Mesozoic and Cenozoic tectonics of the eastern and central Alaska Range: Progressive basin development and deformation in a suture zone

Kenneth D. Ridgway†
Jeffrey M. Trop‡
Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, Indiana 47907-1397, USA
Warren J. Nokleberg
U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025, USA
Cameron M. Davidson§
Department of Geology, Beloit College, Beloit, Wisconsin 53511, USA
Kevin R. Eastham
Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, Indiana 47907-1397, USA

ABSTRACT

Analysis of late Mesozoic and Cenozoic sedimentary basins, metamorphic rocks, and major faults in the eastern and central Alaska Range documents the progressive development of a suture zone that formed as a result of collision of an island-arc assemblage (the Wrangellia composite terrane) with the former North American continental margin. New basin-analysis, structural, and geochronologic data indicate the following stages in the development of the suture zone: (1) Deposition of 3–5 km of Upper Jurassic–Upper Cretaceous marine strata (the Kahiltna assemblage) recorded the initial collision of the island-arc assemblage with the continental margin. The Kahiltna assemblage exposed in the northern Talkeetna Mountains represents a Kimmeridgian–Valanginian backarc basin that was filled by northwestward-flowing submarine-fan systems that were transporting sediment derived from Mesozoic strata of the island-arc assemblage. The Kahiltna assemblage exposed in the southeastern Alaska Range represents a Valanginian–Cenomanian remnant ocean basin filled by west-southwestward–flowing submarine-fan systems that were transporting sediment derived from Paleozoic continental-margin strata uplifted in the along-strike suture zone. A belt of retrograde metamorphism and a regional antilinorium developed along the continental margin from 115 to 106 Ma, roughly coeval with the end of widespread deposition in the Kahiltna sedimentary basins. (2) Metamorphism of submarine-fan deposits of the Kahiltna basin, located near the leading edge of the island-arc assemblage, occurred at ca. 74 Ma, as determined from a new U-Pb zircon age for a synkinematic sill. Coeval with metamorphism of deposits of the Kahiltna basin in the southern part of the suture zone was development of a thrust-top basin, the Cantwell basin, in the northern part of the suture zone. Geologic mapping and compositional data suggest that the 4 km of Upper Cretaceous nonmarine and marginal marine sedimentary strata in this basin record regional subaerial uplift of the suture zone. (3) Shortening and exhumation of the suture zone peaked from 65 to 60 Ma, roughly coeval with the end of widespread deposition in the Kahiltna sedimentary basins. (4) From 60 to 54 Ma, ~3 km of volcanic strata were deposited over deformed sedimentary strata of the Cantwell basin, and several granitic plutons (the McKinley sequence) were emplaced along the suture zone. (5) Following igneous activity, strike-slip displacement occurred from ca. 54 to 24 Ma along the Denali fault system, which had developed in the existing suture zone. Late Eocene–Oligocene strike-slip displacement resulted in the formation of several small sedimentary basins along the Denali fault system. (6) Regional transpressive shortening characterized the suture zone from ca. 24 Ma to the present. Flexural subsidence, related to regional shortening, is represented by late Eocene to Holocene nonmarine deposits of the Tanana foreland basin. Regional subsidence resulted in Miocene coal seams up to 20 m thick and well-developed lacustrine deposits. Overlying the Miocene deposits are ~1.2 km of Pliocene and Holocene conglomeratic deposits. Compositional and paleocurrent data from these younger deposits record regional Neogene uplift of the suture zone and recycling of detritus from older basins to the south that had become incorporated into the uplifted suture zone. Geologic mapping of major thrust faults along the northern and southern margins of the suture zone docu-
ments Paleozoic strata thrust over both Pliocene fluvial deposits and Quaternary glacial deposits of the Tanana basin. These mapping relationships provide evidence that regional shortening continues to the present in the eastern and central Alaska Range.

Keywords: Alaska Range, Cantwell Formation, Kahiltna assemblage, suture zone, Usibelli Group, Wrangellia.

INTRODUCTION

In the northern Pacific region, the collision of allochthonous terranes with continental margins followed by suturing has been a fundamental process in the geologic development of North America and Asia (e.g., Şengör, 1987; Hsu et al., 1990; Plafker and Berg, 1994; Nokleberg et al., 1998). Much of the Mesozoic geologic history of southern Alaska, for example, has been interpreted as the result of the collision and accretion of an island-arc assemblage (the Wrangellia composite terrane) to the continental margin of North America (Fig. 1; Coney et al., 1980; Jones et al., 1982, 1986; Csejty et al., 1982; Pavlis, 1983; Nokleberg et al., 1985; Gehrels and Berg, 1994; Plafker and Berg, 1994). The Wrangellia composite terrane (terminology of Plafker and Berg, 1994) consists of the Alexander (Gehrels and Saleeby, 1987), Peninsular (Jones and Silberling, 1979), and Wrangellia (Jones et al., 1977) terranes and represents the largest allochthonous crustal fragment of southern Alaska (WCT in Fig. 1). Many of the previous geologic studies of the eastern and central Alaska Range have focused on defining the stratigraphy, structure, and paleomagnetic signature of individual terranes (e.g., Jones et al., 1982, 1986; Nokleberg et al., 1985; Plafker et al., 1994; Hillhouse and Coe, 1994). Our study, in contrast, focuses on the late Mesozoic and Cenozoic progressive development of sedimentary basins, faults, and metamorphic rocks that formed along the suture zone between the Wrangellia composite terrane and the former North American continental margin (Figs. 1, 2). We refer to this collisional zone in south-central Alaska as the Alaska Range suture zone (Fig. 3). This paper provides a synthesis of new data from sedimentological analysis of basinal strata, geologic mapping of major faults, and radiometric dating of metamorphic rocks in the Alaska Range suture zone. These data document the progressive growth of the suture zone from its inception as a late Mesozoic deep-marine sedimentary basin to one of the highest active mountain ranges on Earth.

GEOLoGIC SETTING AND PREVIOUS STUDIES

In the eastern and central Alaska Range, the Wrangellia composite terrane has been interpreted to have accreted onto a fragment of the continental margin of North America sometime during the Mesozoic. The Yukon-Tanana terrane represents the continental margin against which the Wrangellia composite terrane eventually accreted and consists of meta-morphosed Paleozoic and Mesozoic sedimentary and igneous rocks (YT in Figs. 1–3; Tempelman-Kluit, 1976; Nokleberg et al., 1992b; Dusel-Bacon et al., 1993; Hansen and Dusel-Bacon, 1998). The precise time of collision of the Wrangellia composite terrane with the continental margin is unclear and has been interpreted to have occurred sometime between the Late Jurassic and Late Cretaceous (e.g., Csejty et al., 1982; Jones et al., 1982; Pavlis, 1982; McClelland et al., 1992a; Cole et al., 1999; Trop et al., 2002; among others). The location of the collision with respect to western North America and the amount of postaccretionary, strike-slip translation is also highly debated (e.g., Umhoefer, 1987; McClelland et al., 1992a; van der Heyden, 1992; Maxson and Tikoff, 1996; Cowan et al., 1997; Mahoney et al., 1999; Stamatakos et al., 2001).

A broad zone of deformation marks the collisional boundary between the Wrangellia composite terrane and the Yukon-Tanana terrane in south-central Alaska. This highly deformed zone, which we refer to as the Alaska Range suture zone, extends from the Talkeetna thrust fault to ~100 km inboard of the highly deformed southern margin of the Yukon-Tanana terrane (Figs. 1–3). Jones et al. (1982) used the term “megasuture zone” on their cross sections through south-central Alaska (see their Fig. 3) in referring to the area between the Yukon-Tanana terrane and the Wrangellia composite terrane. The area that we refer to as the Alaska Range suture zone is one part of the regional suture zone between the Wrangellia composite terrane and northwestern North America (Pavlis, 1982; Coney and Jones, 1985).

Several major faults occur within the Alaska Range suture zone. The southeast-dipping Talkeetna thrust fault marks the boundary between Paleozoic–lower Mesozoic rocks of the Wrangellia composite terrane and Upper Jurassic–Upper Cretaceous deposits of the Kahiltna basin (Figs. 1–3). The next major fault system to the north in the Alaska Range suture zone is the Denali fault system (Figs. 1–3). The Denali fault is a dextral, strike-slip fault that consists of many individual fault segments (Lamphere, 1978). Late Cretaceous and early Cenozoic dextral displacement of up to 400 km probably occurred along the eastern and central segments of the Denali fault system in Alaska and the Yukon Territory (Eisbacher, 1976; Jones et al., 1982; Nokleberg et al., 1985; Plafker et al., 1989). In the study area, the major segment of the Denali fault system is the McKinley fault. On the McKinley fault, estimates of Cenozoic displacement range from 38 km since 38 Ma (Reed and Lamphere, 1974) to 32 km since the Oligocene (Hickman et al., 1977). The northernmost major fault in the Alaska Range suture zone is the Hines Creek fault (Figs. 1–3). In the central Alaska Range, the Hines Creek fault defines the boundary between deposits of the Late Cretaceous–early Eocene Cantwell basin to the south and metamorphosed rocks of the former North American continental margin (i.e., the Yukon-Tanana terrane) (Figs. 2, 3). Early studies interpreted the Hines Creek fault as an older (post–95 Ma) segment of the strike-slip Denali fault system that represented a major terrane boundary (Grantz, 1966; Wahrhaftig et al., 1975). Studies of Cantwell basin strata proximal to the Hines Creek fault indicate that the fault was active during the Late Cretaceous (80–70 Ma) on the basis of paleocurrent data, clast composition of conglomerate, and sandstone petrofacies (Trop and Ridgway, 1997). In the eastern Alaska Range, east of the Cantwell basin (Mount Hayes Quadrangle in Fig. 1), the Hines Creek fault has been mapped as one of a series of Cenozoic thrust faults within the Yukon-Tanana terrane (Nokleberg et al., 1989, 1992b). Strata representing major sedimentary basins are located in and proximal to the Alaska Range suture zone (Figs. 2, 3). The basins become progressively younger to the north (Fig. 2). The basins are the Late Jurassic–Late Cretaceous Kahiltna basins, the Late Cretaceous–early Eocene Cantwell basin, and the late Eocene–Holocene Tanana basin. All of the basins associated with the Alaska Range suture zone have been regionally shortened by folding and faulting (Fig. 3; e.g., Péwé et al., 1966; Wahrhaftig, 1970a, 1970b, 1970c; Csejty et al., 1992; Cole et al., 1999). The deposits in the older basins appear to have been incorporated into a series of thrust sheets between the Wrangellia composite terrane and the former North American continental margin (Fig. 3), and the amount of deformation between basins and within basins decreases northward.
Figure 1. (A) Index map showing location of study area in south-central Alaska (gray rectangular box) and major geologic elements of southern Alaska and northwestern Canada. WCT—allochthonous Wrangellia composite terrane; YT—Yukon-Tanana terrane, part of Mesozoic continental margin of North America; NA—North America craton; CG—Chugach terrane, Mesozoic and Cenozoic subduction-complex deposits; YK—Yakutat terrane, Cenozoic terrane that is currently being accreted to the southern margin of Alaska; TKF—Talkeetna thrust fault; DF—Denali fault; TF—Tintina fault; CF—Castle Mountain fault. Modified from Plafker and Berg (1994). (B and C) Geologic map showing present location of sedimentary basins, tectonostratigraphic terranes, igneous rocks, and major structural elements of the central and eastern Alaska Range. Thin black lines define 1:250,000 quadrangles; quadrangle names are shown in southeast or southwest corners. Solid dark line labeled A–A' on the Healy and Fairbanks Quadrangles represents the line of cross section shown in Figure 3. The Talkeetna thrust fault (Talkeetna Mountains, Healy, and Mount Hayes Quadrangles) defines the tectonic boundary between the allochthonous Wrangellia composite terrane and Upper Jurassic–Upper Cretaceous deposits of the Kahiltna basin (labeled KJk). Upper Cretaceous–lower Eocene deposits of the Cantwell basin are labeled Kcs and Tcv on (Caption continued on p. XXX.)
Figure 1. (Continued.) (Caption continued from p. XXX.) the Healy Quadrangle. The Tanana basin consists of deposits that are located mainly north of the Hines Creek fault and are labeled Tug, Tng, and Qa. Area labeled RM on Mount Hayes Quadrangle is the zone of retrograde metamorphism discussed in the text; anticline symbol within the area labeled RM shows the location of the regional anticlinorium discussed in the text. Valdez Creek shear zone (VCSZ) in southeastern corner of Healy Quadrangle is the Valdez Creek shear zone of the Maclaren Glacier metamorphic belt discussed in the text. Letters (A–D) show location of measured stratigraphic sections in Figure 4. Black arrows represent paleo–flow direction based on sole marks and lithofacies transitions. Adapted from Csejtey et al. (1992), Dusel-Bacon et al. (1993), and Nokleberg et al. (1994b). (D) Legend. Explanation of Paleozoic–Mesozoic tectonostratigraphic terranes and upper Mesozoic sedimentary and igneous rocks that overlap and/or intrude terranes shown in Figures 1B, 1C, and 2. Descriptions and inferred tectonic origins of terranes adapted from Nokleberg et al. (1994a, 1994b, 1998).
**D) UPPER MESOZOIC-CNENZOIC SEDIMENTARY AND IGNEOUS ROCKS**

<table>
<thead>
<tr>
<th>Formation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tanana Group</strong></td>
<td>Qs Quaternary surficial deposits - includes glacial deposits, alluvium, fluvial deposits, and colluvium.</td>
</tr>
<tr>
<td><strong>Canwell Group</strong></td>
<td>QTv Quaternary-Tertiary volcanic rocks - includes andesite, basalt, dacite, tuff, rhyolite, and breccia.</td>
</tr>
<tr>
<td><strong>Kohihtna Group</strong></td>
<td>Tng Pliocene Nanana Gravel - nonmarine conglomerate and minor sandstone, shale, and siltstone.</td>
</tr>
<tr>
<td><strong>Canwell Group</strong></td>
<td>Tug Upper Eocene-Miocene Usibelli Group - nonmarine sandstone, siltstone, conglomerate, and shale.</td>
</tr>
<tr>
<td><strong>Canwell Group</strong></td>
<td>Tv Tertiary undifferentiated volcanic rocks - basalt, andesite, rhyolite, tuff, and minor sandstone and shale.</td>
</tr>
<tr>
<td><strong>Canwell Group</strong></td>
<td>Tg Tertiary plutonic rocks - mainly biotite and biotite-hornblende granite, quartz monzonite, and granodiorite.</td>
</tr>
<tr>
<td><strong>Canwell Group</strong></td>
<td>TKg Cretaceous-Tertiary plutonic rocks - mainly biotite and biotite-hornblende granite and quartz monzonite.</td>
</tr>
<tr>
<td><strong>Canwell Group</strong></td>
<td>TKs Cretaceous-Tertiary sedimentary rocks - nonmarine conglomerate, sandstone, siltstone, and shale.</td>
</tr>
<tr>
<td><strong>Canwell Group</strong></td>
<td>Tcv Paleocene-Eocene upper Cantwell Formation - andesite, basalt, rhyolite, pyroclastic rocks, conglomerate, sandstone, siltstone, and shale.</td>
</tr>
<tr>
<td><strong>Kohihtna Group</strong></td>
<td>Kcs Cretaceous lower Cantwell Formation - nonmarine to marginal-marine conglomerate, sandstone, siltstone, shale, and minor coal and oncolitic limestone.</td>
</tr>
<tr>
<td><strong>Kohihtna Group</strong></td>
<td>Kg Cretaceous plutonic rocks - mostly granite and minor quartz diorite, granodiorite, and diorite.</td>
</tr>
<tr>
<td><strong>Kohihtna Group</strong></td>
<td>Kms Cretaceous mélange - structural melange composed of Devonian-Mississippian tuff and sandstone, Silurian-Devonian limestone, and Jurassic/Cretaceous sedimentary rocks that are lithologically comparable to the Kohihtna assemblage.</td>
</tr>
<tr>
<td><strong>Kohihtna Group</strong></td>
<td>Kjk Jurassic-Cretaceous Kahiittna assemblage - marine shale, siltstone, argillite, chert, conglomerate, limestone, tuff, basalt, and volcaniclastic rocks.</td>
</tr>
<tr>
<td><strong>Kohihtna Group</strong></td>
<td>Kjn Jurassic-Cretaceous Nuttsotna sequence - open-marine shale, siltstone, sandstone, and conglomerate.</td>
</tr>
<tr>
<td><strong>Kohihtna Group</strong></td>
<td>JTrp Triassic Jurassic plutonic rocks - variably deformed granitic plutons, mostly biotite granite.</td>
</tr>
</tbody>
</table>

**PALEOZOIC-MESOZOIC TECTONOSTRATIGRAPHIC TERRANES**

<table>
<thead>
<tr>
<th>Terrane</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP Aurora Peak terrane</td>
<td>Silurian/Triassic metasedimentary rocks and Upper Cretaceous/Tertiary meggranitic rocks. Offset fragment of Cretaceous continental-margin arc (Kluane Schist and Ruby Range batholith) formed in southeastern Alaska and southwestern Yukon Territory.</td>
</tr>
<tr>
<td>MK McKinley terrane</td>
<td>Permian/Triassic flysch, chert, and pillow basalt and Upper Jurassic/Cretaceous flysch, gabbro, and diabase. Interpreted as a fragment of late Paleozoic marine sedimentary basin and one or more Upper Triassic seamounts.</td>
</tr>
<tr>
<td>MI Maclaren terrane</td>
<td>- mid-Cretaceous/Tertiary regionally metamorphosed and penetratively deformed granitic plutonic rocks and Upper Jurassic and older sedimentary rocks and andesite. Offset fragment of Cretaceous continental-margin arc (Kluane Schist and Ruby Range batholith) formed in southeastern Alaska and southwestern Yukon Territory. Represents East Susitna batholith and Maclaren Glacier.</td>
</tr>
<tr>
<td>PN Pingston terrane</td>
<td>Pennsylvania, Permian, and Triassic phylite, marble, chert, limestone, black shale, calcareous siltstone, and minor quartzite, and minor post-Late Triassic gabbro, diabase, and diorite. Fragments of passive continental margin.</td>
</tr>
<tr>
<td>SM Seventymile terrane</td>
<td>Thrust slices of undated metasediment, metasediments, and metabasalts and quartzites prevasively metamorphosed to greenschist facies; and a Mississippian, Permian, and Upper Triassic structural mélangé of pillow basalt, basalt, mafic tuff, chert, argillite, and limestone; and harzburgite and peridotite with minor clinopyroxenite, gabbro, and diabase. Ancient island-arc assemblage.</td>
</tr>
<tr>
<td>ST7 Stikinia terrane</td>
<td>Undated metasedimentary rocks, gneiss, marble, amphibolite, and quartzite that are intruded by Late Triassic/Early Jurassic granitic plutons. Fragments of plutonic parts of an island arc.</td>
</tr>
<tr>
<td>WT Windy terrane</td>
<td>Structural mélangé of Silurian or Devonian limestone and marl, Jurassic(?)/basalt and chert, and Cretaceous marine sedimentary and volcanic rocks that may be tectonic lenses of Kohihtna assemblage. Collage of oceanic fragments along the Denali fault.</td>
</tr>
<tr>
<td>WCT Wrangellia composite terrane</td>
<td>- Upper Paleozoic arc-related marine sedimentary, volcanic, and plutonic rocks; Upper Triassic/Lower Jurassic metabasalt, argillite, and limestone; and Lower Jurassic/Upper Cretaceous arc-related sedimentary, plutonic, and volcanic rocks.</td>
</tr>
<tr>
<td>YT Yukon-Tanana terrane</td>
<td>In study area, consists of polydeformed and poly metamorphosed middle Paleozoic and older sedimentary, volcanic, and plutonic rocks, mainly pelitic schist, quartz schist, quartz-feldspar schist, and sparse marble. Part of continental-margin arc.</td>
</tr>
<tr>
<td>RA/RM Area of retrograde metamorphism within Yukon-Tanana terrane (YT). Regional anticlinorium (RA) is developed within the metamorphosed rocks.</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2. Geologic map and shaded relief topographic map of the Alaska Range suture zone showing major structural elements and sedimentary basins. (A) Geologic map of study area. KJK—Upper Jurassic–Upper Cretaceous deposits of the Kahiltna basins; Kcs and Tcv—Upper Cretaceous–lower Eocene deposits of the Cantwell basin; Tug, Tng, and Qa (north of Hines Creek fault)—upper Eocene–Holocene deposits of the Tanana basin. Black arrows represent paleo–flow direction based on clast imbrication and/or trough or planar cross-stratification. Solid black arrows represent paleo–flow directions in the Cantwell Formation and Usibelli Group. White arrows represent paleo–flow directions in the Tena Gravel. Letters show location of measured stratigraphic sections in Figure 6. See Figure 1 for explanation of other abbreviations and for general location of map. (B) Shaded relief topographic map. Solid black arrows point toward the trace of the Talkeetna thrust fault. This fault marks the boundary between the allochthonous Wrangellia composite terrane (labeled WCT) and deposits of the Late Jurassic–Late Cretaceous Kahiltna basin. White arrows mark the trace of the Denali fault. The Late Cretaceous–early Eocene Cantwell basin is located between the Denali fault and the Hines Creek fault. The late Eocene–Holocene Tanana basin is located mainly north of the Hines Creek fault. Miocene and Pliocene deposits of the Tanana basin are exposed in the foothills directly north of the Hines Creek fault. North of the foothills is the Holocene Tanana basin, an alluvial and swampy lowland, which is being filled by an extensive regional braidplain associated with large braided streams flowing northward from the Alaska Range. The hills northeast of the Tanana basin are the Yukon–Tanana Uplands (labeled YT), composed of quartz-rich metamorphic rocks of the Yukon–Tanana terrane. The Yukon–Tanana terrane represents the former North America continental margin prior to accretion of the Wrangellia composite terrane. Note the northward younging of sedimentary basins in the Alaska Range suture zone. Map is modified from Riehle et al. (1997).

SEDIMENTARY BASINS

In this section, we present a synthesis of our data from sedimentary basins of the central Alaska Range and northern Talkeetna Mountains to provide a framework for understanding the tectonic development of the Alaska Range suture zone. A summary of the characteristics of each sedimentary basin is presented in Table 1.

Kahiltna Basins

Stratigraphy and Depositional Systems

The oldest and southernmost sedimentary-basin deposits within the Alaska Range suture zone are represented by the Upper Jurassic–Upper Cretaceous Kahiltna assemblage (Figs. 2, 3). The Kahiltna assemblage consists of 3–5 km of highly deformed marine mudstone, sandstone, conglomerate, and limestone (Csejty et al., 1992). Outcrops of the Kahiltna assemblage extend for ~800 km in south-central and southwestern Alaska (e.g., Beikman, 1980). In south-central Alaska, the Kahiltna assemblage is exposed in two distinct outcrop belts that are located in the southern Alaska Range and the northern Talkeetna Mountains (Figs. 1B, 2). The two outcrop belts are separated by a prominent topographic lineament known as Broad Pass (Figs. 1B, 2). Fossils described from both outcrop belts are typical of open-marine environments and include bi-valves, belemnites, ammonites, radiolaria, and foraminifera (Jones et al., 1986; Csejty et al., 1992). Fossils from the Kahiltna assemblage exposed in the Talkeetna Mountains range in age from Late Jurassic to Early Cretaceous (Kimmeridgian to Valanginian; Jones et al., 1986; Csejty et al., 1992). In contrast, the ages of fossils from the Kahiltna assemblage in the southern Alaska Range are Early Cretaceous to Late Cretaceous (Valanginian to Cenomanian). In the northeastern corner of the Talkeetna Mountains outcrop belt, strata of the Kahiltna assemblage are metamorphosed to kyanite-garnet schist and gneiss of the Maclaren Glacier metamorphic belt (VCSZ [Valdez Creek shear zone] in Figs. 1B, 2A, 3; Davidson et al., 1992).

Lithofacies transitions and paleocurrent data from the Kahiltna assemblage of the Talkeetna Mountains indicate deposition by northward-flowing submarine-fan systems (Fig. 1B; Eastham et al., 2000). Proximal submarine-fan deposits are exposed adjacent to the Talkeetna thrust fault and consist of three dominant lithofacies—pebble to boulder conglomerate, horizontally stratified sandstone, and laminated siltstone (Fig. 4A). Normal grading and tabular bed geometries characterize the proximal lithofacies and are suggestive of deposition by gravelly sandy turbidity currents (e.g., Hein, 1982; Lowe, 1982; Stow et al., 1996). Medial submarine-fan deposits in the Talkeetna Mountains are best developed in the central part of the outcrop belt and consist of normally graded calcareous sandstone interbedded with siltstone and chert (Eastham and Ridgway, 2002). Distal submarine-fan deposits are best developed in the southeastern part of the outcrop belt and are characterized by normally graded siltstone and mudstone interbedded with thick sections of massive mudstone (Eastham and Ridgway, 2001).

Petrofacies

Conglomerate compositional data from the Kahiltna assemblage indicate different source terranes for the two different outcrop belts. Conglomerate of the Kahiltna assemblage in the Talkeetna Mountains consists mainly of volcanic (greenstone/metabasalt), limestone, and argillite clasts (Fig. 5A). Clast composition changes up section in this outcrop belt; the lower part of the section is dominated by argillite clasts, the middle part of the section is domi-
RIDGWAY et al.

Figure 3. Simplified cross section showing structural relationships between strata of the Kahiltna, Cantwell, and Tanana basins. Location of section shown by black line labeled A–A1 in Figure 1B. Cross section is constructed from structural data collected during this study and from mapping data of Csejtey et al. (1992), Wahrhaftig (1970a, 1970b, 1970c), and Pêweé et al. (1966). Dip isogons show distribution of surface data from which the cross section is interpreted. Dip isogons with solid black circles represent bedding; those with open circles represent foliations. Circled X represents strike-slip motion into the page; circled black circle represents strike-slip motion out of the page. VCSZ—Valdez Creek shear zone. See Figure 1D for explanation of abbreviations.

Conglomerate of the Kahiltna assemblage in the Alaska Range contains mainly silicic volcanic, chert, sandstone, argillite, plutonic, and limestone clasts (Fig. 5B). Three of the limestone clasts collected from the proximal lithofacies shown in Figure 4C contain conodonts restricted to the Silurian, Ordovician–Silurian, and Middle Ordovician–Middle Devonian (A. Harris, 2002, personal commun.). In addition, Csejtey et al. (1992) also reported Devonian conodonts from a limestone clast collected near our measured section (Fig. 4C). Our compositional data and the ages for the limestone clasts indicate a Paleozoic sedimentary and igneous source terrane. Paleozoic continental-margin strata located inboard of the suture zone (forming terranes labeled DL [Dillinger], MK [McKinley], and PN [Pingston] in Fig. 1B) and their along-strike equivalents are interpreted as the source terrane for the Kahiltna assemblage of the southern Alaska Range. For example, the Dillinger terrane contains Ordovician–Devonian limestone that is lithologically similar to and has conodont assemblages similar to limestone clasts in the Kahiltna assemblage of the Alaska Range (e.g., Csejtey et al., 1992; Dumoulin et al., 1998; A. Harris, 2002, personal commun.).

Cantwell Basin

Stratigraphy and Depositional Systems

The Cantwell basin is defined by the outcrop distribution of the Cantwell Formation in the central Alaska Range (labeled Kcs and Tcv in Figs. 2, 3). The east-trending outcrop belt is 45 km wide and 135 km long (Fig. 2). The Cantwell Formation consists of two distinct lithologic units, an upper volcanic unit and a lower sedimentary unit (Table 1; Wolfe and Wahrhaftig, 1970). The sedimentary unit of the Cantwell Formation, herein referred to as the lower Cantwell Formation, consists of conglomerate, sandstone, mudstone, and coal (Wolfe and Wahrhaftig, 1970; Figs. 6A, 6B).
Although thickness varies throughout the basin, the maximum preserved thickness of the lower Cantwell Formation is ~4 km (Hickman et al., 1990; Trop, 1996). Palynologic data indicate that the lower Cantwell Formation is Late Cretaceous (Campanian to Maastrichtian; Ridgway et al., 1997). The upper unit of the Cantwell Formation includes 3 km of basaltic to rhyolitic lavas, pyroclastic rocks, and minor interbedded sedimentary deposits (Gilbert et al., 1976; Nye, 1978; Cole et al., 1999). 40Ar/39Ar ages indicate that the upper Cantwell Formation ranges in age from 60 to 54 Ma (Cole et al., 1999). The contact between the volcanic unit and the underlying sedimentary unit is an angular unconformity in many locations, especially along the southern basin margin, and disconformable elsewhere (Gilbert et al., 1976; Csejtey et al., 1986; Cole et al., 1999). This unconformity represents a hiatus of ~10–20 m.y. (Table 1).

The lower Cantwell Formation unconformably overlies a complex assemblage of Paleozoic to Mesozoic rocks, but overlies the highly deformed Jurassic–Cretaceous Kahiltna assemblage along an angular unconformity at many locations (Figs. 2, 3, 6; Csejtey et al., 1992). The hiatus across the angular unconformity between the Kahiltna basin deposits and the lower Cantwell Formation represents a minimum of ~14 m.y. (Table 1).

The Cantwell basin was filled by three principal types of depositional systems: (1) southward-flowing, stream-dominated alluvial-fan systems in the northern part; (2) eastward-flowing, axial, sand-rich braided-stream systems in the central part; and (3) lacustrine and northward-flowing braided-stream systems in the southern part of the basin (Fig. 2A; Ridgway et al., 1997). Basin asymmetry resulted in a concentration of lacustrine and fluvial deposits adjacent to the deeper southern margin of the basin (Fig. 3). The presence of abundant terrestrially derived organic material, marine dinoflagellates, and oncolitic limestone interbedded within the lower Cantwell Formation indicates a minor marginal-marine influence during deposition (Ridgway et al., 1997). The volcanic rocks of the upper Cantwell Formation were erupted from volcanic sources located along the southwestern margin of the Cantwell basin on the basis of lithofacies analysis, paleocurrent data, and conglomerate composition (Slaugenhoup et al., 1997; Cole et al., 1999).

### Petrofacies

Conglomerate and sandstone compositional data show that distinctive source terranes provided detritus to different parts of the basin during deposition of the lower Cantwell Formation (Figs. 5, 7; Trop and Ridgway, 1997). Sandstone from the northern part of the basin is quartz and lithic rich relative to feldspar (Q 48 F 2 L 50; Fig. 7). The dominant grain types in sandstone from this part of the basin are plagioclase and lithic fragments of argillite, radiolarian-bearing mudstone, and metabasalt (Trop and Ridgway, 1997). Limestone and metabasalt clasts are common in conglomerate from the southern part of the basin (categories OS and I in Fig. 5D). Petrofacies data from the southern part of the Cantwell basin, combined with southward-directed paleocurrent directions (Fig. 2A), indicate that sediment was derived from quartz-rich metamorphic rocks of the Yukon-Tanana terrane (labeled YT in Fig. 2A).

Sandstone from the southern part of the basin has higher proportions of feldspar (Q 44 F 28 L 28; Fig. 7) compared to sandstone from the northern part of the basin (Q 48 F 2 L 50; Fig. 7). The dominant grain types in sandstone from this part of the basin are plagioclase and lithic fragments of argillite, radiolarian-bearing mudstone, and metabasalt (Trop and Ridgway, 1997). Limestone and metabasalt clasts are common in conglomerate from the southern part of the basin (categories OS and I in Fig. 5D). Petrofacies data from the southern part of the Cantwell basin, combined with northward-directed paleocurrent data (Fig. 2A), indicate that sediment was derived from volcanic and sedimentary strata exposed south of the basin (Q 48 F 2 L 50; Fig. 7). The dominant source material is volcanic and sedimentary strata exposed south of the basin (Q 48 F 2 L 50; Fig. 7). The dominant source material is volcanic and sedimentary strata exposed south of the basin (Q 48 F 2 L 50; Fig. 7). The dominant source material is volcanic and sedimentary strata exposed south of the basin (Q 48 F 2 L 50; Fig. 7).

### Tanana Basin

**Stratigraphy and Depositional Systems**

The late Eocene to Holocene Tanana basin is the youngest and northernmost basin asso-
Figure 4. Representative measured stratigraphic sections from strata of the Kahiltna basins discussed in the text. Data were collected as bed-by-bed measurements using a Jacob's staff.
associated with the Alaska Range suture zone (Figs. 1–3). Deposits of the Tanana basin consist of the Usibelli Group, Nenana Gravel, and Quaternary deposits (Table 1). The Usibelli Group and Nenana Gravel are exposed for about ~225 km along the north-central flank of the Alaska Range (Figs. 1–3). The Usibelli Group is ~0.6–0.8 km thick and ranges in age from late Eocene to late Miocene, but the bulk of the deposits are Miocene (Wolfe and Tanai, 1969). A regional west-southwestward regional paleodrainage (Fig. 2A; Table 1).

The Pliocene Nenana Gravel conformably overlies deposits of the Usibelli Group (Table 1; Fig. 3). Our measured section of the Nenana Gravel (Fig. 6D) shows clast-supported, well-organized conglomerate with maximum clast sizes of ~30 cm. Paleocurrent data (Fig. 2A) and lithofacies analysis indicate deposition by north-flowing fluvial systems (Wahrhaftig, 1987; Ridgway et al., 1999a). Wahrhaftig (1987) interpreted the Nenana Gravel as representing deposits from a series of coalescing alluvial fans and braided streams. Recent analysis of the Nenana Gravel suggests that it was deposited during the early and middle Pliocene between ca. 5.4 Ma and 2.9 Ma (Ager et al., 1994). Regional geologic mapping of Quaternary deposits delineates an extensive regional braidplain that is currently filling the Tanana basin (Figs. 1, 2; e.g., Péwé et al., 1966). Much of the Quaternary braidplain is probably related to glacial outwash processes from Pleistocene and Holocene alpine and piedmont glaciers of the Alaska Range (e.g., Wahrhaftig, 1958; Foster et al., 1994). The Holocene Tanana basin is an alluvial and swampy lowland of ~22,000 km² located north of the Alaska Range and south of the Yukon-Tanana Uplands (Figs. 1, 2; Kirschner, 1994). Large braided-stream systems flow transverse to the Alaska Range (e.g., the Kantsinha, Nenana, and Delta Rivers in Fig. 1) and merge into a major axial fluvial system (e.g., the Tanana River in Fig. 1) that drains the basin.

Petrofacies

Sandstone from the Usibelli Group has an average framework-grain mode of Q₆₀F₉₇L₉₂ (Fig. 7) and has a high proportion of polycrystalline quartz (Q₉₂L₁₉₇S₄₈; Ridgway et al., 1999a). Quartz, metasedimentary, igneous, and metamorphic clasts are common in conglomerate from the Usibelli Group (Fig. 5E). In general, the dominance of quartz in the sandstone and the abundance of quartz and metamorphic clasts in conglomerate all indicate a quartz-rich metamorphic source terrane for the Usibelli Group. Regional west-southwestward sediment transport (Fig. 2A), coupled with the compositional data, indicate that metamorphic rocks of the Yukon-Tanana terrane were the most likely source of detritus for the Healy Creek, Suntrana, and Lignite Creek Formations of the Tanana basin.

Sandstone from the Nenana Gravel has an average framework-grain mode of Q₉₆F₉₇L₆₄ (Fig. 7; Ridgway et al., 1999a). The sandstone is rich in lithic fragments, especially volcanic...
LITHOFACIES DESCRIPTIONS (DEPOSITIONAL PROCESSES AND ENVIRONMENTS)

- Coal and carbonaceous shale (suspension fallout and peat accumulation in alluvial-plain swamps and lakes).
- Mudstone: massive siltstone and shale, thin-bedded, marginal-marine dinoflagellate microfossils, lacustrine fish fossils, and well-preserved broadleaf megafossils (suspension fallout in lakes, swamps, and floodplains adjacent to alluvial-fluvial systems).
- Sandstone: nongraded fine- to pebbly sandstone, medium- to thick-bedded, massive to trough/polygonal-stratified, highly channelized, well-preserved broadleaf megafossils (traction transport/bedform migration in braided to meandering streams).
- Conglomerate: medium- to thick-bedded, massive or stratified, highly channelized, mostly clast-supported with subrounded to well-rounded clasts (traction transport/bedform migration on braided-stream/alluvial-fan systems).
- Covered interval
tectonic development of the range. This section presents results of geologic mapping, metamorphic analysis, and geochronologic data that help document the progressive deformation history of the Alaska Range suture zone.

Metamorphism and Deformation Along the Southern Margin of the Yukon-Tanana Terrane

Retrograde Metamorphism

A broad zone of retrograde metamorphism (labeled RM in Fig. 1C, Mount Hayes Quadrangle) in Devonian metamorphic and plutonic rocks occurs along the southern margin of the Yukon-Tanana terrane in the central and eastern Alaska Range. The zone of retrograde metamorphism increases in intensity to the south toward the Denali fault. In the northern part of this area, minerals of the middle to upper amphibolite facies, such as hornblende, biotite, and garnet, are common. These higher-grade minerals are successively replaced to the south by minerals of the lower greenschist facies (Nokleberg and Aleinikoff, 1985; Nokleberg et al., 1992a). Adjacent to the Denali and Hines Creek faults (Fig. 1C), the diagnostic metamorphic minerals are chlorite, albite, actinolite, epidote, and white mica. The presence of these minerals adjacent to the faults indicates development of a zone of retrograde metamorphism that is associated with a strong schistosity and locally with asymmetric folds that exhibit mainly south-southwest vergence (Nokleberg and Aleinikoff, 1985; Nokleberg et al., 1992a). A Cretaceous age for retrograde metamorphism is suggested by K-Ar metamorphic muscovite and biotite dates of 115–106 Ma and a Rb-Sr mineral and whole-rock isochron date of 110 Ma for a granitic gneiss (Nokleberg et al., 1992a).

Regional Anticlinorium Development

Geologic mapping documents a regional anticlinorium (labeled RA in Fig. 1C, Mount Hayes Quadrangle) that is well developed along the southern margin of the Yukon-Tanana terrane. The anticlinorium is defined by folding of the just-described retrograde schistosity, axial planes of south-verging minor folds, and foliation (compositional layering) in the southern Yukon-Tanana terrane from near-horizontal dips in the north to progressive-ly steeper dips to the south. Near the Denali fault, schistosity, axial planes, and isoclines dip steeply south-southwest to vertically (Nokleberg and Aleinikoff, 1985; Nokleberg et al., 1992a, 1992b). Formation of the regional anticlinorium along the southern margin of the Yukon-Tanana terrane postdates the development of the 115–106 Ma retrograde schistosity (discussed in previous section), which has been folded by this structure.

Metamorphism and Deformation of the Maclaren Glacier Metamorphic Belt

The Maclaren Glacier metamorphic belt, part of the Maclaren tectonostratigraphic terrane (Nokleberg et al., 1985, 1994b), contains metamorphosed pelitic rocks, minor amounts of volcaniclastic rocks, and granitic plutons; the belt probably represents deformed and metamorphosed deposits of the Kahiltna assemblage. The Valdez Creek shear zone (VCSZ in the east-central Healy Quadrangle in Fig. 1B) of the Maclaren Glacier metamorphic belt is in the footwall of the Talkeetna thrust fault (Fig. 3). Figure 8 shows the pronounced inverted metamorphic field gradient that occurs in the metamorphic rocks of the Valdez Creek shear zone with kyanite-garnet schist and gneiss in the north and biotite phyllite in the south. South of Valdez Creek (Figs. 8A, 8B), biotite phyllite grades into biotite-bearung submarine-fan deposits of the Kahiltna assemblage that preserve sedimentary structures including graded bedding, flute casts, and sole marks. The inverted metamorphic gradient was produced by top-to-the-south thrusting across the 5-km-thick Valdez Creek shear zone (Fig. 8B; Davidson et al., 1992). The 1-km-thick Valdez Creek tonalite sill was emplaced into the ductile shear zone during deformation (Davidson et al., 1992). Pressure-temperature conditions in the hanging-wall rocks and shear zone suggest that the hanging wall was at least 650 °C when it was juxtaposed against the footwall at ~25 km depth (Davidson et al., 1992). Thrusting must have been followed by rapid exhumation and cooling of the entire metamorphic belt in order to preserve the inverted metamorphic field gradient in the footwall (Davidson et al., 1992).

STRUCTURAL AND METAMORPHIC DATA

Previous studies suggest a significant component of late Mesozoic and Cenozoic deformation and uplift in the eastern and central Alaska Range (Wahrhaftig et al., 1969, 1970a, 1970b, 1970c; Hickman and Craddock, 1976; Sherwood and Craddock, 1979; Csejtey et al., 1992; Nokleberg et al., 1992b; Pfläkker et al., 1992; Fitzgerald et al., 1993, 1995), but little has been published concerning the sequential tectonic development of the range. This section presents results of geologic mapping, metamorphic analysis, and geochronologic data that help document the progressive deformation history of the Alaska Range suture zone.
Figure 8. (A) Geologic map of Valdez Creek area of the McClaren Glacier metamorphic belt (see Healy Quadrangle in Fig. 1B for location, labeled VCSZ—Valdez Creek shear zone). Abbreviations: Grt—garnet-in isograd, St/Ky—staurolite-kyanite-in isograd. (B) Cross section A–A showing the Valdez Creek shear zone. Cleavage and bedding relationships south of the shear zone are shown in the circles above the cross section; solid lines are bedding, and dashed lines are the orientation of axial-planar cleavage. Note that the south-verging folds associated with the Valdez Creek shear zone (left circle) are folded by the north-facing folds (middle and right circles). (C) Explanation of map units and symbols for A, B, and D. (D) U-Pb zircon (open triangle) and \(^{40}\text{Ar}^{39}\text{Ar}\) biotite (open circles) dates across the Valdez Creek shear zone.
Geochronology

New U-Pb and ⁴⁰Ar/³⁹Ar data set limits on the timing of deformation and exhumation of the Maclaren Glacier metamorphic belt. The U-Pb analysis was obtained at the University of British Columbia (J.K. Mortensen, 1993, personal commun.) through the use of standard isotope dilution techniques. ⁴⁰Ar/³⁹Ar data were obtained at Princeton University by Davidson (1991) with the procedures outlined by Onstott and Peacock (1987). Zircon from Davidson (1991) with the procedures outlined by Onstott and Peacock (1987).

Table 2 shows the ⁴⁰Ar/³⁹Ar integrated and plateau dates for the biotite samples. The U-Pb data set limits on the progressive tilting within the lower Cantwell Formation strata and the associated intraformational angular unconformities to have formed when Upper Cretaceous Cantwell deposits, located in the footwalls of bordering thrust faults, were progressively tilted basinward during fault displacement and incorporated into growth footwall synclines. During each major episode of thrust faulting, lower Cantwell Formation deposits in the proximal footwall area of the fault were tilted and eroded, and subsequent lithofacies were deposited on an angular unconformity. Packages of progressively tilted strata, each bounded by angular unconformities, are common elements of thrust-derived deposits within growth footwall synclines (Riba, 1976; DeCelles et al., 1991; Hoy and Ridgway, 1997, 2002).

Late Cenozoic Thrust Faulting in Eastern Alaska Range

Geologic mapping in the eastern Alaska Range demonstrates late Cenozoic thrust faulting on both the north and south sides of the Alaska Range suture zone. Geologic field relationships in the Trident Glacier area on the north side of the Alaska Range (Fig. 9) reveal a series of south-dipping thrust faults that include the Hines Creek and Trident Glacier faults. The Trident Glacier fault places Devonian metasedimentary strata (labeled jc) over Triassic Nenana Gravel (labeled Trn) over upper Cenozoic deposits. A similar relationship is shown where the Donnelly Dome–Granite Mountain thrust fault juxtaposes Devonian metasedimentary strata (jc) and Jurassic–Tertiary plutonic rocks (Tkjg) over Quaternary deposits.

Geologic mapping along the southern margin of the eastern Alaska Range also provides evidence for late Cenozoic thrusting. Mapping in the Rainy Creek area (Fig. 10A), for example, shows that the north-dipping Rainy Creek thrust fault places Upper Triassic metasalt (labeled Trn) over upper Cenozoic deposits (labeled Ts). The Cenozoic sedimentary strata have been rotated to dip as steeply as 75° in the footwall (Fig. 10A). A similar relationship occurs to the east along the north-dipping McCallum Creek fault (Fig. 10B), where Pennsylvanian–Permian volcanioclastic strata (labeled P, PIPs, Pd, Pe) have been thrust across the metamorphic belt.

**)40Ar/39Ar age data, is available on the Web at http://www.geosociety.org/pubs/ft2002.htm. Requests may also be sent to editing@geosociety.org.

Note: See GSA Data Repository (see text footnote 1) for Ar spectra and inverse isochron plots.

††U-Pb date is a lower intercept date from a cord fitted to three zircon fractions with an upper intercept date of 1.3 Ma (Table 2; GSA Data Repository Fig. DR-2 [see footnote 1]).

††See Figure 8 for sample location.

Geologic Society of America Bulletin, December 2002
Figure 9. (A) Geologic map of Trident Glacier area in the northwestern Mount Hayes Quadrangle, eastern Alaska Range, showing late Cenozoic south-dipping thrust faults on north side of range. See Figure 1C for location of map. See legend for explanation of map units and other abbreviations. See text for discussion. Adapted from Nokleberg et al. (1992b). (B) Legend for Figures 9 and 10. Explanation of map units and symbols. Descriptions adapted from Nokleberg et al. (1994a, 1994b, 1998).
over upper Cenozoic sedimentary strata (labeled Ts) and Quaternary glacial deposits (labeled Qs). Some of the upper Cenozoic deposits in this area are late Miocene to Pliocene on the basis of both a 5.5 Ma K-Ar date from an interbedded ash and on Pliocene palynomorphs (Turner et al., 1980; Nokleberg et al., 1992a, 1992b). Along the McCallum Creek thrust fault, upper Cenozoic deposits in the footwall are folded; some fold limbs dip as steeply as 45°.

**DISCUSSION**

**Tectonic and Paleogeographic Model for Development of the Alaska Range Suture Zone**

In this section, our synthesis of the progressive tectonic and paleogeographic development of the Alaska Range suture zone is placed into a framework for the Mesozoic and Cenozoic tectonic evolution of the Alaskan and Canadian Cordillera that is modified from the regional circum–North Pacific tectonic model of Nokleberg et al. (1998). Our model (Fig. 11) utilizes data for the accretion of the Wrangellia composite terrane at a northern paleolatitude and accounts for displacement along major strike-slip faults such as the Denali fault. The time scale and absolute ages are from Gradstein and Ogg (1996). Plate motions and velocities are from the reconstructions of Eberbrecht et al. (1985); these plate reconstructions are not universally accepted (e.g., Bradley et al., 1993).

The earliest record of the Alaska Range suture zone is contained within the stratigraphy of the Kahiltna assemblage. Our analysis shows that the outcrops mapped as Kahiltna assemblage in south-central Alaska represent deposits of two distinct sedimentary basins. The slightly older strata, exposed in the Talkeetna Mountains, are interpreted as the deposits of a Kimmeridgian–Valanginian back-arc basin (labeled KB-TM in Fig. 11A) located on the inboard margin of the Wrangellia composite terrane. Initial collision of the Wrangellia composite terrane as it approached the North American continental margin resulted in uplift and erosion of the island-arc assemblage. The unroofing record contained in proximal conglomerate of the Kahiltna assemblage in the Talkeetna Mountains (Fig. 5A) indicates that by the Late Jurassic–Early Cretaceous, deeper stratigraphic levels of the Wrangellia composite terrane had been exhumed.

The younger strata, exposed in the southern Alaska Range, are interpreted as the deposits of a Valanginian–Cenomanian remnant ocean basin (in the sense of Ingersoll et al., 1995) associated with continued collision of the Wrangellia composite terrane to North America (Figs. 11A and 11B). A remnant ocean basin is a closing ocean basin, which is flanked by at least one convergent margin and whose floor is typically covered by turbidites derived predominantly from an along-strike suture zone (Graham et al., 1975). Collision of the Wrangellia composite terrane resulted in an east to west diachronous suturing of the island arc to the continental margin of North America (Fig. 11A). To the east, uplifted parts of the growing suture zone (southern part of areas labeled COLL and YT in Fig. 11B) incorporated Paleozoic continental-margin strata that provided detritus to submarine-fan systems of the Kahiltna remnant ocean basin. Our interpretation that both Kahiltna basins record collision of the Wrangellia composite terrane is consistent with documentation of regional latest Jurassic–Early Cretaceous uplift of the Wrangellia composite terrane and synorogenic sedimentation in both the Wrangell Mountains and southern Talkeetna Mountains (Szuch and Trop, 2001; Trop et al., 2002). Our interpretation follows the general regional tectonic model of Pavlis (1982) and Wallace et al. (1989) who proposed that a single Kahiltna basin was part of a series of syncollisional basins (the Gravina, Nutzotin, and Dezadeash in Fig. 11A) that were located at the leading edge of the Wrangellia composite terrane. Our in-
Figure 10. Geologic maps of (A) Rainy Creek area and (B) McCallum Creek area in southern Mount Hayes Quadrangle, eastern Alaska Range, showing late Cenozoic north-dipping thrust faults on south side of range. See Figure 1C for locations of maps. See Figure 9 for explanation of map units and other abbreviations. See text for discussion. Adapted from Nokleberg et al. (1992b).
Figure 11. Tectonic and paleogeographic model showing evolution of the Alaska Range suture zone.

Explanation of Map Abbreviations/Symbols

- DF - Denali fault
- TB - Tanana basin
- CW - Cantwell basin
- NB - Nutzotin basin
- DZ - Dezadeash basin
- GB - Gravina basin
- VC - Valdez Creek shear zone
- YA - Yakatat terrane
- NAC - North American craton
- COLL - collage of accreted terranes
- KB-AR - Kahlitna remnant ocean basin (Alaska Range)
- KB-TM - Kahlitna backarc basin (Talkeetna Mountains)
- KB - both Kahlitna basins listed above
- YT - Yukon Tanana terrane
- WCT - Wrangellia composite terrane
- CG - Chugach terrane (subduction complex)

intrabasin volcanic center
deformed sedimentary basin
relative plate motion
terpretation is different from these previous studies, however, in that we interpret the Kahiltna assemblage as representing two distinct sedimentary basins that have been juxtaposed within the Alaska Range suture zone.

127–83 Ma (Barremian–Santonian)

Deposition in the Kahiltna remnant ocean basin was waning during this interval and ended during the Cenomanian (99–94 Ma). Coeval with the end of deposition in the Kahiltna basins was the development of a zone of retrograde metamorphism with ages of 115–106 Ma and development of a regional anticlinorium along the southern margin of the Yukon-Tanana terrane (Fig. 1B). These events suggest a possible link between the end of deposition in the marine basins that separated North America from the Wrangellia composite terrane (Fig. 1B) and the beginning of widespread deformation along the former continental margin of North America (labeled YT and COLL in Fig. 1B). Retrograde metamorphism and development of a regional anticlinorium may have occurred during, and as a result of, the thrusting of the Yukon-Tanana terrane onto deposits of the Kahiltna basins (Fig. 11B). The 110–90 Ma deformational event, which marked the end of deposition in the Kahiltna basins, appears to be a product of regional deformation associated with the ongoing collision of the Wrangellia composite terrane with the North American continental margin. Magnetotelluric surveys and seismic lines across the Alaska Range, for example, have been interpreted as suggesting that deposits of the Kahiltna basins were underthrust beneath the Yukon-Tanana terrane during the middle Cretaceous (Stanley et al., 1990a; Beaudoin et al., 1992). Mapping of the Gravina basin (labeled GB in Fig. 11B), a coeval basin in southeastern Alaska, shows it to have been underthrust beneath the Yukon-Tanana terrane during the middle Cretaceous (McClelland et al., 1991, 1992a, 1992b; McClelland and Mattinson, 2000). Crosscutting relationships and U-Pb age determinations from syn- and posttectonictic plutons suggest that underthrusting of the Gravina basin began between 113 and 97.5 Ma and ended by 90 Ma in southeastern Alaska (McClelland et al., 1992b). Haueussler (1992) also documented a 100–90 Ma contractional deformation event in southeastern Alaska that marked the end of deposition in the Gravina basin. Geologic mapping of structures in the age-equivalent Nutzotine basin (NB in Fig. 11B; Nabesna Quadrangle in Fig. 1C) indicates that it also was deformed by thrust faults and folding from 117 to 105 Ma (Richter, 1976; Manuszak et al., 1999; Manuszak and Ridgway, 2000).

83–65 Ma (Campanian–Maastrichtian)

High-grade metamorphism, thrust-fault deformation, and synorogenic sedimentation characterized the Alaska Range suture zone during the Campanian to Maastrichtian (Fig. 11C). In the southern part of the suture zone, metamorphism of Upper Jurassic–Lower Cretaceous strata of the Kahiltna basin in the Talkeetna Mountains formed the Maclaren Glacier metamorphic belt and Valdez Creek shear zone (labeled VC in Fig. 11C). Our U-Pb zircon date from a synkinematic tonalite sill of the metamorphic belt dates metamorphism and deformation at ca. 74 Ma (Fig. 8D). During the early stages of metamorphism, structural vergence was to the south on the basis of fold orientations from the Valdez Creek shear zone (Fig. 8B). During the final stages of deformation within the metamorphic belt, structural vergence reversed, and the Wrangellia composite terrane was transported over the Maclaren Glacier metamorphic belt along the Talkeetna thrust fault (labeled TK in Fig. 11C).

Coeval with metamorphism in the southern part of the suture zone, the Cantwell basin formed as a thrust-top basin in the northern part of the suture zone (labeled CW in Fig. 11C). Strata of the Cantwell basin were deposed in angular unconformity across deposits of the Kahiltna basin, indicating that the Late Jurassic–early Late Cretaceous Kahiltna basin was deformed prior to the beginning of deposition in the Late Cretaceous Cantwell basin. Growth footwall synclines along the southern margin of the Cantwell basin indicate that formation of the basin was related to displacement on south-dipping thrust faults. Palynological age control for the Cantwell basin places synthrusting deposition between 80–70 Ma (Ridgway et al., 1997). Paleocurrent and provenance data (Figs. 2A, 5C–D, 7) indicate that feldspar-rich oceanic source terranes of the suture zone supplied sediment to the southern part of the Cantwell basin, whereas quartz- and lithic-rich source terranes of the metamorphosed former North American continental margin supplied sediment to the northern part. The evidence for uplifted source terranes on both the “oceanic” and “continental” sides of the Cantwell basin, as well as the dominance of nonmarine deposits and only minor marginal-marine deposits (relative to the open-marine deposits of the Kahiltna basin), indicates that formation of the Cantwell basin was associated with regional subaerial uplift of the Alaska Range suture zone.

65–60 Ma (Danian)

During the early Paleocene, regional uplift and shortening of the Alaska Range suture zone continued (Fig. 11C). In the southern part of the suture zone, deposits of the Kahiltna basin in the Maclaren Glacier metamorphic belt (VC in Fig. 11C) were uplifted and cooled through the biotite closure temperature (~300 °C) by ca. 62 Ma (Fig. 8D). In the northern part of the suture zone, 4000 m of Upper Cretaceous sedimentary strata within the Cantwell basin were uplifted and shortened by a minimum of 15%–23% (Cole et al., 1999). The rapid exhumation of the Maclaren Glacier metamorphic belt in the southern part of the suture zone and the deformation of the Cantwell basin in the northern part of the suture zone indicate significant regional shortening and uplift of the Alaska Range suture zone during the early Paleocene.

60–24 Ma (Selandian– Chattian)

Approximately 3000 m of volcanic rocks (i.e., the upper Cantwell Formation) were deposed in the Cantwell basin from 60 to 54 Ma (Fig. 11D; Cole et al., 1999), and several granitic plutons (the McKinley sequence) were emplaced along the suture zone at ca. 56 Ma (Lanphere and Reed, 1985; West and Layzer, 1994). Lavas and volcaniclastic strata of the upper Cantwell Formation were deposited in angular unconformity over the deformed Upper Cretaceous sedimentary strata of the lower Cantwell Formation. This Late Paleocene–early Eocene volcanism and emplacement of plutons along the Alaska Range suture zone may be a product of remnant subduction-related magmas and/or partial melting of enriched subcontinental lithospheric mantle due to high heat flow in the deeper parts of the suture zone (Lanphere and Reed, 1985; Cole et al., 1999). These magmas probably migrated through the crust along planes of weakness associated with the Alaska Range suture zone and/or transtensional segments of the Denali fault system.

Regional strike-slip tectonics was also important in the development of the Alaska Range suture zone during this time interval (Fig. 11D). Eibach (1976) and Nokleberg et al. (1985) estimated ~400 km of dextral displacement on the Denali fault system on the basis of offset of the Nutzotin Mountains basin (labeled NB in Fig. 11D) and the December basin (labeled DZ in Fig. 11D). At
least some of this displacement occurred during the Eocene and Oligocene on the basis of the age of strata filling the strike-slip basins along the Denali fault system (Cole and Ridgway, 1993; Ridgway and DeCelles, 1993a, 1993b; Ridgway et al., 1995, 1999b; Trop et al., 2001).

The Cantwell basin was further deformed during the Eocene–Oligocene (Cole et al., 1999). The types and orientations of structures found in the upper Cantwell Formation are consistent with right-lateral shear along the Denali fault system (Cole et al., 1999). Cole et al. (1999) calculated a minimum of 2%–14% shortening of strata in the Cantwell basin during this time range. Our interpretation of strike-slip displacement in the Alaska Range suture zone during this time range is consistent with regional plate-reconstruction models that predict a middle to late Eocene (ca. 43 Ma) shift to more oblique, northwestern Pacific plate motion (Engebretson et al., 1985; Kelley, 1993) and/or oroclinal bending of western Alaska that resulted in dextral strike-slip offset along several major faults, including the Denali fault system (Plafker and Berg, 1994).

24 Ma to Present (Aquitanian–Versilian)

The development of a large sedimentary basin in the northern part of the Alaska Range suture zone characterized the Miocene to Holocene. This basin, the Tanana basin (labeled TB in Fig. 11E), was built mainly on continental crust, i.e., the metamorphosed Paleozoic and Mesozoic rocks of the Yukon-Tanana terrane that represent a fragment of the former continental margin of southern Alaska (Fig. 3). We refer to this basin as a foreland basin because of its location on the cratonward side of the Alaska Range orogenic belt and because it appears to have developed as a flexural response to uplift and shortening of the Alaska Range. The quartz-rich sandstone and conglomerate of the Miocene Usibelli Group (Figs. 5, 7) were derived primarily from local metamorphic rocks of the Yukon-Tanana terrane. Thick lacustrine deposits and laterally continuous coal seams up to 20 m thick in the Usibelli Group indicate that the area north of the Alaska Range suture zone subsided during the Miocene. The lacustrine deposits are interpreted to represent periods of rapid tectonic subsidence when drainage systems were poorly organized and ponding occurred along the keel of the foreland basin. The numerous thick coals formed when subsidence was sufficiently rapid so that mires could accumulate and preserve thick peats (in the sense of McCabe and Parrish, 1992), but when fluvial systems were sufficiently organized to minimize siliciclastic contribution to the peat swamps. Subsurface Miocene deposits of the foreland basin extend at least 50 km north of the present outcrop belt. The Arco Totek Hills #1 well (Fig. 1B, Fairbanks Quadrangle), for example, encountered 920 m of strata correlative to the Usibelli Group outcrops along the northern flanks of the Alaska Range (Stanley et al., 1990b). Interpretation of gravity data suggests that the deepest part of the Tanana basin contains 3–3.4 km of Miocene to Holocene deposits (Barnes, 1961; Hite and Nakayama, 1980; Kirschner, 1988). In general, most of the available data indicate a broad area of regional subsidence north of the Alaska Range suture zone during the Miocene with major west-southwest–flowing fluvial systems paralleling the trend of the Miocene Alaska Range. We interpret Miocene basin development as a product of flexural subsidence of the continental crust (i.e., the Yukon-Tanana terrane) associated with isostatic adjustment due to crustal thickening within the suture zone (in the sense of Jordan, 1995). Wahrhaftig et al. (1969) noted that regionally, each formation of the Usibelli Group overlies the underlying formation in a northward transition. This relationship results in a “shingled geometry” between each of the formations of the Usibelli Group. We interpret this northward progression of younger deposits to suggest that flexural subsidence related to the growing suture zone migrated northward during the Miocene.

During the Pliocene and Holocene, a large siliciclastic wedge (Fig. 2) prograded northward into the Tanana foreland basin (Tng and Qa in Fig. 2A). We interpret this clastic wedge as indicating that foreland-basin development and deposition associated with regional uplift of the Alaska Range suture zone during the present. Regional uplift of the Alaska Range suture zone since 5 Ma is recorded by our detailed mapping of thrust faults that place older Paleozoic rocks over sedimentary deposits as young as Quaternary (Figs. 9, 10). The Pliocene Nenana Gravel provides a record of Neogene uplift of the suture zone. The de-trital composition of the Nenana Gravel shows that strata of the Late Cretaceous–early Eocene Cantwell basin had been incorporated into the uplifted suture zone and was providing significant detritus to Pliocene north-flowing alluvial-fan and braided-stream depositional systems (Fig. 5F). Our mapping and basin-analysis data are consistent with apatite fission-track studies that indicate rapid uplift of Mount McKinley (Denali) in the central Alaska Range beginning at ca. 5 Ma (Plafker et al., 1992; Fitzgerald et al., 1993). Uplift rates for the Alaska Range have been about ~1.5 km/m.y. since ~6–5 Ma (Fitzgerald et al., 1995). Uplift of the Alaska Range and deposition of coarse-grained sediments in the Tanana foreland basin mark Neogene reactivation of the Alaska Range suture zone. Neogene reactivation of the suture zone is probably related to (1) the change from a northwest direction to a more due north direction of Pacific plate motion relative to the North American plate at ca. 5.6 Ma (Engebretson et al., 1985; Fitzgerald et al., 1993), (2) an increase (~17 mm/yr) in relative plate velocities (Engebretson et al., 1985), and/or (3) collision of the allochthonous Yakutat terrane along the southern margin of Alaska (Fig. 1A; Plafker and Berg, 1994).

Basin Formation Along Suture Zones

The sedimentary basins of south-central Alaska contain a long-term detailed record of basin development along a suture zone between the Wrangellia composite terrane and the former North American continental margin. Formation and deformation of these sedimentary basins appear to be closely linked with major structural and metamorphic events in the Alaska Range suture zone. We recognize a family of general characteristics of basin development in the Alaska Range suture zone: (1) Each successive basin was built on and slightly cratonward of the underlying older basin. (2) Successive basin-fill deposits are separated by major unconformities. During the hiatus represented by the unconformity, the older basin was deformed by thrust and/or strike-slip faults. (3) Deformed and uplifted strata of older basins were eroded and provided detritus to younger basins. (4) There was a gradual change from marine deposystems in the older basins to nonmarine deposystems in the younger basins.

The progressive migration of sedimentary basins, the uplift and incorporation of older basins into the suture zone, and the recycling of sedimentary detritus into younger basins demonstrates the complex interplay between suture-zone evolution and basin development. Some of the characteristics defined for basin evolution along the Alaska Range suture zone may have application in other areas where sedimentary basins are built over a basement of former allochthonous terranes along long-lived collisional boundaries. The Middle Jurassic to Early Cretaceous Bowser and Late Cretaceous Sustut basins of northern British Columbia, for example, formed above a basement of accreted terranes (Evenchick, 1991).
and have a basinal configuration similar to the Late Jurassic-Late Cretaceous Kahlitna and Late Cretaceous-Eocene Cantwell basins. In both cases, the older, predominantly marine, basins (the Kahlitna and Bowser) were regionally shortened and incorporated into a series of thrust sheets that provided detritus to the younger, mainly nonmarine, basins (the Cantwell and Susitna). Likewise, in both settings, the younger basins are separated from the older basins by regional unconformities, and in both cases, the younger basins were eventually incorporated into the growing suture zone, especially along their proximal margins. The basins along the Alaska Range suture zone may also be similar to basins in western China that are bordered by active thrust and strike-slip faults associated with the Cenozoic Himalayan collision (Graham et al., 1993). Graham et al. (1993) termed these basins “collisional successor basins,” whereas Bally and Snelson (1980) classified these basins as “perisutural basins associated with formation of a compressional megasuture.” Several other recent studies of Asian tectonics have reported multiple episodes of basin formation along long-lived suture zones currently located far inboard of the current thrust and strike-slip faults associated with the Cenozoic Himalayan collision (Graham et al., 1993).

ACKNOWLEDGMENTS

The Purdue University researchers studying the Alaska Range have been supported by grants from the National Science Foundation. Our analysis of the Kahlitna assemblage benefited greatly from support of the U.S. Geological Survey (USGS) Talkeetna Mountains mapping project. Our understanding of the geology of the Alaska Range has benefited from interaction with many Cordilleran geologists. We especially thank Ron Cole for sharing of data and ideas; Phil Brease (Denali National Park and Preserve) for logistical support; Jeanine Schmidt, Mike O’Neill, Peter Oswald, and other members of the USGS Talkeetna Mountains mapping project for field support and helpful discussions; Anita Harris (USGS) for conodont analysis; Jeff Manuszak, Rick Hoy, Shane Smith, Mark Lesh, and Rachel Couch for field assistance and Jay Kalbas for help with drafting figures. Nokleberg’s research in the eastern Alaska Range was supported by the Alaska Mineral Resources Assessment and Trans-Alaska Crustal Transect Programs of the U.S. Geological Survey. Nokleberg gratefully acknowledges invaluable discussions of the geology of south-central Alaska over the years with J.N. Aleinikoff, Fred Barker, H.C. Berg, G.C. Bond, T.K. Bundzen, L.E. Burns, R.G. Coleman, P.J. Coney, Bela Csejtey Jr., S.M. DeBari, R.I. Detterman, Cynthia Dusel-Bacon, W.G. Gilbert, Arthur Grantz, C.S. Grommé, J.W. Hillhouse, Travis Hudson, D.L. Jones, M.A. Langhorne, E.M. MacKevett Jr., T.E. Moore, W.W. Patton Jr., T.L. Pavlis, M.S. Roekes, D.H. Richter, N.J. Silberling, V.B. Sisson, T.E. Smith, D.B. Stone, J.H. Stout, and G.R. Winkler. Robin Ridgway is thanked for editing several versions of the manuscript. We thank D. Bradley, P. Copeland, S. Graham, and G. MACK for constructive reviews of the manuscript.

REFERENCES CITED


MESOZOIC AND CENOZOIC TECTONICS OF THE EASTERN AND CENTRAL ALASKA RANGE


Mesozoic and Cenozoic Tectonics of the Eastern and Central Alaska Range


Manuscript Received by the Society 12 February 2001
Revised Manuscript Received 30 April 2002
Manuscript Accepted 9 May 2002

Printed in the USA