Structural relationships in the eastern syntaxis of the St. Elias orogen, Alaska

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ABSTRACT

The eastern syntaxis in the St. Elias orogen (Alaska, USA) is one of the most complex and least understood regions within the southern Alaska coastal mountain belt. The syntaxis contains many features unique to the orogen that are essential to understanding the structural architecture and tectonic history of the collision between North America and the allochthonous Yakutat microplate. The eastern syntaxis contains the transition from transpressional structures associated with the Queen Charlotte–Fairweather fault system in the east to the Yakataga fold-and-thrust belt (YFTB) to the west. Throughout the eastern syntaxis, a prominent unconformity at the base of the synorogenic Yakataga Formation records an erosional event related to the development of the YFTB. Strain accumulations in the eastern YFTB predate the deposition of the Yakataga Formation, extending estimates for the early development of the St. Elias orogen. Structural and stratigraphic relationships in the eastern syntaxis suggest that forethrusts associated with the transpressional system shut down and were overprinted by fold-and-thrust structures in the Early to latest Miocene. Basement in the eastern syntaxis consists of the Yakutat Group, part of the Chugach accretionary complex, which is carried by numerous low-angle thrust faults in the eastern syntaxis. Exposures of basement and fault patterns within the syntaxis have implications for tectonic reconstructions of the Yakutat microplate and the geodynamics of the orogen.

INTRODUCTION

Throughout most of the Neogene, the Yakutat microplate traveled northward relative to North America, impinging upon the southern margin of Alaska and initiating both proximal and far-field orogenesis (Plafker, 1987; Pavlis et al., 2004; Leonard et al., 2007). The Yakutat microplate is located between the transition from dextral strike-slip motion along the Queen Charlotte–Fairweather fault system to oblique convergence in the core of the St. Elias orogen and ultimately to subduction at the Aleutian Trench. One of the most dynamic areas within the St. Elias orogen is the eastern syntaxis, an area of high topography and structural diversity where northwest-striking, basement-involved transpressional systems to the southeast are juxtaposed against the east- to northeast-striking, thin-skinned Yakataga fold-and-thrust belt (YFTB) to the west (Fig. 1). The intersection of these two structural systems is poorly understood, but critical to unraveling the tectonic history of the Yakutat microplate.

We present an updated description of the eastern syntaxis, characterize the structural architecture of the YFTB, and utilize stratigraphic and structural relationships to help constrain the timing and evolution of deformation in the eastern syntaxis, including the initiation of the YFTB. In addition to an overview of the eastern YFTB, we present a focused study of the Samovar Hills, a key exposure located in the core of the eastern syntaxis at the intersection of structural styles (Fig. 1). The Samovar Hills offer singular insight into the evolution of the YFTB and provide a template for interpreting geologic observations throughout the Yakutat microplate. Our study of the eastern syntaxis helps to resolve the geodynamics of the St. Elias orogen in a critical, and poorly understood, location within the Yakutat microplate.

TECTONIC SETTING

In the eastern Yakutat microplate, onshore basement exposures consist of flysch and accretionary mélangé of the Yakutat Group, part of the late Mesozoic Chugach accretionary complex (Fig. 1) (Plafker et al., 1977). The entire Mesozoic accretionary complex from southern Alaska to Vancouver Island was intruded by distinctive near-trench plutons and locally metamorphosed to high-grade low-pressure–high-temperature metamorphic assemblages during an Early Eocene oceanic spreading ridge subduction event (Pavlis and Sisson, 1995; Bradley et al., 2003; Sisson et al., 2003). A portion of this accretionary complex was excised from the Cordilleran margin to form part of the Yakutat microplate, and transported northward. As a result, in the present collision, variably metamorphosed assemblages of the Chugach accretionary complex form both the autochthonous backstop and part of the allochthonous basement (Plafker, 1987).

The autochthonous rocks are equivalent to the Late Cretaceous to Paleocene Valdez and Orca Groups, which were variably metamorphosed from greenschist to upper amphibolite facies (Richter et al., 2005). The Valdez Group is part of the Chugach terrane, which was accreted to the southern Alaska margin in the Late Cretaceous (Amato and Pavlis, 2010).
The Orca Group is part of the Prince William terrane, which was accreted in the Early Eocene (Plafker et al., 1994). The Contact fault forms the suture between the Prince William terrane and Chugach terrane (Plafker, 1987). The Chugach St. Elias fault (CSEF) forms the suture between the Prince William terrane and the Yakutat microplate (Fig. 1).

The Yakutat Group is regionally metamorphosed to zeolite to prehnite-pumpellyite facies and locally metamorphosed to greenschist facies (Dusel-Bacon, 1994; this study). Building upon mapping by Plakfer and Miller (1957), Richter et al. (2005) subdivided the Yakutat Group into flysch and mélangé assemblages. Paleontological data from outcrop and cores (Jones and Clark, 1973; Rau et al., 1983) suggest that the Yakutat Group is Campanian to Maastrichtian in age (65.5–83.5 Ma; Gradstein et al., 2005). Haussler et al. (2005) estimated a maximum deposition age of 72–74 Ma from detrital zircon data for the Yakutat Group, an age they interpret as within ~5 Ma of the true depositional age.
In contrast to the eastern Yakutat microplate, geophysical studies indicate that basement in the central and western Yakutat microplate consists of a 15–30-km-thick oceanic plateau that is subducting beneath and accreting to North America (Ferris et al., 2003; Pavlis et al., 2004; Eberhart-Phillips et al., 2006; Gulick et al., 2007; Christeson et al., 2010). The relationships and transition between basement lithologies across the Yakutat microplate are unclear, although Plafker (1987) and Plafker et al. (1994) suggested that the transition occurs along the Dangerous River zone (DRZ) (Fig. 1), which they interpreted as a steeply dipping crustal boundary. The DRZ was originally defined from offshore seismic reflection data as the western edge of a basement uplift across which the Cenozoic sedimentary cover sequence for the Yakutat microplate thins dramatically eastward (Bruns, 1982, 1983). Plafker (1987) further delineated the location of the DRZ onshore and assigned a series of faults in the Samovar Hills to the DRZ.

A thick sedimentary sequence that spans most of the Cenozoic overlies Yakutat microplate basement (Fig. 2). The sedimentary cover reaches a total stratigraphic thickness of >10 km (Worthington et al., 2010) and thins to near zero across the offshore DRZ (Bruns, 1982; 1983). In the eastern syntaxis area, three main stratigraphic units compose the cover sequence: the Kulthieth Formation, the Poul Creek Formation, and the Yakataga Formation (Plafker, 1987). Several minor stratigraphic units are present locally, including the siltstone of Oily Lake (Plafker, 1987), herein referred to as the Oily Lake member of the Kulthieth Formation (Fig. 2). Foraminifera analysis for the Oily Lake member in the Samovar Hills indicates an Early to Middle Eocene age (Ulatisian Stage, ca. 42.5–49.5 Ma) (McDougall, 2007) (Plafker et al., 1994).

The Kulthieth Formation is typically 2–3 km thick and consists of fluvial to shallow-marine deltaic deposits including coarse arkosic sandstone, shale, and coal beds (Plafker, 1987; Landis, 2007). West of the study area, the Tokun and Stillwater Formations are the marine equivalents to the Kulthieth Formation (Plafker, 1987). In the Samovar Hills, the basal Kulthieth Formation consists of a white tuffaceous conglomerate, 1–3 m thick, that grades upward into ~500 m of coarse sandstone with coal beds as thick as several meters (Landis, 2007; this study). The Kulthieth Formation in the Samovar Hills is late Early Eocene to early Middle Eocene in age (Plafker, 1987).

The Poul Creek Formation conformably overlies the Kulthieth Formation and includes organic-rich shale, siltstone, glauconitic sandstone, and interbedded tuff (Plafker, 1987; Brennan et al., 2009). The Poul Creek Formation is ~1 km thick and is characterized by low sedimentation rates and was deposited in marine waters along a narrow shelf fringing low-lying coastal mountains (Eyles et al., 1991). The Poul Creek Formation is latest Eocene to Early Miocene in age (Plafker, 1987). The Yakataga Formation rocks are thick interbedded glacimarine sandstone, mudstone, and diamictite deposited on the continental shelf (Eyles and Lagoe, 1990), and are the youngest within the orogen (Middle Miocene to present). The 0–6-km-thick Yakataga Formation contains numerous internal angular unconformities associated with fold and fault growth (Miller, 1957; Worthington et al., 2008, 2010; Broadwell, 2001).

**Yakataga Fold-and-Thrust Belt**

In the western and central Yakutat microplate, the sedimentary cover is decoupled from the Yakutat oceanic plate basement to form the thin-skinned YFTB. Offshore, the deformation front is defined by the Pamplona zone, an active fold-and-thrust system that accommodates ~6 mm/yr of shortening (Worthington et al., 2010; Chapman et al., 2008). The Pamplona zone trends onshore into the Malaspina fault, the active deformation front in the eastern syntaxis area (Fig. 3). Global positioning system (GPS) data suggest that the Malaspina fault may accommodate ~20 mm/yr convergence (Elliott et al., 2010). Because the Malaspina fault and structures within the Pamplona zone are oriented oblique to the plate boundary (Figs. 1 and 3), the width of the active orogenic wedge varies across the region from a minimum of ~35 km in the vicinity of the Samovar Hills to >100 km in the central YFTB (Plafker et al., 1994).

The depth to the basal detachment in the eastern YFTB is constrained by earthquake relocations, including a series of aftershocks associated with the 1979 St. Elias earthquake (Bauer et al., 2008; Estabrook et al., 1992) and offshore seismic data (Worthington et al., 2010), together suggesting that the basal detachment in the central YFTB was deeply buried beneath thrusts prior to exhumation. Previous interpretations of the YFTB structure at depth include a series of duplexes and imbricate thrusts in Cenozoic sedimentary rocks alone (Berger et al., 2008a; Chapman et al., 2008) or also including structurally thickened basement rocks (Wallace, 2008). The interpretation of structure at depth has considerable implications for structural reconstructions and estimates of total shortening.

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**Figure 2. Simplified stratigraphic column for the eastern syntaxis area in the Yakutat microplate.** Stratigraphic thicknesses are schematic and show that the Paleogene sedimentary section thins toward the east. K<sub>ym</sub>—Cretaceous Yakutat Group mélangé; K<sub>y</sub>—Yakutat Group intrusive rocks; T<sub>NN</sub>—Tertiary intrusive rocks; T<sub>k</sub>—Kulthieth Formation; T<sub>o</sub>—Oily Lake member of the Kulthieth Formation; T<sub>e</sub>—Poul Creek Formation; Paleoc—Paleocene; Plio—Pliocene; Pleist—Pleistocene; QT—Quaternary—Tertiary Yakataga Formation.
Figure 3. Geologic map of the eastern syntaxis area. Location is in Figure 1. CSEF is Chugach St. Elias fault.
Total shortening estimates for the St. Elias orogen, based on plate reconstructions and exhumed material, are ≥300 km (Pavlis et al., 2004; Berger et al., 2008a; Chapman et al., 2008). Shortening estimates from published structural reconstructions are lower, generally <100 km (Meigs et al., 2008; Chapman et al., 2008; Wallace, 2008). The YFTB is currently accommodating >3.5 cm/yr of the total 4–5 cm/yr convergence between the Yakutat microplate and North America (Elliott et al., 2009; 2010; Sauber et al., 1997; Fletcher and Freymueller, 2003). These rates are thought to have remained similar since the earliest Pliocene (DeMets et al., 1994). In contrast, estimates of shortening since deposition of the Yakataga Formation using published cross-section restorations range from 5 to 14 mm/yr (Chapman et al., 2008; Meigs et al.; 2008; Wallace, 2008). Explanations for the differences in the rate of shortening include underestimates of fault displacement (Meigs et al., 2008; Chapman et al., 2008) and structural thickening of Yakutat microplate basement at depth (Wallace, 2008).

In addition to questions surrounding the structural architecture at depth in the YFTB, there is considerable uncertainty concerning the potential fault geometry beneath the Bagley Icefield and upper Seward glacier, north of the YFTB (Fig. 1). West of the Yakutat microplate, the Contact fault is a north-dipping reverse fault (Plafker et al., 1994). Although covered by ice, the Contact fault connects with the Fairweather fault in the eastern syntaxis area (Plafker and Thatcher, 2008) (Figs. 1 and 3). Geodetic data (Savage and Lisowski, 1986; Sauber et al., 1997) and fault studies adjacent to the Bagley Icefield (Bruhn et al., 2004) suggest that the Contact fault accommodates some component of dextral shear and may be reactivated as a strike-slip fault in this location (Pavlis et al., 2004; Bruhn et al., 2004). Bruhn et al. (2004) proposed that the oblique convergence of the Yakutat microplate was partitioned between dip slip on north-dipping thrust faults in the YFTB and dextral strike-slip motion on a steeply dipping to vertical Contact fault.

Geomorphically and bedrock apatite [U-Th]/He (AHe) data were presented that indicated southside-up motion across the Bagley Icefield (Berger et al., 2008a). Earthquake relocations reveal a loosely defined, south-dipping limit to seismicity beneath the central YFTB (Berger et al., 2008a; Doser et al., 2007) interpreted (Berger et al., 2008a) as a new fault, the south-dipping Bagley fault, which would represent an orogen-scale backthrust and suggest that the St. Elias orogen is doubly vergent. Furthermore, in Berger et al. (2008a, 2008b) AHe data were combined with data from mineral systems with higher closing temperatures including bedrock apatite fission track (AFT), zircon [U-Th]/He (ZHe), and zircon fission track (ZFT) to suggest that motion on the Bagley fault initiated or greatly increased in the Quaternary, coincident with the end to motion on the CSEF in the central YFTB. In this scenario, two faults could exist beneath the Bagley Icefield: the younger, south-dipping Bagley fault and the older, north-dipping to vertical Contact fault. If the Contact fault dips shallowly to the north, as proposed by Plafker et al. (1994), then the Bagley fault as proposed in Berger et al. (2008a) may cut the older Contact fault.

The model of Berger et al. (2008a, 2008b) is complicated, however, by young (<3 Ma) detrital ZFT ages originating from the Valdez Group beneath the Malaspina–Seward glacier system (Enkelmann et al., 2009, 2010). These data suggest rapid exhumation along the trace of the Contact fault beneath the upper Seward glacier. Enkelmann et al. (2008, 2010) interpreted these ages as evidence for exhumation of transpressional fault slivers along a reactivated Contact fault system, and suggested that the Bagley backthrust is unnecessary. In this model, the Contact fault is either north dipping (Enkelmann et al., 2008) or nearly vertical (Enkelmann et al., 2010).

Spotila and Berger (2010) also suggested that exhumation of transpressional fault slivers beneath the upper Seward glacier is responsible for the young ZFT ages; however, they suggested that these slivers originate along the Fairweather fault in the eastern syntaxis and maintained that west of the eastern syntaxis area, the Bagley fault is a viable model for the apparent south-side-up motion across the Bagley Icefield. Further analysis is needed to determine the geometry and nature of this important structure.

**EASTERN SYNTAXIS**

We define the eastern syntaxis as an ~30° bend in trend of the St. Elias orogen (Fig. 1) that encompasses the transition from basement-involved transpressional structures to thinskinned fold-and-thrust structures. Figure 3

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**Figure 4. Cross-section A–A′ through the Chaix Hills. Location is in Figure 3. CSEF is Chugach St. Elias fault. The fault geometry beneath the Seward glacier is unknown and the faults shown represent a range of possibilities (Berger et al., 2008a; Enkelmann et al., 2010). The internal folding and faulting is not shown for the Cretaceous Yakutat Group flysch (K_y), Yakutat Group mélange (K_ym), or the Tertiary Kulthieth Formation (T_k) at depth (Q—Quaternary). There is a general increase in fold shortening and asymmetry up structural section.**
is a geologic map of the eastern syntaxis area compiled from previously published geologic maps (Plafker and Miller, 1957; Campbell and Dodds, 1982; Richter et al., 2005), new mapping in the 2005–2007 field seasons, aerial and satellite photograph interpretation, and spectral lithologic mapping using Landsat Thematic Mapper (TM) imagery. We also present a schematic cross section through the orogen in Figure 4 illustrating several main structural features. Our mapping suggests that the eastern syntaxis contains at least four major thrust sheets including, from south to north, the Malaspina–Esker Creek fault, Chaix Hills fault, Libbey Glacier fault, and CSEF. In the following we report on each of the major thrust faults and associated thrust sheets.

**Malaspina Fault**

The Malaspina fault is not exposed due to ice cover of the Malaspina Glacier (Fig. 3), but best estimates of its trace suggest that it is oriented oblique (~070) to the major thrust faults structurally higher within the thrust belt (080–115), but subperpendicular to the current Yakutat microplate motion (~337) (Elliott et al., 2010). This orientation suggests the Malaspina fault accommodates predominantly dip-slip motion. We have constrained the location of the Malaspina fault with the structural geometry of the Yakataga Formation in the southern Chaix Hills, earthquake relocations (Estabrook et al., 1992), and data from the Chaix Hills #1A well drilled by Standard Oil in 1961, which penetrated the Poul Creek Formation (Plafker et al., 1975) (Figs. 3 and 4). The Riou Bay #1 well drilled by Standard Oil in 1962 reached a total measured depth of 4300 m in the Yakataga Formation (Plafker et al., 1975). Offset of the Yakataga–Poul Creek Formation contact between the Chaix Hills #1A well and the projected depth of the top of the Poul Creek Formation in the Riou Bay #1 well suggests >1200 m of throw across the fault, assuming limited deformation southeast of the Malaspina fault (Fig. 4).

West of Icy Bay the trace of the Malaspina fault is unknown, but it ostensibly connects with the easternmost fault of the Pamplona zone offshore, an active fault system (Wortington et al., 2010) (Fig. 1). To the east, the Malaspina fault bounds the southern Samovar Hills, where it intersects the Esker Creek fault. The Esker Creek fault also forms the leading edge of deformation to the eastern YFTB and is a northerly reverse fault that places Yakutat Group basement rocks on the Yakataga Formation (Bruhn et al., 2004; Plafker and Thatcher, 2008).

Bedding in the Malaspina thrust sheet dips 10°–30° north to northwest in the Chaix Hills and southern Karr Hills. The Yakataga anticline is present in the Guyot Hills and northern Karr Hills and contains distinctive angular unconformities and growth strata within the Yakataga Formation (Miller, 1957). Broadwell (2001) suggested the Yakataga anticline in the Guyot Hills originated as a detachment fold with a detachment at ~3 km depth. Plafker and Addicott (1976) reported an angular discordance of as much as 60° across an angular unconformity associated with the Yakataga anticline in the northern Karr Hills, leading us to suggest that the Yakataga anticline may not immediately die out along strike to the east. However, we did not observe the Yakataga anticline in exposures on the west side of Taan Fjord (Fig. 3), indicating that the Yakataga anticline may trend into the Chaix Hills fault or be eroded.

East of the Chaix Hills, the Yakataga Formation dips to the west on the crest of a large plunging antiform in the Samovar Hills. We suggest that the west-plunging structure in the Samovar Hills may provide a down-plunge view of the subsurface structure to the west in the Chaix Hills (Fig. 3), and use this relationship as a template for the construction of the cross section in Figure 4.

We interpret a small fault south of the main Malaspina fault based on relocations of aftershocks from the 1979 St. Elias earthquake (Estabrook et al., 1992). This fault is entirely covered by the Malaspina Glacier. The magnitude of slip on this fault is unknown and the offset shown in Figure 4 is schematic.

**Chaix Hills Fault**

The Chaix Hills fault bounds the Malaspina thrust sheet to the north. The Chaix Hills fault is covered by the Agassiz Glacier to the east and the Yangtze Glacier to the west, but it is exposed on either side of the Taan Fjord (Fig. 3). In this location, the Chaix Hills fault consists of two fault strands: the main fault placing Kulthieth Formation to the northwest over Yakataga Formation to the southeast, and a splay fault to the south placing Poul Creek and basal Yakataga Formation on Yakataga Formation (Figs. 3 and 5). Updip reverse slip on the main north-dipping Chaix Hills fault was reported in Bruhn et al. (2004). The fault surface of the southern splay fault along the Taan Fjord also dips to the north and displays reverse slip (Table 1). Yakataga strata in the immediate vicinity of the hanging wall of the Chaix Hills splay fault also display a well-developed, spaced cleavage with bedding-cleavage intersections plunging 58° toward 340. This cleavage was absent in the footwall. Although total offset of the southern splay fault is uncertain, the presence of cleavage suggests that the block of Yakataga strata in the hanging wall of the Chaix Hills splay fault was carried to its present position from beneath a thick Yakataga section. The results suggest that locally the Chaix Hills fault is predominantly dip slip and that the orogen-parallel component of motion is partitioned elsewhere. There is no clear surface evidence for or against recent motion on the Chaix Hills fault.

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**Figure 5.** Photograph looking east toward the Chaix Hills fault and Chaix Hills splay fault. Location is in Figure 3. QT,—Quaternary—Tertiary Yakataga Formation; Tc,—Tertiary Kulthieth Formation.

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**Table 1. Fault Geometry and Slip Vectors**

<table>
<thead>
<tr>
<th>Fault</th>
<th>Orientation (strike/dip)</th>
<th>Slip vector (plunge/trend)</th>
<th>Shear sense</th>
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<td>294/50°</td>
<td>46/054</td>
<td>reverse</td>
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<td>118/70°</td>
<td>54/149</td>
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<td>Lower Hubbis Creek fault</td>
<td>307/88°</td>
<td>45/305</td>
<td>dextral reverse</td>
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<td>Upper Hubbis Creek fault</td>
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<td>0°/315</td>
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</tr>
<tr>
<td>Chugach St. Elias fault</td>
<td>350–360/10°</td>
<td>25°</td>
<td></td>
</tr>
</tbody>
</table>

(Chen, 1962)
In the northern Chaix Hills, the Kulthieth Formation displays a general structural stratification from a moderately homoclinal section in the lower Kulthieth Formation to a more complexly folded section in the upper Kulthieth Formation. The upper Kulthieth Formation appears to be detached from the lower Kulthieth Formation along extensive coal beds near the middle of the stratigraphic section. West of the Tyndall Glacier, a contact between the Kulthieth and Yakataga Formations is preserved in a gentle (~145° interlimb angle), west-plunging syncline. This exposure reveals a critical field relationship: the Yakataga Formation overlying an angular unconformity, on complexly deformed rocks of the upper Kulthieth Formation (Fig. 6). This angular unconformity is herein referred to as the basal Yakataga unconformity.

We observed folds within the Kulthieth Formation during transects on either side of Tyndall Glacier. Folds within the Kulthieth Formation are upright, symmetrical to asymmetric, verging to the south. Overturned limbs of south-verging folds are increasingly common to the north, up structural section (cf. Figs. 6, 7, and 8). Fold wavelengths are a few hundred meters and folds commonly occur within stratigraphic intervals of several tens of meters, bounded by bedding-parallel detachments. Interlimb angles vary from open to tight with a majority of close folds. Hinge thickening is common within coal and shale beds.

The base of the Yakataga Formation consists of ~5 m of red-green rounded pebble conglomerate in a shale matrix overlain by ~3 m of green volcaniclastic sedimentary rock. A bed-parallel detachment is present along the contact between the pebble conglomerate and green volcaniclastic unit, but is above the angular unconformity. It is unclear whether this detachment surface is tectonic in origin or the base of a gravity slide in the Yakataga Formation. Other exposures of the basal Yakataga unconformity in the eastern syntaxis area do not contain a detachment surface. The Poul Creek Formation is notably absent at this locality, indicating erosion to the level of at least the upper Kulthieth Formation; however, a small exposure of the Poul Creek Formation reappears on the east side of the Tyndall Glacier (Fig. 3) (Richter et al., 2005), indicating relief on the unconformity surface or structural relief on the Poul Creek–Kulthieth Formation contact.

The base of the Poul Creek Formation east of the Tyndall Glacier provides a structural marker across the Chaix Hills fault. Based on the depth of the Poul Creek Formation in the Chaix Hills #1A well and surface structural data from the Chaix Hills, we estimate that the main Chaix Hills fault has >4.5 km throw (Fig. 4). This estimate does not take into account structural thickening and imbrication within the Kulthieth Formation and may not be easily related to total displacement.

The Coal Glacier fault (Richter et al., 2005), within the Chaix Hills thrust sheet, is a reverse fault that places the upper Kulthieth Formation...
over the lower Yakataga Formation west of
the Tyndall Glacier and over the Poul Creek
Formation east of the Tyndall Glacier (Fig. 3).
Total offset along this fault is poorly
constrained, but it is at least ~350 m based on the stratigraphic
thickness of the Yakataga Formation in the footwall.
The fault is covered by the Yachtse Glacier to the
west and obscured within the Kulthieth Forma-
tion to the east and may die out along strike.

East of the Tyndall Glacier area, the Kulthieth
Formation dips to the north-northwest and older
stratigraphic levels are exposed to the east toward
the basement-cover contact between the Kul-
thieth Formation and the Yakutat Group north of
the Samovar Hills (Fig. 3). The exposure of the
basement-cover contact is related to both ero-
sion and depositional thinning of the Kulthieth Forma-
tion. Our observations were taken from
helicopter, but near the contact, the Kulthieth
Formation exhibits pervasive intraformational
folding with numerous bed-parallel detach-
ments along shale and coal layers (Fig. 7). The
largest folds are south-verging asymmetric folds
with interlimb angles <60° and wavelengths of
several hundred meters. The folds are enclosed
within stratigraphic packages of a few to several
hundreds of meters. Within the core of the larger
folds, additional bed-parallel detachments and
smaller folds are commonly observed (Fig. 7).

Despite the intraformational folds, a fairly intact
stratigraphic section of the Kulthieth Formation
appears to be exposed along strike from its base
at the Yakutat Group north of the Samovar Hills
to the base of the Poul Creek Formation east of
the Tyndall Glacier. Similar to the Malaspina
thrust sheet, the map pattern in the Chaix Hills
thrust sheet north of the Samovar Hills may pro-
vide an along-strike view of the deeper structural
configuration beneath the Tyndall Glacier
area to the west; however, significant ice cover
handicaps clear conclusions.

Northeast of the Samovar Hills, the Chaix
Hills fault appears to connect with the Dome
Pass fault of Plafker and Miller (1957) that
thrusts Yakutat Group onto the Yakataga Forma-
tion. Across the Seward glacier, the Dome Pass–
Chaix Hills fault system apparently connects
with the Boundary fault north of Yakutat Bay
that emplaces Yakutat Group on Yakutat Group
(Plafker and Thatcher, 2008). Isolated lenses of the
Kulthieth Formation are present east of the
Seward glacier throat in the immediate footwall
of the Dome Pass–Chaix Hills fault system, the map pattern in the Chaix Hills thrust sheet north of the Samovar Hills may pro-
vide an along-strike view of the deeper structural
configuration beneath the Tyndall Glacier
area to the west; however, significant ice cover
handicaps clear conclusions.

Libbey Glacier Fault

We observed the Libbey Glacier fault (Bruhn
et al., 2004) in the northern Chaix Hills at the
base of Haydon Peak and in a nunatak in upper
Libbey Glacier (Figs. 8 and 9). The Libbey Glaci-
er fault in this location was originally mapped
as the Coal Glacier fault (Plafker and Miller,
1957), although that name was subsequently
applied to the fault to the south (Richter et al.,
2005). Rocks in the footwall of the Libbey Glacier
fault consist of the Kulthieth Formation, although the classification of the rocks in the
immediate hanging wall is less certain (Plafker
and Miller, 1957; Richter et al., 2005). The base
of Haydon Peak, in the hanging wall of the Libb-
by Glacier fault, contains tightly folded dark
brown to dark gray siltstone with subordinate
fine-grained sandstone, pebble conglomerate,
basaltic tuff, light gray tuffaceous sandstone,
and light green to gray intrusive rocks (Plafker
and Miller, 1957; Richter et al., 2005). The base
of the siltstone sequence to rocks exposed north
of the Samovar Hills in the Chaix Hills thrust sheet. Stratigraphic relationships suggest that the Plafker
and Miller (1957) siltstone sequence underlies
the lowermost Kulthieth Formation is Paleocene in
age in that location, providing an upper bracket
for the age of the siltstone sequence (Addicott
and Plafker, 1971).

Subsequent mapping (by Bruhn et al.,
2004, and G. Plafker, compiled by Richter et al.,
2005), reassigned the rocks of the siltstone sequence
at the base of Haydon Peak and north of the Samo-
var Hills to the Yakutat Group flysch assemblage.
The siltstone sequence west of the Tyndall Glaci-
er, in the hanging wall of the Libbey Glacier

Figure 8. Photograph look-
ing west at the Libbey Glaci-
er fault across the Tyndall Gla-
cier. Location is in Figure 3.
This outcrop was only observed from
across the Tyndall Glacier, and the rocks in the hang-
ing wall could be Cretaceous
Yakutat Group mélange (Kym)
or sedimentary rocks of the
Yakutat microplate such as
Tertiary Poul Creek Forma-
tion (Tpc). Tk—Kulthieth Forma-
tion. Light-colored slope
wash obscures darker brown
to reddish-brown rocks in the
footwall of the fault that cuts
the fold in the upper indetermi-
ate unit.
fault, was reassigned to the Kulthieth Formation with associated mafic intrusive rocks (Richter et al., 2005). Our observations immediately west of the Tyndall Glacier in the hanging wall of the Libbey Glacier fault, however, suggest greater complexity. In that area, the rocks in the hanging wall of the Libbey Glacier fault consist of dark brown to reddish-brown mudstone and siltstone with abundant felsic dikes and sills that are tightly folded into recumbent folds with wavelengths of a couple hundred meters (Fig. 8). Localized faults are present in the core of the folds and lose displacement upsection (Fig. 8). Farther west, coarser-grained, light-colored sandstone of the Kulthieth Formation is clearly present in the Libbey Glacier thrust sheet; however, additional study is needed to positively identify the assemblages immediately west of the Tyndall Glacier in the hanging wall of the Libbey Glacier fault. Based on lithologic and structural similarities, we suggest that these rocks may be part of the Yakutat Group mélange, the Kulthieth Formation, the Poul Creek Formation, or some combination of these.

Half-way up the southern flank of Haydon Peak is a prominent color change that marks a lithologic contact separating Yakutat Group mélange below from lighter colored, brownish-red sedimentary rocks lacking intrusive rocks above (Fig. 9). Although only observed from a distance, these rocks appear to be folded into series of recumbent antiline-syncline pairs with wavelengths of hundreds of meters to several hundred meters (Fig. 9). Pfafker and Miller (1957) suggested that the contact was a steeply dipping angular unconformity with local offset along numerous minor faults. Our observations demonstrate that the contact is subhorizontal and suggest that the contact may be a fault contact, although faulting may have locally exploited an existing angular unconformity. Richter et al. (2005) assigned the rocks on top of Haydon Peak to the Yakutat Group, although they did not recognize a lithologic change along the southern flank other than a mapped fault. The lithology and style of deformation (cf. Fig. 7) suggest that the rocks at the top of Haydon Peak may be equivalent to the Kulthieth Formation present at moderate elevation on the west side of the Tyndall Glacier. Furthermore, G. Pfafker (2011, personal commun. to T. Pavlis) observed coal at some locations on the top of Haydon Peak during reconnaissance work. The younger over older relation interpreted here between the Kulthieth Formation and the Yakutat Group mélange is consistent with the possibility of a faulted unconformity. We traced the contact on the southern flank of Haydon Peak to the east where it climbs in elevation and ultimately is truncated by the CSEF along the southeast flank of Mount St. Elias (Fig. 3).

South of Mount Augusta, Richter et al. (2005) mapped rocks in the hanging wall of the Libbey Glacier fault as greenschist facies Valdez Group. Like the Yakutat Group, the Valdez Group is part of the Chugach accretionary complex and is lithologically similar to the Yakutat Group, but was accreted to the southern Alaskan margin prior to the collision of the Yakutat microplate (Pfafker, 1987). Campbell and Dodds (1982), however, assigned these rocks to the Yakutat Group. Where observed in this location, the hanging wall of the Libbey Glacier fault contains dark brown to gray phyllite and low-grade chloritic schist (Fig. 10) that we correlate along strike to the lower metamorphic grade Yakutat Group mélange exposed south of Mount St. Elias and west of the Seward glacier throat. The footwall contains intensely folded, light-colored, fine-grained siltstone and argillite with little apparent metamorphism (Fig. 10), similar to the Yakutat Group flysch in the Samovar Hills and elsewhere. This interpretation of the Libbey Glacier fault shifts the position of the CSEF higher up the flank of Mount Augusta, consistent with the mapping of Campbell and Dodds (1982).

Spotila and Berger (2010) analyzed samples from either side of the Libbey Glacier fault, south of Mount Augusta, for apatite and zircon (U-Th)/He (AHe and ZHe) cooling age determinations (Figs. 3, yellow circles). In the footwall of the fault, to the south, Spotila and Berger (2010) reported an AHe age of 0.59 Ma and Enkelmann et al. (2010) reported a ZHe age of 55.29 Ma. In the hanging wall to the north, Berger and Spotila (2008) reported an AHe age of 0.56 Ma and Enkelmann et al. (2010) reported a ZHe age of 3.48 Ma. This unusual pattern of AHe and ZHe age pairs is similar to ages measured across the CSEF in the central YFTB (Berger et al., 2008a); in that study, it was suggested that the CSEF was active ca. 5 Ma during the closure of the younger ZHe age, but inactive since ca. 1 Ma based on the similar AHe ages. A similar history of deformation may exist for the Libbey Glacier fault at this location, suggesting that significant differential exhumation across the Libbey Glacier fault has not occurred over the past ~0.5 Ma and that current rapid exhumation is the result of uplift associated with other structures. The ZHe cooling age in the footwall predates the development of the St. Elias orogen and limits the total exhumation in the footwall block to 6–7 km.

Chugach–St. Elias Fault

The CSEF separates sedimentary rocks of the Yakutat microplate from the Orca Group of the Prince William terrane in the western and
central Yakutat microplate (Fig. 1). In the eastern syntaxis, however, the Orca Group appears to be absent and rocks of the Yakutat microplate are in fault contact with metamorphic rocks correlated to the Valdez Group of the Chugach terrane (Plafker, 1987; Plafker et al., 1994). We label this fault contact the CSEF, following previous studies (e.g., Plafker et al., 1994), although it is unclear if the CSEF of the western and central Yakutat microplate is the same as the CSEF in the eastern syntaxis region.

The CSEF in the eastern syntaxis places complexly deformed amphibolite metamorphic facies rocks onto the Yakutat Group mélangé. The CSEF marks one of the most distinctive lithologic changes within the orogen, but because of the extreme topography in the eastern syntaxis region, we relied heavily on aerial photography and satellite imagery to determine the trace of the CSEF. In addition to moving the trace of the CSEF higher on Mount Augusta as discussed here, we assign much of the area south of Mount Huxley to the Yakutat Group mélangé (Fig. 3) and place the CSEF closer to the base of Mount Huxley along a prominent topographic escarpment and spectral boundary identified in Landsat TM imagery.

The rugged topography of the eastern syntaxis allows for a robust estimation of the three-dimensional geometry of the CSEF. We draped a geologic map over a 60 m digital elevation model for the eastern syntaxis area and used a script written by one of us (R. Bruhn, at the University of Utah) to match intersections between fault planes and topography to the observed fault trace (Fig. 11). To estimate the robustness of the best-fit fault planes, we varied fault dip (±10°) and fault strike (±20°) and plotted the resulting intersection lines against the observed fault trace. We then constructed vertical sections spaced 1 km apart along the CSEF and oriented perpendicular to the trace of the CSEF at that point. We determined point intersections between the plotted lines and the vertical section plane. Next, we calculated the distance in meters between the point intersection of the estimated fault trace and the point intersection of the observed CSEF trace within each vertical section plane. We summed these distances for each fault intersection trace, which we used as an approximate measure of misfit. We repeated this procedure for each fault segment of the CSEF shown in Figure 11 (A, B, and C). We report misfit as a relative percent by dividing the misfit for each fault trace against the summation of the minimum misfit and two maximum misfit traces fit to that segment.

The results suggest that in the eastern syntaxis area, the CSEF dips 10°–30° toward 350°–360° (Fig. 11). We have a high degree of confidence in the estimated fault geometry around Mount St. Elias (segment A, Fig. 11) and Mount Augusta (segment C, Fig. 11); however, where the CSEF passes beneath the Newton Glacier (segment B, Fig. 11), our estimation of fault dip is not robust. In general, the dip of the CSEF in the eastern syntaxis is significantly shallower than in the central YFTB, where it was reported (Bruhn et al., 2004) that the CSEF dips to the north at 40° with almost pure dip-slip motion. The best-fit fault plane intersection to the CSEF trace west of Mount St. Elias suggests that the fault dip is as shallow as 10°. Because of the steep topography, the fault plane for segment A (green line, Fig. 11) intersects the surface on the north side of the ridge between Mount Huxley and the Bagley Icefield. On the north side of Mount Huxley, fault segment A dips in the same direction, but less steeply than topography. Based on this geometric projection and the juxtaposition of amphibolite grade rocks of the Valdez Group to the east against lower grade rocks of the Orca Group to the west, we tentatively map the CSEF at this location (Figs. 3 and 11). The position of the CSEF at this location west of Mount Huxley is roughly coincident with an unnamed fault, separating the Valdez Group and Orca Group, included in regional geologic maps (Plafker, 1987; Plafker et al., 1994; Richter et al., 2005). Our interpretation suggests that the CSEF in the eastern syntaxis area may be a partial klippe (Figs. 3, 4, and 11). This relationship suggests that the CSEF may no longer root into its original fault system at depth and may have been offset by faults beneath the Bagley Icefield and upper Seward glacier (Berger et al., 2008a; Enkelmann et al., 2010; Spotila and Berger, 2010).

**Faults East of the Seward Glacier Throat**

A few linear glacial valleys trend east-northeast and may contain unrecognized structures within the Yakutat Group mélangé east of the Seward glacier throat (Fig. 3). During limited reconnaissance mapping, we identified scattered small nunataks of Yakutat Group flysch south of Mount Owens, but were unable to determine if these were in fault contact beneath the Yakutat Group mélangé, similar to the structural relationship along the Libbey Glacier fault, or large blocks within the mélangé. We also observed a lithologic and metamorphic juxtaposition between greenschist facies phyllites on a ridge just north of Mount Owens and zeolite facies graywacke to the south within the Yakutat Group on the northern slope of Mount Owens. Finally, the upper Seward glacier throat itself is a good candidate for an unrecognized structure based on the elevation difference and offset between the Valdez Group at Mount Augusta and exposures of the Valdez Group east of Mount Owens along the Fairweather fault system (Fig. 3) (Campbell and Dodds, 1982), although the...
fault relationships between these two areas are covered by the Seward glacier and are unclear. We tentatively map faults at these locations and emphasize the need for further study (Fig. 3).

**SAMOVAR HILLS**

The Samovar Hills make up the core of the eastern syntaxis region and were mapped by Plafker and Miller (1957) and Plafker (1987). We spent five weeks in the 2006 and 2007 field seasons in the Samovar Hills working on detailed mapping and fault kinematic studies. We focused our efforts on the two major fault systems in the central Samovar Hills, the Hubbs Creek and Marvitz Creek faults, and on the large anticlinorium in the western Samovar Hills. The results of our mapping are presented as a geologic map in Figure 12 and as two cross sections across the Samovar Hills (Figs. 13 and 14).

These cross sections were created by loading the geologic map into structural modeling software (2DMove created by Midland Valley, www.mve.com) and projecting structural features onto the plane of section. Contacts, faults, and bedding traces were projected in both the dip direction and along strike using a calculated trend and plunge of various fold axes for the along-strike projection following the methods outlined in Pavlis and Bruhn (2011). For our fault studies, we measured fault surfaces and shear sense indicators directly wherever possible. For fault zones with large populations of
Figure 12. Geologic map of the Samovar Hills. Location is in Figure 3. Q—Quaternary, T—Tertiary, K—Cretaceous.
Figure 13. Cross-section B–B’ through the Samovar Hills, oriented approximately in the dip direction. Location is in Figure 12. QT$_y$—Quaternary–Tertiary Yakataga Formation; $T_k$—Kulthieth Formation; $K_y$—Cretaceous Yakutat Group flysch; hcv—Hubbs Creek volcanics.

Figure 14. Cross-section C–C’ through the Samovar Hills, oriented approximately in the strike direction. Location is in Figure 12. QT$_y$—Quaternary Yakataga Formation; $T_k$—Kulthieth Formation; $T_{ol}$—Oily Lake member; $K_y$—Cretaceous Yakutat Group flysch; hcv—Hubbs Creek volcanics.
fault planes and shear sense indicators with little variation, we used a simple average for overall fault geometry. Where fault zones were buried or complex, populations of subsidiary faults were measured and paleostrain calculated using a variation on the technique of Krantz (1988) (following Bruhn and Pavlis, 1981; Bruhn et al., 2004). These methods assume that fault slip occurs in the direction of maximum resolved shear stress and that the null-motion direction (m-pole) is perpendicular to the slip vector within the fault plane. For each subsidiary fault, we measured the fault plane orientation, the slip direction (slickenline orientation), and estimated shear sense. We plotted each slip direction and calculated each m-pole based on the orientation of the individual fault planes. We then contoured the m-poles and calculated the best-fit lineation (β-axis). Where exact fault geometry was unknown and kinematic indicators varied, we fit a plane between fault strike, as determined from map trace, and the β-axis to estimate the overall fault zone orientation. The overall slip vector for the fault zone was assumed to occur along the intersection of the estimated fault plane and the great circle orthogonal to the β-axis. As expected, the calculated slip vectors generally were within a few degrees of the best-fit great circle for directional (slickenline) data. We attempted to ensure that our fault plane and slip vector calculations were also consistent with field observations of displacement based on other geologic constraints. Fault zones that had subsidiary fault populations with large variation in slip direction or with multiple slickenlines on the fault surfaces were discarded, and data for those fault zones are not presented here. In these cases, we suspect that multiple phases of deformation may have occurred. Best estimates of fault geometry and average slip vectors are discussed in the following and presented in Table 1 and Figure 15.

Figure 15. (A) Equal area, lower-hemisphere, stereonet plots of geometry and kinematic data for selected faults in the Samovar Hills area (faults labeled in Fig. 12). For the Lower Hubbs Creek Fault and fault 3, the fault plane and slip vector were determined using a variant on the paleostrain method of Krantz (1988) (see text); all other faults and kinematic data were measured directly. The best fit slip vector and fault geometry for each fault are presented in Table 1. (B) Fold axes within the Samovar Hills area. The single plot of the fold axis in the Yakataga Formation (Fm.) comes from the large plunging box anticline. Two distinct populations of fold axes are present and related to deformation associated with an older transpressional system (green circle) and the Yakataga fold-and-thrust belt (blue circle). (C) Poles to bedding in the Samovar Hills, separated by rock unit; mem.—member).
Hubbs Creek Fault

The Hubbs Creek fault system separates three distinct fault blocks with different stratigraphic sequences: (1) a western fault block that contains several hundred meters of Kulthieth Formation unconformably overlying Yakutat Group basement; (2) a fault splay between the two strands of the Hubbs Creek fault that exposes only volcanic rocks, the Hubbs Creek volcanics, but does not expose the base of the volcanic sequence; and (3) an eastern fault block that exposes only the Yakutat Group basement (Fig. 12). The Yakataga Formation overlaps all three of these fault blocks along the angular basal Yakataga unconformity. Because of these stratigraphic relationships, we divide the Hubbs Creek fault into the lower Hubbs Creek fault, where the Hubbs Creek volcanics abut the Kulthieth Formation, and the upper Hubbs Creek fault, where the fault places the Yakataga Formation against itself (Fig. 12).

The lower Hubbs Creek fault is buried by young sediments in a stream valley, but subsidiary fault populations suggest that the fault is a dextral oblique thrust fault dipping northeast (Table 1; Fig. 15). This is in good agreement with a measurement by Plafker (1987) east of Hubbs Creek suggesting that the fault dips 75° toward ~035. The Hubbs Creek fault is difficult to trace farther to the southeast, however, where it projects toward a prominent, undated landform and may ultimately merge with the Esker Creek fault system (Fig. 12).

The lower Hubbs Creek fault also appears to truncate steeply dipping faults that bound the Hubbs Creek volcanics (Figs. 12 and 13). We identified a small outcrop south of the trace of the lower Hubbs Creek fault where the Hubbs Creek volcanics were juxtaposed against the Yakutat Group along a subvertical fault with almost pure dextral strike-slip motion (fault 1, Table 1; Fig. 15). We did not directly observe the fault bounding the eastern side of the Hubbs Creek volcanics, but traced the lithologic contact to the boundary with the overlying Yakataga Formation where it intersects a younger fault zone (discussed herein). Along the projected trace of the eastern bounding fault to the Hubbs Creek volcanics, bedding within the Yakataga Formation contained minor dextral offset (<15 m), possibly as a result of limited reactivation of this fault since deposition of the Yakataga Formation.

A syncline that plunges 38° toward 323 in the Kulthieth Formation and 37° toward 341 in the Yakataga Formation is located in the footwall of the Hubbs Creek fault, suggesting that folding postdates the basal Yakataga unconformity. Adjacent to the fault, a series of upright to overturned folds in the Kulthieth Formation with axial planes subparallel to the main fault plane are superimposed on the eastern limb of this syncline. These folds have wavelengths of ~10–30 m and interlimb angles <30°. These folds are not present in the Yakataga Formation along the Hubbs Creek fault and may be older than the Yakataga Formation or related to mechanical differences in the stratigraphy.

The upper Hubbs Creek fault is exposed in a small topographic notch along the ridgeline and dips steeply to the northeast with dextral motion (Table 1; Figs. 12 and 15). Despite the similar geometry to the lower Hubbs Creek fault, the slip vector for the upper Hubbs Creek fault plunges 25°–30° less steeply. A low-angle, north-dipping thrust fault intersects the upper Hubbs Creek fault and places the Yakataga Formation over the Kulthieth volcanics and Yakatag Group along strike (fault 2, Table 1; Figs. 12 and 15). The fault cuts bedding in the Kulthieth Formation at a low angle; this, with the younger-on-older thrust relationship, implies that this fault postdates deposition and folding of the Kulthieth Formation. Displacement on this low-angle fault is unknown, but the fault appears to tip out within ~2 km to the east (Fig. 12). This fault may have locally exploited the basal Yakataga unconformity as a detachment.

The lower plunge of the slip vector for the upper Hubbs Creek fault may be recording motion on this younger, shallowly dipping fault, in which case the slip vector for the lower Hubbs Creek fault may be more representative of the primary older movement history.

In map pattern, the basal Yakataga unconformity shows little to no offset across the Hubbs Creek fault, suggesting limited displacement since deposition of the Kulthieth Formation (Fig. 12). The orientation of the slip vector for the lower Hubbs Creek fault is comparable to the regional dip and dip direction of bedding in the Kulthieth Formation (25°–40° toward 310–340). Structural restoration to a time equivalent with the basal Kulthieth unconformity removes the regional, northward dip of the Kulthieth Formation in the hanging wall of the Kulthieth-Esker Creek fault system and reduces the plunge of the slip vector on the lower Hubbs Creek fault, increasing the strike-slip component of motion.

Oily Lake Member

Between the Hubbs Creek fault and the Marvitz Creek fault the Yakatag Group basement is overlain by 100–150 m of green to maroon, mottled, tuffaceous mudstone and siltstone (Fig. 12) that we correlate to the siltstone of Oily Lake mapped by Plafker (1987). We refer to this unit as the Oily Lake member of the Kulthieth Formation following preliminary sedimentological work (Landis, 2007; Witter et al., 2009). Local gravel conglomerates are present throughout the Oily Lake member and have angular clasts suspended in a mudstone matrix. A thin (1–2 m) rounded pebble conglomerate is deposited unconformably on the Kulthieth Group at the base of the Oily Lake member (Fig. 16).

In the central Samovar Hills, the Oily Lake member thins to the northeast, where it is ultimately cut out by an angular unconformity at the base of the Kulthieth Formation (Fig. 16). We traced this contact to the southwest where the Oily Lake member is truncated against the Marvitz Creek fault. Bedding within the Oily Lake member generally dips 40°–60° toward 020–070. Several folds are present within the Oily Lake member with axes plunging an average of 14° toward 298 (Fig. 15). The strike of bedding and trend of fold axes is subparallel to the strike of the Hubbs Creek fault and Marvitz Creek fault, but at a high angle to bedding within the overlying Kulthieth Formation that dips 45°–50° toward 300–340.

The Oily Lake member is also exposed in the southern Samovar Hills where it crops out along the north side of Marvitz Creek (Fig. 12). The map pattern suggests that bedding may dip moderately southwest. However, the limited exposures consist of highly fractured mudstones with poor indicators of bedding orientation.

Marvitz Creek Fault

The Esker Creek fault bounds the southeastern Samovar Hills and intersects or connects with the Malaspina fault near an ~45° bend in the topographic front of the Samovar Hills. The Marvitz Creek fault splays off of the Esker Creek fault system near this intersection, striking subparallel to the trace of the Hubbs Creek fault (Fig. 12). To the south, the Marvitz Creek fault juxtaposes Yakutat Group basement and the Oily Lake member against the Kulthieth Formation; however, displacement decreases toward the north where the Marvitz Creek fault splits into multiple fault strands (Figs. 12 and 14).

Although the Marvitz Creek fault is obscured by young river gravel along much of its trace, we observed a small segment of fault rocks related to the structure on the west side of Marvitz Creek. The fault dips steeply to the southwest and displays apparent normal displacement of Kulthieth Formation over the Oily Lake member (Table 1). The steeply dipping fault may have originated as a reverse fault that was tilted by younger folding. The fault strikes to the north where it dies out along the Kulthieth Formation–Oily Lake member contact. We did not
observe any offset of bedding within the Kulthieth Formation to the northwest.

We also measured subsidiary fault populations at two fault splays from the Marvitz Creek fault that bound a small exposure of the Hubbs Creek volcanics. The western splay fault emplaces the Hubbs Creek volcanics against the oily Lake member (fault 3, Table 1; Fig. 15). We could not follow this fault to the north within the Oily Lake member due to poor exposure, and we did not observe any significant offset of the angular unconformity at the base of the Kulthieth Formation. The eastern splay fault is also poorly exposed, but juxtaposes the Yakutat Group and the Hubbs Creek volcanics and appears to be a nearly vertical, dextral strike-slip fault (fault 4, Table 1; Fig. 15). This fault did not offset the base of the Oily Lake member (Fig. 12) and may predate the main Marvitz Creek fault. Plafker (1987) and Plafker et al. (1994) suggested that the contact between the Hubbs Creek volcanics and Yakutat Group at the Marvitz Creek locality is depositional, a relationship supported by well data to the southeast (Plafker, 1971; 1987; Rau et al., 1983). The fault rocks we observed along this contact may be related to minor reactivations of an originally depositional contact. Between the two splay faults, the Hubbs Creek volcanics are in depositional contact with the Oily Lake member.

**Samovar Hills Anticlinorium**

Perhaps the most prominent structural feature of the Samovar Hills is a large (~10 km wide) box anticline in the Yakataga Formation that plunges 30° toward 270 (Plafker, 1987; Bruhn et al., 2004; this study). The fold is consistent with a hanging-wall anticline above the Malaspina thrust fault with a steeply dipping forelimb (~80°) and a more moderately dipping backlimb (30°–40°) (Figs. 13 and 14). Restoration of the cross section in Figure 13 suggests >3 km of slip across the Malaspina fault to construct the anticlinorium. The thickness of the Yakataga Formation in the footwall of the Malaspina fault shown in Figure 13 is unknown, but may be an underestimate based on the Riou Bay #1 well, drilled in the footwall of the Malaspina fault in the Chaix Hills, that encountered >4 km of Yakataga Formation (Fig. 4). Within the Yakataga Formation, dip domains in the box anticline are sharply divided by kink folds; however, the expression of the anticline in the deeper structural and stratigraphic levels has remained unclear. As part of an effort to resolve the general structure of the Samovar Hills, we mapped extensively the Kulthieth Formation and the center of the anticline.

Just below the basal Yakataga unconformity in the box anticline, the strike of bedding in the Kulthieth Formation is subparallel to the Yakataga Formation, but dips 10°–30° more steeply than the overlying Yakataga Formation in a similar down-dip direction, excluding overturned bedding in the Kulthieth Formation on the southern limb of the anticline (Fig. 14). This observation not only suggests that deformation began prior to the deposition of the Yakataga Formation in the Samovar Hills, but also suggests that deformation related to this specific anticline predates the Yakataga Formation. Removal of the dip in the Yakataga Formation to a time equivalent with the basal Yakataga unconformity yields an approximate restoration to a gentle anticline in the Kulthieth Formation plunging 10°–20° toward the west with a forelimb dipping ~20° to the south and a backlimb dipping 10°–15° to the north (interlimb angle of 145°–150°).

Toward the core of the anticlinorium, bedding in the Kulthieth Formation steepens and a series of parasitic (wavelengths of ~1 km) overturned folds plunge 30°–65° toward the north and west (Plafker, 1987) (Fig. 13). We did not observe any angular unconformities at this stratigraphic level of the Kulthieth Formation or any significant faults that cut bedding. We observed pervasive bedding-parallel detachments along coal and shale layers and evidence for flow of these strata into overthickened hinge zones. We suspect that a roof detachment or series of detachment surfaces separates the overturned parasitic folds and the more modestly folded bedding higher in the Kulthieth Formation, near the basal Yakataga unconformity. Similar structures are common in the coal-bearing Kulthieth strata throughout the YFTB. At the base of the overturned folds, exposed near the ridgeline on the west side of Marvitz Creek, there is a major detachment, indicating that the parasitic folds are intraformational detachment folds. We tentatively correlate this detachment zone to another bedding-parallel detachment at a similar stratigraphic interval between Marvitz and Hubbs Creek (Figs. 12–14). The location of the overturned folds within the core of the Samovar Hills anticlinorium and near the projected intersection of the axial planes to the box fold in the Yakataga Formation suggests that much of the deformation at this stratigraphic and structural level may be related to tightening of the anticlinorium after deposition of the Yakataga Formation.

Numerous upright folds in the lower Kulthieth Formation that plunge 15°–25° toward the west are in a complex area structurally and stratigraphically beneath the detachment zone at the base of the overturned folds. The decrease in the plunge of the folds compared to the overturned folds and the box anticline...
in the Yakataga Formation is indicative of an overall decrease in plunge of the Samovar Hills anticlinorium along trend to the east. The largest folds have wavelengths to 150 m, with many superimposed smaller folds (wavelengths <20 m) (Fig. 13). Locally, bedding-parallel detachments may exist structurally beneath these smaller folds, including along the Marvitz Creek fault, but we did not observe detachments at the base of the Kulthieth Formation west of Marvitz Creek, where the Kulthieth Formation is separated from the east side of the Hubbs Creek volcanics by an angular unconformity.

Beneath the unconformity, near the center of the Samovar Hills anticlinorium, the Oily Lake member contains a series of tight, overturned folds verging southwest with fold axes plunging 10°–15° toward the northwest (Fig. 12). These folds are subparallel to the northern Marvitz Creek fault and may be related to strain accumulated across the Marvitz Creek fault zone. We suggest that the Marvitz Creek fault, the tight folds in the Oily Lake member adjacent to the Marvitz Creek fault, and shortening within the core of the Samovar Hills anticlinorium are interrelated.

**DISCUSSION**

### History of Deformation

The eastern syntaxis region and the Samovar Hills in particular record the clearest record of the three-dimensionality in the deformation history for the Yakutat microplate. This history includes an early strike-slip to oblique transpressional environment as the Yakutat microplate traveled northward along the North American margin, complex structural overprints as these transpressional structures were translated into the Alaskan eastern syntaxis region, and waning transpressional deformation and the initiation of fold-and-thrust style deformation.

In the Samovar Hills, the Hubbs Creek volcanics are in fault contact with the Yakutat Group along a small fault segment intersecting the Marvitz Creek fault and on the east side of Hubbs Creek (Fig. 12). At Hubbs Creek, dextral strike-slip movement along the fault bounding the east side of the Hubbs Creek volcanics occurred before deposition of the Yakataga Formation. The fault segment intersecting the Marvitz Creek fault is truncated to the north by an unconformity at the base of the Early to Middle Eocene (ca. 42.5–49.5 Ma; McDouggall, 2007) Oily Lake member, placing relatively precise timing constraints on the slip observed along this segment. Although scant, the available evidence suggests a very early history of dextral strike-slip deformation at this point within the Yakutat microplate, consistent with models for the tectonic evolution of the Yakutat microplate as it was translated northward along the North American margin (Plafker, 1987; Pavlis et al., 2004) and with the observation of a long-lived strike-slip southwestern boundary to the Yakutat microplate, the offshore Transition fault (Christeson et al., 2010).

Series of open folds with axial planes subparallel to the Hubbs Creek fault and Esker Creek fault are present within the Oily Lake member (Figs. 12 and 15). Southeast of the Samovar Hills, the Hubbs Creek fault connects with the Esker Creek fault, which is a forethrust associated with the transpressional margin in the eastern Yakutat microplate (Bruhn et al., 2004; Plafker and Thatcher, 2008) (Fig. 3). The folds in the Oily Lake member record shortening subperpendicular to these forethrusts and may indicate the development or continuation of transpressional to northeast-convergent deformation. We suggest that this deformation may partially record the northwest translation of the Yakutat microplate along the southeast Alaska margin by the right-lateral Contact, Fairweather, and Queen Charlotte fault systems. The folds in the Oily Lake member are truncated by the angular unconformity at the base of the Kulthieth Formation (Figs. 12 and 16). The Kulthieth Formation in the Samovar Hills is late Early Eocene to early Middle Eocene in age (Plafker, 1987), constraining the deformation in the Oily Lake member to the Early to Middle Eocene. The unconformity at the base of the Kulthieth Formation is likely related to this deformational event.

Following deposition of the Kulthieth Formation, the record of deformation in the Yakutat microplate expands dramatically. In the Samovar Hills, the Kulthieth Formation is folded within the Samovar Hills anticlinorium and juxtaposed with the Hubbs Creek volcanics along the Hubbs Creek fault. Because the Yakataga Formation is incorporated into the Samovar Hills anticlinorium, but the basal Yakataga unconformity is minimally offset by the Hubbs Creek fault, we propose that displacement along the Hubbs Creek fault preceded development of the anticlinorium (Fig. 12). At the least, development of the anticlinorium continued into Yakataga Formation time, whereas motion on the Hubbs Creek fault had essentially ended. This observation is an important structural relationship that locally demonstrates the end of deformation associated with a transpressional system in the Hubbs Creek–Esker Creek fault system and the initiation and growth of the YFTB associated with the Samovar Hills anticlinorium and Malaspina fault. The timing of this transition is constrained by the basal Yakataga unconformity.

### Basal Yakataga Unconformity

The precise age of the base of the Yakataga Formation in the eastern syntaxis is uncertain because the age of the Yakataga Formation varies across the orogen, generally decreasing in age from west to east (Plafker et al., 1994). The oldest recorded age from outcrops at Icy Bay is Early Pliocene (ca. 3.0–3.5 Ma), although the base of the section is not exposed (Lagoe and Zellers, 1996). At Yakataga Reef in the central YFTB and in offshore industry wells south-west of Icy Bay, the base of the Yakataga Formation is latest Miocene to earliest Pliocene in age (ca. 5–6 Ma) (Arnaud, 2010; Lagoe and Zellers, 1996; Zellers, 1995), probably close to the age of the base of the Yakataga Formation in the eastern syntaxis area. The basal Yakataga unconformity is an angular unconformity above folded Middle Eocene rocks of the Kulthieth Formation in the Samovar Hills. Thus, in the eastern syntaxis area, the unconformity cuts out Middle Eocene to latest Miocene–earliest Pliocene strata. In the central and western YFTB a more complete stratigraphic section is present and the Yakataga Formation commonly conformably overlies older strata, including the Late Eocene to Early Miocene Poul Creek Formation (Plafker, 1987; Brennan et al., 2009), suggesting that the erosional and deformational event related to the basal Yakataga unconformity in the eastern syntaxis occurred between the Early Miocene and the latest Miocene to earliest Pliocene. Because the Yakutat microplate converges obliquely with North America, this deformation event may be time transgressive. In this scenario, we speculate that deformation may have progressed west to east, as the Yakutat microplate was translated northwestward into the southern Alaskan margin.

In addition to constraining the timing of fold-and-thrust belt development in the Samovar Hills area, the basal Yakataga unconformity records strain accumulation in the YFTB prior to the deposition of the Yakataga Formation. West of the Tyndall Glacier in the northern Karr Hills (Fig. 6) and in the Samovar Hills anticlinorium, the development of fold-and-thrust structures predates the Yakataga Formation. Despite an angular unconformity reported at the base of the Yakataga Formation in parts of the central YFTB (Miller, 1971; Plafker, 1987; Wallace, 2008), previous studies have generally assumed the initiation of fold-and-thrust style deformation and deposition of the Yakataga Formation were roughly coincident (Eyles et al., 1991; Plafker et al., 1994; Pavlis et al., 2004; Meigs et al., 2008; Berger et al., 2008b; Chapman et al., 2008; Wallace, 2008). This assumption may be good in the western to central YFTB,
but the assumption is less appropriate toward the eastern YFTB because deposition of the Yakataga Formation was diachronous.

The presence of deformation prior to deposition of the basal Yakataga Formation has considerable implications for reconstructing the structural history of the YFTB and reconciling the present rate of deformation with the total observed shortening. Pfafker et al. (1994) noted 45% shortening in the Paleogene compared to 25% shortening in the Neogene in the central YFTB; in Chapman et al. (2008), >75 km shortening was reported in the Paleogene strata compared to ~25 km shortening in the Yakataga Formation alone. In Chapman et al. (2008), it was assumed that the disparity between deformation recorded in the Paleogene and Neogene sections was related to either duplexing of the Kulthieth Formation and erosion of the Yakataga Formation above the structurally higher thrust sheets (e.g., Meigs et al., 2008), or nondeposition of the Yakataga Formation on what are now the structurally higher thrust sheets. However, the discrepancies in shortening between the Paleogene section and Yakataga Formation could also be related to deformation in the Early to Late Miocene, as indicated by eroded structures beneath the basal Yakataga unconformity.

The level of erosion recorded by the basal Yakataga unconformity, the amount of shortening within the Kulthieth Formation, and the degree of structural discordance across the basal Yakataga unconformity provide indirect evidence that deformation may have significantly preceded deposition of the Yakataga Formation in the eastern syntaxis area. However, if the current high rates of convergence across the Yakutat microplate extended into Miocene, much of this deformation could have occurred within only a few million years prior to the deposition of the Yakataga Formation. Additional work is needed to more precisely constrain the timing and amount of shortening in the eastern syntaxis area.

Reducing the total shortening recorded in the YFTB since the onset of deposition of the Yakataga Formation in the latest Miocene decreases estimates of the rate of shortening over that time period. This exacerbates an already unresolved mismatch between current rates of convergence and total observed shortening from cross-section restorations (Worthington et al., 2010; Chapman et al., 2008; Meigs et al., 2008; Wallace, 2008). Structural restoration of the Yakataga Formation in Figure 4 yields >17 km of shortening and, when combined with the range of ages for the Yakataga Formation, suggests a minimum shortening rate of ~2–6 mm/yr. This rate is an order of magnitude less than GPS derived shortening rates of ~3.5 cm/yr across the eastern YFTB (Elliott et al., 2009, 2010).

St. Elias Orogenic System

There is evidence for active slip only on the Malaspina fault (Elliott et al., 2010; Estabrook et al., 1992) among the major north-dipping thrust faults within the eastern YFTB. AHe ages decrease slightly to the south across the Chaix Hills fault, although this decrease is not statistically significant as an indicator of fault slip (Berger et al., 2008b). AHe age pairs suggest that the Libbey Glacier fault may not be currently active (Berger et al., 2008b). We suggest that the CSEF may be a partial klippe that no longer roots into a deeper fault system (Figs. 4 and 11), indicating that the CSEF is probably not active. The position of the CSEF at high elevation on the steep southern flanks of Mount St. Elias and Mount Augusta also suggests that the CSEF is not active (Figs. 3 and 4). Although the exact mechanisms remain unclear, active shortening within the eastern St. Elias orogenic wedge appears to be concentrated at toe of the wedge, at the Malaspina fault, and beneath the Bagley Icefield and upper Seward glacier along the Bagley-Contact fault system. This spatial relationship forms a narrow orogenic wedge with a cross-sectional width of as little as 35 km and a basal décollement dipping 5°–10° toward the north at 12–16 km depth. The surface slope of the wedge changes across the Libbey Glacier fault, with an average slope of 15° north of the fault and an average slope of 2° in the thrusted sedimentary cover south of the Libbey Glacier fault (Fig. 4).

Many researchers suggest that the Malaspina fault may be the youngest part of the YFTB because of the narrow width of the eastern YFTB, active slip on the Malaspina fault, the position of the Malaspina fault at the eastern end of the YFTB, and because the Malaspina fault represents the deformational limit to the eastern YFTB (Plafker et al., 1994; Bruhn et al., 2004; Chapman et al., 2008). Therefore, the evidence for significant contraction on the Malaspina fault in pre-Yakataga time and perhaps even pre-Kulthieth time as recorded by deformation in the Samovar Hills is surprising. The long-lived record of contraction on the Malaspina fault and structural overprinting in the Samovar Hills may indicate that the eastern syntaxis has remained fixed over time, consistent with geodynamic models for the St. Elias orogen (Koons et al., 2010).

To the southeast of the eastern syntaxis area, the orogenic margin is slightly transpressive with dextral strike slip partitioned on the Fairweather fault and dip slip partitioned on forethrusts such as the Esker Creek fault (McAleer et al., 2009; Pfafker and Thatcher, 2008; Elliott et al., 2010; Bruhn et al., 2004). The orientations of the Esker Creek fault and Fairweather fault become increasingly perpendicular to the direction of current Yakutat microplate motion as they connect with the Malaspina fault and Bagley-Contact fault system, respectively, in the eastern syntaxis area (Fig. 3). This change in orientation corresponds to an increase in the width of the YFTB toward the west and creates a restraining bend along the Fairweather-Contact fault system in the northern eastern syntaxis (Fig. 1). We suggest that both the Bagley-Contact fault system and the Malaspina fault accommodate an increased amount of convergence across the eastern syntaxis as their orientations change.

Structural style changes across the orogenic wedge, with folding increasing up structural section. Folds at the toe of the wedge in the Malaspina thrust sheet are generally open, upright, and have relatively long wavelengths of as much as a few kilometers. Folds in the Kulthieth Formation within the Chaix Hills and Libbey Glacier thrust sheets have shorter wavelengths of hundreds of meters and are generally asymmetric, verging to the south with steep to overturned southern limbs. In the structurally highest thrust sheets, the Yakutat Group mélangé is intensely folded, often with chaotic bedding, although much of this structural complexity is probably inherited from its deposition and deformation within an accretionary complex.

CSEF

In the eastern syntaxis, the CSEF places amphibolite facies rocks of the Valdez Group on the low-grade to unmetamorphosed Cretaceous and Tertiary rocks of the Yakutat microplate (Fig. 3) (Plafker et al., 1994). The presence of these high-grade metamorphic rocks has several implications for the structure of the St. Elias orogen in the eastern syntaxis area. The Contact fault forms the southern boundary to the Chugach terrane and Valdez Group (Pfafker, 1987); however, the Contact fault is located north of the high-grade rocks of Valdez Group where it connects with the Fairweather fault beneath the upper Seward glacier (Fig. 1). We propose that the low-angle CSEF in the eastern syntaxis is an erosional remnant of the Contact fault–Fairweather fault system preserved at high elevation with Valdez Group strata in its hanging wall. Pfafker et al. (1994) suggested that these rocks were translated into their present position along the Fairweather fault.

If the CSEF in the eastern syntaxis is an erosional remnant of the Contact fault–Fairweather fault system, as we propose, it raises questions concerning the CSEF in the central and western Yakutat microplate. Specifically, how does the CSEF of the western and central YFTB...
connect into the fault systems of the eastern syntax? Also, how do Prince William terrane rocks between the CSEF and the Bagley-Contact faults to the west relate structurally to the Yakutat mélangé in the eastern syntax? These are essential questions that will need to be addressed in further research.

The high metamorphic grade at high elevation and young AHe and ZHe ages for the Valdez Group in the St. Elias area (Berger et al., 2008b; Enkelmann et al., 2010) indicate significant tectonic exhumation. The geometry of the dextral Fairweather fault to Contact fault transition in the eastern syntax area forms a restraining bend that is also consistent with tectonic exhumation (Figs. 1 and 3). It is unclear if this exhumation may be related to slip along the south-dipping Bagley backthrust, as proposed in Berger et al. (2008a), structural thickening of the Yakutat Group at depth south of the Contact fault, or some combination of both. The Chugach terrane exposed at the surface north of the Bagley Icefield and upper Seward glacier displays a lower metamorphic grade and has produced older AHe ages (Berger et al., 2008b), suggesting significantly less tectonic exhumation north of the Bagley-Contact fault.

Implications of the Yakutat Group in the Eastern Syntax

It is generally accepted that the Yakutat microplate was excised from the Cordilleran margin and subsequently carried northward; however, there is considerable debate concerning where it originated. The most specific restoration of the Yakutat microplate proposes that the DRZ is a displaced segment of the Chatham Strait fault (Plafker, 1987; Plafker et al., 1994) (Fig. 17). The Chatham Strait fault is a dextral strike-slip fault linking the Denali fault and Queen Charlotte fault system and is located ~600 km southeast of the Samovar Hills. The northern suture of the Chugach accretionary complex, the Border Ranges fault, is truncated by the Chatham Strait fault, suggesting a total post-Cretaceous displacement of ~150–200 km (Hudson et al., 1982; Pfafker, 1987; Gehrels, 2000). Pfafker et al. (1994) suggested that in Paleocene to Eocene time, the Chatham Strait fault cut through previously accreted terranes, the accretionary complex, and into the Kula or Pacific plate to juxtapose the Yakutat Group and oceanic crust across the fault. Pfafker (1987) proposed that motion on the Fairweather fault initiated in the Oligocene, trapping this segment of oceanic crust and continental crust (Pfafker, 1987; Pfafker et al., 1994), and cited the Hubbs Creek fault and Marvitz Creek fault in the Samovar Hills as a possible exposure of the DRZ.

The results of our research in the Samovar Hills suggest that the Hubbs Creek and Marvitz Creek faults may not be part of the DRZ as defined by Pfafker (1987). The Yakutat Group underlies the Kulthieth and Yakataga Formations west of the Hubbs Creek fault and is present within the core of the Samovar Hills anticlinorium in the hanging wall of the Malaspina fault (Fig. 13). The Marvitz Creek fault abruptly loses displacement and tips out near the center of the Samovar Hills anticlinorium; we propose that this is related to the formation of the anticlinorium. This provides evidence that the Marvitz Creek fault did not have significant displacement after deposition of the Kulthieth Formation, but it does not rule out the possibility that this fault represents a reactivated older basement fault. The Samovar Hills anticlinorium plunges to the west within the Malaspina thrust sheet and shows no discontinuity with the observed structure in the Chaix Hills. No evidence exists to indicate that the Hubbs Creek and Marvitz Creek faults mark the DRZ or to determine how much farther westward the Yakutat Group is present in the subsurface between the Chaix Hills and Malaspina–Esker Creek faults.

The Yakutat Group–sedimentary cover contact dips to the northwest within the Chaix Hills thrust sheet, broadly similar to the westward plunge direction of the Samovar Hills anticlinorium in the Malaspina thrust sheet. This orientation preserves a stratigraphically complete, albeit deformed, section of the Kulthieth Formation with younger stratigraphic levels exposed along strike to the west (Fig. 3). Additional subsurface information is required to determine a western limit to the Yakutat Group at depth within the Chaix Hills thrust sheet.

The Yakutat Group is also exposed within the Libbey Glacier thrust sheet and structurally higher, unnamed thrust sheets in the Mount St. Elias region. Our analysis revises the position of the CSEF, placing it higher along the southern flank of Mount St. Elias and Mount Haxley. Here, a low-angled thrust separates high-grade metamorphic rocks of the St. Elias massif to the north from rocks of dramatically different metamorphic grade and composition to the south, including the Yakutat Group. This relationship suggests that basement exposures south of Mount St. Elias are not part of the North American backstop. This interpretation of these rock assemblages in the Libbey Glacier thrust sheet places Yakutat Group strata >40 km west of the Samovar Hills (Fig. 3). Our observations did not allow us to determine how much further west the Yakutat Group is present in the Libbey Glacier thrust sheet.

Our observations of the Yakutat Group in the eastern syntax raise questions about the relationship between the Chatham Strait fault and the DRZ. If the DRZ is a lithologic boundary between Yakutat Group to the east and basaltic basement to the west, as proposed by Pfafker (1987) and Pfafker et al. (1994), then the
predicted length of the DRZ is ~275 km from the Transition fault offshore to the Samovar Hills (Fig. 1). The predicted length of the DRZ increases to >325 km by including the exposures of the Yakutat Group within the Libbey Glacier thrust sheet. These lengths do not include a restoration of the fold-and-thrust belt or consider shortening within the Yakutat Group. If oceanic basaltic sediments were emplaced next to the Yakutat Group along the DRZ by dextral movement on the Chatham Strait fault, then we would expect at least 275 km of slip on the Chatham Strait fault, significantly more than the documented displacement. The problem is exacerbated by the presence of the Admiralty Island volcanics (25–27 Ma), which are offset ~100 km along the Chatham Strait fault (Hudson et al., 1982; Ford et al., 1996; Loney et al., 1967). The offset of these volcanics suggests that at least half of the total post-Cretaceous displacement on the Chatham Strait fault may have occurred after the Yakutat microplate was excised from the margin (Plafker et al., 1994).

CONCLUSIONS

The eastern syntaxis of the St. Elias orogen contains at least four major thrust faults, including the Malaspina fault, Chaix Hills fault, Libbey Glacier fault, and the CSEF. We have revised previous interpretations of the trace of the CSEF, which is the Yakutat microplate suture, to higher along the south and east flank of Mount Augusta and higher along the south flank of Mount St. Elias and Mount Huxley. The CSEF dips 10°–30° toward 350–360 in the eastern syntaxis area, shallower than the CSEF in the central YFTB, and may be overlain by a partial klippe. The St. Elias orogenic wedge in the eastern syntaxis area is narrow; convergence is currently accommodated at the toe on the Malaspina fault–Esker Creek fault system and beneath the Bagley Icefield and upper Seward glacier on the poorly understood Bagley-Contact fault system that connects with the Fairweather fault to the southeast. The geometry and intersection of the major fault systems suggest that convergence increases toward the eastern syntaxis area as the Esker Creek fault intersects with the Malaspina fault and as the Fairweather fault transitions into the Bagley-Contact fault system. Evidence from the Samovar Hills for contraction on the Malaspina fault in pre-Yakataga time suggests that the Malaspina fault may not be among the youngest structures within the YFTB; however, it does appear to be one of the most active.

The Yakutat Group is carried in thrust sheets to the north and west of the previously mapped position of the DRZ in the Samovar Hills and may be structurally thickened in the subsurface. The contact between the Kultuhieth Formation and Yakutat Group is exposed in the Chaix Hills thrust sheet north of the Samovar Hills, and the Libbey Glacier thrust sheet carries Yakutat Group strata where exposed at Haydon Peak and Mount Augusta. These locations extend the estimates for the length of the DRZ to >325 km. In the Samovar Hills, the Marvitz Creek fault forms a splay off the Malaspina–Esker Creek fault system that abruptly loses displacement within the core of the Samovar Hills anticlinorium. The Hubbs Creek fault records older strike-slip motion, but does not bound the Yakutat Group to the west. The presence of the Yakutat Group at high structural levels in the eastern syntaxis area casts doubt on the genetic link between the DRZ and the Chatham Strait fault, and the Marvitz Creek fault and Hubbs Creek fault in the Samovar Hills do not appear to be related to the Chatham Strait fault. The Chatham Strait fault is a key constraint in some tectonic reconstructions of the Yakutat microplate (Plafker, 1987; Plafker et al., 1994). Relaxing this constraint allows for a greater transport distance of the Yakutat microplate; however, it does not preclude the possibility that the Yakutat microplate originated along the southeastern Alaska margin.

We conclude that fold-and-thrust–style deformation began in the Early to latest Miocene in the eastern syntaxis area. The basal Yakataga unconformity, observed throughout the eastern YFTB, cuts out Middle Eocene to latest Miocene strata. The erosional event responsible for the unconformity occurred between the Early Miocene and latest Miocene. Structural relationships in the Samovar Hills suggest that this erosional event brackets the transition from basement-involved transpressional deformation to fold-and-thrust–style deformation within the Malaspina–Esker Creek thrust sheet as the Yakutat microplate was translated into the syntaxis area. Angular relationships across the basal Yakataga unconformity also demonstrate that deformation related to the eastern YFTB initiated prior to the deposition of the Yakataga Formation. The initiation of the fold-and-thrust belt was coincident with an end to oblique transpressional deformation. The Kultuhieth Formation and older strata in the eastern syntaxis record the earliest stages of fold-and-thrust–style deformation. It is unclear whether the timing of the transition to fold-and-thrust deformation is only applicable to the eastern syntaxis or may apply to the YFTB to the west in a synchronous or time-transgressive manner. Extending the timing for the initiation of the YFTB reduces geologic estimates of rates of convergence over the life of the orogen.


