Sedimentary record of transpressional tectonics and ridge subduction in the Tertiary Matanuska Valley–Talkeetna Mountains forearc basin, southern Alaska

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ABSTRACT

The Chickaloon, Arkose Ridge, Wishbone, and Tsadaka Formations consist of more than 2800 m of Paleocene-Oligocene sedimentary and volcanic strata that are the products of sedimentation, volcanism, and faulting in the Matanuska Valley–Talkeetna Mountains forearc basin. These deposits provide a record of early Tertiary tectonic processes that formed the southern Alaska convergent margin. The northern margin of the forearc basin is characterized by nonmarine sandstone, conglomerate, and minor mudstone that interfinger with volcanic strata. On the basis of lithofacies, paleocurrent, and compositional data, the northern basin margin deposits are interpreted to represent southward prograding alluvial-fluvial systems. New \(^{40}\)Ar/\(^{39}\)Ar ages from detrital feldspars in volcaniclastic sandstone and from igneous clasts in conglomerate suggest that these deposits were derived from Middle Jurassic and Paleocene-Eocene volcanic arc-related rocks. Stratigraphic and structural data from the northern basin margin adjacent to the Castle Mountain fault document syndepositional faulting that produced footwall growth synclines in the forearc basin. Paleocene-Oligocene strata exposed along the southern margin of the forearc basin are characterized by nonmarine sedimentary deposits that lack volcanic strata. Lithofacies, paleocurrent, and compositional data from these deposits are interpreted as recording northward prograding alluvial-fluvial systems that were derived from metavolcanic and metasedimentary source terranes of the accretionary prism. Both northern and southern basin-margin deposits merge into basin-axis deposits characterized by thick sections of carbonaceous mudstone and coal, and minor channelized sandstone. Basin-axis strata are interpreted as products of high-sinuosity fluvial and lacustrine environments that drained southwestward into the ancestral Cook Inlet basin.

Unlike most previously studied ancient forearc basins, the Matanuska Valley–Talkeetna Mountains basin contains a fairly complete stratigraphic record of nonmarine sedimentation and volcanism. These deposits record multiple episodes of transpressional deformation that may be related to northward translation of the forearc basin along the continental margin, oroclinal bending of Alaska, and/or subduction of a spreading ridge. To evaluate the record of ridge subduction in Paleocene-Oligocene forearc basin deposits, two reconstructions are presented. In one reconstruction, the forearc basin and accretionary prism...
were translated northward as a single block with most displacement accommodated along inboard dextral strike-slip faults such as the Castle Mountain and Denali fault systems. In this reconstruction, ridge subduction beneath the forearc basin would have occurred at ca. 54–50 Ma, coeval with basinward progradation of coarse-grained deposystems, and with syndepositional displacement and growth-syncline development along the Castle Mountain fault. In the second reconstruction, in addition to displacement on inboard strike-slip faults, significant northward displacement was accommodated along the Border Ranges and Hanagita faults. These fault systems separated the forearc basin from the accretionary prism. In this reconstruction, the forearc basin and accretionary prism were translated separately and have different displacement histories; ridge subduction beneath the forearc basin would have occurred at ca. 61–58 Ma. The sedimentary record of ridge subduction in this reconstruction is represented by a basinwide unconformity and/or deposition of relatively fine-grained deposits in the forearc basin. We prefer the first reconstruction, but until additional high-resolution geochronological data are available, and the displacement histories of major fault systems are better known, both reconstructions are feasible.

Keywords: ridge subduction, Chugach terrane, Peninsular terrane, Wrangellia composite terrane, geochronology, sedimentology, forearc basin, tectonics, transpression.

INTRODUCTION

Forearc basin deposits provide a long-term record of tectonic processes responsible for the growth of convergent plate margins. Due to their proximity to both magmatic arcs and accretionary prisms, forearc basin deposits may record both inboard arc-related volcanism and outboard deformation within the subduction complex (e.g., Dickinson and Seely, 1979). Most of the conceptual framework for forearc basins is based on studies of the Great Valley Group in California (e.g., Dickinson and Rich, 1972; Ingersoll, 1978a, 1978b, 1979, 1983; Dickinson and Seely, 1979; Moxon and Graham, 1987; Linn et al., 1991, 1992; Williams, 1997) and the Peninsular Ranges in Baja Mexico (e.g., Busby-Spera, 1986; Morris and Busby-Spera, 1988; Busby et al., 1998). The general sedimentologic model for forearc basins predicts a progressive evolution from deep-marine through shallow-marine to nonmarine deposystems, with progressive filling of the basin (Ingersoll, 1979; Dickinson, 1995). Previous research focused mainly on the sedimentology and petrofacies of marine and deltoid deposits of ancient forearc basins; notably lacking from the literature are detailed studies of ancient nonmarine deposits within the context of forearc basin development (e.g., Fulford and Busby, 1993). The Matanuska Valley–Talkeetna Mountains forearc basin in south-central Alaska contains 2800 m of well-exposed and relatively undeformed Paleocene–Oligocene nonmarine strata (Fig. 1; Winkler, 1992), and thus provides an excellent opportunity to evaluate the stratigraphic and structural development of an ancient nonmarine forearc basin. In this study, we present new \(^{40}\text{Ar}/^{39}\text{Ar}\) geochronologic ages, measured stratigraphic sections, lithofacies analyses, and compositional data from Paleocene–Oligocene deposits of the Matanuska Valley–Talkeetna Mountains forearc basin. New stratigraphic and structural cross sections are presented to better define relationships between sedimentation and deformation in the forearc basin. Integration of these new data sets also allows us to develop tectonic reconstructions that demonstrate the early Tertiary tectonic development of the Matanuska Valley–Talkeetna Mountains forearc basin. The stratigraphy of this forearc basin records regional transpression related to terrane
Sedimentary record of transpressional tectonics and ridge subduction.

Tanana basin

170°W 150°W
Alaska
Canada
250 km
60°N
U.S.A. Gulf of Alaska

Area of Figure 1A

A)

SUBSIDING MESOZOIC-QUATERNARY BASINS
- CB - Copper River basin
- SB - Susitna basin
- CIB - Cook Inlet basin,

UPLIFTED MESOZOIC-CENOZOIC BASINS
- MT - Matanuska Valley-Talkeetna Mountains basin
- WB - Wrangell Mountains basin, KB - Kahlilta basin
- NB - Nutzotin basin

WRANGELLO COMPOSITE TERRANE:
- P - Peninsular terrane, A, Alexander terrane,
- W - Wrangellia terrane

AXES OF LATE CRETACEOUS-QUATERNARY ARCS:
- P - Peninsular terrane, A, Alexander terrane,
- W - Wrangellia terrane

CIB - Cook Inlet basin, A)

B)

Denali fault

Yukon composite terrane

North American craton

0 200 km

0 150° 140° 62° 60°

CIB

AL

AT

P, Peninsular terrane, A, Alexander terrane,
W, Wrangellia terrane

Quaternary-recent Aleutian arc
Quaternary Wrangell arc
Late Cretaceous-Tertiary Alaska Range-Talkeetna Mountains arc

CB - Copper River basin, SB - Susitna basin
CIB - Cook Inlet basin
MT - Matanuska Valley-Talkeetna Mountains basin
WB - Wrangell Mountains basin, KB - Kahlilta basin
NB - Nutzotin basin

C)

UPLIFTED MESOZOIC-CENOZOIC BASINS

SMCT

5.4 cm/yr

F-QCF

4.6 cm/yr

SMCT

area of Fig. 3

Kodiak Island

Prince William Sound

Gulf of Alaska

Chugach Mountains

MT - Matanuska Valley-Talkeetna Mountains basin

SMCT - Susitna basin

Alaska Range-Talkeetna Mountains arc

Prince William Sound

Gulf of Alaska

CIB - Copper River basin, A)

B)

Denali fault

Yukon composite terrane

North American craton

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Alaska Range-Talkeetna Mountains arc

Prince William Sound

Gulf of Alaska
translation, subduction of oceanic crust, ridge subduction, and/or oroclinal bending along the early Tertiary accretionary convergent margin of southern Alaska.

GEOLOGIC SETTING

Forearc Basin, Accretionary Prism, and Volcanic Arc

Over 7600 m of Upper Cretaceous–Lower Tertiary sedimentary strata are exposed in a ~90 km long and 20 to 70 km wide outcrop belt in the Matanuska Valley, southern Talkeetna Mountains, and northern Chugach Mountains (Fig. 1). We refer to these deposits as the Matanuska Valley–Talkeetna Mountains forearc basin. This basin developed between a coeval accretionary prism to the south (present coordinates) and a volcanic arc to the north (present coordinates) (Little, 1988; Little and Næs- ter, 1989; Winkler, 1992).

The southern margin of the forearc basin deposits is bounded by metamorphosed Triassic-Paleogene marine sedimentary deposits, oceanic basalt, and mélangé of the Southern Margin composite terrane (Figs. 1, 2, 3; Plafker et al., 1994). These deposits represent one of the largest accretionary prisms on Earth (Plafker et al., 1994). The age of strata, degree of structural deformation, and grade of metamorphism within the accretionary prism progressively decreases southward. The Border Ranges/Hanagita fault system marks the boundary between the accretionary prism and the forearc basin (Figs. 1, 2; MacKevett and Plafker, 1977; Roeske et al., this volume). This fault system accommodated mainly Mesozoic dip-slip and Cenozoic dextral strike-slip displacement (e.g., Pavlis, 1982; Little and Næs- ter, 1989; Little, 1990; Pavlis and Crouse, 1989; Roeske et al., 1993, this volume; Smart et al., 1996). The amount of Cenozoic strike-slip displacement is presently unclear, with inferred displacements ranging from a few tens of km (e.g., Little and Næs- ter, 1989) to more than 700 km (e.g., Smart et al., 1996; Roeske et al., this volume). Along the northern margin of the forearc basin, strata depositionally onlap Upper Cretaceous-Quaternary arc-related volcanic and plutonic rocks (TKg and Ttv on Figs. 2B, 3; Nokleberg et al., 1994). The northeast-trending Castle Mountain fault system bisects the arcward margin of the forearc basin (Figs. 1, 3). Cenozoic dextral offset of several tens of kilometers has been proposed along this fault system (Grantz, 1966; Clardy, 1974; Detterman et al., 1976; Fuchs, 1980).

Forearc basin, accretionary prism, and volcanic arc construction are the products of northeastward to northwestward subduction of the Farallon, Kula, and Pacific oceanic plates beneath the northwestern Cordillera margin throughout the Late Cretaceous and Tertiary (Plafker and Berg, 1994; Plafker et al., 1994). Matanuska Valley–Talkeetna Mountains forearc basin sedimentation, volcanism, and plutonism apparently ceased during the Neogene. The southwestern extension of the Matanuska Valley–Talkeetna Mountains basin is marked by the modern Cook Inlet, which includes an active volcanic arc, forearc basin, and accretionary prism located above the northwestward-subducting Pacific plate (Fig. 2C; Magoon et al., 1976; Haeussler et al., 2000).

Accreted Terranes and Translation History

The Matanuska Valley–Talkeetna Mountains forearc basin and associated volcanic arc were constructed upon the allochthonous Peninsular terrane (Fig. 1B), a ~7 km thick sequence of Lower to Upper Jurassic volcanic rocks, granitic plutons, and marine sedimentary strata (Nokleberg et al., 1994). The Peninsular terrane represents the westernmost segment of the Wrangellia composite terrane, a subcontinent-scale terrane consisting of three tectonostratigraphic terranes (P, A, and W on Fig. 1B) that were juxtaposed by the late Paleozoic. Paleomagnetic, paleontologic, and lithologic evidence indicate that the composite terrane was located ~30° south of its present latitude with respect to cratonic North America during the Late Triassic (Hillhouse and Coe, 1994) and was subsequently translated northward throughout the late Mesozoic and early Cenozoic (Plafker and Berg, 1994). Paleomagnetic studies indicate that Late Cretaceous sedimentary strata of the Matanuska Valley–Talkeetna Mountains forearc basin (Kn on Figs. 3, 4) were deposited ~2800 ± 2000 km south of their present latitude relative to cratonic North America (Stamatakos et al., 1989). Paleomagnetic data from Paleocene-Eocene strata (Tar and Tc on Figs. 3, 4) indicate that the forearc basin was positioned ~1600 ± 1200 km south of its present latitude during deposition (Stamatakos et al., 1989). Similarly, paleomagnetic data from Late Cretaceous-Paleocene ophiolites of the accretionary prism imply ~1400 ± 1000 km of northward latitudinal displacement from 57 to 45 Ma (SMCT on Fig. 1; Coe et al., 1985; Bol et al., 1992). Paleomagnetic data indicate that the basin and accretionary prism were at their present latitude by ca. 50–45 Ma (Stamat- kos et al., 1988; Hillhouse and Coe, 1994). Thus, the forearc basin and accretionary prism probably originated south of their present latitude and were translated northward during the Late Cretaceous–early Tertiary. Northward displacements were accommodated by orogen-parallel dextral strike-slip fault systems, including the Denali (Fig. 1; Nokleberg et al., 1994) and Border Ranges/Hanagita fault systems (Roeske et al., 1993, this volume; Smart et al., 1996).

STRATIGRAPHIC AND GEOCHRONOLOGIC DATA

Sedimentary strata of the Matanuska Valley–Talkeetna Mountains forearc basin consist of a lower marine package and an upper nonmarine package. The marine package consists of Cretaceous mudstone, sandstone, limestone and minor conglomerate, and has a maximum preserved thickness of ~4800 m (Kn and Km on Figs. 3, 4; Grantz and Jones, 1960; Csejtey et al., 1978; Winkler, 1992). The nonmarine package, the focus of this study, consists of Paleocene-Oligocene conglomerate, sandstone, mudstone, coal, and minor interbedded lava flows and tuffs. The maximum preserved thickness of the Paleocene-Oligocene non-
marine deposits is ~2800 m (Little and Naeser, 1989; Winkler, 1992; this study). The Paleocene-Oligocene stratigraphy consists of four formations—the Chickaloon, Arkose Ridge, Wishbone and Tsadaka Formations (Tc, Tar, Tw, and Tsd on Figs. 3, 4; Csiejty et al., 1978; Winkler, 1992). The age, lithofacies, thickness, and stratigraphic equivalents of each formation is briefly described below based on our new measured stratigraphic sections and 40Ar/39Ar age determinations (Table 1) in combination with data reported from previous studies. Procedures for the 40Ar/39Ar analyses are presented in Appendix 1.
Figure 3. Generalized geologic map of the Matanuska Valley and southern Talkeetna Mountains in the Anchorage and Talkeetna Mountains quadrangles. Dark gray areas (Tar, Tc, and Tw) represent mostly nonmarine Tertiary sedimentary strata that are the focus of this study. Numbered black circles represent the locations of new measured stratigraphic sections discussed in text. Lettered open circles represent locations of measured sections from Little (1988). See Figures 1B and 1C for map location. Geology modified from Winkler (1992), Csejtey et al. (1978), and Wilson et al. (1998).
Figure 4. Age-event diagram for late Mesozoic and Cenozoic stratigraphy of the Matanuska Valley, Talkeetna Mountains, and Cook Inlet. 1 and 2—rock units as described by Winkler (1992), Trop and Ridgway (1999), and this study; 3—depositional and deformational events based on results of this study, Clardy (1974), Fuchs (1980), and Little and Naeser (1989); 4—after Hudson (1983), Wallace and Engebretson (1984), Bradley et al. (2000), and Moll-Stalcup (1994); 5—Nokleberg et al. (1994), Plafker and Berg (1994), includes Denali fault (Lanphere, 1978; Nokleberg et al., 1994; Ridgway et al., 1995, 1999), Tintina fault (Gabrielse, 1985; Dover, 1994), Castle Mountain fault (Fuchs, 1980; Silberman and Grantz, 1984), and Border Ranges fault (Little, 1990; Roeske et al., 1993, this volume; Smart et al., 1996); 6—Engebretson et al. (1985), Hillhouse and Coe (1994), Plafker et al. (1994), Plafker and Berg (1994), Pavlis and Sisson (1995), and Bradley et al. (2000).
**Chickaloon Formation**

The Chickaloon Formation consists of ~1500 m of mudstone, sandstone, and coal with minor conglomerate and tuff (Fig. 4; Little, 1988; Flores and Stricker, 1993a, 1993b). This formation is exposed between the Castle Mountain and Border Ranges fault systems (Tc on Figs. 2B, 3) and overlies Upper Cretaceous to Lower Jurassic strata along an angular unconformity (Figs. 3, 4; Winkler, 1992). The Chickaloon Formation is gradationally overlain by the Eocene Wishbone Formation along a conformable contact at most locations, but locally this contact is an angular unconformity (Figs. 3, 4; Clardy, 1974; Fuchs, 1980). A late Paleocene–early Eocene age for the Chickaloon Formation is defined by plant megafossils (Wolfe et al., 1966; Little, 1988), palynomorphs (Little, 1988), isotopic ages of interbedded airfall tuffs from the upper part of the formation (55.8 to 52.2 Ma; n = 5; Triplehorn et al., 1984), and fission track ages of crosscutting dikes (47.8–41.3 Ma, n = 2; Little and Naeser, 1989). Whereas the age of the uppermost Chickaloon Formation is well constrained by dated airfall tuffs, the lower Chickaloon Formation may represent all or part of the Late Paleocene prior to 55.8 Ma (oldest dated tuff).

**Arkose Ridge Formation**

The Arkose Ridge Formation consists of sandstone, conglomerate, and minor mudstone, coal, tuff, and lava flows, and has a maximum preserved thickness of 1600 m (Silberman and Grantz, 1984; Trop and Ridgway, 1999). Outcrops of the Arkose Ridge Formation are confined to the north side of the Castle Mountain fault system (Tar on Fig. 3; Winkler, 1992). The base of the Arkose Ridge Formation unconformably overlies Jurassic igneous and metamorphic rocks (Ji and Jps on Fig. 3); the top of the formation is unconformably overlain by Quaternary surficial deposits (Qs on Fig. 3) or unnamed Tertiary volcanic rocks (Tv on Fig. 3). K-Ar ages from interbedded volcanic rocks (56–46 Ma; n = 6; Silberman and Grantz, 1984) indicate that the Arkose Ridge Formation is Late Paleocene to Middle Eocene (Fig. 4). Accordingly, the Arkose Ridge Formation is partly coeval with the Upper Paleocene–Lower Eocene Chickaloon Formation (Winkler, 1992), which is exposed south of the Castle Mountain fault system (Tc on Fig. 3). Five of the six K-Ar ages reported from the Arkose Ridge Formation, however, are younger than the fission track and K-Ar ages reported from tuffs of the uppermost Chickaloon Formation. Thus, the Arkose Ridge Formation may be correlative with the uppermost Chickaloon Formation and/or the Wishbone Formation, which gradationally overlies the Chickaloon Formation (see description below).

**Wishbone Formation**

The Wishbone Formation consists mainly of conglomerate and sandstone (Clardy, 1974; Fuchs, 1980; this study). The maximum preserved thickness of the Wishbone Formation

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**TABLE 1. $^{40}$Ar/$^{39}$Ar AGES FOR TERTIARY VOLCANIC ROCKS, MATANUSKA VALLEY–TALKEETNA MOUNTAINS**

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Geographic location*</th>
<th>Stratigraphic position</th>
<th>Rock type</th>
<th>Mineral</th>
<th>Age (Ma)$^3$</th>
<th>Notes$^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM1-54</td>
<td>Billy Mountain Section 22</td>
<td>8 m above top of Wishbone Formation</td>
<td>Tuff</td>
<td>Plagioclase</td>
<td>37.3 ± 2.1</td>
<td>Single-crystal laser fusion, 11 single crystals</td>
</tr>
<tr>
<td>WC1-CC1-BR (basalt clast)</td>
<td>Wishbone Hill Section 8</td>
<td>12 m above base of Wishbone Formation</td>
<td>Basalt</td>
<td>Whole rock</td>
<td>56.8 ± 0.3</td>
<td>Furnace step-heat</td>
</tr>
<tr>
<td>BOX2-CC2-2 (granite clast)</td>
<td>Box Canyon Section 18</td>
<td>252 m above base of Wishbone Formation</td>
<td>Granite</td>
<td>Biotite</td>
<td>59.7 ± 0.3</td>
<td>Furnace step-heat</td>
</tr>
<tr>
<td>CA1-TV-1300</td>
<td>Castle Mountain Section 11</td>
<td>4 m above top of Wishbone Formation</td>
<td>Basalt</td>
<td>Whole rock</td>
<td>&lt;61.0 Ma</td>
<td>Furnace step-heat</td>
</tr>
<tr>
<td>SUN1-3.6</td>
<td>Boulder Creek Section 19</td>
<td>231 m above faulted base of Chickaloon Formation</td>
<td>Volcaniclastic sandstone</td>
<td>Sanidine</td>
<td>177.0 ± 1.2</td>
<td>Single-crystal laser fusion, 4 single crystals</td>
</tr>
</tbody>
</table>

*See Figure 3 for measured section locations.

$^1$Stratigraphic units and unit abbreviations from Anchorage 1:250 000 quadrangle of Winkler (1992) and Figure 3 (this study).

$^2$Preferred ages reported in text. Ages for BM1-54, WC1-CC1-BR, and SUN1-3.6 represent isochron analyses. Age for BOX2-CC2-2 represents plateau age from step-heating analysis. Age of CA1-TV-1300 represents maximum age value from step-heating analysis.

$^3$Explanation of furnace step-heat and laser fusion analytical methods presented in Appendix 1. Analytical data and age spectra available from the authors upon request.

$^4$Originally interpreted as Arkose Ridge Formation (Tar) by Winkler (1992). Interpreted as Wishbone Formation (Tw, this study) on the basis of new stratigraphic, sedimentologic, and compositional data.

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ranges from <150 m north of the Castle Mountain fault system to >1100 m south of the fault system (Tw on Fig. 5). South of the fault system the Wishbone Formation gradationally overlies early Eocene strata of the Chickaloon Formation, but north of the fault system the formation unconformably overlies folded Lower Jurassic to Tertiary strata along an angular unconformity (Figs. 3, 5; Csejtey et al., 1978; Fuchs, 1980; Winkler, 1992). The Wishbone Formation is overlain by unnamed Tertiary volcanic rocks, the Oligocene Tsadaka Formation, or Quaternary surficial deposits along a disconformity or angular unconformity (Figs. 3, 5).

The age of the Wishbone Formation was previously interpreted as Eocene (ca. 55–34 Ma) on the basis of (1) sparse age-diagnostic palynomorphs (K. Piel, personal commun., cited in Clardy, 1974), and (2) a gradational lower contact with early Eocene strata of the Chickaloon Formation (Fuchs, 1980). Due to the lack of datable material in the Wishbone Formation, we analyzed plagioclase feldspar from an airfall tuff exposed ~7 m above uppermost strata of the Wishbone Formation (unnamed Tertiary volcanic rocks, Tv on Fig. 3) to provide a minimum age for the Wishbone Formation. Eleven single-crystal 40Ar/39Ar analyses define a late Middle Eocene isochron age of 37.3 ± 2.1 Ma (BM1-54 on Table 1 and Figs. 5, 6). A basalt flow located ~4 m above the uppermost Wishbone Formation was also analyzed to constrain the minimum age of the Wishbone Formation (CA1-TV-1300 on Table 1 and Figs. 5, 6). 40Ar/39Ar whole rock step-heating ages are very discordant and no valid isochrons were derived. Attempted isochrons have 40Ar/39Ar values greater than atmospheric values, suggesting that excess argon is present. Thus, the age of the basalt is interpreted as being younger than the minimum value in the age spectrum (ca. 61 Ma; Fig. 6). 40Ar/39Ar analysis of two igneous clasts contained in conglomerates of the Wishbone Formation provides crude maximum ages of deposition. Step heating analysis of biotite from a granite clast yielded a moderately concordant age spectrum with a plateau age of 59.7 ± 0.3 Ma (sample BOX-CC2-2 on Table 1 and Figs. 5, 6). A basalt clast yielded a discordant age spectrum with ages from ca. 36 to 55 Ma. An isochron age of 56.8 ± 0.3 Ma is defined by steps 3–7 (sample WC1-CC1-BR on Table 1 and Figs. 5, 6). These age interpretations are consistent with the previously reported Eocene palynomorphs from the Wishbone Formation and with isotopic and fission track ages of airfall tuffs from the upper part of the Chickaloon Formation (55.8 to 52.8 Ma; n = 5; Triplehorn et al., 1984; Figs. 4, 5). In summary, no direct age data are available for the formation; the possible age of the Wishbone Formation ranges from 52.2 ± 1.6 Ma (youngest dated tuff in uppermost Chickaloon Formation) to 37.3 ± 2.1 Ma (tuff overlying uppermost Wishbone Formation).

Tsadaka Formation

The Tsadaka Formation is limited in outcrop distribution to the lower Matanuska Valley (Tsd on Fig. 3) and has a maximum preserved thickness of ~200 m (Fig. 4). This formation consists of poorly sorted, boulder to cobble conglomerate with minor mudstone and sandstone. Palynomorphs recovered from the Tsadaka Formation indicate a middle to late(?) Oligocene age (ca. 29–24 Ma; Clardy, 1974; Fig. 4). The Tsadaka Formation overlies folded Paleocene-Eocene strata of the Chickaloon and Wishbone Formations along an angular unconformity (Clardy, 1974). The top of the Tsadaka Formation is eroded and overlain by Quaternary surficial deposits.

DEPOSITIONAL SYSTEMS

New measured stratigraphic sections, lithofacies analyses, paleocurrent data, and maximum particle size data from 22 study sites (sections 1–22 on Fig. 3) provide a database for reconstructions of the depositional systems of the early Tertiary Matanuska Valley–Talkeetna Mountains forearc basin. These new data are integrated with previous geologic mapping studies (Fuchs, 1980) and sedimentologic analyses that were limited to more localized parts of the basin (Clardy, 1974; Little, 1988; Flores and Stricker, 1993a, 1993b).

Proximal Lithofacies: Stream-Dominated Alluvial-Fan Deposits

The northern and southern margins of the forearc basin are characterized by interbedded conglomerate and sandstone deposits that range in thickness from 50 to 700 m (Figs. 5, 7, 8A). These deposits are most common adjacent to the Castle Mountain fault along the northern basin margin (northern outcrops of Tw and Tc on Figs. 5, 7) and adjacent to the Border Ranges fault along the southern basin margin (Tc outcrops adjacent to BRF on Figs. 3, 5, 7; Little, 1988). Three distinct lithofacies characterize these deposits.

Lithofacies 1: Unorganized, Boulder-Cobble Conglomerate

Description. This lithofacies is characterized by unorganized, clast-supported conglomerate with angular to subrounded clasts. Conglomerate beds are broadly lenticular (10–20 m) and are arranged into 5 to 15 m thick upward-finining packages. Subordinate sandstone and mudstone beds cap the upward-finining sequences. Interbedded with the poorly organized, clast-supported conglomerates are minor matrix-supported cobble-pebble conglomerates that often contain outsized boulders.

Interpretation. The framework support, lenticular bed geometries, and crude upward-finining trends of Lithofacies 1 indicate deposition by high-energy streamflow processes. The poorly organized, clast-supported conglomerates of this lithofacies were most likely deposited by stream-driven, high-density, gravelly traction carpets (Todd, 1989) and/or hyperconcentrated flood flows (Pierson, 1980; Smith, 1986). These types of flows are reported from modern humid alluvial-fans that are influenced by seasonal floods (Wells and Harvey, 1986). The matrix-supported conglomerates are interpreted as being deposited by
Figure 5. Generalized measured stratigraphic sections, stratigraphic positions of new $^{40}$Ar/$^{39}$Ar age determinations, and inferred correlations of Tertiary strata within the Matanuska Valley–Talkeetna Mountains forearc basin. Stratigraphic sections are from bed-by-bed measurements using a Jacob staff. Numbered sections (22, 18, 11, 8, 12, 13, 14) are from this study; lettered sections (A–F) are from Little (1988). See Figure 3 for section locations and Figure 6 for $^{40}$Ar/$^{39}$Ar data.

ABBREVIATIONS
Tv - unnamed volcanic rocks
Tc - Chickaloon Formation
Tw - Wishbone Formation
Km - Matanuska Formation
JTrt - Talkeetna Formation
Ji - Jurassic intrusive rocks
Mzu - Mesozoic metased. rocks

LITHOLOGIC SYMBOLS
- Massive cobble-boulder conglomerate
- Thick bedded, pebble-cobble conglomerate
- Hematitic cobble conglomerate
- Planar-/ trough-cross-stratified sandstone
- Mudstone and pebble conglomerate
- Mudstone, sandstone, and coal
- Interbedded mudstone and locally coal
- Volcaniclastic sandstone and ashfall tuff
- Lava, pumice, tuff, volcaniclastic sandstone, and conglomerate

* = new $^{40}$Ar/$^{39}$Ar age determinations (Ma)
Figure 6. 40Ar/39Ar age data for feldspar phenocrysts from an airfall tuff (BM1-54), whole rock basalt (CA1-TV-1300), biotite and whole rock from igneous clasts (BOX-CC2-2, WC1-CC1-BR) from conglomerates, and detrital feldspars from a volcaniclastic sandstone (SUN2-3.65). See Table 1 and Figure 5 for geographic location and stratigraphic position of each sample. See Appendix 1 for 40Ar/39Ar analytical procedures and data treatment.
Figure 7. Representative measured stratigraphic sections of the Matanuska Valley–Talkeetna Mountains basin showing changes in Paleocene-Oligocene lithofacies from the northern basin margin to the southern basin margin. See Figure 3 for section locations. See Figure 5 for explanation of lithofacies symbols. Due to space limitations, only a 150 m representative part of each measured section is shown.
debris flows on the basis of the poor sorting and coarseness, in combination with a lack of tractive transport indicators or basal scour (Johnson, 1970).

**Lithofacies 2: Organized, Imbricated Conglomerate**

**Description.** Well-organized, clast-supported conglomerate is the most common lithofacies along the northern and southern basin margins. Pebble- and cobble-size clasts dominate this lithofacies. Upward-fining packages are well developed in this lithofacies (Figs. 8B, 8C). Individual packages grade upward from imbricated or massive cobble conglomerate to massive or planar cross-stratified pebbly sandstone and/or carbonaceous mudstone. Clast imbrication and low-angle cross-stratification are common sedimentary structures (Fig. 8D). Individual beds are 0.5 to 2.5 m thick and extend tens of meters laterally.

**Interpretation.** The upward-fining trends, clast imbrication, lenticular bed geometries, and presence of current-generated sedimentary structures all indicate that deposition of this lithofacies was mainly by streamflow processes. The organized conglomerate lithofacies is closely comparable to gravel and coarse-grained sand deposited in braided streams under waning flow conditions by accretion of progressively smaller clasts in channels and on longitudinal bars (Collinson, 1986). Interbedded mudstones probably record stagnation and fluvial channel abandonment.

**Lithofacies 3: Cross-Stratified Sandstone**

**Description.** A third lithofacies common to basin margin deposits is characterized by massive to planar- and trough-cross-stratified sandstone. These sandstones are medium- to coarse-grained, moderately sorted, and have tabular geometries. Individual sandstone units are amalgamated into broad sheet-like complexes with internal discontinuities such as scour and reactivation surfaces. Individual foresets in the stratified sandstones have average thicknesses of 40–70 cm. Plant fossils are common in this lithofacies.

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Figure 8. Photographs of alluvial-fan and braided-stream lithofacies along the northern margin of the Matanuska Valley–Talkeetna Mountains forearc basin. See Figure 3 for measured section locations. A: Boulder and cobble conglomerate and minor sandstone of the uppermost Wishbone Formation (Tw) at section 11. The conglomerates are overlain by unnamed Tertiary volcanic rocks (Tv). Exposure is approximately 200 m thick. B and C: Broadly lenticular upward-fining conglomeratic packages at sections 19 and 18, respectively. Typical packages consist of 2–7 m thick imbricated pebble-cobble conglomerate (Gcml) that grades upward into massive conglomerate, massive and trough-cross-stratified sandstone (Sm/St), and mudstone (Fsm). Person (right center, arrow) for scale in Figure 8C. Exposure in Figure 8B is approximately 200 m thick. D: Organized, clast-supported boulder and cobble conglomerate common along the northern basin margin (section 22). Bedding dips ~14° to the northwest (right in photograph). Hammer (lower center) for scale.
**Interpretation.** Lithofacies 3 is interpreted as having been formed by streamflow processes. Evidence for streamflow processes includes the trough and planar cross-stratification. The abundant stratification, with foresets in the 40–70 cm thick range, indicates that deposition was primarily by subaqueous three-dimensional ripples (dunes) and two-dimensional ripples (sandwaves) in shallow channels (Harms et al., 1982). The sheetlike geometries and average foreset thicknesses documented for Lithofacies 3 are indicative of deposition in unconfined fluvial systems with multiple shallow channels.

**Summary**

We interpret the three lithofacies common along the forearc basin margins to represent deposits of stream-dominated alluvial-fan systems (e.g., Boothroyd and Nummedal, 1978; Ridgway and DeCelles, 1993a). Stream-dominated alluvial fans are fans whose surface processes are characterized by perennial stream flow (Collinson, 1986). These types of fans have also been referred to as wet fans (Schumm, 1977; Schumm et al., 1987) and humid fans (Fraser and Suttner, 1986). In our depositional interpretation, the boulder-cobble conglomerate of Lithofacies 1 is interpreted as the product of localized hyperconcentrated flows in the proximal parts of the fan system associated with flood-flow conditions. The organized, imbricated conglomerate of Lithofacies 2 represents normal-flow deposition in proximal and medial parts of the alluvial-fan system characterized by streamflow processes. The cross-stratified sandstones of Lithofacies 3 are interpreted as representing distal sand-rich parts of stream-dominated alluvial fans. Distal parts of these types of fans are commonly dominated by sandy linguoid bar deposition (Boothroyd and Nummedal, 1978; Boothroyd and Ashley, 1975). Stream-dominated alluvial fans adjacent to the Castle Mountain fault along the northern basin margin transported sediment southward based on paleocurrent data (Fig. 9). Similar alluvial-fan deposystems adjacent to the Border Ranges fault along the southern basin margin transported sediment northwestward (Fig. 9; Little, 1988).

**Medial Lithofacies: Sandy Braided Stream Deposits**

Amalgamated 700–1000 m thick sections of channelized sandstone are present north of the Castle Mountain fault in the northwestern part of the basin (Tar outcrops on Fig. 3; section 3 on Fig. 7; Trop and Ridgway, 1999) and adjacent to the Border Ranges fault system along the southern basin margin (Tc outcrops adjacent to BRF on Fig. 3; section 3 on Fig. 5; Little, 1988).

**Lithofacies 1: Channelized Planar Cross-Stratified Sandstone**

**Description.** This lithofacies consists of lenticular, fine- to medium-grained sandstone beds that are 0.6–2.0 m thick and...
over 10–20 m in length. Amalgamated lenticular sandstone beds form broad ~20 m thick sandstone sheets that fine upward (Fig. 10A). These sandstone sheets consist of massive to planar cross-stratified, medium-grained sandstone that grades upward into ripple-laminated, fine-grained sandstone capped by structureless to laminated mudstones. Trough cross-stratification and horizontal stratification are also common sedimentary structures in this lithofacies. Basal scours have relief of ~0.25–0.80 m and commonly include fossilized tree branches and leaves. Subordinate mudstone beds are 0.2–10 m thick, structureless to laminated, and are laterally continuous at the outcrop scale (10–50 m). Thin interbeds of carbonaceous shale and coal are also present in this lithofacies.

**Interpretation.** The amalgamated sandstones are interpreted as being formed by streamflow processes in low-sinuosity, fluvial systems. Evidence for fluvial deposition includes the presence of cross-stratification, upward-fining packages, and lenticular bed geometries. The amalgamated sheetlike architecture of sandstones and the scale of individual sedimentary structures (25–50 cm thick planar foresets) suggest that deposition occurred by migration of transverse and longitudinal sandbars in low-sinuosity streams (Miall, 1978; Rust, 1978; Harms et al., 1982). The amalgamation of sandstone beds is attributed to high-frequency switching of channels across an unconfined depositional surface whereas upward-fining packages likely resulted from eventual abandonment of channel complexes. The

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**Figure 10.** Photographs of interbedded volcanic and sedimentary strata along the northern margin of the Matanuska Valley–Talkeetna Mountains forearc basin. A: Sandstone and lava flows characteristic of sandy braided stream deposits of the Arkose Ridge Formation at section 3. Exposure includes massive and trough cross-stratified sandstone and 2–5 m thick basaltic lava flows. White arrows (upper left) denote upper and lower contact of a 25 m thick section of basalt flows. Sandstones consist of highly amalgamated, broad shallow channel deposits. Exposure is approximately 250 m thick. Tadpole symbol (upper right) shows dip of bedding. B: Interbedded fluvial volcaniclastic sandstone (Sh) and lithic-pumice tuff breccia (T) with outsized lithic blocks (B) of tuff and pumice. These volcanic deposits are interbedded with nonvolcanic fluvial conglomerates (not shown). Outcrop is from the upper part of the Wishbone Formation at section 18. Person (lower right) for scale. C: Nonvolcanic pebble-cobble conglomerate (Gcmi) with interbedded lithic tuff and pumice (T), and felsic lava flows (L). Outcrop is from the Wishbone Formation at section 18. Exposure is approximately 35 m thick. D: Nonvolcanic pebble-cobble conglomerate (Gcmi) overlain by nonvolcanic massive mudstone, lithic tuff and pumice, and airfall tuff. Section is overlain by lava flows (L) of the unnamed Tertiary volcanic rocks (Tv on Figure 3). Black arrow (lower left) marks top of channelized nonvolcanic conglomerate. Outcrop is from the Wishbone Formation at section 18. Exposure is approximately 240 m thick. Person (white arrow, lower right) for scale.
thick sections of this lithofacies (700–1000 m thick) suggest that extensive braidplains were well developed along the northern and southern basin margins. Most mudstones were probably deposited in overbank areas by suspension fallout of silt and clay during waning flow following floods. Limited paleocurrent data (n = 9) from planar cross-stratified sandstones along the northwestern basin margin (section 3 on Figs. 3, 7, 9) indicate southward sediment transport.

**Basin Axis Lithofacies: Sinuous Stream, Swamp, and Lacustrine Deposits**

The axis of the forearc basin is characterized by abundant fine-grained siliciclastic and coal deposits (Figs. 5, 7, 11A). Two distinct lithofacies make up the basin-axis deposits.

**Lithofacies 1: Fine-Grained Sandstone, Mudstone, and Coal**

*Description.* This lithofacies includes channelized, fine-grained sandstone, laminated sandstone and shale, and carbonaceous shale and coal (Fig. 11A). Large-scale, inclined heterolithic strata consisting of laminated siltstone and sandstone are common in this lithofacies. Clay-draped trough and ripple cross-stratification, flaser bedding, wavy bedding, climbing-ripple stratification, and bioturbation are also characteristic of this lithofacies. Plant megafossils are extremely abundant with fossilized leaves being exquisitely preserved (Wolfe et al., 1966).

**Interpretation.** We interpret the intricate mixture of channelized sandstone and mudstone, in addition to the type, scale, and arrangement of sedimentary structures as indicative of deposition in tidally influenced fluvial and estuary systems (Clifton, 1982; Eisma, 1998). Channelized, fine-grained sandstone deposits probably represent deposition in upper estuary channels, whereas tabular carbonaceous mudstones and coals were deposited in nearby fluvial marshes and tidal flats. Flaser to wavy bedding and clay-draped ripples suggest repeated fluctuations in current velocity, a depositional feature characteristic of tidally influenced environments (Eisma, 1998). Inclined heterolithic strata common in this lithofacies are characteristic of...
deposits formed by sandy fluvial point bars in micro- to mesotidally-influenced reaches of river systems (Smith, 1985; Thomas et al., 1987). This tidally influenced lithofacies is restricted to the Chickaloon and Arkose Ridge Formations and is only found in the western part of the basin axis (sections 3, 7, and 8 on Fig. 3).

Lithofacies 2: Trough Cross-Stratified Sandstone and Ripple-Laminated Siltstone

**Description.** This lithofacies consists of medium- to fine-grained sandstone and ripple laminated siltstone. The sandstones form upward-finings, lenticular units that are 1–2 m thick, tens of meters wide, and encased in carbonaceous ripple-laminated siltstone (Fig. 11B). Typical upward-finings consist of basal medium-grained, trough cross-stratified sandstone (Fig. 11C) that grade into fine-grained, ripple-laminated sandstone. Individual sandstones are separated by thick packages of micaceous, ripple-laminated siltstones. Coarse seams up to 3.5 m thick are present (Fig. 11D). Paleocurrent data (n = 164) from trough cross-stratification in this lithofacies indicate westward sediment transport (Fig. 9).

**Interpretation.** Basin-axis strata are interpreted to have been deposited by longitudinal, westward-flowing, high-sinuosity fluvial systems. The upward-finings, trough cross-stratified sandstones of the basin-axis are typical of point bar and levee deposits of high-sinuosity stream systems (Allen, 1970a, 1970b; Jordan and Pryor, 1992). The thick ripple-laminated siltstone deposits represent deposition in overbank fluvial environments.

VOLCANIC DEPOSITS

Interbedded volcanic and sedimentary strata are well exposed along the northern margin of the Matanuska Valley–Talkeetna Mountains forearc basin. Lava flows and volcaniclastic deposits are the two most common volcanic units documented in our measured stratigraphic sections.

Lava Flows

**Description**

Basaltic and felsic lava flows are locally interbedded with sedimentary deposits along the northern basin margin (section 3 on Fig. 7; Figs. 10A, 10B, 10C). Lava flows are particularly abundant in the Arkose Ridge Formation north of the Castle Mountain fault (Silberman and Grantz, 1984; this study; Tar on Fig. 3). Most lava beds are massive, 2 to 5 m thick, and traceable for hundreds of meters.

**Interpretation**

Most of the lava flows were probably deposited in subaerial settings based on the absence of pillow structures or interbedded lacustrine facies, and the association with interbedded alluvial-fluvial deposits (see descriptions above). Several pillow-shaped lava flows, however, are present in the upper part of the Arkose Ridge Formation. These deposits are interpreted to represent subaqueous deposition in local lacustrine environments (Trop and Ridgway, 1999). Fluvial sandstones that depositionally overlie basalt flows in the Arkose Ridge Formation contain abundant basaltic lithic fragments, indicating that basalt flows were subaerially exposed and were a sediment source for younger sedimentary deposits of the Arkose Ridge Formation (Trop and Ridgway, 1999).

Volcaniclastic Deposits

Volcaniclastic deposits are common north of the Castle Mountain fault system in the Arkose Ridge and Wishbone Formations (Silberman and Grantz, 1984; this study; sections 18, 20, and 22 on Figs. 3, 5). Minor volcaniclastic strata are present south of the fault system in the Chickaloon Formation (Triplehorn et al., 1984; Little, 1988). Three distinct volcaniclastic lithofacies were documented in our measured stratigraphic section data.

Lithofacies 1: Pumice-Rich Sandstone

**Description.** Pumice-rich sandstones are the most common volcaniclastic deposits along the northern basin margin. These deposits are characterized by horizontal stratification (Sh on Fig. 10B), trough- and planar-cross-stratification, and lenticular geometries with scoured bases. Volcaniclastic sandstone beds are 0.20 to 0.80 m thick, are medium- to coarse-grained, and consist of pumice fragments, epiclastic volcanic lithic fragments, and plagioclase and quartz crystals. Framework grains are moderately sorted with grain shapes ranging from subangular to subrounded.

**Interpretation.** The high proportion of stratified, juvenile volcanic detritus indicates that this lithofacies formed by fluvial reworking of unconsolidated pyroclastic deposits. These deposits formed contemporaneously with, or relatively shortly after pyroclastic eruptions.

Lithofacies 2: Pumice-Rich Tuff

**Description.** Massive, tabular, pumice-rich tuffs are exposed in the Arkose Ridge and Wishbone Formations along the northern basin margin (Figs. 10B, 10C, 10D). This lithofacies is poorly sorted with grain sizes ranging from 0.5 mm to 250 cm (Fig. 10B). Framework grains include abundant pumice with subordinate amounts of basaltic lithic fragments, euhedral quartz and plagioclase crystals, and vitric shards. Individual beds can be traced for several hundred meters and bed thicknesses range from 10 cm to >5 m. Beds tend to thicken into underlying fluvial channels.

**Interpretation.** The lateral persistent of individual beds, lack of evidence for tractive transport, and textural features suggest that the tuffs were deposited by pyroclastic flows (Fisher and Schminke, 1984; Cas and Wright, 1987).
Lithofacies 3: Volcanic Airfall Tuff

Description. Airfall tuffs are common in the Chickaloon Formation and the uppermost Wishbone Formation and range in thickness from >25 cm north of the Castle Mountain fault (section 22 on Figs. 5, 10D) to a few millimeters south of the Castle Mountain fault (sections 6 and 7 on Fig. 3; Triplehorn et al., 1984). Framework grains consist mainly of plagioclase with minor volcanic and sedimentary rock fragments in a kaolinitic matrix (Triplehorn et al., 1984; this study). The average estimated diameter of framework grains range from 0.5 mm north of the Castle Mountain fault (section 9 on Fig. 3; this study) to <0.25 mm south of the fault (section 9 on Fig. 3; Triplehorn et al., 1984).

Interpretation. On the basis of textural features described by Triplehorn et al. (1984), we interpret this lithofacies as being deposited by airfall tuffs associated with suspension fallout from pyroclastic eruptions along the northern basin margin.

CONGLOMERATE COMPOSITIONAL DATA

New compositional data from Paleocene-Oligocene conglomerates of the Matanuska Valley–Talkeetna Mountains forearc basin, in combination with our geochronologic data and previously published compositional data (Clardy, 1974; Little, 1988; Trop and Ridgway, 1999), help identify source terranes that contributed sediment to the basin. Clast composition data from conglomerates were collected by counting all pebble- and cobble-size clasts in a delineated rectangle on an outcrop face, usually yielding a population of 100 or more clasts. A total of ~5900 clasts were counted from 59 different conglomerate beds. Thin sections were made of representative clast types to check field identifications. Recalculated conglomerate compositional data are presented on Figures 12 and 13.

Conglomerate Clast Types

Paleocene-Oligocene conglomerates are generally polymictic with a dominance of igneous clast types, mainly andesite, tuff, basalt, pumice, and granite (Figs. 12, 13). Andesite clasts are brown or tan with plagioclase feldspar phenocrysts in a fine-grained glassy matrix. Basalt clasts are dark gray or black. Metabasalt (greenstone) clasts exhibit low-grade metamorphic features, including foliated textures and chlorite alteration. The metabasalt clasts are grouped with the basalt clasts due to their petrologic similarities. We identified three main types of tuff clasts: laminated green and white crystalline tuffs, gray siliceous tuffs, and gray crystal-vitric tuffs. Pumice clasts are white or gray, and altered. Plutonic clasts include mostly granite and granodiorite and subordinate tonalite and diorite; some of the plutonic clasts have a weakly foliated texture. Sedimentary and metamorphic clast types include chert, argillite, quartz-mica schist, amphibolite, lithic sandstone, siltstone, and limestone.

Clast composition of conglomerates from the Matanuska Valley–Talkeetna Mountains forearc basin deposits can be divided into three distinct petrofacies: volcanic, plutonic, and mixed. Figure 12. Histograms showing composition of clasts from Paleocene-Eocene conglomerates characteristic of the volcanic petrofacies common along the northern basin margin. Note the relative abundance of volcanic clast types (andesite, tuff, basalt, and pumice) compared to plutonic and other (mainly sedimentary and metamorphic) clast types. Histograms are positioned in relative stratigraphic order within individual measured sections. n = total number of clasts counted in measured section. See Figure 3 for measured section locations.
volcanic rocks exposed north of the Castle Mountain fault. Volcanic clasts consist of basalt/metabasalt, andesite, tuff, and pumice. Diagnostic clast types can be matched with previous studies by Clardy (1974) and Winkler (1978). The modal clast composition of the plutonic petrofacies is 76% plutonic, 18% volcanic, 3% metamorphic, and 3% sedimentary (Fig. 13). The most abundant clast types are granite, granodiorite, diorite, amphibolite, quartz-mica schist, and quartz. Most of the clast types are petrographically similar to Lower to Upper Jurassic and Upper Cretaceous–Tertiary plutonic and metamorphic rocks that are presently exposed along the northern basin margin (Ji, Jps, and TKg on Fig. 3; Clardy, 1974; Trop and Ridgway, 1999). Derivation from these northern source terranes is supported by consistent southeastward- to southwestward-directed paleocurrent indicators along the northern margin of the forearc basin (Fig. 9). Our new data and interpretations for the plutonic petrofacies are consistent with previously published petrofacies data from the Wishbone Formation (Clardy, 1974).

**Plutonic Petrofacies**

The plutonic petrofacies includes the Tsadaka Formation (Tsd on Fig. 3) and the Arkose Ridge Formation (Tar on Fig. 3). The modal clast composition of the plutonic petrofacies is 76% plutonic, 18% volcanic, 3% metamorphic, and 3% sedimentary (Fig. 13). The most abundant clast types are granite, granodiorite, diorite, amphibolite, quartz-mica schist, and quartz. Most of the clast types are petrographically similar to Lower to Upper Jurassic and Upper Cretaceous–Tertiary plutonic and metamorphic rocks that are presently exposed along the northern basin margin (Ji, Jps, and TKg on Fig. 3; Clardy, 1974; Trop and Ridgway, 1999). Derivation from these northern source terranes is supported by consistent southeastward- to southwestward-directed paleocurrent indicators along the northern margin of the forearc basin (Fig. 9). Our new data and interpretations for the plutonic petrofacies are consistent with previous studies by Clardy (1974) and Winkler (1978).

**Mixed Volcanic-Metamorphic Petrofacies**

The mixed volcanic-metamorphic petrofacies is best developed along the southern basin margin. Conglomerate clast counts obtained during this study (site 23 on Fig. 3) and from a previous study (sites A–H on Fig. 3; Little, 1988) document abundant metabasalt/basalt, metasiltstone, quartz-mica schist, chert, and granitic clasts in conglomerates along the southern basin margin. These clast types are similar to lithologies exposed in the metamorphosed accretionary prism deposits (Mzm and Kvg on Fig. 3) and the southernmost outcrops of the Talkeetna Formation (JTrt on Fig. 3). Upper Triassic and possibly Jurassic-Cretaceous radiolaria extracted from chert clasts in these conglomerates are consistent with derivation from the adjacent McHugh Complex of the accretionary prism (MzM on Fig. 3; C.D. Blome, 1988, personal

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**Figure 13.** Histograms showing composition of clasts from Paleocene-Oligocene conglomerates characteristic of plutonicpetrofacies along the northern basin margin. Histograms are positioned in relative stratigraphic order within individual measured sections. n = total number of clasts counted within measured section. See Figure 3 for measured section locations.
commun., cited in Little and Naeser, 1989). Northeastward- to northwestward-directed paleocurrent indicators (n = 35; Fig. 9) and the arrangement of alluvial-fluvial lithofacies transitions along the southern basin margin indicate derivation from southern source terranes (Fig. 5; Little, 1988; Little and Naeser, 1989).

STRUCTURAL CONTROLS ON BASIN DEVELOPMENT

Syndepositional Paleocene-Eocene Displacement on the Castle Mountain Fault

Cross sections shown on Figures 2B and 14A show the general structural characteristics of the northern forearc basin margin. Note that Paleocene-Eocene strata exposed in the footwall of the north-dipping Castle Mountain fault system form asymmetric synclines that have steep northern limbs (Fig. 14A). A particularly well exposed footwall syncline is located at Castle Mountain, near measured section 11 on Figure 3. At this location, Eocene strata exposed immediately south of the Castle Mountain fault (Tw on Fig. 14A) dip 85° to 65° SW whereas stratigraphically younger strata exposed further south have progressively shallower dips ranging from 65° to 5° SW (Tv and Tv on Fig. 14A). The stratigraphically youngest Paleocene-Eocene sedimentary strata (uppermost Tw on Fig. 14A) are separated from overlying unnamed Tertiary volcanic rocks (lowermost Tv on Fig. 14A) along an angular unconformity with ~8° discordance. The angular unconformity is easily identified by abrupt contrasts in color and lithology (Figs. 8A, 14B, 14C). A footwall syncline with similar stratigraphic and structural relationships is also exposed south of the Castle Mountain fault at Puddingstone Hill (Tv outcrop north of section 13 on Fig. 3). The thickest accumulations of Paleocene-Eocene alluvial-fan deposits are concentrated in footwall synclines along the north-dipping Castle Mountain fault system (e.g., sections 8 and 11 on Figs. 3, 5).

We interpret the progressively tilted beds documented in Paleocene-Eocene strata as forming when these deposits, located in the footwall of the Castle Mountain fault system, were progressively tilted basinward (southward) during north-
side-up fault displacement and incorporated into a footwall growth syncline. Footwall growth synclines are footwall folds in which deposition occurs during structural growth of the syncline (e.g., Hoy and Ridgway, 1997, 2002). During each episode of north-side-up displacement on the Castle Mountain fault, sediments in the proximal footwall area were tilted and younger sediments were deposited on an angular unconformity. Packages of progressively tilted strata are common elements of deposits related to synsedimentary shortening (i.e., Riba, 1976; DeCelles et al., 1991; Ridgway et al., 1997).

**DISCUSSION**

**Nonmarine Forearc Basin Development**

The ~2800 m of Paleocene-Oligocene deposits in the Matanuska Valley and Talkeetna Mountains contain a long term record of nonmarine sedimentation in a forearc basin. Most previous sedimentological studies of ancient forearc basins have focused on marine deposits (e.g., Ingersoll, 1979; Heller and Dickinson, 1985; Busby-Spera, 1986; Morris and Busby-Spera, 1988; among others) with only a few studies addressing nonmarine deposits (e.g., Kuenzi et al., 1979; Vessel and Davies, 1981; Fulford and Busby, 1993). In addition, preservation of arc-proximal deposits in most ancient forearc basin is rare (Smith and Landis, 1995; Dickinson, 1995). Our analysis of the Matanuska Valley–Talkeetna Mountains forearc basin deposits, in contrast, documents well-preserved sedimentary and volcanic strata along the basin margin that was adjacent to the coeval volcanic arc.

Paleocene-Oligocene coarse-grained sedimentary strata exposed along the southern and northern forearc basin margins are interpreted as mainly stream-dominated alluvial fan and braided stream deposits. Northern basin margin sedimentary deposits are interbedded with lava flows, tuff, and volcaniclastic sandstone. These volcanic deposits are interpreted as the products of episodic eruptions of coeval volcanoes that bordered the northern basin margin. Southern basin margin deposits, in contrast, lack interbedded volcanic strata. Basin margin coarse-grained deposits interfinger with and locally overlie carbonaceous mudstone, coal, and fine- to medium-grained sandstone along the basin axis (Fig. 5). We interpret the finer-grained strata as representing deposits of sinuous fluvial systems and overbank swamps and lakes. Unlike lithofacies exposed along the northern basin margin, basin axis strata include few volcanic deposits; only thin airfall tuffs are reported from Paleocene-Eocene formations exposed south of the Castle Mountain fault system (Fig. 5; Triplehorn et al., 1984).

Along the northern and southern basin margins, as well as the basin axis, the nonmarine sedimentary deposits are characterized by an overall upward-coarsening megasequence. This megasequence is clearly seen in the measured sections shown on Figure 5. Note that the lower part of most of the measured sections consists of mudstones, overlain by sandstones, which are in turn overlain by conglomerates. We interpret this megasequence as the product of basinward progradation of alluvial-fan and fluvial deposystems in response to syndepositional uplift on the Castle Mountain and Border Ranges fault systems. Growth synclines preserved in the footwall of the Castle Mountain fault (Fig. 14) are interpreted as the result of north-side-up displacement during deposition of the Wishbone Formation. Fault-related sedimentation associated with the Border Ranges fault was a product of uplift of the accretionary prism and associated syndepositional displacement along northward-dipping oblique-slip faults (Little, 1988; Little and Naeser, 1989). Our analysis indicates that in the Matanuska Valley–Talkeetna Mountains forearc basin, nonmarine deposition was closely linked to displacement on major basin-bounding faults. There is also a distinctive upsection change in volcanic lithofacies in the megasequence along the northern, arc-proximal basin margin. In the lower part of the megasequence, sedimentary strata are interbedded with mainly airfall tuffs, in the middle part of the megasequence volcaniclastic sandstones become more common, and in the upper part of the megasequence sedimentary strata are interbedded with lava flows. In addition, overlying the megasequence along the northern basin margin are thick sections of primary volcanic deposits (Tv on sections 22, 18, and 11 on Fig. 5). We interpret this upsection change in volcanic lithofacies as representing trenchward migration of the volcanic arc and/or progradation of volcanic deposits during Paleocene-Oligocene development of the Matanuska Valley–Talkeetna Mountains forearc basin.

Our petrofacies, geochronologic, and paleocurrent data provide insight on the provenance of the Matanuska Valley–Talkeetna Mountains forearc basin deposits. The volcanic and plutonic petrofacies (Figs. 12, 13), common along the northern basin margin, indicate derivation from both remnant and coeval volcanic arcs. $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 59.7 Ma and 56.8 Ma from igneous clasts in conglomerates are interpreted as having been derived from the coeval volcanic arc, whereas detrital feldspars with ages of 170–180 Ma are interpreted as being derived from an older Jurassic arc exposed along the northern basin margin (Table 1). Paleocene-Oligocene deposits along the southern margin of the forearc basin were derived mainly from metabasalts, metasiltstones, and granitic plutons that characterize the uplifted accretionary prism deposits. Our data suggest that in this nonmarine forearc basin, both arc-margin and trench-margin source terranes contributed large amounts of sediment to the basin.

**Forearc Basin Development and Regional Tectonics**

This section presents a combined synthesis and tectonic interpretation of sedimentological, compositional, and structural data from the Tertiary Matanuska Valley–Talkeetna Mountains forearc basin. Plate motions and velocities are from the reconstructions of Engebretson et al. (1985); these plate reconstructions are not universally accepted (e.g., Bradley et al., 1993). The time scale and absolute ages are from Gradstein and Ogg (1996).
**Latest Maastrichtian–Early Paleocene (ca. 67–62 Ma)**

A major basinwide angular unconformity marks the contact between deep-marine deposits of the Upper Cretaceous Matanuska Formation and Upper Paleocene–Lower Eocene fluvial-estuarine deposits of the Chickaloon Formation in the Matanuska Valley–Talkeetna Mountains forearc basin (Fig. 4; Csejtey et al., 1978; Winkler, 1992). Near the contact with overlying fluvial deposits of the Chickaloon Formation, the Matanuska Formation contains marine fossils suggestive of deposition in bathyal water depths (>500 m below sea level; Jones, 1967; Bergquist, 1961). Eustatic sea-level changes during the latest Cretaceous–earliest Paleocene were less than 100 m (Haq et al., 1988). Thus, the magnitude of base level change between deposition of the uppermost Matanuska Formation (>500 m below sea level) and the lowermost Chickaloon Formation (sea level or above sea level) requires tectonic uplift of the forearc basin (Fig. 15A). Latest Cretaceous–Early Paleocene uplift is also indicated along the trenchward margin of the forearc basin, where locally the Chickaloon Formation depositionally overlies metamorphosed Late Cretaceous accretionary prism deposits (section A on Fig. 3; Little, 1988; Winkler, 1992). Early Maastrichtian (ca. 75 Ma) accretionary prism deposits (Kvg on Fig. 3) were underthrust, metamorphosed, and rapidly uplifted (~0.55 mm/yr) prior to unconformable onlap of the nonmarine Upper Paleocene (ca. 61–52 Ma) Chickaloon Formation (Little and Naeser, 1989).

From a regional perspective, the latest Cretaceous (Maastrichtian) to Early Paleocene unconformity and associated...

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**Figure 15 (on this and following page).** Simplified block diagrams showing the latest Cretaceous to Eocene development of the Matanuska Valley–Talkeetna Mountains forearc basin. A: Latest Cretaceous to Early Paleocene tectonic uplift and erosion of Late Cretaceous deep marine sedimentary strata (Matanuska Formation) and older forearc basin deposits. B: Late Paleocene to Early Eocene renewed forearc basin subsidence and nonmarine/estuarine sedimentation. Alluvial fans and braided streams deposited coarse-grained strata (northern outcrops of Arkose Ridge and Chickaloon Formations) along the northern basin margin coeval with arc magmatism (AT). Alluvial fans and braided streams also deposited coarse-grained strata along the southern basin margin (southern outcrops of Chickaloon Formation) coeval with uplift in the accretionary prism (SMCT). Alluvial fans and braided streams merged with fine-grained sinuous streams, swamps, and lakes along the basin axis (Chickaloon Formation). C: Early to Middle(? ) Eocene alluvial fans along the northern basin margin (Wishbone Formation) prograded southward into the basin axis in response to syndepositional displacement on the Castle Mountain fault (CMF). Along the southern basin margin, alluvial fans and braided streams (southern outcrops of upper Chickaloon Formation) prograded northward into the basin axis coeval with uplift along the Border Ranges fault (BRF). The basin was deformed and intruded by plutons and sills during the Middle to Late Eocene. With the exception of a brief, localized episode of alluvial fan deposition during the Late Oligocene (Tsadaka Formation), the forearc basin remained topographically inverted throughout the Early Oligocene to recent.
B. Late Paleocene-Early Eocene  
(ca. 60–50 Ma)

- Active volcanoes north of forearc basin
- Lava, tuff, pumice, tuff, volcaniclastic sandstone and conglomerate deposited along proximal northern basin margin; ash deposited along basin axis
- Sandstone/conglomerate > mudstone
- Low-sinuosity braided streams
- Multistoried sandstone sheets from amalgamation of channels
- Frequent channel avulsion
- Vegetated interfluves
- Sandstone/conglomerate > mudstone
- Low-sinuosity braided streams on alluvial fans and braidplains
- Moderate depositional gradient
- Southward-dipping paleoslope
- Basal onlap across erosional surface
- Detritus derived from local northern igneous and metamorphic sources

C. Early to Middle Eocene  
(ca. 49–37? Ma)

- Active volcanoes north of forearc basin
- Lava, tuff, pumice, ash, volcaniclastic sandstone and conglomerate deposited along proximal northern basin margin; ash deposited along basin axis
- Sandstone/conglomerate > mudstone
- Low-sinuosity braided streams on moderate to high gradient alluvial fans
- Southward-dipping paleoslope
- Progradation of alluvial fans across finer-grained sinuous stream, swamp, and lake deposits
- Detritus derived from local northern igneous and metamorphic sources including Paleocene volcanic rocks
- Sandstone/conglomerate > mudstone
- Low-sinuosity braided streams on moderate to high gradient alluvial fans
- Southward-dipping paleoslope
- Progradation of alluvial fans across finer-grained sinuous stream, swamp, and lake deposits
- Detritus derived from local northern and southern basin margins

deformation in the forearc basin was contemporaneous with crustal shortening throughout the northwestern Cordillera (see discussion in McClelland et al., 1992, and Trop et al., 1999). This regional-scale deformation may have been related to Late Cretaceous accretion of the allochthonous Wrangellia composite terrane (e.g., Nokleberg et al., 1994; Pfafker and Berg, 1994), rapid subduction of the Kula plate (Wallace and Engebretson, 1984; Engebretson et al., 1985), and/or accretion of an enormous wedge of metasedimentary strata in the accretionary prism (Mzu on Figs. 2, 3; Pfafker et al., 1994).

Deformation in the forearc basin may have also been partly coeval with northward latitudinal translation of the forearc basin and underlying Wrangellia composite terrane. Paleomagnetic studies by Stamatakos et al. (1988, 1989) from the Matanuska, Chickaloon, and Arkose Ridge Formations, as well as unnamed Middle to Late Eocene pluons and sills (Tg on Fig. 3), indicate that the forearc basin was positioned ~2800 ± 2000 km south of its present latitude relative to cratonic North America during the latest Cretaceous (ca. 80–70 Ma), ~1600 ± 1200 km south of its present latitude during the Upper Paleocene–Lower Eocene (ca. 61–50 Ma), and at or near its present position by the Middle to Late Eocene (45.5 to 36.8 Ma).

**Late Paleocene–Middle Eocene (ca. 61–50 Ma)**

Following late Maastrichtian–early Paleocene uplift and subaerial exposure of the forearc basin, the mainly nonmarine Chickaloon, Arkose Ridge, and Wishbone Formations were deposited over deformed Upper Cretaceous marine strata (Fig. 15B). These formations represent progradation of proximal, gravel-rich alluvial-fluvial deposystems over more distal, mud-rich sinuous fluvial environments (discussed above). We attribute progradation of proximal deposystems to syndepositional displacement on the Castle Mountain and Border Ranges fault systems (discussed above).

The timing of Late Paleocene–Early Eocene (ca. 56–50 Ma) fault-related, coarse-grained sedimentation in the Matanuska Valley–Talkeetna Mountains forearc basin was broadly coeval with multiple tectonic events important in the development of the northwestern Cordillera continental margin. These include (1) a northwestward shift in Kula plate motion; (2) subduction of the Kula-Farallon ridge or another unidentified spreading center (discussed in a later section); (3) northward translation of the forearc basin and accretionary prism; (4) dextral displacement on regional faults; and (5) regional counterclockwise oroclinal bending of Alaska. These tectonic events are briefly discussed below within the context of forearc basin development. The Upper Paleocene–Lower Eocene Chickaloon and Arkose Ridge Formations were deposited during a northwestward shift in Kula plate motion starting at ca. 54 Ma (56 Ma event of Wallace and Engebretson [1984] and Lonsdale [1988] recalibrated to magnetic time scale of Cande and Kent [1992]). This plate shift prompted dextral oblique plate convergence along the northwestern Cordilleran continental margin (Engebretson et al., 1985; Lonsdale, 1988). Dextral oblique convergence may have resulted in northward displacement of the forearc basin and accretionary prism along orogen-parallel dextral faults (Pfafker and Berg, 1994). The timing of possible northward translation of the forearc basin and accretionary prism based on paleomagnetic data (Coe et al., 1985; Stamatakos et al., 1988, 1989; Bol et al., 1992) was broadly coeval with large dextral displacements along regional fault systems. For example, estimates of up to 400 km of dextral displacement have been proposed along the eastern part of the Denali fault system during the interval from ca. 57 to 38 Ma (Fig. 1; Eisbacher, 1976; Nokleberg et al., 1985). Similarly, Roeseke et al. (1993, this volume) and Smart et al. (1996) proposed 700 to >1000 km of Early Eocene (ca. 58 to 50 Ma) dextral displacement along the Border Ranges/Hanagita fault system (Fig. 1).

**Late Paleocene–Early Eocene coarse-grained deposition in the Matanuska Valley–Talkeetna Mountains forearc basin may have also been coeval with oroclinal bending of Alaska. Geo-logic and paleomagnetic data indicate that from ca. 65 to 50 Ma parts of southwestern and south-central Alaska were rotated 45° to 60° counterclockwise about a vertical axis (see Pfafker and Berg, 1994, for summary). The Matanuska Valley–Talkeetna Mountains forearc basin is presently located in the axial region of the orocline, a position of expected localized compression during orocline formation (Grantz, 1966).**

**Middle Eocene–Early Oligocene (49–30 Ma)**

The forearc basin deposits were deformed, uplifted, and partly eroded during the Early Eocene to Early Oligocene as recorded by an angular unconformity separating the Lower Eocene Wishbone Formation from the Upper Oligocene Tasada Formation (Fig. 3; Barnes, 1962; Clardy, 1974). Along the northern basin margin, oblique slip along the Castle Mountain fault system may have been coeval with unconformity development (Fuchs, 1980). During this stage of forearc basin development, silicic dikes and pluons (Tg on Fig. 3) intruded Tertiary sedimentary strata throughout the forearc basin (36.8–45.5 Ma, n = 10; fission track and K-Ar, Little and Naeser, 1989; Silbermann and Grantz, 1984), accretionary prism (42.9–49.6 Ma; n = 4; fission track; Little and Naeser, 1989), and volcanic arc (39.9–43.6 Ma; n = 2; K-Ar, Adams et al., 1985). Coeval with silicic intrusions was basinward (southward) progradation of volcanic deposits along the northern basin margin and/or basinward migration of the volcanic arc. These processes are documented in the upsection change in volcanic lithofacies (discussed earlier) and in the hundreds of meters of unnamed Tertiary volcanic rocks (Tv on Figs. 3, 5) that directly overlie Upper Paleocene-Eocene sedimentary strata (Chickaloon and Wishbone Formations) along the northern basin margin (sections 11, 18, and 22 on Fig. 5; Csejtey et al., 1978; Winkler, 1992).

Middle Eocene–Early Oligocene deformation and magmatism in the forearc basin was coeval with plate reorganization in the Pacific basin (47 Ma event of Engebretson et al., 1985; Lonsdale, 1988). Following subduction of the Kula plate, there was a change to north to northwest motion of the Pacific plate begin-
ning at ca. 50 Ma (Engebretson et al., 1985; Plafker and Berg, 1994). After this change, convergence with the continental margin was relatively slower and more orthogonal than during the Late Paleocene–Early Eocene (ca. 61–50 Ma). Middle Eocene–Early Oligocene changes in forearc magmatism may record an increase in the dip of the subducting oceanic slab caused by a decrease in the rate of relative plate convergence, an increase in the age of the subducting crust following plate reorganization (47 Ma event of Engebretson et al., 1985), and/or subduction of the age of the subducting crust following plate reorganization. Early Oligocene changes in forearc magmatism may record an increase in the dip of the subducting oceanic slab caused by a decrease in the rate of relative plate convergence, an increase in the age of the subducting crust following plate reorganization (47 Ma event of Engebretson et al., 1985), and/or subduction of the age of the subducting crust following plate reorganization (47 Ma event of Engebretson et al., 1985), and/or subduction of the Kula-Farallon spreading ridge, or another unidentified spreading center (Bradley et al., 2000, this volume). Paleomagnetic studies of 45.5 to 36.8 Ma plutons indicate that the forearc basin was positioned at or near its present position relative to North America during the Middle to Late Eocene (Stamatakos et al., 1988). Some strike-slip displacement continued on the Denali fault system, located north of the forearc basin, during the Late Eocene–Early Oligocene (Fig. 1B; Ridgway and DeCelles, 1993b; Cole et al., 1999; Ridgway et al., 2002).

**Late Oligocene–Recent (ca. 29–0 Ma)**

Sedimentation resumed in the forearc basin during deposition of the Upper Oligocene Tsadaka Formation. Conglomerates of the Tsadaka Formation were deposited across an angular unconformity above folded Paleocene–Eocene strata (Chickaloon and Wishbone Formations). Our facies and paleocurrent data (Figs. 9, 13) show that coarse-grained granitic detritus was derived from the dissected Paleocene–Eocene volcanic arc and older plutonic source terranes that are presently exposed along the northern basin margin. Outcrops of the Tsadaka Formation are only found in the lower part of the Matanuska Valley (Tsd on Fig. 3) and thus may reflect localized alluvial-fan deposition.

Neogene deformation in the forearc basin included dextral strike-slip displacement on the east-west–trending Castle Mountain fault system, dextral motion on west-northwest–trending strike-slip faults, and sinistral movement on northeast-trending strike-slip faults (Bruhn and Pavlis, 1981; Detterman et al., 1974; Fuchs, 1980; Lahr et al., 1986). Recent earthquakes (1984, M5.7; 1996, M4.6) indicate that the Castle Mountain fault remains an active transpressional structure (Haussler et al., 2000). Late Oligocene to Recent (ca. 30–0 Ma) dextral transpression in the forearc basin was probably driven by northwestward thrusting of the Pacific plate (Wallace and Engebretson, 1984; Engebretson et al., 1985) and collision of the allochthonous Yakutat terrane along the outboard margin of southern Alaska (Plafker et al., 1994).

**Record of Ridge Subduction in Forearc Basin Deposits**

The Kula-Farallon spreading ridge, or another unidentified spreading center, was subducted beneath accretionary prism deposits of the Southern Margin composite terrane (Fig. 1B) between 61 and 50 Ma (Pavlis and Sisson, 1995; Kusky et al., 1997; Kusky and Young, 1999; Bradley et al., 2000, this volume). Geologic evidence for ridge subduction in the accretionary prism deposits includes diachronous “near-trench” magmatism (Bradley et al., 2000), gold mineralization (Haussler et al., 1995), and regional high-grade metamorphism and anatectic melting (Sisson et al., 1989; Barker et al., 1992; Pavlis and Sisson, 1995). The timing of ridge subduction was apparently diachronous along the continental margin in response to subduction of a ridge that was oriented subparallel to the trench (Bradley et al., 1993). For example, “near-trench” plutons show a distinct progression from ca. 61 Ma \(^{40}\text{Ar}/^{39}\text{Ar}\) and K-Ar ages in southwestern Alaska to ca. 50 Ma \(^{40}\text{Ar}/^{39}\text{Ar}\) and K-Ar ages in south-eastern Alaska (Bradley et al., 2000). This age progression suggests that a triple junction, possibly the Kula–Farallon–North America junction, migrated southeasterward during the early Tertiary (modern coordinates in Fig. 1; Sisson and Pavlis, 1993; Bradley et al., 2000). Migration of a trench-ridge-trench triple junction past a given point would likely be accompanied by subduction of progressively more buoyant, topographically higher lithosphere (the spreading ridge) followed by less buoyant, topographically lower lithosphere (e.g., Thorkelson and Taylor, 1989). Thus, subduction of a sufficiently large spreading ridge could prompt adjustment of the topographic profile of the accretionary prism and possibly the forearc basin through vertical uplift. In this section, we evaluate the possible record of early Tertiary ridge subduction in the Matanuska Valley–Talkeetna Mountain forearc basin deposits. Two reconstructions are presented to address contrasting interpretations concerning the amount of Tertiary strike-slip displacement along the Border Ranges/Hanagita fault system (Fig. 1). We prefer the minimum strike-slip displacement reconstruction because the timing of ridge subduction in this reconstruction would have been coeval with progradation of coarse-grained deposystems and intrusion of primitive igneous melts into the Matanuska Valley–Talkeetna Mountains forearc basin (discussed below). However, until additional high-resolution geochronologic data are available for the ages of the forearc basin deposits, and the displacement histories of major fault systems are better known, both reconstructions are feasible. It is also important to note that early Tertiary ridge subduction was broadly coeval with several tectonic events that may have also influenced forearc basin deposition (discussed above).

**Reconstruction 1—Minimum Tertiary Strike-Slip Displacement on Border Ranges Fault**

Several observations from previous studies indicate a maximum of a few tens of kilometers of Late Paleocene to Middle Eocene dextral displacement along the Border Ranges fault system in south-central Alaska. For example, geologic mapping along the southern margin of the forearc basin reports Upper Paleocene–Lower Eocene forearc basin deposits (the Chickaloon Formation) on both sides of the Border Ranges fault (sections A, B, C on Fig. 3; Little, 1988; Little and Naeser, 1989). In addition, middle Eocene plutons reportedly intrude the Border Ranges fault along the southern margin of the forearc basin (Little and Naeser, 1989) as well as east of our study area in the Cordova and Middleton Island quadrangles (Winkler and
Plafker, 1981). In this minimum strike-slip reconstruction, the forearc basin and accretionary prism were translated northward as a single block with most displacement accommodated along inboard strike-slip faults such as the Denali fault system (Fig. 1). In this reconstruction, the age of “near-trench” plutons presently exposed directly south of the forearc basin across the Border Ranges fault (between longitudes 150°–145° W) records the time during which the spreading ridge was subducted outboard of the forearc basin. \(^{40}\text{Ar}/^{39}\text{Ar}\) ages (53.4–52.2 Ma; Bradley et al., 2000) and K-Ar ages (54.5 to 50 Ma; Bradley et al., 1993) of these near-trench plutons indicate Early Eocene ridge subduction in this area. Ridge subduction in this reconstruction would have been coeval with deposition of coarse-grained deposits of the uppermost Chickaloon Formation and Wishbone Formation in the forearc basin, and with syndepositional displacement along the Castle Mountain and Border Ranges/Hanagita fault systems. Previous studies of ridge subduction processes have predicted vertical uplift of the accretionary prism and forearc basin during ridge subduction (e.g., Thorkeleson and Taylor, 1989). In the minimum strike-slip reconstruction, uplift of the forearc region may be recorded in the thick coarse clastic wedges that prograded basinward from both the northern and southern forearc basin margins during the Early Eocene. In this reconstruction, upflow of hot mantle through the slab window may have increased the crustal elevation of the forearc basin and reactivated major basin-bounding fault systems (i.e., the Castle Mountain and Border Ranges faults). The footwall growth synclines along the Castle Mountain fault may be a product of this vertical uplift. This deformation may also have resulted in basinward progradation of coarse-grained deposystems producing the overall upward-coarsening mega-sequence that characterizes Paleocene-Oligocene deposits of the Matanuska Valley–Talkeetna Mountains forearc basin (Fig. 5).

In the minimum strike-slip reconstruction, ridge subduction was also coeval with igneous activity along both the arcward and trench margins of the forearc basin. Along the southern margin of the forearc basin, dike swarms intruded the accretionary prism along the Border Ranges fault between 55 and 52 Ma (Little, 1988). Age-equivalent lava flows (56–46 Ma) of the Arkose Ridge Formation along the northern basin margin have primitive initial \(^{87}\text{Sr}/^{86}\text{Sr}\) isotopic ratios (0.7042–0.7047; Silberman and Grantz, 1984), indicating little crustal contamination and possible development of a “slab-free” window during ridge subduction beneath the forearc basin (e.g., Plafker et al., 1989; Winkler, 1992). This interpretation would be consistent with studies of Tertiary ridge subduction in California that have suggested that the slab window provides a pathway for the upward flux of mantle into the overlying continental lithosphere (Dickinson and Snyder, 1979; Cole and Basu, 1992, 1995; Dickinson, 1997).

Reconstruction 2—Maximum Tertiary Strike-Slip Displacement on Border Ranges Fault

In contrast to estimates of minimum Tertiary strike-slip displacement (tens of km) on the central part of the Border Ranges fault near the Matanuska Valley (Little and Naeser, 1989), large amounts (700 to >1000 km) of dextral displacement have been proposed for the southeastern part of the fault system (Roeske et al., 1993, this volume; Smart et al., 1996). In the maximum strike-slip reconstruction, in addition to displacement on inboard strike-slip fault systems, significant northward displacement was accommodated along the Border Ranges/Hanagita fault system. This fault system separated the forearc basin from the adjacent accretionary prism (Figs. 1B, 3). In the maximum strike-slip displacement reconstruction, the forearc basin and accretionary prism were not translated northward as a single block (i.e., they have different displacement histories). Using the estimated 700 km of dextral translation, the Matanuska Valley–Talkeetna Mountains forearc basin would have a restored Paleocene-Eocene position adjacent to accretionary prism deposits that are presently exposed near Kodiak Island (Fig. 1B). In this reconstruction, near-trench plutons that would have been proximal to the Matanuska Valley–Talkeetna Mountains forearc basin have \(^{40}\text{Ar}/^{39}\text{Ar}\) and U-Pb ages of 61.1 to 57.8 Ma (ages from Kodiak Island and the Shumagin Islands in Bradley et al., 2000). Ridge subduction in this reconstruction would be coeval with unconformity development, and/or with initial subsidence and fine-grained sedimentation of the lower Chickaloon Formation in the forearc basin (Fig. 5). In this reconstruction, the predicted increase in crustal elevation associated with subduction of progressively more buoyant, topographically higher lithosphere (i.e., the spreading ridge) would be represented by the regional unconformity between the Upper Cretaceous Matanuska Formation and Upper Paleocene–Lower Eocene Chickaloon Formation. Subduction of buoyant lithosphere would have been followed by subduction of less buoyant, topographically lower lithosphere, which may be represented in the forearc basin record by reinitiation of subsidence during the beginning of Chickaloon Formation deposition. This interpretation is presently limited by the poor resolution of the maximum age of the Chickaloon Formation (see earlier discussion). Igneous rocks in the forearc basin with ages that are consistent with ridge subduction in the maximum strike-slip reconstruction have not been reported.

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APPENDIX 1. \( {\text{Ar}}^{40}/\text{Ar} \) ANALYTICAL PROCEDURES

\( {\text{Ar}}^{40}/\text{Ar} \) Analytical Procedures

Samples analyzed by the \( {\text{Ar}}^{40}/\text{Ar} \) method at the University of Nevada, Las Vegas, were wrapped in Al foil and stacked in 6 mm inside diameter pyrex tube. Individual packets averaged 3 mm thick and neutron fluence monitors (ANU 92-176, Fish Canyon Tuff sandstone) were placed every 5–10 mm along the tube. Synthetic K-glass and optical grade CaF\(_2\) were included to monitor neutron induced argon interferences from K and Ca. Loaded tubes were packed in an Al container and irradiated for 14 hours in the D3 position on the core edge of the 1 MW TRIGA type reactor at the Nuclear Science Center at Texas A&M University. Samples are shielded against thermal neutrons by a 5 mm thick jacket of B\(_4\)C powder, which rotates about its axis at a rate of 0.7 revolutions per minute to mitigate horizontal flux gradients. Correction factors for interfering neutron reactions on K and Ca were: \( (\text{Ar}^{40}/\text{Ar})_K = (2.54 \pm 3.18) \times 10^{-5}, \) \( (\text{Ar}^{37}/\text{Ar})_K = (2.89 \pm 0.06) \times 10^{-5}, \) and \( (\text{Ar}^{39}/\text{Ar})_K = (7.06 \pm 0.01) \times 10^{-5}. \) J factors were determined by fusion of 3–4 individual crystals of ANU 92-176, which gave reproducibilities of 0.1 to 0.2%. No significant neutron fluence gradients were present within individual packets of crystals as indicated by the excellent reproducibility of the single-crystal fluence monitor fusions. Variation in neutron fluence along the 100 mm length of the irradiation tubes was <2%. An error in J of 0.5% was used in all age calculations.

Irradiated crystals together with CaF\(_2\) and K-glass fragments were placed in a Cu sample tray in a high-vacuum extraction line and fused using a 20 W CO\(_2\) laser. Sample viewing during laser fusion was by a video camera system and positioning was via a motorized sample stage. Samples analyzed by the furnace step heating method utilized a double vacuum resistance furnace similar to the Staudacher et al. (1978) design. Reactive gases were removed by a single MAP and two GP-50 SAES getters prior to being admitted to a MAP 215-50 mass spectrometer by expansion. The relative volumes of the extraction line and mass spectrometer allow 80% of the gas to be admitted to the mass spectrometer for laser fusion analyses and 76% for furnace heating analyses. Peak intensities were measured using a Balzers electron multiplier by peak hopping through seven cycles; initial peak heights were determined by linear regression to the time of gas admission. Mass spectrometer discrimination and sensitivity was monitored by repeated analysis of atmospheric argon aliquots from an on-line pipette system. Measured \( {\text{Ar}}^{40}/\text{Ar} \) ratios were 289.55 ± 0.17 and 290.14 ± 0.49 during this work, thus discrimination corrections of 1.02055–1.01848 (4 AMU) were applied to measured isotope ratios. The sensitivity of the mass spectrometer was \( 6 \times 10^{-17} \) mol mV\(^{-1}\) with the multiplier operated at a gain of 30 over the Faraday cup. Line blanks averaged ~5 mV for mass 40 and 0.02 mV for mass 36 during laser fusion analyses and 40 mV for mass 40 and 0.15 mV for mass 36 for furnace heating analyses. Computer automated operation of the sample stage, laser, extraction line and mass spectrometer as well as final data reduction and age calculations were done using LabSpec software written by B. Idleman (Lehigh University). An age of 27.9 Ma (Steven et al., 1967; Cebula et al., 1986) was used for the Fish Canyon Tuff sandstone fluence monitor in calculating ages for samples. All analytical errors are reported at the 1\(\sigma\) level.


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