Kinematic Analysis from Tectonites in the Northern Part of the Big Delta Quadrangle, East-Central Alaska

By Douglas H. Oliver and Cynthia Dusel-Bacon

Abstract

New structural analysis has helped define a polyphase deformation history in ductilely deformed tectonites between the Chena and Salcha Rivers in the Yukon-Tanana Upland of east-central Alaska. The sedimentary, intrusive, and volcanic protoliths have been metamorphosed and subjected to partitioned noncoaxial shearing. We have integrated kinematic indicators from outcrop motion-plane views and oriented thin sections with nine quartz *c*-axis fabric analyses. Top-to-the-northwest, top-to-the-southeast, and local top-to-the-southwest shear senses that are preserved are the products of discrete deformation events. In other parts of the Yukon-Tanana Upland, the top-to-the-northwest and top-to-the-southeast fabrics previously were suggested to have resulted from Early Jurassic crustal contraction and mid-Cretaceous extension, respectively. The West Point orthogneiss, which occurs in the core of a high-grade igneous-metamorphic complex in the northeastern part of the Big Delta quadrangle, may have been exhumed during the mid-Cretaceous deformational event, but the top-to-the-southwest fabrics contained in the structurally low carbonaceous unit remain problematic. Unusual tectonites containing multiple quartz lattice-preferred-orientation domains provide additional evidence of polyphase deformation. Quartz *c*-axis fabric analysis on a domain-by-domain basis suggests that the analyzed fabric resulted from partial overprinting during strain-partitioned ductile shearing.

Introduction

The metamorphic rocks of the Yukon-Tanana Upland reflect a complex deformational and metamorphic history. These rocks, generally referred to as the Yukon-Tanana terrane, compose the largest tectonostratigraphic terrane in the northern Cordillera. They are fault bounded along most of their length by the right-lateral Tintina and Denali Fault systems on the northeast and southwest, respectively. This polygenetic terrane has been subdivided on the basis of differences in the composition and age of protoliths and the structural and metamorphic histories of its components (for example, Foster and others, 1985, 1994; Nokleberg and others, 1989; Hansen and others, 1991; Dusel-Bacon and Cooper, 1999). Previous kinematic and geochronologic studies have delineated the following three major deformational events across the Yukon-Tanana terrane from the United States-Canadian border to Fairbanks, Alaska (Hansen and others, 1991; Pavlis and others, 1993; Hansen and Dusel-Bacon, 1998; Day and others, 2000; Dusel-Bacon and others, 2002): (1) pre-latest Triassic, northeastward-directed, margin-normal contraction of the structurally high level oceanic Seventymile terrane and structurally high level marginal-basin assemblages of the Yukon-Tanana terrane (the Taylor Mountain assemblage of Hansen and Dusel-Bacon, 1998—recently renamed the Fortymile River assemblage by Dusel-Bacon and others, 2002—and the Nisutlin assemblage of Hansen and Dusel-Bacon, 1998) during west-dipping subduction and closure of the Anvil ocean; (2) Early Jurassic, northwestward-directed, inferred margin-parallel contraction and imbrication that resulted in emplacement of the structurally high, outboard assemblages onto parautochthonous continental-margin rocks of the ancient Pacific margin, including the Lake George assemblage of Dusel-Bacon and Cooper (1999) (previously referred to as the Lake George subterrane of the Yukon-Tanana terrane by Pavlis and others, 1993); and (3) Early Cretaceous southeastward-directed crustal extension that resulted in exposure of the structurally deepest, parautochthonous continental-margin rocks of the Lake George assemblage.

This chapter presents new kinematic data from a study area between the Chena and Salcha Rivers in the northern part of the Big Delta quadrangle (fig. 1). The data were collected during a topical study by Dusel-Bacon and others (1998) of the framework geology and syngenetic base-metal potential of greenschist-facies carbonaceous rocks correlated by Dusel-Bacon and others (1998) with the Nasina assemblage of Wheeler and McFeely (1991), and of a unit of quartz-chlorite-muscovite semischist and associated metasedimentary rocks, marble, and greenstone that was formerly referred to as the Butte subterrane of the Yukon-Tanana terrane by Pavlis and others (1993) hereinafter referred to as the Butte assemblage. We also collected kinematic data in the amphibolite-facies metaigneous and metamorphic rocks of the West Point area to compare the deformational and thermal history of this area with that of the sillimanite-bearing Salcha River gneiss dome (terminology of Dusel-Bacon and others, 2002) to the southeast (fig. 1). U-Pb zircon and $^{40}Ar/^{39}Ar$ mica data relating to those high-grade areas are presented by Dusel-Bacon, Wooden, and Layer (this volume).

Previous Studies in the Chena-Salcha Rivers Area

A detailed reconnaissance map of the study area (fig. 1) was originally made by Weber and others (1978). Subsequent petrologic and field studies defined a sillimanite gneiss dome that structurally underlies the surrounding greenschist-facies rocks in an area that straddles the Salcha River (Dusel-Bacon and Foster, 1983). Later kinematic analysis of the structural contact between the greenschist-facies rocks and the Salcha River gneiss dome revealed the contact to be a folded low-angle extensional detachment that formed during east-southeastward-directed crustal extension (Pavlis and others, 1993). Detailed mapping in the upper Chena River area by Smith and others (1994) formally defined the West Point Complex—a topographically high area of upper amphibolite-facies metamorphic rocks that were intruded by abundant premetamorphic and postmetamorphic felsic to intermediate-composition igneous rocks. Smith and others (1994) interpreted this complex to be gradational into the adjacent unit that forms the lowest unit of a stratigraphic and decreasing metamorphic-grade sequence (from bottom to top) of (1) quartzite-dominant basement rocks (Fairbanks schist unit of Robinson and others, 1990); (2) primarily metavolcanic rocks, marble, augen gneiss, and pelitic schist (Chena River sequence of Smith and others, 1994); (3) calcareous schist and phyllite (Dan Creek unit of Smith and others, 1994); (4) carbonaceous rocks (Nasina assemblage, fig. 1; Blackshell unit of Smith and others, 1994); and (5) phyllite, semischist, and marble (Butte assemblage). Smith and others correlated their Blackshell unit and the overlying Butte assemblage with the Keevy Peak Formation and the Totatlanika Schist, respectively, in the Alaska Range (Wahrhaftig, 1968, 1970).

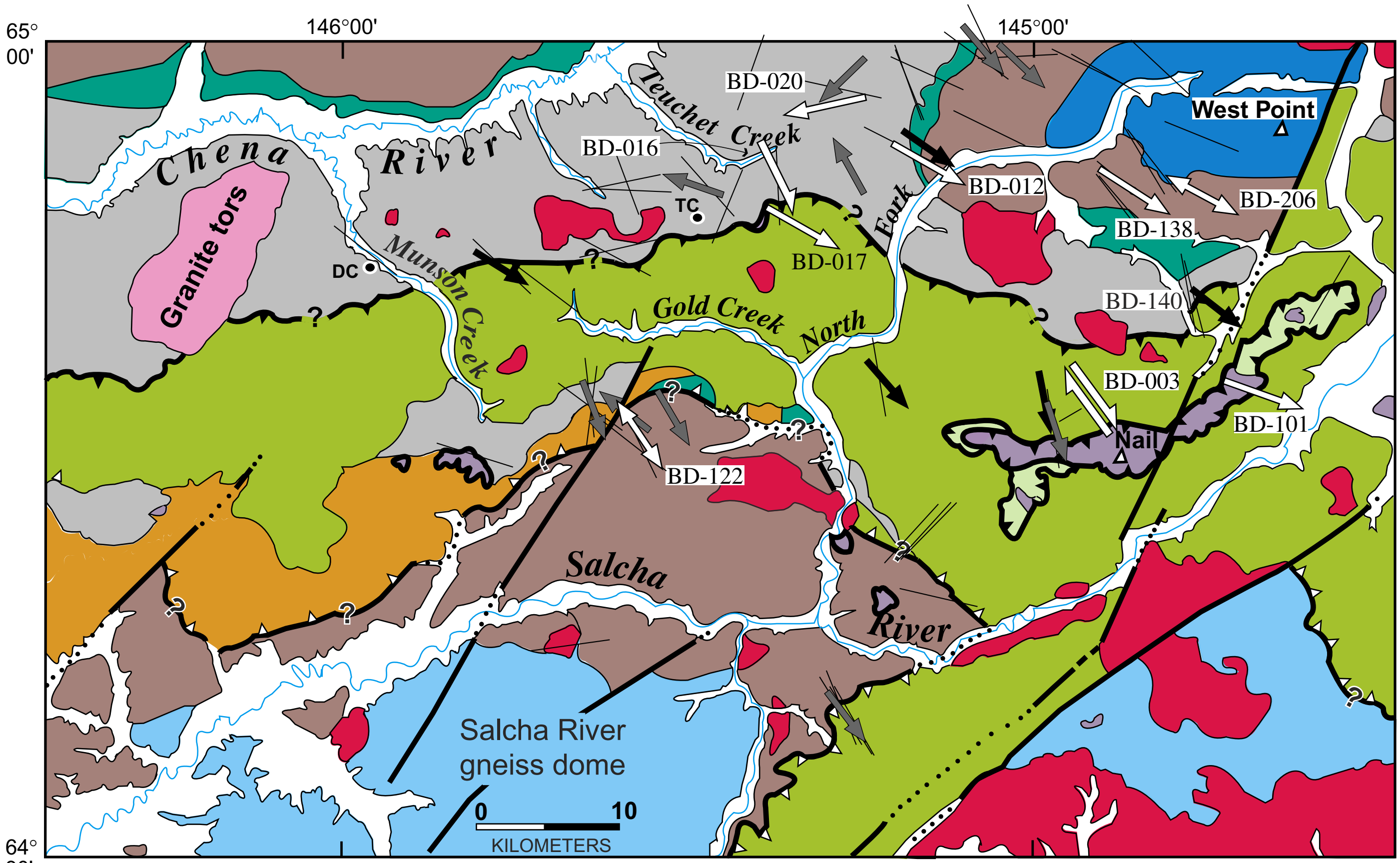
Throughout the study area (fig. 1), contacts between the various assemblages are not exposed and generally occur in saddles. Results from diamond drilling within the carbonaceous Nasina assemblage in the Teuchet Creek and Munson Creek areas (fig. 1) revealed that the contacts of major lithologic variations within this assemblage are strongly sheared and, in places, are the locus of quartz veining, suggesting some degree of structural modification or even structural emplacement. Drilling within the carbonaceous rocks further revealed that foliation, lithologic contacts, and sulfide bodies all approximately parallel one another at a gentle dip of approximately 20° S. (J.R. Bressler, oral commun., 2002). The contact between the greenschist-facies Butte and Nasina assemblages was interpreted by Foster (1992) and Smith and others (1994) to be a low-angle thrust fault, though not on the basis of any structural data, and so the low-angle fault may, instead, be an extensional detachment. Although an actual fault contact between these units is rarely visible in the field, the best evidence for it is the presence of a sliver of ultramafic rock along the contact, just east of the most highly mineralized sulfide section penetrated during drilling (TC, fig. 1), suggesting structural interleaving of an oceanic rock type between two different continental-margin assemblages.

Deformational History of Tectonites of the Chena-Salcha Rivers Area

The deformed phyllite, schist, and gneiss (tectonites) of the Chena-Salcha Rivers area preserve a complex and poorly understood structural history. As elsewhere in the Yukon-Tanana composite terrane (Pavlis and others, 1993; Hansen and Dusel-Bacon, 1998), rocks in the study area (fig. 1) have undergone multiple episodes of ductile and brittle deformation, metamorphism, and, locally, thermal reheating related to Cretaceous and (or) Tertiary igneous activity. The style of deformation within the various greenschist- and amphibolite-facies units is broadly similar, consisting of flat-lying to gently dipping foliation, locally developed elongation lineation, centimeter- to meter-scale folds, and crenulations and spaced cleavage in the lower-grade rocks. Given the sparse outcrop exposure in the study area and its geologic complexity, an indepth understanding of the deformational history will require more detailed study.

Although the rocks in the study area (fig. 1) show evidence of brittle deformation, this chapter focuses on the ductile-deformational history that largely preceded it. Textures of sedimentary, intrusive, and volcanic protoliths are preserved in some of the greenschist-facies rocks, although primary bedding (S_0) is not commonly observed. Relic protolith textures are less common in the higher-grade amphibolite-facies rocks that make up the West Point Complex and the Salcha River gneiss dome in the northeastern and southwestern parts of the study area, respectively. Most tectonites display a penetrative ductile foliation (S_1) consisting of flattened, commonly elongate, recrystallized and (or) comminuted mineral grains. The intensity of tectonite fabric formation varies significantly both across the study area and within individual outcrops, largely as a result of strain partitioning, as evidenced by the discrete bands of mylonite found in many outcrops across the study area. Microlithons—thin septa of rock whose internal foliation is sharply discordant to the shear bands that enclose it—that are locally well formed further attest to the partial overprinting of earlier formed fabrics, although not all lithologic units may have undergone a common deformational history. Folds, ranging from close to isoclinal in interlimb angle, show no systematic trends with respect to the orientation of their fold axes and likely formed at different times during the deformational history. Though not as common as folds, boudins are also observed, most of which are consistent with northeast-southwestward crustal extension.

Many of the tectonites in the study area (fig. 1) also display a mineral-elongation lineation (L_e) consisting of sheared mica or rodded quartz. The trend of L_e varies considerably across the study area but is mostly northwest-southeastward, although clear northeast-southwestward trends are observed in a few areas, notably in the Nasina assemblage in the Teuchet Creek area and in an isolated area in the Butte assemblage adjacent to the low-angle fault southwest of the ultramafic (peridotite) body near VABM Nail (peridotite of Salcha



EXPLANATION

Surficial deposits (Quaternary)

Postmetamorphic granitoids (Tertiary and Cretaceous)

STRUCTURALLY HIGHER ROCKS

Peridotite (purple), greenstone, metalimestone, metachert, and metasedimentary rocks (Triassic, Permian, and Mississippian–Seventymile terrane)

Greenschist-facies semischist, phyllite, quartzite, marble, and greenstone (Mississippian and Devonian)–Butte subterrane of the Yukon-Tanana terrane of Pavlis and others (1993)

Greenschist-facies quartzofeldspathic mylonite schist and gneiss (Mississippian and Devonian)

STRUCTURALLY LOWER ROCKS

Greenschist-facies carbonaceous quartzite and phyllite and felsic and mafic metavolcanic rocks (Mississippian and Devonian)–Nasina assemblage of Wheeler and McFeely (1991)

Amphibolite-facies calcareous phyllite and marble

Amphibolite-facies peltic schist, quartzite, marble, and amphibolite

Amphibolite-facies sillimanite gneiss, quartzite, and marble

Amphibolite-facies quartzite, marble, pelitic schist, and orthogneiss–West Point Complex of Smith and others (1994)

Contact

Fault; dotted where concealed

Thrust fault; sawteeth on upper plate, queried where uncertain

Low-angle normal fault; sawteeth on upper plate, dotted where concealed, queried where uncertain

Kinematics based on quartz *c*-axis fabric analysis (top-to-the-northwest and coaxial shear)

Tectonites with multiple quartz lattice-preferred orientation domains showing opposing shear senses based on quartz *c*-axis fabric analysis

Microkinematic indicators (top-to-the-northwest shear)

Mesokinematic and macrokinematic indicators (top-to-the-northwest shear)

Trend of elongation lineation

BD-017 Kinematic samples referred to in text

Mineralized diamond-drill hole at Teuchet Creek (TC) and Drone Creek (DC) properties

Named peak

Figure 1. Geologic map of northern part of the Big Delta quadrangle, east-central Alaska (modified from Weber and others, 1978), showing distribution of linear and planar fabric elements and kinematic interpretations.

River of Foster and others, 1994; “Nail” allochthon of Southworth, 1984; hereinafter referred to as the Nail allochthon). Particularly well formed microlithons are observed both in the Teuchet Creek area (Watkinson, 1992) and in the area of carbonaceous and quartzofeldspathic rocks just west of the northeast-trending fault south of Gold Creek (fig. 1), suggesting local preservation of earlier-formed fabrics that may have been obliterated elsewhere.

As a fabric element, L_e generally forms parallel to the direction of maximum principle extension for the deformational event that formed it (Anderson, 1948). L_e alone, however, cannot uniquely constrain the aggregate sense of shear that the rock has undergone. Relative to the structural reference frame (X parallel to L_e, Z normal to foliation, and Y perpendicular to X and Z), fabric asymmetries in the motion (XZ) plane provide a means of evaluating kinematics (for example, Berthé and others, 1979; Simpson and Schmid, 1983; Hanmer and Passchier, 1991; Passchier and Trouw, 1996).

Motion-plane views observed in the field show relatively few kinematic indicators, mostly consisting of weakly formed S–C fabrics, σ-porphyroclasts (with “tails” of comminuted mineral grains streaming from them), and asymmetric folds. Micro-shear-sense indicators, however, were present in approximately 20 percent of the motion-plane thin sections. The microkinematic indicators we commonly observed include S–C fabrics, rotated porphyroclasts, σ-porphyroclasts, and quartz grain-shape preferred orientation (GSPO), although the confidence level of these indicators—a function of the number of indicators per thin section, degree of asymmetry, and asymmetric consistency—is generally low. In addition, some opposing shear-sense indicators were observed in closely proximal tectonites (pelitic schist) south of Gold Creek (fig. 1).

Quartz-rich tectonites in the Chena-Salcha Rivers area (fig. 1) commonly display petrofabrics characterized by a well-formed quartz lattice-preferred orientation (LPO) when viewed under crossed polars with the gypsum plate inserted. LPOs result when quartz grains rotate or recrystallize during shearing into crystallographic orientations conducive to ductile deformation. Dislocation glide, the principle mechanism responsible for ductile deformation in quartz, involves propagation of defects through the crystal lattice at moderate to high temperatures. Basal, prism, and rhomb crystallographic planes provide the primary slip surfaces in quartz, with defect migration in the crystallographic <*a*> or <*c*> directions. Measurements of *c*-axis orientations in siliceous tectonites is an accepted kinematic technique for differentiating coaxial from noncoaxial shear, establishing the sense of shear, and also can provide information regarding the physical conditions during deformation (Schmid and Casey, 1986; Law, 1990). Symmetrical (orthorhombic) versus asymmetric (monoclinic or triclinic) stereograms of *c*-axis distributions can be used to differentiate coaxial from noncoaxial shear in quartz-rich tectonites, and shear sense can be determined from the sense of asymmetry (fig. 2).

Quartz *c*-axis fabric analysis was conducted on nine siliceous tectonites that represent mylonitized quartzite or transposed quartz veins. Following the method of Turner and Weiss (1963), we measured quartz *c*-axes in the XZ plane on a petrographic microscope equipped with a universal stage. A minimum of 250 *c*-axes were measured, unless otherwise indicated. Equal-area, lower-hemisphere stereograms with the XZ plane as the perimeter circle are shown in figure 2. Fabric elements of the stereoprojections were evaluated in terms of strength, asymmetry, and active slip systems.

Seven out of the nine thin sections of quartz-rich rocks from the study area (fig. 1) for which we measured quartz *c*-axes exhibit a single well-developed LPO, as evidenced by uniform interference colors when viewed under crossed polars with the gypsum plate inserted, thus indicating a single coherent alignment of the quartz *c*-axes in the sample. However, thin sections of two quartz-rich greenschist-facies tectonites from the study area are unusual in that multiple distinct LPO domains, as indicated by an ordered distribution of interference colors, are preserved. Initial quartz *c*-axis petrofabric analysis of these samples produced stereoplots unlike those typically observed in nature and did not allow for a shear-sense determination. However, by utilizing a detailed analysis of quartz *c*-axes petrofabrics on a domain-by-domain basis across each thin section, consistent patterns of shear sense were revealed. Individual domains in sample BD–003 (fig. 3*A*) show opposing shear senses. For domains with high-order interference colors (blue), the quartz grains indicate top-to-the-northwest shear, whereas domains with low-order interference colors (yellow) show well-defined top-to-the-southeast fabrics. In addition, domains characterized by deep-orange or dark-blue interference colors, indicative of quartz grains whose *c*-axes are normal to the plane of the thin section, show triclinic patterns of quartz *c*-axis distributions. Sample BD–016 (fig. 3*B*) shows a similar pattern of alternating LPO domains that record opposing top-to-the-northwest and top-to-the-southeast shear senses. Microkinematic indicators (GSPO) contained within the LPO domains of this sample also indicate opposing senses of shear, corroborating the results of quartz *c*-axis petrofabric analysis in the various domains. In sample BD–016, the top-to-the-southeast fabrics are more monoclinic, and the top-to-the-northwest fabric asymmetries more triclinic, than for comparable domains in sample BD–003. Sample BD–016 also contains a single domain near extinction (dark blue area, fig. 3*B*) that yielded a strongly triclinic quartz *c*-axis distribution. Tectonites showing multiple LPO domains have previously been reported from geologic units in the Teslin suture zone of the central Yukon Territory, Canada (Oliver, 1998), believed to be correlative with greenschist-facies rocks of the study area (Hansen and others, 1991).

The combination of quartz *c*-axis petrofabrics and macro/microkinematic indicators reveal a complex and somewhat ambiguous deformational history. In the localities where shear sense is evident, both top-to-the-northwest and top-to-the-southeast shear senses are preserved, in some places in close proximity to each other (fig. 1). Only within the vicinity of the West Point Complex are top-to-the-northwest shear fabrics absent. In addition, some quartz *c*-axis petrofabrics do not reveal a clear sense of shear (fig. 2). While some of these fab-

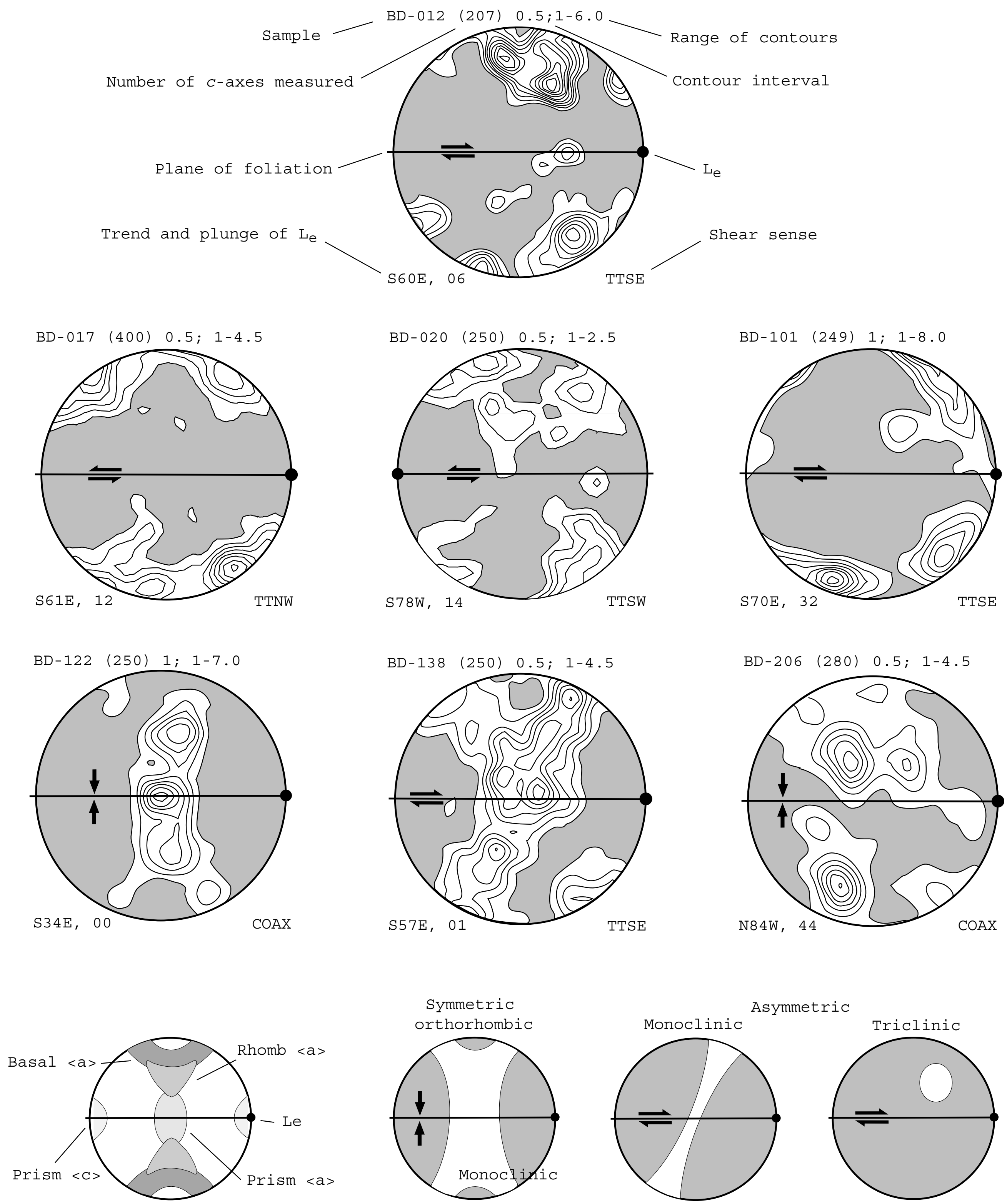


Figure 2. Equal-area, lower-hemisphere stereonet projections of quartz *c*-axis petrofabrics viewed within motion plane (XZ plane—that normal to foliation and parallel to L_e) (see fig. 1 for sample locations and kinematic interpretations). Gray areas represent <1 normal Gaussian distribution with contour intervals representing either 0.5 or 1.0 increments above normal 1 Gaussian distribution. Arrows show shear sense interpreted from fabric asymmetry. Letters at lower right corner denote interpreted shear sense: TTNW, top-to-the-northwest; TTSE, top-to-the-southeast; TTSW, top-to-the-southwest; COAX, coaxial shear or no shear sense determined. Plots were contoured using STEREOPLOTII program (Mancktelow, 1993). Inset at bottom left is a schematic stereogram showing *c*-axis locations indicative of the principal quartz-slip systems. Insets at bottom center and right are schematic stereograms of orthorhombic, monoclinic, and triclinic *c*-axis fabrics.

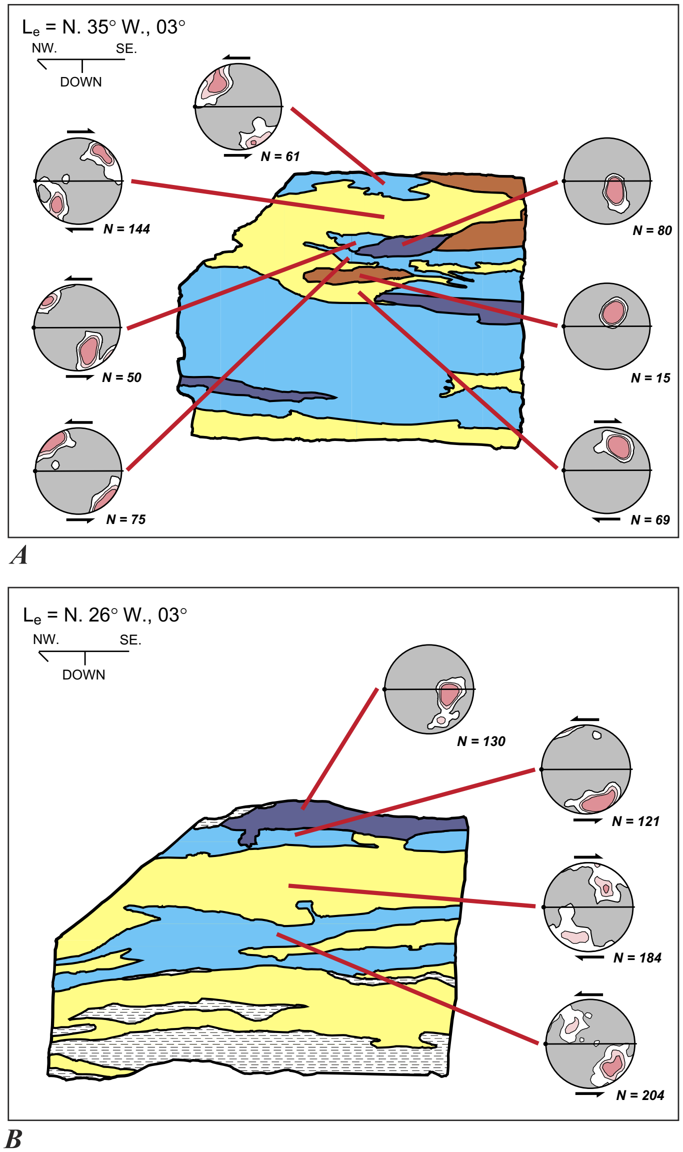


Figure 3. Schematic drawing of thin sections of samples BD-003 (*A*) and BD-016 (*B*), showing domains of quartz *c*-axis petrofabrics as determined by interference colors when viewed under crossed polars with gypsum plate inserted. Lower-hemisphere stereonet projections are for *c*-axes contained within specific thin-section domains. Gray areas, <1 normal Gaussian distribution; white, pink, and red areas, 1 to 2, 2 to 3, and >3 normal Gaussian distribution, respectively. Height of thin-section drawings, 2 cm. See text for explanation of colors.

rics are orthorhombic and indicative of coaxial (that is, flattening) deformation (sample BD–122, fig. 2), others lack a coherent pattern but are consistent with coaxial (sample BD–206) or noncoaxial (sample BD–012) shear. Kinematic determinations on structurally low tectonites of the Nasina assemblage record top-to-the-southwest shear senses, in addition to the more widespread top-to-the-northwest fabrics. Top-to-the-southeast fabrics, though not recorded in the Nasina assemblage itself, occur in the subjacent pelitic schist unit west of West Point and at the base of the structurally(?) overlying Butte assemblage north of Gold Creek and south of West Point (fig. 1).

Interpretation of the Kinematic Data

Our kinematic data from the Chena-Salcha Rivers area are consistent with, and support the results of, previous structural investigations of tectonites in assemblages of the Yukon-Tanana Upland farther to the southeast in the southern part of the Eagle quadrangle and in the northeastern part of the Tanacross quadrangle (Hansen and Dusel-Bacon, 1998). In those other areas, both structurally higher and structurally lower rock assemblages commonly display a well-formed top-to-the-northwest fabric that locally has been overprinted by top-to-the-southeast fabrics. The top-to-the-southwest fabrics locally the present in the Nasina assemblage in study area (fig. 1) are anomalous. Previous kinematic studies in east-central Alaska have identified relatively few tectonites with this specific shear sense (Pavlis and others, 1993; Hansen and Dusel-Bacon, 1998). In addition, the top-to-the-northeast shear senses reported in amphibolite-facies rocks of the Taylor Mountain assemblage (recently renamed the Fortymile River assemblage by Dusel-Bacon and others, 2002) to the east were not observed in the Chena-Salcha Rivers area.

Top-to-the-northwest fabrics across the Yukon-Tanana composite terrane are interpreted to have resulted from obduction of outboard oceanic and marginal-basin rocks onto the North American continental margin, with continued imbrication and shortening of both upper- and lower-plate assemblages (for example, Hansen and others, 1991; Pavlis and others, 1993; Dusel-Bacon and others, 1995; Hansen and Dusel-Bacon, 1998). In the eastern Yukon-Tanana Upland, $^{40}Ar/^{39}Ar$ cooling ages constrain this northwestward-directed contraction to the Early Jurassic (Cushing, 1984; Hansen and others, 1991; Dusel-Bacon and others, 2002).

The later, top-to-the-southeast deformation, present in several areas within the Yukon-Tanana Upland, has been attributed to mid-Cretaceous crustal extension that exhumed structurally lower rocks and juxtaposed them against structurally higher assemblages (Pavlis and others, 1993; Dusel-Bacon and others, 1995; Hansen and Dusel-Bacon, 1998). In the study area (fig. 1), these top-to-the-southeast fabrics are best formed around the West Point Complex. Rims of zircon crystals separated from orthogneiss in the core of the West Point Complex yield an ion microprobe U-Pb age of 111±2 Ma (see Dusel-Bacon, Wooden, and Layer, this volume). Dusel-Bacon, Wooden, and Layer (this volume) interpret this age to represent either the time of igneous crystallization of the granitic protolith or, less likely, the time of regional metamorphism of a Devonian or Mississippian intrusion (the U-Pb age of many of the zircon cores), suggesting that the orthogneiss may have been emplaced and (or) metamorphosed during the mid-Cretaceous crustal-extension episode postulated for other areas of the upland. Top-to-the-southeast fabrics are also present around the Salcha River gneiss dome in the vicinity of the folded low-angle extensional detachment that is inferred to separate it from the overlying lower-grade rocks (Pavlis and others, 1993), and along the southeastern margin of the Nail allochthon (fig. 1), consistent with downdropping of these structurally high klippen during regional crustal extension.

Evidence contained within the polydeformed quartz tectonites is consistent with this interpretation of both contractional and extensional deformation. Preserved fabrics in both samples BD–003 and BD–016 (fig. 3) show opposing top-to-the-northwest and top-to-the-southeast shear fabrics that could have formed as a result of polyphase deformation. In our interpretation, strain partitioning resulted in the preservation of remnants of earlier-formed top-to-the-northwest fabrics within both samples. The ragged boundaries between *c*-axis domains are similar to what has been experimentally created by using octochloropropane during strain partitioning (Win Means, oral commun., 1996). In these experiments, deformation within shear bands superimposed on existing grain orientations was by grain-boundary migration. Because the grains themselves are typically irregular and the shear bands are only a few grains wide, the boundary separating the sheared and unsheared grains is also uneven.

Other possible explanations do not satisfactorily explain these tectonites. The tectonites cannot have resulted from rotation of earlier-formed fabrics during progressive simple-shear deformation. Although feldspars, pyrite, and garnet all are known to rotate as rigid bodies during shearing, quartz deforms ductilely even at moderate temperatures and pressures. In addition, rotations during simple shear occur along an axis parallel to the structural Y-direction. To create the observed fabrics would require a rotation of 180° in the X- or Z-direction. Isoclinal folding is also implausible. Refolding a layer with fabric asymmetries back upon itself will not reverse the sense of shear in the overturned limb. Folding along an axis parallel to the extension direction could create opposing fabrics, but only if the folding occurred after ductile shearing. We know of no evidence suggesting late northeast-southwestward crustal contraction in the Yukon-Tanana Upland. Folding before or during ductile shearing would result in the same shear sense in both limbs. Finally, we consider it unlikely that these fabrics could have resulted from coaxial flattening where differences in the orientations of quartz grains in a primary fabric have been accentuated. Fabric asymmetries are not typically associated with coaxial flattening, and sample BD–016 (fig. 3*B*) contains microkinematic indicators in addition to the quartz *c*-axis fabrics. Furthermore, earlier ductile-deformation events would probably have created a coherent quartz LPO in these tectonites, thus minimizing differences in the initial orientation of quartz grains.

In general, quartz petrofabrics associated with noncoaxial deformation are expected to show monoclinic asymmetries, in that the observed L_e allows the orientation of the motion plane to be established. In contrast, remnant quartz petrofabrics from an earlier deformational event are more likely to be triclinic because the motion planes for both older and more recent deformational events will probably not have the same geometry, and so the now-misaligned monoclinic fabrics from the earlier deformation will appear triclinic. In both our samples with the opposing shear-sense domains, the top-to-the-southeast fabrics are more monoclinic, and the top-to-the-northwest fabrics more triclinic, as would be expected if top-to-the-southeast shearing overprinted existing top-to-the-northwest fabrics. In addition, the strongly triclinic quartz *c*-axis fabrics recorded in LPO domains with deep-orange or dark-blue interference colors may represent a rigid-body rotation of the top-to-the-northwest fabrics along an axis parallel to the extension direction during a later top-to-the-southeast deformation. The multiple triclinic domains observed in sample BD–003 (fig. 3*A*) may represent a progressive rotation of preexisting top-to-the-northwest fabrics through 90° until they are in an orientation conducive to basal <*a*> slip during top-to-the-southeast extension.

The top-to-the-west-southwest direction of tectonic transport measured in the Teuchet Creek area, including sample BD–020 (fig. 2), though unusual for the study area (fig. 1), is close to the due-west direction of tectonic transport determined for amphibolite-facies rocks in the Central Creek area in the southeastern part of the Big Delta quadrangle (Hansen and Dusel-Bacon, 1998; Day and others, 2002; Dusel-Bacon and others, 2002). Day and others (2002) reported new U-Pb ages of 116±4 and 116±2 Ma from spot analyses on the rims of zircons from two different gneiss units in the Central Creek area. They interpreted these ages as the time of prograde mid-Cretaceous metamorphism, which they propose accompanied westward-vergent thrusting in that area.

Absence of asymmetric structural elements in tectonites of the Butte assemblage that contain the anomalous northeast-trending L_e, southwest of the Nail allochthon, makes it impossible to know whether they underwent a southwestward-vergent phase of deformation or whether the tectonites record the northeastward-vergent deformation interpreted to be the oldest (orogen-normal) deformation preserved in the structurally high Fortymile River assemblage (previously named the Taylor Mountain assemblage) in the Fortymile River area near the Alaska-Yukon Territory border (Hansen and Dusel-Bacon, 1998) and at the base of the Nail allochthon (Pavlis and others, 1993). Given the polyphase deformational history and the additional structural complexity resulting from Cenozoic normal faulting, assignment of these anomalous transport directions to a single cause is impossible.

Conclusions

1. Tectonites between the Chena and Salcha Rivers record a complex ductile-deformation history. Kinematic analysis has identified widespread top-to-the-northwest and top-to-the-southeast shear senses and, in the structurally low Nasina assemblage, more local top-to-the-northwest fabrics.
2. Previous structural studies in several areas of the Yukon-Tanana terrane provide a basis for interpreting our kinematic

results. The top-to-the-northwest fabrics are interpreted to have resulted from Early Jurassic thrusting of allochthonous tectonites over the North American continental margin, and the top-to-the-southeast fabrics from mid-Cretaceous crustal extension that exhumed structurally lower rocks. The particularly well formed top-to-the-southeast fabrics around the West Point Complex may have formed during tectonic exhumation of the igneous and metamorphic complex, similar to the exhumation proposed for the Salcha River gneiss dome. The significance of the top-to-the-southwest fabrics is unknown.
3. Unusual siliceous tectonites containing quartz LPO domains record evidence of polyphase deformation. Earlier-formed fabrics exist as remnants after partial overprinting during strain-partitioned ductile shearing. Quartz c-axis fabric analysis on a domain-by-domain basis provides a means of recognizing these earlier events and determining their shear sense.

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