results of 1:63,360-scale geologic mapping and related field studies in the south-central Tyonek Quadrangle, Alaska: Late Paleocene?-middle Eocene transtension and post-Oligocene inversion on the northwest periphery of the Cook Inlet forearc basin (poster): American Association of Petroleum Geologists Cordilleran Section Meeting, May 22-24, Anchorage, Alaska.: Alaska Division of Geological & Geophysical Surveys, 1 sheet. https://doi.org/10.14509/30139.

Gillis, R.J., Wartes, M.A., Herriott, T.M., LePain, D.L., Benowitz, J.A., Wypych, Alicja, Donelick, R.A., O'Sullivan, P.B., and Layer, P.W., 2022, ^{40}Ar/^{39}Ar and U-Pb geochronology of Cretaceous-Paleocene igneous rocks and Cenozoic strata of northwestern Cook Inlet, Alaska: Linkages between arc magmatism, cooling, faulting, and forearc subsidence: Alaska Division of Geological & Geophysical Surveys Professional Report 125 v. 1.1, 78 p. https://doi.org/10.14509/30554.

Grantz, Arthur, 1965, Geologic map and cross-sections of the Nelchina area, south-central Alaska: U.S. Geological Survey Open-File Report 65-65, scale 1:63,360, 4 sheets.

Gregersen, L.S., and Shellenbaum, D.P., 2016, Top Mesozoic unconformity subcrop map, Cook Inlet basin, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigation 2016-4, 1 sheet, scale 1:500,000. https://doi.org/10.14509/29658

Hacker, B.R., Kelemen, P.B., Rioux, Matthew, McWilliams, M.O., Gans, P.B., Reiners, P.W., Layer, P.W., Söderlund, Ulf, and Vervoort, J.D., 2011, Thermochronology of the Talkeetna intraoceanic arc of Alaska: Ar/Ar, U-Th/He, Sm-Nd, and Lu-Hf dating: Tectonics, v. 30, no. 1. https://doi.org/10.1029/2010TC002798

Hackett, S.W., 1976, Speculative tectonic evolution of the Cenozoic Shelikof Trough, south-central Alaska, in Alaska Division of Geological & Geophysical Surveys, Short notes on Alaskan geology - 1976: Alaska Division of Geological & Geophysical Surveys Geologic Report 51D, p. 13–17. https://doi.org/10.14509/383

Haeussler, P.J., Best, T.C., and Waythomas, C.F., 2002, Paleoseismology at high latitudes: Seismic disturbance of upper Quaternary deposits along the Castle Mountain fault near Houston, Alaska: Geological Society of America Bulletin, v. 114, p. 1,296–1,310.

Idleman, Bruce, Trop, J.M., and Ridgway, K.D., 2011, Geochronological evidence for rapid forearc subsidence and sedimentation during Paleogene spreading ridge subduction along the southern Alaska convergent margin: Geological Society of America, Abstracts with Programs, v. 43, p. 439.

Koehler, R.D., Reger, R.D., and Frohman, R.A., 2012, The Castle Mountain fault, south-central Alaska: New lidar-based observations on the sense of slip, Eos Trans. American Geophysical Union, Fall Meeting. Supplimental, Abstract #S53D-2530: Alaska Division of Geological & Geophysical Surveys, 1 p., 1 sheet. https://doi.org/10.14509/24724.

Kortyna, C., Donaghy, E., Trop, J.M., and Idleman, B., 2013, Provenance signature of a forearc basin modified by spreading ridge subduction: detrital zircon geochronology and detrital modes from the Paleogene Arkose Ridge Formation, southern Alaska: Basin Research, v. 25, p. 1–25. https://doi.org/10.1111/bre.12033

Kuyl, L., Trop, J., Gillis, R., and O'Sullivan, P., 2023, U-Pb detrital zircon geochronology of Paleogene forearc basin strata in south-central Alaska: sediment routing and provenance in a terrestrial forearc basin: Geological

Society of America Southeastern and Northeastern Joint Section Meeting, March 15–20, Reston, VA, *Abstracts with Programs*, v. 55, n. 2, doi: 10.1130/abs/2023SE-385561.

Lahr, J.C., Page, R.A., Stephens, C.D., and Fogleman, K.A., 1986, Sutton, Alaska, earthquake of 1984: evidence for activity on the Talkeetna segment of the Castle Mountain fault system: Bulletin of the Seismological Society of America, v. 76, p. 967–983.

Little, T.A., 1990, Kinematics of wrench and divergent-wrench deformation along a central part of the Border Ranges Fault System, Northern Chugach Mountains, Alaska: Tectonics, v. 9, no. 4, p. 585–611.

Magoon, L.B., Adkison, W.L., and Egbert, R.M., 1976, Map showing geology, wildcat wells, Tertiary plant fossil localities, K-Ar age dates, and petroleum operations, Cook Inlet area, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map 1019, 3 sheets, scale 1:250,000.

Marrett, R.A., and Allmendinger, R.W., 1990, Kinematic analysis of fault-slip data: Journal of Structural Geology, v. 12, p. 973–986.

McGrath, A.G., and Davison, Ian, 1995, Damage zone geometry around fault tips: Journal of Structural Geology, v. 17, no. 7, p. 1,011–1,024.

Shellenbaum, D.P., Gregersen, L.S., and Delaney, P.R., 2010, Top Mesozoic unconformity depth map of the Cook Inlet basin, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigation 2010-2, 1 sheet, scale 1:500,000. https://doi.org/10.14509/21961

Sunderlin, David, Trop, J.M., Idleman, B.D., Brannick, Alexandria, White, J.G., and Grande, Lance, 2014, Paleoenvironment and paleoecology of a late Paleocene high-latitude terrestrial succession, Arkose Ridge Formation at Box Canyon, southern Talkeetna Mountains, Alaska: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 401, p. 57–80. https://doi.org/10.1016/j.palaeo.2014.02.012

Terhune, P.J., Benowitz, J.A., Trop, J.M, O'Sullivan, Paul, Gillis, R.J., and Freymueller, J.T., 2019, Cenozoic tectono-thermal history of the southern Talkeetna Mountains, Alaska: Multiple topographic development drivers through time: Geosphere, v. 15, no. 5, p. 1,539–1,576.

Trop, J.M., Ridgway, K.D., and Spell, T.L., 2003, Sedimentary record of transpressional tectonics and ridge subduction in the Tertiary Matanuska Valley–Talkeetna Mountains forearc basin, southern Alaska, *in* Sisson, V.B., Roeske, S.M., and Pavlis, T.L., eds., Geology of a transpressional orogen developed during ridge-trench interaction along the north Pacific margin: Geological Society of America Special Paper 371, p. 89–118.

Trop, J.M., Szuch, D.A., Rioux, Matthew, and Blodgett, R.B., 2005, Sedimentology and provenance of the Upper Jurassic Naknek Formation, Talkeetna Mountains, Alaska: Bearings on the accretionary tectonic history of the Wrangellia composite terrane: Geological Society of America Bulletin, v. 117, p. 570–588. https://doi.org/10.1130/B25575.1

Wilson, F.H., Hults, C.P., Schmoll, H.R., Haeussler, P.J., Schmidt, J.M., Yehle, L.A., and Labay, K.A., comps., 2012, Geologic map of the Cook Inlet region, Alaska, including parts of the Talkeetna, Talkeetna Mountains, Tyonek, Anchorage, Lake Clark, Kenai, Seward, Iliamna, Seldovia, Mount Katmai, and Afognak 1:250,000-scale quadrangles: U.S. Geological Survey Scientific Investigations Map 3153, 76 p., 2 sheets, scale 1:250,000.

Winkler, G.R., 1992, Geologic map and summary geochronology of the Anchorage 1° × 3° quadrangle, southern Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-2283, scale 1:250,000.