The Mystic subterrane (partly) demystified: New data from the Farewell terrane and adjacent rocks, interior Alaska

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Abstract

The youngest part of the Farewell terrane in interior Alaska (USA) is the enigmatic Devonian–Cretaceous Mystic subterrane. New U-Pb detrital zircon, fossil, geochemical, neodymium isotopic, and petrographic data illuminate the origin of the rocks of this subterrane. The Devonian–Permian Sheep Creek Formation yielded youngest detrital zircons of Devonian age, major detrital zircon age probability peaks between ca. 460 and 405 Ma, and overall age spectra like those from the underlying Dillinger subterrane. Samples are sandstones rich in sedimentary lithic clasts, and differ from approximately coeval strata to the east that have abundant volcanic lithic clasts and late Paleozoic detrital zircons. The Permian Mount Dall conglomerate has mainly carbonate and chert clasts and yielded youngest detrital zircons of latest Pennsylvanian age. Permian quartz-carbonate sandstone in the northern Farewell terrane yielded abundant middle to late Permian detrital zircons.

Late Triassic–Early Jurassic mafic igneous rocks occur in the central and eastern Mystic subterrane. New whole-rock geochemical and isotopic data indicate that magmas were rift related and derived from subcontinental mantle. Triassic and Jurassic strata have detrital zircon age spectra much like those of the Sheep Creek Formation, with major age populations between ca. 430 and 410 Ma. These rocks include conglomerate with clasts of carbonate ± chert and youngest detrital zircons of Late Triassic age and quartz-carbonate sandstone with youngest detrital zircons of Early Jurassic age. Lithofacies indicating highly productive oceanographic conditions (upwelling?) bracket the main part of the Mystic succession: Upper Devonian bedded barite and phosphatic Upper Devonian and Lower Jurassic rocks.

The youngest part of the Mystic subterrane consists of Lower Cretaceous (Valanginian–Aptian) limestone, calcareous sandstone, and related strata. These rocks are partly coeval with the oldest parts of the Kahiltna assemblage, an overlap succession exposed along the southern margin of the Farewell terrane.

INTRODUCTION

The Farewell terrane (Alaska, USA) is a regionally extensive, deformed continental fragment (Fig. 1) made up of Proterozoic, Paleozoic, and Mesozoic rocks; understanding its history is a critical component in unraveling the complex tectonic story of Alaska. Key questions center around its cratonic origins, its separation from and subsequent interactions with other terranes, and its eventual incorporation into the Alaskan tectonic collage. Proterozoic and Paleozoic strata that form the core of Farewell are more thoroughly studied than younger parts of this terrane and have well documented ties to multiple terranes including the Arctic Alaska, Livengood, White Mountains, Kilbuck, and Alexander terranes (Fig. 1; Blodgett et al., 2002; Dumoulin et al., 2002, 2014, 2018b; Bradley et al., 2014). These ties are supported by diverse data sets including faunal assemblages, lithologic successions, and detrital zircon ages.

Overlying Devonian and younger rocks of the Mystic subterrane represent the continued evolution of the Farewell terrane and are expected to have recorded key events and interactions as it was accreted to northwestern North America. However, the basic lithostratigraphy, geologic evolution, terrane affinities, and tectonic interactions of the Mystic remain incompletely understood. Recent studies have elucidated specific aspects of Mystic subterrane geology (Malkowski and Hampton, 2014), and available data suggest linkages between Farewell and insular terranes (i.e., Alexander and Wrangelia) outboard of western North America during the late Paleozoic and possibly later (Beranek et al., 2014; Malkowski and Hampton, 2014). Fossil and detrital zircon data also indicate continuing connections between terranes of the Arctic realm and Siberia (Bradley et al., 2003; Colpron and Nelson, 2011) and/or
Baltica (Ershova et al., 2016). In this paper, we use new U-Pb detrital zircon, fossil, geochemical, neodymium isotopic, and petrographic data from the northern, central, and eastern parts of the Mystic subterrane (Fig. 2) to illuminate the Devonian and younger evolution of the Farewell terrane as a means of evaluating its tectonic interactions with other Alaskan terranes and, ultimately, western North America.

The Livengood and White Mountains terranes (Fig. 1) of Silberling et al. (1994) have lithologic and faunal features that suggest ties to the Farewell terrane during the early Paleozoic (Blodgett et al., 2002; Dumoulin et al., 2014). New detrital zircon data from rocks in these terranes that are coeval with the lower part of the Mystic subterrane allow us to test whether these linkages extended into the middle Paleozoic.

### GEOLOGIC SETTING

The Farewell terrane (Decker et al., 1994; Bundtzen et al., 1997; Bradley et al., 2003) is made up of a Proterozoic basement complex overlain by younger Proterozoic through Mesozoic rocks. Farewell exposures span an area of more than 87,000 km² in south-central Alaska, and they are cross-cut by and displaced along multiple Cenozoic strike-slip faults (Fig. 2). Rocks of the Farewell terrane are broadly grouped into the Nixon Fork, Dillinger, and Mystic subterranes, and Figure 3 shows the generalized lithostratigraphy and spatial associations of these three subterranes across the six geographic areas outlined in Figure 2.

The Nixon Fork subterrane is a Proterozoic through Devonian carbonate platform that overlies the only observed exposures of Proterozoic basement.
Figure 2. Generalized geologic map of the Farewell terrane and location of some detrital zircon localities discussed in text. See Figure 4 for an enlarged version of areas E and F and key to locality symbols. White areas on map are covered by snow or ice. The western and central parts of the Alaska Range extend through areas E and F.
Figure 3. Stratigraphy of the Mystic subterrane; data sources are given in text. See Figure 2 for location of areas A–F. Lower–Middle Devonian carbonate strata in areas D–F are faunally and lithologically similar to the upper part of the Nixon Fork carbonate platform and are likely depositional or tectonic outliers of that platform. Absolute ages in time scale boundaries and chronostratigraphy are from Walker et al. (2012). Lithic grain abbreviations: Lm—metamorphic; Ls—sedimentary; Lv—volcanic; Qm—monocrystalline quartz; ss—sandstone. Time scale abbreviations: A—Aptian; B/V—Berriasian–Valanginian; C—Cuisian; Camb.—Cambrian; Cret.—Cretaceous; E—Emsian; Ei—Eifelian; Fa—Famennian; Fr—Frasnian; G—Guadalupian; Gi—Givetian; H/B—Hauterivian-Barremian; L—Lower; Lc—Lochkovian; Lo—Lopingian; Lu—Ludlow; M—Middle; Miss.—Mississippian; Mo—Moscovian; N—Norian; Ord.—Ordovician; P—Pliensbachian; Penn.—Pennsylvanian; Pr—Pragian; S—Sinemurian; Se—Serpukhovian; Sil.—Silurian; T—Touraisian; U—Upper; V—Visean; W—Wenlock. Stratigraphic column abbreviation: C—central.
in the Farewell terrane (Fig. 2). The Dillinger subterrane consists of a Cambrian(?) through Devonian sedimentary succession that is interpreted to be the deep-water equivalent of the Nixon Fork carbonate platform. Rocks of the carbonate platform and deep-water successions locally interinger and grade into each other, and they are interpreted to have formed along a passive margin (Bradley, 2008). The lithostratigraphy of these two subterranes is discussed in detail elsewhere (Decker et al., 1994; Bundtzen et al., 1997; Bradley et al., 2003, 2014; Dumoulin et al., 2018b).

The Mystic subterrane is an overlap assemblage comprising Devonian through Lower Cretaceous rocks that overlie strata of both the Nixon Fork and Dillinger subterranes. We refer to the Mystic as a subterrane of the Farewell terrane in order to be consistent with nomenclature in previous studies (e.g., Bundtzen et al., 1997; Malkowski and Hampton, 2014). Rocks included in the Mystic subterrane are widely but sparsely distributed through much of the Farewell terrane but are thickest and most abundant to the southeast in areas A and C, and we suggest that they represent progradational or tectonic outliers of the Nixon Fork platform. A progradational relationship has been documented elsewhere in the Farewell terrane: the Dyckman Mountain unit (east of area A; Fig. 2) consists of Lower–Middle Devonian platform facies (Bradley, 2008; Decker et al., 1994, 1997; Malkowski and Hampton, 2014). Rocks included in the Mystic subterrane are widely but sparsely distributed through much of the Farewell terrane but are thickest and most abundant to the southeast in the central and western Alaska Range (Fig. 2). The overall succession is typically bounded by unconformities, although the lower contact (Mystic rocks above Nixon Fork or Dillinger strata) locally appears conformable (Decker et al., 1994). The upper contact is a major angular unconformity overlain by sedimentary rocks of the Upper Cretaceous Kuskokwim Group in the west and the Upper Jurassic(?)–Uppercretaceous Kauhtna assemblage to the east (Bundtzen et al., 1997; Wilson et al., 2015). In many areas, both the upper and lower contacts are faulted. Stratigraphy of the Mystic subterrane varies considerably across its geographic extent and is discussed below using representative sections from six map areas (A) central Medfra quadrangle, (B) northern Taylor Mountains quadrangle, (C) White Mountain area in the southern McGrath quadrangle, (D) central Lime Hills quadrangle, (E) southeastern McGrath-northeastern Lime Hills quadrangles, and (F) western Talkeetna quadrangle (areas A through F in Figs. 2, 3; all quadrangles are 1:250,000 scale).

### STRATIGRAPHY OF THE MYSTIC SUBTERRANE

The oldest rocks assigned to the Mystic subterrane are Lower–Middle Devonian limestones (e.g., map unit lDl of Bundtzen et al., 1994, 1997; see also Blodgett et al., 2002; Table 1, sample 11AD201AA) that overlie rocks of the Dillinger subterrane in areas D through F (Figs. 2, 3). These rocks are coeval with, and lithologically similar to, the youngest strata of the Nixon Fork subterrane in areas A and C, and we suggest that they represent progradational or tectonic outliers of the Nixon Fork platform. A progradational relationship has been documented elsewhere in the Farewell terrane: the Dyckman Mountain unit (east of area A; Fig. 2) consists of Lower–Middle Devonian platform facies of the Nixon Fork that overstepped older Dillinger basin facies (Dumoulin et al., 2000). Upper Devonian carbonate and siliciclastic rocks overlie older Devonian strata in areas C through F (Reed and Nelson, 1980; Gilbert, 1981; Bundtzen and Gilbert, 1991; Bundtzen et al., 1994, 1997) and include distinctive minerals such as barite and phosphate that typically form in highly productive oceanographic settings. Rare shallow-water carbonate rocks of Mississippian, Pennsylvanian, Permian, and Triassic ages are found chiefly on and adjacent to the Nixon Fork platform (areas A through C, western area D; Patton et al., 1980; McRoberts and Blodgett, 2002; Gilbert, 1981; Bundtzen et al., 1994).

Siliciclastic strata of middle to late Paleozoic age crop out sparsely in areas A, D (eastern part), and E, and widely in area F (Figs. 2, 3). These units include unnamed Permian strata in area A (Patton et al., 1980), the upper part of the Devonian–Permian Sheep Creek Formation (Bundtzen et al., 1997) in area E, and the Permian (and older?) “Mystic assemblage” of Malkowski and Hampton (2014) and the Permian Mount Dall conglomerate (Reed and Nelson, 1980; Sunderlin, 2008) in area F. Late Triassic–Early Jurassic mafic igneous rocks (areas C through F) are intercalated with and overlain by a variety of Triassic and Jurassic sedimentary strata (Reed and Nelson, 1980; Gilbert, 1981; Bundtzen et al., 1994, 1997). Lower Cretaceous fossiliferous limestone and siliciclastic rocks form the uppermost part of the Mystic in areas A, E, and F (Jones and Silberling, 1979; Patton et al., 1980; Reed and Nelson, 1980).

In contrast with the relatively homogenous and regionally consistent, predominantly passive margin successions of the underlying Nixon Fork and Dillinger subterranes, lithologies of the Mystic subterrane—which include shallow-water carbonate, diverse siliciclastic, and volcanic rocks—suggest a more active tectonic setting (Bundtzen et al., 1997). Upper Paleozoic sedimentary strata of the Mystic have been interpreted as foreland deposits associated with the late Paleozoic Browns Fork orogen (Bradley et al., 2003). Widespread mafic volcanic rocks (Tatina River volcanics and related units) of Late Triassic and/or Early Jurassic age may have formed in a continental margin rift setting (Bundtzen et al., 1997). At least some of the lithologic variation within the Mystic may reflect topographic irregularities inherited from the underlying Nixon Fork–Dillinger passive margin.

### SAMPLES AND METHODS

In this paper, we present new fossil, geochemical, isotopic, lithologic, and U-Pb detrital zircon data from a variety of Mystic subterrane units in areas A, E, and F (Figs. 2–4). These data include geochemical, fossil, and lithologic data from Upper Devonian bedded barite, black shale, and phosphatic chert in areas E and F; detrital zircon, fossil, geochemical, and petrographic data from upper Paleozoic and Mesozoic strata in areas A, E, and F; and geochemical and neodymium isotopic data from Triassic–Jurassic mafic igneous rocks in areas E and F. We also discuss new detrital zircon results from Devonian and Mississippian(? ) strata in the Livengood and White Mountains terranes, respectively (Livengood 1:250,000-scale quadrangle; Fig. 1). Previously unpublished fossil data are presented in Table 1. Chronostratigraphic correlations follow Walker et al. (2012).

Detrital zircon sample coordinates and descriptions are presented in Table 2, and summaries of detrital zircon U-Pb age populations are presented together with relevant stratigraphic data and age constraints in Table 3.
TABLE 1. LOCATIONS AND DESCRIPTIONS OF SAMPLES ANALYZED FOR FOSSILS FROM THE FAREWELL TERRANE, ALASKA

<table>
<thead>
<tr>
<th>Sample; quadrangle (locality [loc.] no.)</th>
<th>Latitude (°N); longitude (°W)</th>
<th>Sample description (relevant photographs)</th>
<th>Fossils</th>
<th>Age and/or depositional setting (CAI)</th>
<th>Source and comments</th>
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<tbody>
<tr>
<td>Devonian carbonate rocks</td>
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<tr>
<td>12AD331M McGrath A2 (loc. 2)</td>
<td>62.0189 153.8833</td>
<td>Concretion (9 cm diam); coral in calcareous radiolarite matrix (Fig. 5G)</td>
<td>Coral: Cystiphyloides sp.</td>
<td>Probable Middle Devonian</td>
<td>C. Stevens, 2014, personal commun.</td>
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<tr>
<td>77APa507B* Medfra C4</td>
<td>63.6517 154.5867</td>
<td>Corals in dolomitic matrix, brachiopod and echinoderm fragments</td>
<td>Coral: Sociophyllum sp. cf. S. glomeratum (Crickmay), which occurs in Northwest Territories, Canada</td>
<td>Late Middle Devonian (Givetian)</td>
<td>C. Stevens, 1999, personal commun.</td>
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<tr>
<td>Carbonate rocks associated with the late Paleozoic Mystic assemblage (and/or unit Pzus?)</td>
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<tr>
<td>03ADw400A Talkeetna C6 (loc. 7) (Reed and Nelson, 1980, their loc. 16)</td>
<td>62.5267 152.6328</td>
<td>Crinoidal grainstone, foraminifers, bryozoan and brachiopod fragments, minor Ls, chert clasts (Fig. 6G)</td>
<td>Conodonts: Devonian: Icriodus sp.; Late Miss: Gnaithodus bilineatus Roundy; Miss or Penn: Cavusgnathus sp. or Adetognathodus sp.; Penn: gondolelled frag; Idiognathoides sp., Idiognathoides sp., or Streptognathodus sp.</td>
<td>No older than Pennsylvanian to very Early Permian, with redeposited Devonian and Late Mississippian conodonts; lag deposit (3.5–4)</td>
<td>A. Harris, 2004, personal commun.</td>
</tr>
<tr>
<td>03ADw415H Talkeetna C6 (loc. 9)</td>
<td>62.6168 152.7807</td>
<td>Fine dolomitic limestone</td>
<td>Conodonts: Oulodus? sp. indet.</td>
<td>Silurian–Middle Devonian (5)</td>
<td>A. Harris, 2004, personal commun.; sample erroneously reported as barren by Bradley et al. (2007)</td>
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<td>Permian Mount Dall conglomerate</td>
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<tr>
<td>00ADw100 Talkeetna C5 (loc. 11)</td>
<td>62.5944 152.1681</td>
<td>Clast AD-DM-1, 17 x 13 cm diam, fine carb</td>
<td>Conodonts: Belodelia sp. (1 element), indet. ozarkodinid S2 element (1), indet. elements (12 frags)</td>
<td>Silurian–Devonian (4–4.5)</td>
<td>J. Repetski, 2017, personal commun.</td>
</tr>
<tr>
<td>00ADw100H Talkeetna C5 (loc. 11)</td>
<td>62.5944 152.1681</td>
<td>Clast, 20 x 20 cm diam, bioclastic (cinoidal) grainstone (Figs. 9F, 9G)</td>
<td>Foraminifers: Earlantia moderata grp.; Paraarchaediscus sp., indet. endothyrids, ?Paraarchaediscus kytjubensis, Endothyra prica, “Nodosarchaediscus” sp., ?Viseidiscus primaevus, “Priscella” sp., Alg.: Stacheoides sp., Epistacheoides sp.; incertae sedis: Diplosphaerina and/or Eotubolina sp.</td>
<td>Late Mississippian(?); typical Northern Hemisphere taxa (no Tethyan forms); abraded bioclasts and ooids indicate high-energy deposit with probable reworking; well size-sorted allochems suggest winnowing</td>
<td>P. Brencich, 2016, personal commun.; this sample also produced conodonts of Early–Middle Penn (early, but not earliest, Morrowan–Desmoinesian) age (Bradley et al., 2003), so foraminifers may be redeposited</td>
</tr>
<tr>
<td>00ADw100J Talkeetna C5 (loc. 11)</td>
<td>62.5944 152.1681</td>
<td>Clast, ~20 cm diam, bioclastic (cinoidal) grainstone</td>
<td>Foraminifers: Paraarchaediscus sp., indet. endothyrids, “Priscella” sp., “Nodosarchaediscus” sp., Endothyra aff. E. obsolete, Paraarchaediscus infantis, Pseudomodotomiscus priscus, Archaediscus sp., ?Paraarchaediscus planus (Bozorgia), Paraarchaediscus aff. convexus.; incertae sedis: Diplosphaerina and/or Eotubolina sp.</td>
<td>Late Mississippian(?); typical Northern Hemisphere taxa (no Tethyan forms); abraded bioclasts and ooids indicate high-energy deposit with probable reworking; well size-sorted allochems suggest winnowing</td>
<td>P. Brencich, 2016, personal commun.</td>
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<td>Permian strata</td>
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<tr>
<td>77APa149* Medfra C4</td>
<td>63.6667 154.5833</td>
<td>Bryozoan-crinoid-brachiopod grainstone, 10–20% detrital quartz</td>
<td>Barren of conodonts but yielded phosphatic brachiopod fragments, phosphatized spines, spicules, steinkerns</td>
<td>Silurian–Devonian (4–4.5)</td>
<td>A. Harris, 1999, personal commun.; ts has likely shell fragments of Atomodesma</td>
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<td>Triassic strata</td>
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<tr>
<td>12AD331N McGrath A2 (loc. 12)</td>
<td>62.0207 153.6909</td>
<td>Fine carb clast cgl; matrix includes detrital quartz, feldspar, chert grains</td>
<td>Conodonts: Dvorakia sp. (4 elements), ozarkodinid spp. indet. (2 P and 4 S elements), conform elements (6, most likely of Icriodus, Distomodus, and/or Decorconus spp.), indet. gen. and spp. fragments (~12)</td>
<td>Ordovician(?), Silurian–Devonian (2.57, 3, 4, 4.5)</td>
<td>J. Repetski, 2017, personal commun.; sample includes clasts and matrix</td>
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(continued)
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<thead>
<tr>
<th>Sample; quadrangle (locality [loc. no.])</th>
<th>Latitude (°N); longitude (°W)</th>
<th>Sample description (relevant photographs)</th>
<th>Fossils</th>
<th>Age and/or depositional setting (CAI)</th>
<th>Source and comments</th>
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<tbody>
<tr>
<td>11ADw119V McGrath B1 (loc. 13) Jurassic strata</td>
<td>62.3915 153.0828</td>
<td>Very fine carl clast (22 cm diam)</td>
<td>Barren of conodonts</td>
<td>Early Jurassic (Sinemurian); warm, shallow-water, tropical to subtropical inner shelf setting</td>
<td>J. Repetski, 2011, personal commun.</td>
</tr>
<tr>
<td>12AD320H Lime Hills D3 (loc. 21)</td>
<td>61.9691 153.7843</td>
<td>Large cobble of quartz sandstone with bivalve debris (Fig. 13D)</td>
<td>Bivalves: Gryphaea rockymontana Warren, Pinna sp., Ostrea sp., possible pelecypod, fine-ribbed form</td>
<td>Early Jurassic (Sinemurian); warm, shallow-water, tropical to subtropical inner shelf setting</td>
<td>R. Blodgett, 2014, personal commun.</td>
</tr>
<tr>
<td>13AD409AA Lime Hills D3 (loc. 17)</td>
<td>61.8044 154.0484</td>
<td>Bioclastic limestone with smooth shell fragments</td>
<td>Bivalves: Gryphaea rockymontana Warren</td>
<td>Early Jurassic (Sinemurian); warm, shallow-water, tropical to subtropical inner shelf setting</td>
<td>R. Blodgett, 2014, personal commun.</td>
</tr>
<tr>
<td>13SB28F McGrath B1 (loc. 20)</td>
<td>62.3818 153.1349</td>
<td>Very fine to fine calcareous sandstone (Fig. 13C)</td>
<td>Ammonites: ariettid, possibly Coroniceras sp. (Fig. 13C), specimen from second horizon could be same form or ?Leptechioceras sp.</td>
<td>Early Jurassic (early? Sinemurian); specimen from second horizon could be same age or late Sinemurian</td>
<td>T. Poulton, 2014; personal commun.; two fossil horizons ~10 ft stratigraphically apart</td>
</tr>
<tr>
<td>13SB28F McGrath B1 (loc. 20)</td>
<td>62.3818 153.1349</td>
<td>Very fine to fine calcareous sandstone (Fig. 13C)</td>
<td>Ammonites: Paracoroniceras sp. (Fig. 13C), specimen from second horizon</td>
<td>Early Jurassic (Sinemurian)</td>
<td>J. Haggart, 2014; personal commun.</td>
</tr>
<tr>
<td>76ANs17C¹ Talkeetna B6 (Reed and Nelson, 1980, their loc. 24)</td>
<td>62.4983 152.6000</td>
<td>Limestone with abundant echinoderm fragments, partly replaced by chert</td>
<td>Crinoid: Pentacrinus similar to Pentacrinus subangulatus alaska Springer</td>
<td>Early(?) Jurassic</td>
<td>D.L. Jones, 1977, personal commun.; field notes and fossil reports indicate Jurassic and Cretaceous strata occur here</td>
</tr>
<tr>
<td>75AR38A, 75AR39*; 76Dt147 Talkeetna C6 (Reed and Nelson, 1980, their loc. 28)</td>
<td>62.5333 152.8833</td>
<td>Brown to black, ferruginous, calcareous siltstone to sandstone that underlies Buchia-bearing limestone</td>
<td>Ammonites (arietids, Coroniceras sp.), belemnites, bivalves (Entoliium sp., ?Eopecten sp., Gryphaea cf. G. rockymontana, Oxytoma cf. O. cygnipes, Plagiostoma sp., ?Plicatura sp., Weyla sp.), and brachiopods (Liosipherina rostrata, rhynchoellids)</td>
<td>Early Jurassic (early Sinemurian)</td>
<td>R. Imlay, 1975, 1976, personal commun.; Sandy and Blodgett (2000); field notes and fossil reports indicate Jurassic and Cretaceous strata occur here</td>
</tr>
<tr>
<td>76AR16, 76AR17¹ Talkeetna B6 (Reed and Nelson, 1980, their loc. 29)</td>
<td>62.4792 152.8205</td>
<td>Fossiliferous calcareous sandstone that overlies Dillinger strata with angular unconformity</td>
<td>Ammonite (Coroniceras sp.), bivalves (?Eopecten sp., Gryphaea cf. G. rockymontana, Pleuronoma sp., Weyla sp.), and rhynchoellid brachiopods</td>
<td>Early Jurassic (early Sinemurian)</td>
<td>R. Imlay, 1976, personal commun.</td>
</tr>
<tr>
<td>76AR13 McGrath B1</td>
<td>62.3417 153.3028</td>
<td>Shell beds in limy, ferruginous sandstone, ~25–75 ft above base of unit</td>
<td>Bivalves (?Entoliium sp., ?Grammatodon sp., Lima sp., Weyla sp.), brachiopods</td>
<td>Early Jurassic</td>
<td>R. Imlay, 1976, personal commun.; field notes indicate that strata of this unit are interbedded with mafic igneous rocks (B. Reed, 1976, personal commun.)</td>
</tr>
<tr>
<td>84BT116¹ McGrath B1</td>
<td>62.3889 153.0306</td>
<td>No information available</td>
<td>Bivalves (?Eopecten sp., Entoliium sp.)</td>
<td>Probably Jurassic</td>
<td>Elder and Miller (1991); latitude and longitude based on T, R, S and elevation data</td>
</tr>
</tbody>
</table>

Note: Localities are shown on Figure 4 except where noted. Lithic grains: Ls—sedimentary. CAI—conodont color alteration index; carb—carbonate; cgl—conglomerate; diam—diameter; frag—fragment. Miss—Mississippian; Penn—Pennsylvanian; T, R, S—township, range, section; ts—thin section.

¹Latitude and longitude were determined using station location on a field sheet.

TABLE 1. LOCATIONS AND DESCRIPTIONS OF SAMPLES ANALYZED FOR FOSSILS FROM THE FAREWELL TERRANE, ALASKA (continued)
Detrital zircon U-Pb age determinations were done by Apatite to Zircon, Inc. (now GeoSep Services; Moscow, Idaho, USA), using laser ablation-inductively coupled plasma–mass spectrometry (LA-ICP-MS) techniques at Washington State University (GeoAnalytical Lab, Pullman, Washington, USA). The Supplemental Materials contain a detailed description of analytical methods, complete data tables including U-Pb concordia diagrams for all samples (Table 1).

![Graphical representation of the geology of southeastern McGrath, northeastern Lime Hills, and southwestern Talkeetna quadrangles, showing location of samples. MP—Mystic Pass. Number 2 within sample symbols at localities 12 and 17 indicates 2 samples were analyzed.](image-url)
<table>
<thead>
<tr>
<th>Sample Unit</th>
<th>Quadrangle (locality [loc.] no.)</th>
<th>Latitude (°N)</th>
<th>Longitude (°W)</th>
<th>Description (relevant photographs)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farewell terrane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07ADw711A Sheep Creek Fm.</td>
<td>McGrath A2</td>
<td>62.0126</td>
<td>153.7116</td>
<td>Medium sandstone, chert, quartz, plag, Lm</td>
<td>Strata contain possible plant fossils</td>
</tr>
<tr>
<td>09PH160A Sheep Creek Fm.</td>
<td>McGrath B2</td>
<td>62.4794</td>
<td>153.8853</td>
<td>Chert clast conglomerate (Fig. 6F)</td>
<td>DZ data first presented by Malkowski (2010)</td>
</tr>
<tr>
<td>11AD2A Sheep Creek Fm.</td>
<td>Lime Hills D4</td>
<td>61.7595</td>
<td>154.3250</td>
<td>Medium sandstone, quartz, chert, plag</td>
<td>Strata interbedded with lithologies like those of sample 11AD3A</td>
</tr>
<tr>
<td>11AD3A Sheep Creek Fm.</td>
<td>Lime Hills D4 (loc. 5)</td>
<td>61.7605</td>
<td>154.3174</td>
<td>Bioclastic siltstone, chert &gt; quartz</td>
<td>Bed contains brachiopods of prob Penn–Perm age (Gilbert et al., 1990)</td>
</tr>
<tr>
<td>11AD4A* Sheep Creek Fm.</td>
<td>Lime Hills D4 (loc. 5)</td>
<td>61.8639</td>
<td>154.4222</td>
<td>Very fine sandstone, quartz, plag, chert</td>
<td>Bed contains Late Penn (or Perm) fusulinids (Bundtzen et al., 1997)</td>
</tr>
<tr>
<td>11AD6B Sheep Creek Fm.</td>
<td>Lime Hills D4</td>
<td>62.4046</td>
<td>153.9333</td>
<td>Graded very coarse to medium sandstone, chert, quartz, plag</td>
<td></td>
</tr>
<tr>
<td>11AD7B Sheep Creek Fm.</td>
<td>Lime Hills D4 (loc. 4)</td>
<td>62.2677</td>
<td>153.9566</td>
<td>Bioclastic very fine to fine sandstone, chert, quartz, chert</td>
<td></td>
</tr>
<tr>
<td>12AD320G Sheep Creek Fm.</td>
<td>Lime Hills D3</td>
<td>61.9657</td>
<td>153.7864</td>
<td>Fine sandstone, quartz, chert, carb</td>
<td></td>
</tr>
<tr>
<td>12AJJ16A Sheep Creek Fm.</td>
<td>Lime Hills D3</td>
<td>61.8281</td>
<td>152.9000</td>
<td>Pebble conglomerate, carbonate, quartz, Lm (sandstone) (Fig. 6E)</td>
<td></td>
</tr>
<tr>
<td>12SB120B Sheep Creek Fm.</td>
<td>Lime Hills D3</td>
<td>61.7874</td>
<td>154.0769</td>
<td>Medium sandstone, quartz, plag, Lm</td>
<td></td>
</tr>
<tr>
<td>76AR16C* Sheep Creek Fm.</td>
<td>Talkeetna B6 (loc. 6)</td>
<td>62.4792</td>
<td>152.8205</td>
<td>Medium sandstone, chert, plag, carb</td>
<td></td>
</tr>
<tr>
<td>11AD202C Lower Mystic assemblage</td>
<td>Talkeetna C6 (loc. 10)</td>
<td>62.5710</td>
<td>152.7575</td>
<td>Medium to pebbly sandstone, chert, Lm, Ls (Figs. 6H–6K)</td>
<td></td>
</tr>
<tr>
<td>03ADw407D* Lower Mystic assemblage</td>
<td>Talkeetna C5 (loc. 8)</td>
<td>62.7139</td>
<td>152.3931</td>
<td>Medium to coarse metasandstone, altered lithic clasts include Lm, Lm, minor quartz, plag</td>
<td></td>
</tr>
<tr>
<td>03ADw415C Lower Mystic assemblage</td>
<td>Talkeetna C6 (loc. 9)</td>
<td>62.6166</td>
<td>152.7807</td>
<td>Gravel conglomerate, Lm, Ls, chert</td>
<td></td>
</tr>
<tr>
<td>00ADw100 Mount Dall conglomerate</td>
<td>Talkeetna C5 (loc. 11)</td>
<td>62.5944</td>
<td>152.1681</td>
<td>00ADw100B, 00ADw100E, 00ADw100AA: pebble conglomerate; 00ADw100BB: medium sandstone, for all, chert &gt; carb and/or Ls, rare Lm, quartz (Figs. 9A–9E)</td>
<td>DZ sample is composite of 00ADw100B, 00ADw100E, 00ADw100AA, and 00ADw100BB</td>
</tr>
<tr>
<td>97ADw122 Permian strata Medfra C3 (loc. 1, Fig. 2)</td>
<td>Medfra C3 (loc. 1, Fig. 2)</td>
<td>63.6145</td>
<td>154.1877</td>
<td>97ADw122A: quartz siltstone; 97ADw122B–97ADw122F, silty to pebbly bioclastic limestone, 5%–30% quartz (Figs. 9H–9J)</td>
<td>DZ sample is composite of 97ADw122A–97ADw122F</td>
</tr>
<tr>
<td>97ADw119 Permian strata Medfra C3 (loc. 2, Fig. 2)</td>
<td>Medfra C3 (loc. 2, Fig. 2)</td>
<td>63.6595</td>
<td>154.1870</td>
<td>97ADw119B, 97ADw119C, and 97ADw119E: carbonate pebble conglomerate (Figs. 9K–9L)</td>
<td>DZ sample is composite of 97ADw119B, 97ADw119C, and 97ADw119E; strata mapped as unit Ksu by Patton et al. (1980)</td>
</tr>
<tr>
<td>11ADw119A Triassic strata</td>
<td>McGrath B1 (loc. 13)</td>
<td>62.3915</td>
<td>153.0828</td>
<td>Very fine to fine sandstone, chert, quartz, carb, wms (Figs. 10D–10F)</td>
<td>Strata mapped by Bundtzen et al. (1997) as Sheep Creek Formation</td>
</tr>
<tr>
<td>12AJJ20A Triassic strata</td>
<td>McGrath A2 (loc. 12)</td>
<td>62.0207</td>
<td>153.6909</td>
<td>Carb pebble conglomerate, quartz, plag, kspar (Figs. 10A–10C)</td>
<td>Strata mapped by Bundtzen et al. (1997) as Sheep Creek Formation</td>
</tr>
<tr>
<td>12AJJ20B Triassic strata</td>
<td>McGrath A2 (loc. 12)</td>
<td>62.0226</td>
<td>153.6915</td>
<td>Carb pebble conglomerate, quartz, plag, Lp (Figs. 10A–10C)</td>
<td>Strata mapped by Bundtzen et al. (1997) as Sheep Creek Formation</td>
</tr>
<tr>
<td>11ADw203C Triassic–Jurassic strata Talkeetna C6 (loc. 16)</td>
<td>Talkeetna C6 (loc. 16)</td>
<td>62.5722</td>
<td>152.8295</td>
<td>Pebble volcanioclastic sandstone, andesitic clasts, altered glass shards (Fig. 10K)</td>
<td></td>
</tr>
<tr>
<td>11SB112A Jurassic strata</td>
<td>McGrath B1 (loc. 19)</td>
<td>62.3765</td>
<td>153.1224</td>
<td>Very fine sandstone, 80% quartz, carb, Lm, plag, chl, wms (Figs. 13A, 13B)</td>
<td></td>
</tr>
<tr>
<td>12SB107C Jurassic strata</td>
<td>McGrath B1 (loc. 15)</td>
<td>62.3333</td>
<td>153.2960</td>
<td>Very fine sandstone, quartz, plag, carb, wms (Fig. 10L)</td>
<td></td>
</tr>
<tr>
<td>12AD320H Jurassic strata</td>
<td>Lime Hills D3 (loc. 21)</td>
<td>61.9691</td>
<td>153.7843</td>
<td>Very fine to fine quartz-carb sandstone with coarse bivalve fragments (Fig. 13D)</td>
<td></td>
</tr>
<tr>
<td>13AD409D Jurassic strata</td>
<td>Lime Hills D3 (loc. 17)</td>
<td>61.8044</td>
<td>154.0484</td>
<td>Very fine to fine sandstone, quartz, chert, phosphate (Figs. 13E, 13F)</td>
<td></td>
</tr>
<tr>
<td>13SB28F Jurassic strata</td>
<td>McGrath B1 (loc. 20)</td>
<td>62.3818</td>
<td>153.1349</td>
<td>Very fine to fine sandstone, carb &gt; quartz, wms, chl (Fig. 13C)</td>
<td></td>
</tr>
<tr>
<td>98ADw212 Cretaceous strata Medfra B3 (loc. 3, Fig. 2)</td>
<td>Medfra B3 (loc. 3, Fig. 2)</td>
<td>63.4517</td>
<td>154.2200</td>
<td>98ADw212A: fine sandstone, chert &gt; quartz, Lm, plag, wms; 98ADw212C: pebble to granule conglomerate, chert &gt; Ls &gt; Qp (Fig. 13J)</td>
<td>DZ sample is composite of 98ADw212A, 98ADw212C; strata mapped as unit Ksu by Patton et al. (1980)</td>
</tr>
</tbody>
</table>
S1), and a summary of calculated age populations for each sample (Table S2). Raw, uninterpreted U-Pb data were also published as a U.S. Geological Survey (USGS) Data Release (Dumoulin et al., 2018a). We calculated a concordia age (including decay constant error) for each analysis and used this as the preferred age of the associated detrital zircon grain instead of using either the 206Pb/238U or 207Pb/206Pb age (Ludwig, 1998; Nemchin and Cawood, 2005). The concordia age makes optimum use of both decay schemes and obviates the need to choose an arbitrary age threshold for selecting the 206Pb/238U or 207Pb/206Pb age as the “preferred age” for an individual grain (Ludwig, 1998). Additionally, the concordia age calculation gives probability of concordance (POC) for each analysis, which provides a useful means of assessing concordance for all grains regardless of age. After calculating the concordia age and associated statistics for each analysis, we screened the data for uncertainty and probability of concordance. Analyses with >10% age uncertainty (at 1σ) were excluded or “filtered” from plots and statistical treatments. Grains with a POC <0.1 were also excluded unless the grain was older than 1000 Ma and had a calculated concordance (comparison of 206Pb/238U or 207Pb/206Pb ages) between 80% and 105%. Data that were excluded are reported in Table S1 (footnote 1). The results of the statistical comparisons for all samples are shown in the Supplemental Materials (Table S3 [footnote 1]), and select results are discussed in the text below.

After screening all of the data, we used the DZstats tool (version 2.2) of Saylor and Sundell (2016) to plot the cumulative distribution function for different sample sets and to calculate a variety of comparative metrics including Kolmogorov-Smirnoff (K-S) and Kuiper tests and cross-correlation, likeness, and similarity coefficients of probability density plots (PDPs) for all samples. The Supplemental Materials (footnote 1) also contain geochemical data for mafic igneous rocks (Table S5) that are discussed and summarized in plots below.

### MIDDLE–UPPER DEVONIAN STRATA

Deep-water Middle and Upper Devonian rocks occur at or near the base of the Mystic subterrane in areas E and F (Fig. 3). These strata make up map units Ds and Dcs in the northern Lime Hills quadrangle (Gilbert et al., 1990; Bundtzen and Gilbert, 1991), part of the lower Sheep Creek Formation in the McGrath quadrangle (Bundtzen et al., 1997), and an interval in the lower part of map unit

**TABLE 2. LOCATIONS AND DESCRIPTIONS OF DETRITAL ZIRCON SAMPLES ANALYZED FROM THE FARROW, LIVENGOOD, AND WHITE MOUNTAINS TERRANES, ALASKA (continued)**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Unit</th>
<th>Quadrangle (locality [loc. no.])</th>
<th>Latitude (°N)</th>
<th>Longitude (°W)</th>
<th>Description (relevant photographs)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farewell terrane (continued)</td>
<td>Cretaceous strata</td>
<td>Talkeetna C6 (loc. 16)</td>
<td>62.5722</td>
<td>152.8295</td>
<td>Very fine to medium sandstone, quartz, plag, kspar, Ls, Lm, Ls, wm, biotite, chlorite (Fig. 13K)</td>
<td></td>
</tr>
<tr>
<td>Livengood terrane</td>
<td>Cascade Ridge unit</td>
<td>Livengood B3 (CR, Fig. 1)</td>
<td>65.4895</td>
<td>148.4703</td>
<td>Fine to medium sandstone, carb, quartz, chert</td>
<td></td>
</tr>
<tr>
<td>White Mountains terrane</td>
<td>Globe unit</td>
<td>Livengood B3 (G, Fig. 1)</td>
<td>65.3016</td>
<td>148.2080</td>
<td>Fine sandstone, 80%–90% quartz, minor chert, Ls, tourmaline</td>
<td></td>
</tr>
</tbody>
</table>

Note: Localities are shown on Figure 4 except where noted. Lithic grains: Lm—metamorphic; Lp—plutonic; Ls—sedimentary; Ly—volcanic; carb—carbonate; chl—chlorite; DZ—detrital zircon; kspar—potassium feldspar; Perm—Pennsylvanian; Perm—Permanian; plag—plagioclase feldspar; prob—probably; Qp—polycrystalline quartz; wm—white mica.

*Latitude and longitude were determined using station location on a field sheet.
Pzus in the Talkeetna quadrangle (Reed and Nelson, 1980). Lithologies include dark gray to black shale, siltstone, and varicolored chert.

Black shale in unit Ds (locality [loc.] 1, Fig. 4) includes an interval of bedded barite ~50 m thick (Gagaryah deposit; Bundtzen and Gilbert, 1991). Barite textures range from massive to laminated to nodular (Figs. 5A–5D). Frasnian concretions consist of lime mudstone with locally abundant calcitized radiolarians (Fig. 5G), and are ca. 425–298 Ma (Table 1). They include a Late Devonian coral Dendrostromella sp. and Frasnian conodonts (Bundtzen et al., 1997). Thin-section textural analysis of this unit indicates that corals and other shallow-water biota were redeposited into a deeper-water, off-shelf setting.

Reed and Nelson (1980) described an interval of unknown thickness in their unit Pzus (loc. 3, Fig. 4) made up of black shale and phosphatic chert bearing distinctive fluorapatite concretions ("blackballs"); they presented no petrographic or geochemical documentation of these strata. The concretions, 3–4 cm in diameter (Fig. 5H), contain a well-preserved Famennian radiolarian fauna (Reed and Nelson, 1980). Our thin-section studies found abundant radiolarians in a matrix of dark brown phosphate intergrown with pale quartz, calcite, and minor barite (Figs. 5I, 5J). Geochemical analysis (inductively coupled plasma–mass spectrometry) of two concretions (combined) found 14.4% P (32.6% Pb; Table S4 [footnote 1]).

Bedded barite, black shale, calcareous radiolarite, and phosphorite typically form in environments characterized by high productivity, such as coastal areas affected by upwelling currents (e.g., Dumoulin et al., 2004). Implications of these Mystic lithofacies are discussed further below.

### Devonian–Permian Upper Sheep Creek Formation

#### Lithologies and Fossil Data

The Sheep Creek Formation (Devonian–Permian) consists chiefly of fine- to coarse-grained siliciclastic strata exposed in the central part of the Mystic subterrane (areas D, E). The unit was proposed by Bundtzen et al. (1997) to

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TABLE 3. UPPER PALEOZOIC CLASTIC UNITS OF THE FAREWELL TERRANE, ALASKA

<table>
<thead>
<tr>
<th>Unit</th>
<th>Location</th>
<th>Age constraint</th>
<th>Detrital zircon data (Ma)</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Sheep Creek</td>
<td>Area E (locs. 4, 5, 6)</td>
<td>Penn–Perm</td>
<td>43S ± 10 to 368 ± 7</td>
<td>Heterolithic sl, ss, cgl; subordinate chert-clast cgl and calcareous sandstone to silty lms</td>
</tr>
<tr>
<td>Formation (B)</td>
<td></td>
<td></td>
<td>459–405</td>
<td>Sheep Creek(? strata at locality 6 have 80% quartz; youngest DZs 368 ± 7 Ma</td>
</tr>
<tr>
<td>Lower Mystic assemblage</td>
<td>Area F (locs. 7–10)</td>
<td>Miss–Penn</td>
<td>316 ± 5 to 340</td>
<td>Lv-rich ss, sl, cgl</td>
</tr>
<tr>
<td>(M)</td>
<td></td>
<td></td>
<td>445–424, 347–335</td>
<td>DZ data set includes two samples from Malkowski and Hampton (2014)</td>
</tr>
<tr>
<td>Upper Mystic assemblage</td>
<td>Areas E?, F</td>
<td>Middle Perm DZs</td>
<td>267 ± 6</td>
<td>Lv-rich ss, sl, cgl</td>
</tr>
<tr>
<td>(M)</td>
<td></td>
<td></td>
<td>ca. 425, ca. 298</td>
<td>Data from Malkowski and Hampton (2014); probable outlier of this unit in area E has youngest DZs 282 ± 5 Ma</td>
</tr>
<tr>
<td>Mount Dall conglomerate</td>
<td>Area E (loc. 11)</td>
<td>Early Perm</td>
<td>304 ± 6</td>
<td>Chert- and/or carbonate-clast cgl, ss, sl</td>
</tr>
<tr>
<td>(R)</td>
<td></td>
<td></td>
<td>ca. 1840, 349</td>
<td>Strata mapped as unit Ksu by Patton et al. (1980) but considered Perm by others</td>
</tr>
<tr>
<td>Permian(?)</td>
<td>Area A (loc. 2, Fig. 2)</td>
<td>Middle Perm DZs</td>
<td>256 ± 4</td>
<td>Quartz-rich to calcareous ss, sl</td>
</tr>
<tr>
<td>conglomerate (P)</td>
<td></td>
<td></td>
<td>256</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Area A (loc. 2, Fig. 2)</td>
<td>Late Dev DZs</td>
<td>369 ± 5</td>
<td>Carbonate-clast cgl</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>369</td>
<td></td>
</tr>
</tbody>
</table>

Note: Units defined by: B—Bundtzen et al. (1997); M—Malkowski and Hampton (2014); P—Patton et al. (1980); R—Reed and Nelson (1980). Areas are as in Figure 2; localities (loc.) are as in Figure 4 except where noted. "Youngest" is youngest detrital zircon age as defined in text, with >20 uncertainty. cgl—conglomerate; Dev—Devonian; DZs—detrital zircons; lms—limestone; Lv—lithic volcanic clast; Miss—Mississippian; Penn—Pennsylvanian; Perm—Permian; siltstone; ss—sandstone.
Figure 5. Lithologic features of Middle(?) and Upper Devonian sedimentary rocks, shown in outcrop photographs [A, B, E, F, H], thin section scans (C, D, G, I), and a photomicrograph (J). See Figure 4 for locations. (A–D) Bedded barite at Gagaryah deposit, locality 1; barite textures range from massive to nodular (in B, C) to laminated (in D). (E–G) Limy concretions, locality 2; G shows typical microtexture of finely laminated calcareous radiolarite and the coral Cystiphylloides sp. of probable Middle Devonian age (Table 1). (H–J) Fluorapatite concretions, locality 3, consist of dark brown phosphate intergrown with pale quartz, calcite, and minor barite (in I) and contain Famennian radiolarians (in J).
Detrital Zircon Data

Detrital zircon U-Pb ages were determined for ten samples here considered to be from the upper Sheep Creek Formation, as well as an additional sample that may belong to this unit (Table 2; Figs. 4, 7). Four samples (07ADw711A, 09PH160A, 11AD6B, 11AD7B) were collected from sections in the southeast McGrath quadrangle that were mapped as Sheep Creek (subunit PDs) by Bundtzen et al. (1997); one of these (11AD7B; loc. 4, Fig. 4) is from a bioclastic sandstone layer near the stratigraphic midpoint of the subunit that produced fusulinid foraminifers of Late Pennsylvanian to possibly Permian age (R.C. Douglas in Bundtzen et al., 1997). Three samples (11AD2A, 11AD3A, and 11AD4A) are from the map unit uPzs in the Lime Hills D-4:1:63,360-scale quadrangle (north-central part of the Lime Hills 1:250,000-scale quadrangle; Gilbert et al., 1990); one of these (11AD3A; loc. 5, Fig. 4) is from a calcareous siltstone bed containing spiriferid and rhynchoconulid brachiopods of probable Pennsylvanian or Permian age according to these authors. Three samples (12AD320G, 12AJJ16A, 12SB120B) come from the Lime Hills D-3:1:63,360-scale quadrangle, have similarities in lithology and stratigraphic position to the upper Sheep Creek Formation in the McGrath quadrangle, and have been included in the Sheep Creek during recent mapping (Box et al., 2015a).

Our final sample is from the west-central Talkeetna quadrangle (76AR16C, Table 2; loc. 6, Fig. 4), from vertically bedded, fine-grained sandstone that is unconformably overlain (B. Reed, 1976, personal commun.) by sandy limestone containing Jurassic fossils (sample 76AR13, Table 1). The sample consists of >80% angular to rounded monocrystalline quartz, with minor plagioclase feldspar, chert clasts, and carbonate. Petrographically, this sample is unlike any other upper Sheep Creek sample examined for this study, but resembles instead Jurassic strata discussed below. Its stratigraphic position suggests inclusion in the upper Sheep Creek, however, and we provisionally consider it to be part of that unit, although a single young (Triassic) zircon obtained from this sample (and discussed below) could provide support for a younger age.

Detrital zircon spectra from our ten Sheep Creek samples—including the two from beds with late Paleozoic fossils—all have Devonian and older age populations (Fig. 7). Calculated ages of the youngest age populations, and hence maximum depositional ages, range from 435 ± 10 to 374 ± 9 Ma (Silurian to early Late Devonian). One sample (11AD3A) contains a single grain of Permian age (ca. 258 Ma) and a grain of latest Pennsylvanian age (ca. 300 Ma; Table S1 [footnote 1]). The calculated maximum depositional age of the quartzose sandstone from the Talkeetna quadrangle (sample 76AR16C; loc. 6, Fig. 4) is slightly younger at 368 ± 7 Ma (late Late Devonian), and this sample also contains a single grain of Triassic age (ca. 232 Ma; Table S1). All eleven samples have dominant age probability peaks with maxima between ca. 480 and 405 Ma and a wide array of older, mainly Proterozoic, grains.

Quantitative metrics show some variation in the similarity of the Sheep Creek samples, as PDP cross-correlation coefficients range from 0.43 to 0.93 for all inter-sample comparisons (Table S3 [footnote 1]; Saylor and Sundell, 2016). Sample 09PH160A produces the lowest values among all samples and also plots farthest from all other samples on the MDS diagram (Fig. 7C). More than half of the inter-sample comparisons have PDP cross-correlation coefficients >0.75 (Table S3). Similarity coefficients are >0.77 for all Sheep Creek comparisons, and likeness coefficients range from 0.52 to 0.81 (Table S3).
Figure 6. Lithologic features of the upper Sheep Creek Formation of Bundtzen et al. (1997) and lower Mystic assemblage of Malkowski and Hampton (2014), shown in outcrop photographs (A, F, H, I), thin section scans (B, E, G, J), and photomicrographs (C, D, K). See Figure 4 and Table 2 for locations. (A–F) Upper Sheep Creek Formation is fine- to coarse-grained siliciclastic turbidites, seen here at locality (loc.) 4 (in A–D) and samples 12AJJ16A (in E) and 09PH160A (in F). Lithofacies include heterolithic siltstone to sandstone (in B, E), calcareous, fossiliferous sandstone (in C, D), and chert conglomerate (in F); clast types include quartz (q), sedimentary lithic grains (Ls), and carbonate grains (c); fossils include bryozoan (b) and echinoid (e) fragments. (G–K) Lower Mystic assemblage includes a layer of crinoidal grainstone (in G; loc. 7) that contains foraminifers (f) and Pennsylvanian (to Permian?) conodonts (Table 1); flysch in this unit (in H–K; loc. 10) includes graded beds (in I) with notable volcanic lithic grains (Lv).
PALEOZOIC STRATA (MAP UNIT Pzus)

Lithologies and Fossil Data

Rocks at least partly coeval with the Sheep Creek Formation make up map unit Pzus (undivided sedimentary rocks) of Reed and Nelson (1980) in the Talkeetna quadrangle (area F, Figs. 2, 3). This unit is a “depositionally and structurally complex” assemblage of diverse rock types, but “flyschoid sedimentary rocks” (graywacke, mudrock, grit, chert pebble conglomerate) and various types of volcanogenic rocks (including pillow basalt) predominate (Reed and Nelson, 1980, p. 7). Reed and Nelson (1980) recognized as part of unit Pzus a graywacke-dominated sequence that grades downward into sparse beds of Upper Mississippian and Middle Pennsylvanian echinoderm-pellet limestone and upward into massive chert-limestone conglomerate that is at least in part...
terrestrial. The conglomerate in turn grades upward into the Permian Mount Dall conglomerate (Reed and Nelson, 1980; Sunderlin, 2008), suggesting a Carboniferous–Permian age for the graywacke sequence. Older lithologies encompassed in unit Pzus include the Upper Devonian shale and phosphatic chert discussed above as well as Middle and Upper Devonian redbeds and reefood limestone (Reed and Nelson, 1980).

New conodont (Table 1) and lithologic data from one of the limy layers in the graywacke sequence (loc. 7, Fig. 4; Reed and Nelson, 1980, their loc. 16) support a late Paleozoic age for this layer and indicate that it formed as a size-sorted lag deposit. The layer is crinoidal grainstone with foraminifers, bryozoan and brachiopod fragments (some of which are bored), lime peloids, and ~10% non-carbonate clasts (mainly siliceous mudstone and radiolarian chert) up to 4 mm in diameter (Fig. 6G). The conodont assemblage contains elements no older than Pennsylvanian (possibly Permian?), as well as reworked Devono-

nate and Late Mississippian elements (A. Harris, 2004, personal commun.). The most likely age of the conodont assemblage is consistent with the Middle Pennsylvanian age based on foraminifers reported by A. Armstrong (in Reed and Nelson, 1980). The assemblage has been winnowed; all fine-grained material has been removed. Numerous small, pink to clear, subhaled rounded zircons were found in the heavy mineral residue that remained after processing for conodonts.

Reed and Nelson (1980) provided no petrographic details for the upper Paleozoic graywacke sequence in unit Pzus. Recent studies, and our new data, indicate that this sequence encompasses several compositional variants.

Malkowski and Hampton (2014) described rocks of unit Pzus in the area of Mystic Pass (Fig. 4), the type locality of their “Mystic assemblage.” Strata in the Mystic Pass area are sandstone, siltstone, mudstone, and subordinate conglomerate, interpreted as low- to high-density sediment gravity flow deposits that formed in a submarine fan environment. Sandstones are uniformly rich in mafic to intermediate volcanic lithic grains (average 66% of all grains and >80% of lithic grains) with subordinate chert and sedimentary clasts, and only a few percent each of monocrystalline quartz and feldspar. Conglomerate layers, 1–4.5 m thick, contain rounded clasts ≤10 cm in diameter that are mainly volcanic rocks and chert.

Bradley et al. (2007) briefly described strata at two localities within map unit Pzus that are west and northeast of Mystic Pass (Fig. 4), for which we provide additional petrographic and fossil data. Deformed turbidites at sample site 03ADw407 (loc. 8, Fig. 4) consist chiefly of altered lithic clasts, some of which are mafic volcanic grains with lathwork textures. Carbonate alteration and replacement are pervasive. Discrete grains of monocrystalline quartz and feldspar are rare. Strata at sample site 03ADw415 (loc. 9, Fig. 4) include slate, granule conglomerate, sandstone, rare micritic limestone, and a 1-m-thick ashfall tuff with a U-Pb zircon age (Bradley et al., 2007) of ca. 223 Ma. Bradley et al. (2007) interpreted the tuff and associated sandstone and conglomerate section as Triassic, but additional data indicate a more complex picture, with rocks of several ages present and stratigraphic relations between the lithologies uncertain. A fine crystalline dolomitic limestone layer interbedded with conglomerate at one end of the section contains conodonts of Silurian–Middle Devonian age (Table 1). Coarse grained, pebbly sandstone in contact with the tuff consists chiefly of volcanic lithic clasts. Pebble elongation layering in this sandstone is at a high angle to the contact, implying a structural or unconformable relation between the two lithologies. Granule conglomerate a few tens of meters topographically above the tuff (sample 03ADw415C) has clasts (to 4 mm) made up in subequal amounts of volcanic rocks, sedimentary lithic grains, and chert (some with radiolarians ± siliceous sponge spicules).

We studied another unit Pzus section southwest of Mystic Pass (loc. 10; Fig. 4). Rocks here are very thin- to medium-bedded argillite, limy siltstone, sandstone, and granule conglomerate (Figs. 6H–6K). Beds are graded and contain locally abundant shale rip-up clasts. Sandstone and conglomerate consist mainly of sedimentary lithic clasts and chert grains (most radiolarian bearing) with 5%–15% mafic volcanic lithic clasts (Figs. 6J, 6K). Calcite cement is common, and several limy layers contain abundant bioclasts, including echi-

noderms and bryozoan debris, ostracodes, and agglutinated and calcareous foraminifers.

Thus, siliciclastic beds in unit Pzus examined for this study and described by Malkowski and Hampton (2014) contain notably more volcanic lithic clasts and less monocrystalline quartz than do those in the Sheep Creek Formation. Both units contain abundant chert grains and rare limy, fissiliferous beds.

**Detrital Zircon Data**

Our sample from locality 10 (11AD202C; Fig. 4; Table 2) yielded a detrital zircon age spectrum much like those of our Sheep Creek Formation samples, but with a Mississippian (Visean) youngest age population of 340 ± 5 Ma (Fig. 8A; Table S2 [footnote 1]) and a single grain of early Permian age (ca. 288 Ma; Table S1). Detrital zircon data from two localities in unit Pzus published by Bradley et al. (2007) yielded age spectra that were broadly similar to that from locality 10 but include more abundant Mississippian age populations and have mid-Mississippian youngest age populations of ca. 347 and 335 Ma (samples 03ADw415C and 03ADw407D; Table 2; Fig. 8A). The MDS plot (Fig. 8C) shows that these three samples, herein called “lower Mystic assemblage” on the basis of lithologic and detrital zircon similarities with strata so designated by Malkowski and Hampton (2014), are all generally similar but do show some separation in MDS space. We attribute the variation to differences in the proportion of Devonian and Mississippian grains that otherwise define statistical populations with similar ages.

Quantitative metrics show some variation in the similarity of our three “lower Mystic assemblage” samples (Table S3 [footnote 1]; Saylor and Sundell, 2016). PDP cross-correlation coefficients range from 0.46 to 0.80 and are lowest for sample 03ADw407D. This sample also plots farthest from the other two in the MDS plot (Fig. 8C). The maxima in the KDE diagram for this sample is slightly younger than for the other two, and it does not contain as many Silurian grains (Fig. 8A). Similarity coefficients are >0.79 for...
Figure 8. Detrital zircon kernel density estimate (KDE) diagrams (A), cumulative distribution function plot (B), and multi-dimensional scaling (MDS) plot (C) for samples from the Mystic assemblage, Mount Dall conglomerate, and unnamed Permian (and older?) strata in the Medfra quadrangle together with the composite age spectrum for the Sheep Creek Formation. See Table 2 and Figures 2 and 4 for sample descriptions and locations. KDEs were generated using adaptive kernel density estimation (Vermeesch, 2012); each histogram bin represents ~25 m.y. The purple vertical band in panel A approximately indicates the Silurian period (ca. 444–419 Ma) and the blue vertical band approximately indicates the Mississippian and Pennsylvanian periods (ca. 359–299 Ma). The inset for sample 97ADw122 shows the KDE for the youngest age population with 5 m.y. histogram bins; the single unshaded bin was excluded from the weighted average calculation (see text for details). Y-axis on inset figure is number of grains. Solid lines between symbols in the MDS plot represent nearest neighbors, and dashed lines represent next-nearest neighbors. Short sample labels in parentheses in A are keyed to symbols in the MDS plot, and stress value is indicated by “S” (Vermeesch, 2013).
all three sample comparisons, and likeness coefficients range from 0.52 to 0.69 (Table S3).

**PERMIAN MOUNT DALL CONGLOMERATE**

**Lithologies and Fossil Data**

The Mount Dall conglomerate (Reed and Nelson, 1980) is an interval of conglomerate, sandstone, siltstone, and mudstone ~1500 m thick that is widely exposed in area F. A flora of ferns, cyclopteroids, and cordaitaleans and local rhyynchonellid and strophomenid brachiopods indicate a probable early Permian age (Mamay and Reed, 1984; Sunderlin 2008). The unit is characterized by fining-upward sequences tens of meters thick and likely formed in a coastal braidplain setting (Sunderlin, 2008). Bradley et al. (2003) interpreted the Mount Dall as a foreland basin succession deposited during the early Permian Browns Fork orogeny. Clasts in the Mount Dall are mainly diverse carbonate rocks and chert, and carbonate clasts have yielded faunas of both middle and late Paleozoic age. Reed and Nelson (1980) reported Middle Devonian (?) megafossils, and a large clast of fine-grained carbonate produced Silurian–Devonian conodonts (Table 1). Three large clasts of skeletal packstone to grainstone yielded Pennsylvanian conodonts (one fauna could be as young as earliest Permian; Bradley et al., 2003). Foraminifers in one of these clasts and in an additional clast of similar lithology are of Late Mississippian (?) age and may have been redeposited; the fauna consists of typical Northern Hemisphere taxa and includes no Tethyan forms (P. Brenckle, 2018, personal commun.; Table 1).

We examined the Mount Dall conglomerate (Figs. 9A–9G) at several localities within the middle 500 m of its stratigraphic extent—the interval studied in detail by Sunderlin (2008). Sand grains and coarser clasts in our samples are mainly chert (many with rare to abundant radiolarians) and fine-grained carbonate lithologies consistent with a deep-water setting such as calcareous radiolarite, muddy spiculite, and tentaculitid limestone (Figs. 9D, 9E). Bioclastic wackestone to grainstone, containing crinoids, bryozoans, foraminifers, algae, and local ooids and likely derived from a shallow-water environment, occurs mainly as boulders (20–30 cm in diameter; Figs. 9F, 9G). Other subordinate clast types include intraformational conglomerate (Fig. 9B), and sandstone to siltstone made up of mostly of monocrystalline quartz, carbonate, and feldspar. Volcanic lithic clasts (Fig. 9D) are rare components of some samples, and distinctive grains of phosphatic radiolarian chert occur in several. As noted by Bradley et al. (2003), metamorphic lithic clasts are absent.

**Detrital Zircon Data**

A composite sample of pebble conglomerate and interbedded sandstone at locality 11 (Fig. 4; Table 2) produced abundant Devonian and Carboniferous detrital zircon grains and an array of older Paleozoic and Precambrian grains with a subordinate probability peak at ca. 1840 Ma (sample 00ADw100, Fig. 8A). The youngest age population is latest Pennsylvanian (304 ± 6 Ma; Table S2 [footnote 1]).

**PERMIAN (AND OLDER?) STRATA IN THE MEDFRA QUADRANGLE**

**Lithologies and Fossil Data**

Permian strata in area A (Medfra quadrangle; Figs. 2, 3, 9H–9J) consist chiefly of yellowish orange–weathering sandstone, sandy limestone, siltstone, and conglomerate that contain middle Permian (Guadalupian) brachiopods (Patton et al., 1980, 1994). Other fossils include bryozoans and a new species of trilobite (Hahn and Hahn, 1993). The unit (map unit Ps of Patton et al. [1980]) is 60–120 m thick and is bounded above and below by unconformities or discontinuities (Patton et al., 1977, 1980; Andrews and Rishel, 1982). New petrographic, paleontologic, and detrital zircon data illuminate the depositional setting and provenance of this unit.

Sandstone (e.g., loc. 1, Fig. 2) is thin to medium bedded with local small-scale ripples and cross-laminae, millimeter-scale cylindrical burrows, larger trace fossils such as Zoophycos, plant fragments, and woody debris. Samples are fine to coarse grained and cemented by silica and/or calcite; grains are angular to rounded. Composition ranges from relatively clean quartz arenite to calcarenite to lithic arenite rich in mica and metamorphic rock fragments (Patton et al., 1980). Feldspar, tourmaline, phosphate, glauconite, and dolomite are minor components of some samples. Skeletal fragments are locally abundant and may be partly or completely replaced by silica.

Limestone layers are chiefly skeletal supportstone with common non-carbonate grains. Echinoderm, brachiopod, and diverse bryozoan bioclasts predominate, with lesser pelecypod, cephalopod, gastropod, and rugose coral debris (Fig. 9J). Many skeletal grains are abraded, and some are bored. A few samples consist almost exclusively of calcareous prisms that are likely shell fragments of the Permian prismaticnacreous bivalve genus Atomodesma (Fig. 9I). The prisms are slightly curved, 10–40 µm thick, and as much as 1.5 mm long; some display dark and light bands from tens to hundreds of microns thick that are probable growth bands. The curvature and slenderess of these prisms differentiate them from those of Cretaceous inornacel bivalve shells (Kauffman and Runnegar, 1975).

Several compositionally distinct types of chiefly clast-supported conglomerate and pebbly sandstone have been included in the Permian unit. The first type overlies Proterozoic calcareous and pelitic schist and consists of pebbles and granules of calcschist, quartz-mica schist, and chloritic schist in a limy, sandy matrix that contains Permian brachiopods (Patton and Dutro, 1979; Patton et al., 1980) as well as fragments of bryozoans, echinoderms, and prismaticnacreous bivalves. Non-carbonate grains are 20%–50% of the matrix and include quartz, albite, white mica, chlorite, and biotite. A sample of this matrix
Figure 9. Lithologic features of upper Paleozoic Mystic subterrane rocks, Talkeetna and Medfra quadrangles, shown in outcrop photographs (A–C, F, H, K), photomicrographs (D, E, G), and thin section scans (I, J, L). (A–G) Mount Dall conglomerate, locality loc. 11 (Fig. 4): clasts are mostly fine-grained carbonate (white, gray, and tan clasts in B and C; c in D) and chert (black clasts in B and C; rc in D and E [white spheres are recrystallized radiolarians]); accessory clast types include intraformational conglomerate (cg in B), volcanic lithics (Lv in D), and boulders of bioclastic grainstone (in F, G) which contain crinoid (cr) and bryozoan (b) fragments. Approximate height between base of photo and mountain top in A is 600 m. (H) Permian siliciclastic strata (Ps; loc. 1, Fig. 2) in fault contact with Permian (?) conglomerate (P(?)c; loc. 2, Fig. 2). (I–J) Permian strata include limy layers with fragments of prismatolaminate bivalves (Atomodesma; a in I) as well as bryozoans and crinoids (in J). (K–L) Permian (?) limestone conglomerate contains clasts of silty peloidal grainstone (cp) and limestone (m).
processed for conodonts yielded only phosphatic brachiopod fragments and phosphatized spines, spicules, and bryozoan zoolithic steinkerns (Table 1).

A second compositional variant is massive limestone conglomerate (Figs. 9H, K, L) ~50 m thick that overlies Devonian carbonate strata at locality 2 (Fig. 2). Patton et al. (1980) tentatively assigned a Cretaceous age to this section, but noted that it could be as old as Permian. Cretaceous rocks in the Medfra quadrangle are typically dominated by clasts of quartz and chert (Patton et al., 1980), leading Andrews and Rishel (1982) and Bradley et al. (2003) to favor a Permian age for the strata at locality 2. Beds are 20 cm to 2 m thick; meter-thick cross-beds occur locally. Imbricate clasts indicate that current transport was toward the southeast (Bradley et al., 2003). Beds are clast supported and contain rounded pebbles and cobbles up to 9 cm in diameter in a matrix of fine- to very coarse-grained sandstone; 40%–90% of the sand-sized and coarser clasts in samples we examined are carbonate. Dominant clast types are peleoid (± bioclast) grainstone with ≤20% quartz and feldspar silt, fine crystalline dolostone, lime mudstone, slightly to strongly recrystallized metalimestone, and medium- to coarse-crystalline calcitic marble (Fig. 9L). Non-carbonate clasts are mainly metamorphic and sedimentary lithic fragments, quartz, mica, and chert.

Detrital Zircon Data

Our samples were collected from limy, micaceous quartz siltstone and sandstone containing Permian fossils at locality 1 and limestone conglomerate at locality 2 (Fig. 2; Table 2). The limestone conglomerate (sample 97ADw119) contained a broad array of Paleozoic and Proterozoic grains, and the youngest age population is 369 ± 5 Ma (Famennian). In contrast, the fossiliferous sandstone sample (97ADw122) yielded abundant Permian and Early Triassic detrital zircon (28% of all grains analyzed) together with minor Late Devonian (Famennian), mid-Silurian, Neoproterozoic, and Paleoproterozoic age populations (Fig. 8A). The youngest single grain analyzed was Late Triassic (ca. 229 Ma), but it does not overlap with any of the other analyses. The next-youngest grains (n = 20) range in age from ca. 271 to 239 Ma, and they all overlap within 2σ uncertainty and have a weighted average age of 256 ± 4 Ma with a MSWD of 1.4 (see inset in Fig. 8A; Table S2 [footnote 1]). Thus, we interpret these grains to make up a single population and define an earliest late Permian depositional age for this sample—an age compatible (within uncertainty) with the fossil age reported by Patton et al. (1994). The presence of one Late Triassic and five Early Triassic grains in this sample raises the possibility of a Triassic depositional age, and there are Triassic strata mapped nearby in the same area. However, the Triassic rocks are lithologically very different from the rocks collected for this study that also contain Permian fossils (Patton et al., 1977, 1980).

The fossiliferous sandstone (sample 97ADw122) is quite dissimilar from all other samples described herein, yielding PDP cross-correlation coefficients ranging from 0.00 to 0.09 (Table S3 [footnote 1]; Saylor and Sundell, 2016). The age spectrum for the limestone conglomerate (sample 97ADw119) is distinct from that of the fossiliferous sandstone. It has some statistical similarity to samples 11AD2A (Sheep Creek Formation; Fig. 7A) and 03ADw415C (lower Mystic assemblage; Fig. 8A), producing PDP cross-correlation coefficients of 0.51 and 0.58, respectively (Table S3 [footnote 1]; Saylor and Sundell, 2016). Otherwise, this sample does not appear to be similar to any of the other samples considered herein.

Depositional Setting

Faunal and sedimentologic data indicate that the Permian succession in the Medfra quadrangle accumulated primarily in a shallow-marine setting with a temperate paleoclimate. Most of the sandstones and conglomerates contain marine fossils and probably represent strandline deposits. Atomodesma is an epifaunal to semi-infaunal bivalve that occupied a variety of inner sublittoral habitats (Kauffman and Runnegar, 1975). Intervals such as the massive limestone conglomerate at locality 2 (Fig. 2) that lack indigenous fossils could have formed in a fluviatile environment.

The echinoderm- and bryozoan-dominated fauna (e.g., James, 1997) and the presence of atomodesmid bivalves (Kauffman and Runnegar, 1975) suggest a temperate paleoclimate during deposition of the Permian succession. Prismatic debris derived from Atomodesma and related forms has been identified elsewhere in Alaska, chiefly from areas with mid-paleolatitude settings during the Permo-Triassic (Silberling et al., 1997): the Arctic Alaska–Chukotka terrane (Dover et al., 2004, their loc. 98), the Rampart Group in the Livgood area (Broségé et al., 1969), the Tahkandit Limestone in east-central Alaska (Laurentian margin; Brabb and Grant, 1971), and the Goodnews terrane in southwestern Alaska (Kauffman and Runnegar, 1975). The trilobite identified by Hahn and Hahn (1993) from Permian strata in the Medfra quadrangle also suggests a temperate to cool-water setting, as it belongs to a genus known only from Upper Carboniferous and Lower Permian rocks of the Arctic (Yukon Territory, Canada; Ellesmere Island, Nunavut, Canada; Spitsbergen, Norway).

Upper Triassic Conglomerates

Upper Triassic sedimentary rocks occur widely but sparsely throughout the Mystic subterrane (Fig. 3). In the north and west (areas A and B), they consist of shallow-water carbonate successions that deepen upward into chert and mudstone (Silberling et al., 1997; McRoberts and Blodgett, 2002); elsewhere (areas C through F; Bundtzen et al., 1997), strata of this age include shale, chert, conglomerate, and volcaniclastic sandstone interlayered with and intruded by...
mafic igneous rocks that are further discussed below. New detrital zircon data described below indicate that two intervals of carbonate- and chert-clast conglomerate in area E are of likely Late Triassic age. These strata have some lithologic similarities to Triassic rocks in the Medfra quadrangle (area A), as well as to the Permian Mount Dall conglomerate in area F.

Southeastern McGrath Quadrangle

Rocks at locality 12 (Figs. 4, 10A–10C) were originally included in the Sheep Creek Formation and tentatively correlated with the Permian Mount Dall conglomerate by Bundtzen et al. (1997). The section consists of >100 m of massive, mainly clast-supported conglomerate with a maximum clast diameter of ~8 cm (average ~2–3 cm; Fig. 10B). Strata we examined lacked sedimentary structures; Bundtzen et al. (1987) reported local pebble imbrication suggestive of crude channel configurations. Rounded pebbles of fine-grained limestone predominate (Fig. 10C); some limy clasts contain minor amounts of quartz silt, dolomite rhombs, and/or micritic peloids. Bioclasts are rare, and none could be specifically identified. The conglomerate has a sandy matrix of carbonate clasts with subordinate grains of monocrystalline quartz, locally abundant feldspar, and rare chert.

A composite sample of clasts and matrix yielded conodont elements of Ordovician (?) and Silurian–Devonian age that had been variously heated and deformed (J. Repetski, 2017, personal commun.; Table 1). Conodont color alteration index values of individual elements are 2.5(?), 3, 4, and 4.5 and indicate that host rocks reached temperatures ranging from ~100 to 300 °C (Epstein et al., 1977). Some conodont elements are texturally “pristine” whereas others are severely fractured. These findings imply that the conglomerate at locality 12 was derived from rocks that experienced a range of thermal and deformational histories prior to their Triassic redeposition.

Although the conglomerate at locality 12 is grossly similar to carbonate clast-rich parts of the Mount Dall conglomerate, the two units differ in some petrographic details. Carbonate clast types are more diverse in the Mount Dall, and fossiliferous limy clasts are more abundant. The feldspathic sandy matrix locally prominent at locality 12 has no counterpart in the parts of the Mount Dall section that we studied.

East-Central McGrath Quadrangle

Strata at locality 13 (Fig. 4) occur within the Triassic–Jurassic Tatina River volcanics as mapped by Bundtzen et al. (1997). About 15 m of fine-grained to pebbly sandstone and clast-supported conglomerate (Figs. 10D–10F) overlie more than 20 m of dark-weathering siltstone. Maximum clast size is ~10 x 20 cm; most clasts are 0.5–6 cm in diameter.

Chert clasts predominate in sandstone and conglomerate, and include argillaceous, dolomitic, and radiolarian-rich variants (Figs. 10E, 10F). Pebby beds contain common carbonate clasts, including lime mudstone, dolostone, sparry calcite, and calcareous spiculite. Monocrystalline quartz grains are notable in the sandy layers; feldspar grains are minor. Rare clast types include dark mudstone, granular phosphate, quartz-carbonate sandstone with echinoderm debris, and bivalve shell fragments made of prismatic calcite. A 20-cm-diameter clast of fine-grained carbonate processed for conodonts was barren (Table 1). Bundtzen et al. (1997) described chert-cobble pebble conglomerate as a part of subunit IJs (Lower Jurassic) of their Tatina River volcanics, but detrital zircon data (discussed below) suggest a Triassic age for this lithology.

Detrital Zircon Data

Detrital zircon data (Fig. 11) come from two samples of feldspathic sandy matrix of the carbonate conglomerate at locality 12, and a sample of fine-grained sandstone with abundant cherty clasts at locality 13 (Fig. 4; Table 2). The three spectra have youngest grain population ages of 208 ± 3 to 218 ± 3 Ma (Late Triassic; Norian), and all samples have prominent age probability peaks at ca. 420 Ma and few Precambrian grains. The sample from locality 13 also contains a few Permo-Carboniferous grains that define a minor age population at ca. 267 Ma (n = 3; Table S2 [footnote 1]) and a single Jurassic grain (ca. 186 Ma). The MDS plot in Figure 11C illustrates the similarity between the two carbonate clast conglomerate samples (UT1 and UT2 in Fig. 11C) and their separation from the fine-grained sandstone (UT3). The detrital zircon age spectrum for the fine-grained sandstone is more similar to those of the Lower Jurassic sedimentary samples (see below) and the Sheep Creek composite data because it has a broader array of Paleozoic grains and a larger (though still minor) proportion of Precambrian ages. Quantitative metrics show broad similarity among the three Triassic samples, with PDP cross-correlation coefficients ranging from 0.74 to 0.81 (Table S3; Saylor and Sundell, 2016).

Mafic igneous rocks (basalt, diabase, and gabbro) of Late Triassic and/or Early Jurassic age occur in areas C through F of the Mystic subterrane and have been called the Tatina River volcanics in area E by Bundtzen et al. (1997) (Figs. 2, 3). Late Triassic (Norian) ammonites and halobid and monotid bivalves occur in shale that is interlayered with basalt and agglomerate in areas D and E (Bundtzen et al., 1994, 1997), and Triassic (?) radiolarians are found in chert interbedded with basalt in area C (Gilbert, 1981). However, B.L. Reed (1976, personal commun.) suggested that some mafic igneous rocks in the eastern McGrath quadrangle (area E) were Jurassic, on the basis of field relations with sedimentary strata containing Early Jurassic fossils (Table 1, sample 76AR13). New geochemical and isotopic data (Table S5 [footnote 1]) from mafic igneous rocks...
Figure 10. Lithologic features of Triassic and Jurassic Mystic subterrane rocks, shown in outcrop photographs (A, B, D, G, J–L) and thin section scans (C, E, F, H, I). See Figure 4 for locations. (A–C) Conglomerate at locality 12 is made mostly of rounded, fine-grained limestone clasts. Approximate height between lower left of photo and mountain top in A is 300 m. (D–F) Conglomerate at locality 13 contains abundant clasts of pale to medium gray carbonate and brown to black radiolarian chert (rc). (G–I) Coralline limestone (cl; close view of coral in H) overlies vesicular basalt (vb; microtexture shown in I) at locality 14. (J, K) Agglomerate (in J) interbedded with volcanioclastic sandstone at locality 16. (L) Diabase sill intrudes sandstone at locality 15. DZ—detrital zircon.
Figure 11. Detrital zircon kernel density estimate (KDE) diagrams (A), cumulative distribution function plot (B), and multi-dimensional scaling (MDS) plot (C) for samples of Triassic, Jurassic, and Cretaceous strata. See Table 2 and Figure 4 for sample descriptions and locations. KDEs were generated using adaptive kernel density estimation (Vermeesch, 2012); each histogram bin represents ~25 m.y. The vertical bands in panel A approximately represent the following time periods: purple = Silurian (ca. 444–419 Ma); blue = Mississippian and Pennsylvanian (ca. 359–299 Ma); pink = Triassic (ca. 252–201 Ma); green = Jurassic (ca. 201–145 Ma). Solid lines between symbols in the MDS plot represent nearest neighbors, and dashed lines represent next-nearest neighbors. Short sample labels in parentheses in A are keyed to symbols in the MDS plot (“SCcomp” in panel C refers to the Sheep Creek Formation composite data set shown in Figure 7), and stress value is indicated by “S” (Vermeesch, 2013). Note that sample 11AD203C is not included in the Upper Triassic composite data set.
rocks in area E (Figs. 2, 12) and detrital zircon data from correlative strata in area F (Figs. 2, 11) help us to better understand these rocks.

**Geochemical and Isotopic Data**

Most outcrops we examined in area E are diabase, but at locality 14 (Fig. 4), altered vesicular basalt (sample 11AD20A; Fig. 10I) is interlayered with limestone containing poorly preserved corals (Figs. 10G, 10H). Overall, mafic igneous rocks typically have diabasic textures of jackstraw plagioclase and interstitial clinopyroxene, with strong but variable static replacement by greenschist facies minerals (dominantly chlorite, epidote, and calcite). Major elements (Table S5 [footnote 1]) were affected by low-grade metamorphism, but some generalizations can be made about them. The rocks are all tholeiitic basalts (based on high FeO_total/MgO) ranging from 46% to 53% SiO_2. Titanium (as TiO_2) averages 2.1%, but ranges from 0.8% to 3.4%.

Trace element data (Fig. 12; Table S5 [footnote 1]) are consistent with formation in a continental rift setting as previously suggested by Bundtzen et al. (1997). On a plot of the immobile elements Hf-Th-Ta (Fig. 12A; Wood et al., 1979), most of the samples are in the field representing enriched or plume-type mid-ocean ridge basalt (E-MORB), continental rift basalts, and/or continental flood basalts. Two samples plot separately in the subduction-related arc magma field. On multi-elemental plots (spidergrams) normalized to normal mid-ocean ridge basalt (Fig. 12B; Sun and McDonough, 1989), most samples are similar to E-MORB and ocean island basalt (OIB), with the exception of the two samples that plotted anomalously in Figure 12A. These samples show evidence for depletion of Nb and Ta relative to the light rare earth elements (i.e., La) which we attribute to subduction processes. Field occurrence and secondary mineral suites of these two samples are similar to those of our other samples. We infer they are part of the Late Triassic–Early Jurassic suite and suspect that their distinct geochemical characteristics were inherited from their magma sources.

Neodymium isotopic data (Table S5 [footnote 1]) were obtained for a subset of the mafic igneous samples, including the two apparently subduction-related samples. All samples yielded ƐNd values ranging between +1.2 and +4.9. The ƐNd values do not correlate with SiO_2, MgO, or Sm/Nd; such a correlation is expected when older crust is assimilated during fractionation. Instead, we interpret the isotopic values to reflect the composition of the magma source materials. Depleted mantle model ages calculated from these data range from 1.0 to 0.6 Ga, indicating that the mafic rocks most likely derived from partial melting of ca. 1.0 Ga subcontinental mantle lithosphere beneath the Farewell terrane. The mafic magmas were not derived by direct partial melting of the asthenosphere or oceanic mantle. Mafic magmatism is a common feature in rift-related tectonic environments, and we tentatively interpret these mafic igneous rocks to represent a Late Triassic and/or Early Jurassic rift or extensional event in or around the Farewell terrane. However, independent structural or sedimentologic evidence for rift-related tectonism during this time period has not yet been identified.

**Detrital Zircon Data**

Map unit Pzbs in the Talkeetna quadrangle map of Reed and Nelson (1980) consists of pillow basalt, pyroxene gabbro, agglomerate, tuff, and associated sedimentary strata that may correlate with the rocks described above. At locality 16 (Figs. 4, 10J, 10K), we collected one sample of volcanioclastic tuffaceous sandstone that contains abundant andesitic lithic clasts and glassy shards altered to chlorite. These strata differ from the Upper Triassic conglomerates and the Lower Jurassic sedimentary rocks described above and below, respectively, because they are directly associated with volcanic rocks and contain substantial volcanic detritus. The sample (11AD203C, Table 2) yielded a small number of detrital zircons (n = 21) with the youngest age population at ca. 226 Ma (n = 3; Fig. 11A; Table S2 [footnote 1]), which is consistent with a Triassic depositional age. However, the sample also contained a single grain of Jurassic age (ca. 196 Ma; Table S1). Other grains are of Paleozoic and Precambrian age, with a minor age population at ca. 1045 Ma (n = 4; Fig. 11; Table S2). Quantitative metrics show that this sample has some similarity to sample 97ADw119 (Medfra Permian?) sample in Fig. 8, with a PDP cross-correlation coefficient of 0.58 (Table S3; Saylor and Sundell, 2016), although both of these samples yielded relatively small numbers of detrital zircon. Comparisons with all other samples yielded PDP cross-correlation coefficients of 0.29–0.43 (Table S3).

# LOWER JURASSIC SEDIMENTARY ROCKS

**Lithologies and Fossil Data**

Jurassic sedimentary rocks are widely but sparsely distributed in the Mystic subterrane (Fig. 3). We describe here lithologies, fossil assemblages, and detrital zircon data from five newly recognized localities in area E that contain Lower Jurassic strata. Four are along the southeastern boundary of the Farewell terrane and on trend with Early Jurassic fossil localities previously documented in area F (Talkeetna quadrangle; e.g., Reed and Nelson, 1980), but locality 17 (Fig. 4) is within a large expanse previously mapped as Dillinger subterrane.

Lower Jurassic strata in the northwestern Talkeetna quadrangle were included in the Kahiltna assemblage by Reed and Nelson (1980; their map unit KJs) but were described by these authors as a lithologically and faunally distinctive subunit of reddish-brown weathering sandstone and dark gray shale that contains ammonites, brachiopods, and pelecypods. Jurassic rocks form small outcrops that overlie strata of the Dillinger subterrane, and they are isolated from the main mass of Kahiltna flysch. Their contact with Dillinger strata is generally a fault but locally was interpreted as an angular unconformity (Jones and Silberling, 1979; Reed and Nelson, 1980). Jones and Silberling (1979) noted that Jurassic strata, which they considered part of
Figure 12. Geochemical plots for Late Triassic–Early Jurassic mafic igneous rocks from the Mystic subterrane (samples colored the same in each plot; see Table S5 [footnote 1] for data). (A) Hi-Th-Ta plot of Wood et al. (1979) showing Mystic subterrane samples with fields for oceanic and continental igneous rocks generated in different tectonic environments; most Mystic samples fall in the field of enriched mid-ocean ridge basalt (E-MORB), continental rift, and continental flood basalts; two samples fall in the subduction-related (crustal contamination) magma field. N-MORB—normal mid-ocean ridge basalt; OIB—ocean island basalt. (B) Multi-element plots ("spidergrams") of Mystic subterrane igneous samples normalized to N-MORB compositions (after Sun and McDonough, 1989); examples are also given (from Sun and McDonough, 1989) of E-MORB and OIB, oceanic arc (Kermadec arc: Smith et al., 1997), and continental arc (Chilean Andes: Turner et al., 2016). Shaded gray box shows position in spidergrams of Nb and Ta, elements relatively depleted in arc-related igneous rocks. Most Mystic sample compositions range between those of typical E-MORB and OIB (also characteristic of continental rift or flood basalts). Two samples (shown by dashed lines) have arc-like compositions, although with less prominently depleted Nb-Ta.
their Dillinger terrane, are a few tens of meters thick, include limy and phosphatic layers, and are directly overlain by Lower Cretaceous rocks in some areas, as described below. The fauna of the Jurassic rocks is quite diverse and includes belemnites and crinoids in addition to forms listed above; the most precisely dated fossils indicate an age of early Early Jurassic (early Sinemurian; Table 1).

Thin sections from Jurassic limestone at locality 18 (Fig. 4; Reed and Nelson, 1980, their loc. 28) that were examined for this study consist of nodoidal grainstone with fragments of pelecypods, brachiopods, bryozoans, and possible red algae. Some bioclasts are bored, and some have micritic rims. Scattered non-carbonate grains (≤5%–10%) are mainly notably rounded monocrystalline quartz, with subordinate clasts of chert, siltstone, phosphate, and volcanic rocks.

In the eastern McGrath quadrangle, rocks with Jurassic fossils (Table 1) occur along trend from the Talkeetna Jurassic localities. According to Reed and Nelson (1980), Jurassic strata in the McGrath quadrangle are intercalated with pillow basalt and volcanic flows. However, Bundtzen et al. (1997) interpreted pillow basalt in this area as part of a Triassic map unit (Trab) overlain by a 45-m-thick section (their map unit IJs) that contains Jurassic bivalves (Table 1; Elder and Miller, 1991); unit IJs comprises bluish-white phosphatic shale, volcanioclastic sandstone, and chert-clast conglomerate.

Our findings support a Jurassic age for some mafic igneous rocks in the McGrath quadrangle, and indicate the occurrence of several distinct Jurassic lithologies in the McGrath and Lime Hills quadrangles (Fig. 4). Strata on trend to the southwest of unit IJs, but mapped as part of the Kahiltna assemblage by Bundtzen et al. (1997), include very fine-grained quartz-carbonate sandstone (locs. 15, 19, and 20, Fig. 4; Figs. 13A–13C) that is unlike any petrofacies described from the Kahiltna (e.g., Karl et al., 2013, 2015). Carbonate (as grains and cement) makes up 15% to >80% of our samples; non-carbonate grains are mainly monocrystalline quartz (Fig. 13B), with lesser plagioclase feldspar, chert, sedimentary lithic clasts, chlorite, and white mica. A carbonate-rich version of this lithology at locality 20 (Table 1) produced Early Jurassic (Sinemurian) ammonites (Fig. 13C) similar to those found in the Talkeetna quadrangle. A more quartz-rich sandstone is intruded by diabase at locality 15 (Fig. 10L).

Sandy coquinitoid limestone in the Lime Hills quadrangle (locs. 17 and 21, Fig. 4; Fig. 13D) yielded bivalves of Sinemurian age, including a distinctive oyster species also found in the Talkeetna faunas (R. Blodgett, 2014, personal commun., Table 1). Monocrystalline quartz grains are a minor but ubiquitous component of limy beds at both localities. Bivalve coquinas at locality 21 also contain foraminifers, gastropods, and crinoid fragments. Those at locality 17 are associated with distinctive, very fine- to medium-grained sandstone similar in composition to the quartz-rich sandstone at localities 15 and 19, but containing notably more rounded quartz grains as well as clasts and patches of phosphate (Figs. 13E, 13F). X-ray diffraction (XRD) analysis of a sample of this sandstone confirms the presence of ~10% phosphate (apatite group), in addition to 64% quartz, 15% plagioclase (anorthite), and 12% illite (A. Boeihke, 2014, personal commun.).

Detrital Zircon Data

We obtained detrital zircon data from strata containing Jurassic fossils at three localities (locs. 17, 20, and 21, Fig. 4), from quartzose sandstone intruded by diabase (loc. 15, Fig. 4), and from a similar sandstone ~10 km to the northeast (loc. 19, Figs. 4, 11; Table 2). All five samples produced age spectra that are broadly similar, with prominent, and in four samples dominant, age populations between ca. 427 and 409 Ma and a diverse range of Precambrian ages (Fig. 11). Both sandstone samples and two of the fossiliferous samples contained Early Jurassic age populations ranging from ca. 195 to 184 Ma (Fig. 11). The third fossiliferous sample (13AD409D, loc. 17)—the most compositionally and texturally mature—yielded an Early Devonian youngest age population (409 ± 10 Ma; Table S2 [footnote 1]), two Permian grains (ca. 267 and 257 Ma), and a single earliest Cretaceous grain (ca. 144 Ma; Table S1). This sample also contained the largest number of Precambrian grains. The MDS plot (Fig. 11C) shows clustering of all of the Jurassic samples except the one noted outlier (LJ4, sample 13AD409D). All of the Lower Jurassic samples and one of the Upper Triassic samples (UT3, sample 11ADw119A) also cluster together with the Sheep Creek Formation composite data set (SC comp in Fig. 11C), indicating notable similarity among them. Quantitative metrics show variable similarity among the Jurassic samples, with PDP cross-correlation coefficients ranging from 0.84 to 0.01 (Table S3; Saylor and Sundell, 2016).

Depositional Setting

Lithologic and faunal data from our new samples and previous collections constrain the depositional setting of Lower Jurassic strata in areas E and F. The non-carbonate component in our samples is compositionally mature (quartz dominated) and locally texturally mature (predominantly rounded grains). These features, in addition to the presence of phosphate and bored bioclasts, are consistent with condensed sedimentation forming winnowed lag deposits on a shelf. The spiriferid brachiopod species identified by Sandy and Blodgett (2000) at locality 28 of Reed and Nelson (1980) suggests a temperate or low-latitude setting. Mesozoic spiriferids generally preferred deeper-water shelf environments, but the ecologic niche of the Talkeetna species has not yet been determined (Sandy and Blodgett, 2000). Oyster coquinas at our localities 17 and 21 probably accumulated in relatively shallow- and warm-water (tropical to subtropical) settings (R. Blodgett, 2014, personal commun.).

CRETACEOUS STRATA

Lower Cretaceous (pre-Albian) strata—the youngest part of the Farewell terrane (Decker et al., 1994)—are most thoroughly documented in the Medfra quadrangle (Patton et al., 1977, 1980). Here we provide new petrographic information on the Medfra quadrangle rocks, describe a newly discovered
Figure 13. Lithologic features of Jurassic and Cretaceous strata in and adjacent to the Mystic subterrane, shown in outcrop photographs (A, C, E, G), a photomicrograph (B), and thin section scans (D, F, H-K). See Figure 4 for locations except where indicated. (A, B) Sandstone at locality (loc.) 19 contains a youngest detrital zircon population of Early Jurassic age and ~80% monocrystalline quartz grains. (C) Early Jurassic (Sinemurian) ammonite, locality 20 (Table 1). (D) Sinemurian bivalves, locality 21 (Table 1). (E-I) Strata at locality 17 include blue-gray–weathering, phosphatic, Jurassic sandstone (in E, F; dark clasts in F are phosphate) and tan–to orange-weathering Cretaceous limestone (in E) comprising two lithofacies: Buchia coquina of probable Valanginian age (in G, H; Table 1) and Hauterivian–Barremian beds rich in coarsely prismatic inoceramid shell fragments (in I; Table 1; cf. prism size here with that in Permian shells in Fig. 9I). (J, K) Albian (or younger) conglomerate (in J; loc. 3, Fig. 2) rich in clasts of radiolarian chert (rc) and heterolithic sandstone (in K; loc. 16) with abundant quartz (white grains) and sedimentary lithic clasts (brown grains).
and partly coeval succession in area E, and identify additional occurrences of correlative strata in area F (Figs. 2, 3). We also present detrital zircon evidence for the existence of siliciclastic strata of Albian or younger age that are in contact with rocks of the Farewell terrane in areas A and F.

Aptian and Older Strata

In the Medfra quadrangle (Figs. 2, 3), Lower Cretaceous rocks that depositionally overlie Triassic (to Jurassic?) strata comprise three subunits, each bounded by an unconformity (Patton et al., 1977, 1980). Sandy, fossiliferous limestone makes up the lowest subunit, which is 20 m thick. Fossils include belemnites and pelecypods (Buchia sublaevis, Buchia crassicollis) that indicate a Valanginian age. These rocks are overlain by 90 m of Hauterivian and Barremian siltstone, sandstone, and conglomerate that contain the belemnite Acroteuthis sp. as well as inoceramid bivalves. Coarser layers consist mostly of quartz, calcareous bioclasts, chert, and metamorphic lithic clasts in various proportions; bioclasts are mainly equant inoceramid shell prisms (100–140 µm thick). The uppermost subunit is 210 m of dark mudstone with sparse, rounded granules and pebbles of chert and rare cephalopods including Tropaeum sp. of Aptian age. Fauna and lithology indicate that the Lower Cretaceous succession accumulated in a deepening-upward marine environment.

Lower Cretaceous limestones approximately coeval with the lower two Cretaceous subunits in the Medfra quadrangle were found immediately above Lower Jurassic strata at locality 17 in the Lime Hills quadrangle (Figs. 4, 13E). The Mesozoic section here is highly condensed (<10 m thick), folded, and locally intruded by felsic dikes. Cretaceous rocks weather brown to tan and range from 5–30 cm thick (Figs. 13E, 13G). Two faunally distinct lithofacies are recognized (R. Blodgett, 2014, personal commun.; Table 1). The older is closely to moderately packed bivalve shell coquina of early Cretaceous (Berriasian–Valanginian, most likely Valanginian) age. It consists mainly of thin (0.7 mm to <100 µm thick) disarticulated valves and fragments of Buchia sp. with minor quartz silt and rare belemnite fragments in a matrix of argillaceous micrite (Figs. 13G, 13H). The younger is fine-grained limestone of middle Early Cretaceous (Hauterivian–Barremian) age made up chiefly of the prismatic elements of inoceramid bivalves, with rare larger shell fragments (Fig. 13I), a few belemnite rostrums, and locally abundant foraminifers, calcispheres, and radiolarians.

Several meters of Lower Cretaceous limestone, interbedded with chert and siltstone, overlie Lower Jurassic strata in area F (west-central Talkeetna quadrangle; Jones and Silberling, 1979; Reed and Nelson, 1980, their locs. 24 and 28; Table 1). Valanginian pelecypods (Buchia crassicollis solida; R. Imlay, 1975, personal commun.) are found in these rocks, which in thin section consist mostly of disaggregated inoceramid shell prisms, minor rounded to subangular monocrystalline quartz sand, rare mudstone clasts, and traces of other bioclasts including ostracodes and foraminifers.

Albian (or Younger?) Strata

Lithologies

Two sections of sedimentary rocks intimately associated with strata of the Mystic subterrane appear, on the basis of calculated minimum ages of detrital zircon populations, to be Albian (late Early Cretaceous) or younger. The first is in the Medfra quadrangle (loc. 3, Fig. 2) and consists of unfossiliferous siliciclastic strata overlying Devonian shallow-water carbonate rocks of the Nixon Fork subterrane. Patton et al. (1980) suggested a Cretaceous age for the siliciclastic section, but Andrews and Rishel (1982) considered it to be Permian because it is locally overlain by coquinite limestone bearing a diverse assemblage of Permian fossils. The siliciclastic rocks are fine-grained sandstone interbedded with pebbly sandstone and conglomerate with subangular to sub-rounded pebbles to 1 cm in diameter. Gray, black, and green chert makes up 40%–60% of clasts in both fine- and coarse-grained strata; many chert grains contain abundant radiolarians and/or siliceous sponge spicules (Fig. 13J). Subordinate clast types include monocrystalline quartz, brown mudstone, phyllite, quartz-mica schist, and plagioclase feldspar.

The second locality is in the Talkeetna quadrangle (loc. 16, Fig. 4). Here 5–10 m of micaceous sandstone, siltstone, and dark argillite with possible plant fragments and/or mud chips topographically underlie altered tuffaceous (?) and volcaniclastic rocks that we include in the Triassic–Jurassic mafic igneous rock unit discussed above. Sandstone is very fine to medium grained, poorly sorted, and heterogeneous, with grains of monocrystalline and polycrystalline quartz, plagioclase and potassium feldspar, white mica, biotite, and chlorite, as well as chert (some with radiolarians), and an array of other sedimentary, volcanic, metamorphic, and plutonic lithic clasts (Fig. 13K).

Detrital Zircon Data

Detrital zircon samples from both localities have youngest grain populations of ca. 105 Ma (late Albian; Fig. 11A) along with prominent Early Jurassic age populations at ca. 193 Ma and an array of Paleozoic and Precambrian grains. These spectra are similar to those from parts of the Cretaceous Kahiltna assemblage, which is an overlap succession exposed south and east of the southeastern margin of the Farewell terrane (Ridgway et al., 2002; Kalbas et al., 2007; Hults et al., 2013).

LIVENGOOD AND WHITE MOUNTAINS TERRANES

Middle Paleozoic siliciclastic rocks that are partly coeval with the lower part of the Mystic succession include the Devonian Cascaden Ridge unit in the Livengood terrane and the Mississippian (?) Globe unit in the White Mountains terrane (Fig. 1). New detrital zircon data from these units allow us to test
proposed linkages between Livengood-area strata and the Farewell terrane that were based on faunal and lithologic correlations (e.g., Blodgett et al., 2002; Dumoulin et al., 2014).

**Lithologies and Fossil Data**

The Cascaden Ridge unit (Weber et al., 1992) consists mainly of interbedded shale, siltstone, and graywacke, with subordinate polymictic conglomerate and limestone, and a locally recognized (Tweedrger et al., 2016) layer of peralkaline rhyolite. Cascaden Ridge limestone contains a diverse Middle Devonian biota of brachiopods, bryozoa, calcareous algae, conodonts, rugose and tabulate corals, echinoderms, gastropods, orthocoronic nautiloids, ostracodes, pelecypods, plant fragments, scaphopods, stromatoporoids, tentaculitids, and trilobites (Weber et al., 1994). Gastropods are most like those from coeval Farewell terrane units to the southwest and have Siberian paleogeographic affinities (Blodgett et al., 2002), but trilobites resemble species from the Canadian Arctic Islands (Weber et al., 1994). Conglomerate clasts include chert, mudstone, sandstone, and felsic to intermediate igneous rocks (Athey and Craw, 2004). Petrographic analysis of graywacke suggests a collision orogen source, with some local input from the underlying Ordovician Livengood Dome Chert (Gergen et al., 1988).

The Globe unit (Weber et al., 1992; Wilson et al., 2015) consists of gray, fine- to medium-grained, partly bimodal quartzite that is massive to thinly interbedded with slate, phyllite, or claystone and intruded by Triassic mafic igneous rocks. The unit is unfosiliferous and largely fault bounded; the Mississippian age is based on lithologic correlation with the Keno Hill quartzite in the Yukon Territory (Weber et al., 1992). As noted above, however, lower Paleozoic rocks in the White Mountains terrane have faunal features that suggest non-Laurentian affinities and argue against correlation of White Mountains terrane strata with coeval units in western Canada (e.g., Dumoulin et al., 2014).

**Detrital Zircon Data**

Our sample of the Cascaden Ridge unit (loc. CR, Fig. 1) is fine- to medium-grained sandstone with subequal amounts of carbonate clasts (including crinoid fragments), monocrystalline quartz, and chert. It has a prominent age population at 410 ± 4 Ma that indicates an Early Devonian maximum depositional age, along with a scattering of older Paleozoic and Proterozoic grains (sample 07ADw703A, Fig. 14). Our sample from the Globe unit (loc. G, Fig. 1) is fine grained and made up of ~80%–90% subangular to rounded grains of monocrystalline quartz and minor amounts of chert, sedimentary lithic clasts, and tourmaline. The detrital zircon spectrum (sample 07ADw702A, Fig. 14) is somewhat similar to that from the Cascaden Ridge unit, with a nearly coeval Early Devonian maximum depositional age (408 ± 5 Ma) but a considerably smaller proportion of Devonian grains.

The MDS plot in Figure 14C shows that the Globe and Cascaden Ridge samples are distinct from one another despite the overlap in the youngest age populations. The Globe quartzite sample is most similar to the Sheep Creek Formation composite data set (SC comp in Fig. 14C) and other strata that cluster in the same region of the plot. The Cascaden Ridge sample plots closer to the composite data set for our “lower Mystic assemblage” (LM comp in Fig. 14C) and has the strongest similarity to the composite data set for Upper Triassic strata described above (UTr comp in Fig. 14C). The MDS plot shows that the detrital zircon spectra for the Globe unit and the Keno Hill quartzite of Beranek et al. (2010) cluster closer together relative to other samples and sample composites, but the PDP cross-correlation coefficient of 0.17 suggests a low degree of similarity (Table S3 [footnote 1]). Faunal features of strata associated with the Globe unit and Keno Hill quartzite suggest different regions of origin for these two units, and comparison of their detrital zircon age spectra is consistent with this interpretation.

**CORRELATIONS AND POTENTIAL CLASTIC SOURCES WITHIN THE FAREWELL TERRANE**

Devonian and younger strata discussed above have similarities and differences with coeval rocks elsewhere in the Farewell terrane that illuminate the overall evolution and history of this crustal fragment. Petrographic and detrital zircon data indicate that Paleozoic and Mesozoic clastic strata of the Mystic subterrane were likely derived at least in part—though not exclusively—from erosion of older parts of the Farewell terrane.

**Devonian Strata**

Lithofacies like the bedded barite, concretion-bearing black shale, and phosphatic chert described above have not been reported from correlatives but above in other parts of the Mystic subterrane. At least four small barite occurrences have been found in the central Lime Hills quadrangle (area D, Fig. 2); like the Gagaryah deposit described above, they may have formed as sedimentary-exhalative deposits (Bundtzen et al., 1994). However, occurrences in the central Lime Hills quadrangle are a few meters or less thick and consist chiefly of massive beds, lesser veins, breccias, and nodules that are hosted by carbonate rocks of the Barren Ridge Limestone (uppermost unit of the Dillinger subterrane; likely Early Devonian age). The central Lime Hills quadrangle barites are thus smaller and older (if they are indeed syngenetic) than the Gagaryah deposit, and are not associated with organic-rich black shale.

Fossil data suggest that strata equivalent to Devonian coral-bearing shale in the southern Mystic subterrane may also occur to the north. Corals found in float near Permian strata in the Medfra quadrangle (Table 1) are coeval with corals found as concretions in black shale in the McGrath quadrangle, but the depositional position of the Medfra corals is uncertain (W. Patton, 1999,
personal commun.). The Medfra form (*Sociophyllum* sp. cf. *S. glomerulatum*) is of Givetian (late Middle Devonian) age and compares most closely with a species found in northern Laurentia (Northwest Territories, Canada). The Medfra corals could have come from clasts in Permian conglomerate, or from concretions in a poorly exposed (shaly?) interval below the Permian strata. If the latter interpretation is correct, their depositional setting could be analogous to that of redeposited Middle Devonian corals in the McGrath quadrangle. Additional study of field relations is needed to understand the significance of the Medfra Givetian corals.

**Upper Sheep Creek Formation**

Siliciclastic turbidites that compose the upper part of the Sheep Creek Formation differ from turbidites of the underlying Dillinger subterrane in overall lithologic sequence and petrography. Carbonate interbeds are generally rare or absent in Sheep Creek turbidite sections, in contrast to the Devonian Barren Ridge Limestone, which is dominantly a carbonate unit, and the Silurian Terra Cotta Mountains Sandstone, which contains abundant interbeds of pure limestone (e.g., calcareous radiolarite) and calcareous sandstone and conglomerates.
made up chiefly of carbonate clasts (e.g., Bundtzen et al., 1997). The Sheep Creek has plant debris not found in the Dillinger units and locally abundant late Paleozoic fossils. Lastly, Sheep Creek sandstones typically contain more chert clasts and less mica and metamorphic lithic clasts than do the Silurian–Devonian Dillinger turbidites. Petrography of Sheep Creek turbidites also differs from that of the partly coeval “Mystic assemblage” of Malkowski and Hampton (2014), which contains abundant mafic volcanic clasts.

Comparison of detrital zircon spectra of our Sheep Creek Formation samples with composite plots for Silurian–Devonian Dillinger subterrane turbidites (Barren Ridge Limestone and Terra Cotta Mountains Sandstone) shows strong similarity between the three units (Fig. 15). The MDS plot in Figure 16 shows that the three composite data sets cluster together, with the Sheep Creek (SC) and Barren Ridge (BR) points essentially overlapping. Quantitative metrics for comparison of the three composite data sets also indicate strong similarity, with PDP cross-correlation coefficients of 0.76 for the comparisons (Table S3 [footnote 1]; Saylor and Sundell, 2016). Many Sheep Creek turbidite sections lack precise age control, and our detrital zircon results are consistent with the interpretation that much of this lithofacies is of Devonian age and contains a detrital zircon population largely to entirely derived through recycling of underlying Dillinger strata. However, even our samples from beds bearing late Paleozoic fossils (locs. 4 and 5, Fig. 4) contained only two grains of late Paleozoic age (ca. 258 and 300 Ma in sample 11AD3A; Fig. 7). Our findings thus suggest that although the Sheep Creek Formation and the Mystic assemblage may be at least partly coeval, the source(s) of late Paleozoic zircons and volcanic clasts that supplied Mystic assemblage turbidites did not obviously contribute sediment to the Sheep Creek Formation.

Other Upper Paleozoic Strata

Our findings, combined with those of Malkowski and Hampton (2014), indicate that at least five upper Paleozoic lithofacies can be distinguished in the Mystic subterrane on the basis of petrography and detrital zircon age spectra (Table 3). The first, described above, is the upper Paleozoic part of the Sheep Creek Formation, which generally lacks volcanic clasts and detrital zircon age populations younger than Devonian. The second is typified by our three samples from map unit Pzus (Reed and Nelson, 1980), which contain notable volcanic lithic clasts and Mississippian detrital zircons. Despite some subtle variation in detrital zircon age populations between our three samples, the composite detrital zircon age spectrum (denoted by Pzus in Fig. 15) compares favorably with the composite spectrum from the “lower Mystic assemblage” of Malkowski and Hampton (2014) (Fig. 15). The composites also cluster together on the MDS plot in Figure 16 (LM and LMA, respectively) and have a PDP cross-correlation coefficient of 0.60 (Table S3 [footnote 1]). Thus, we provisionally include all five samples in the “lower Mystic assemblage.”

The lower Permian Mount Dall conglomerate has a detrital zircon spectrum quite similar to that of the “lower Mystic assemblage” (Figs. 15, 16) but...
Figure 16. Non-metric multi-dimensional scaling (MDS) plots after Vermeesch (2013) of detrital zircon samples from our study compared with those from other areas of Alaska and western Canada. See text for explanation of samples. Short sample labels are explained in the table to the right. Solid line denotes nearest neighbor in dissimilarity space; dashed line denotes next-nearest neighbor; stress value is indicated by “S” (Vermeesch, 2013). References for data to the right. Solid line denotes nearest neighbor in dissimilarity space; dashed line denotes next-nearest neighbor; stress value is indicated by “S” (Vermeesch, 2013). References for data shown on the plot are given in text; Medfra indicates samples from the Medfra 1:250,000-scale quadrangle; MH denotes Mystic assemblage (ass.) data of Malkowski and Hampton (2014).

... differs from these strata in composition and depositional setting. Chert clasts are abundant in both successions, but volcanic detritus is rare in the Mount Dall. Carbonate clasts are more numerous in the Mount Dall and include a distinctive component of Carboniferous crinoidal-bryoan limestone. Dillinger subterrane units are a plausible source for the chert and deep-water carbonate clasts that predominate in the Mount Dall (Bradley et al., 2003). Other detritus may be derived from unit Pzus, such as the Devonian limestone clasts ascribed to this source by Reed and Nelson (1980). Younger carbonate layers in unit Pzus (e.g., loc. 7, Table 1) are a possible source for the Carboniferous crinoidal limestone boulders, whose large size implies a nearby provenance. The limestones in both the layers and the boulders have similar faunas and likely formed as well-winnowed lag deposits. Distinctive pebbles of phosphatic radiolarian chert in the Mount Dall are texturally identical to the "blackball" chert in unit Pzus (Reed and Nelson, 1980).

The “upper Mystic assemblage” of Malkowski and Hampton (2014) includes two samples. One sample from unit Pzus has a volcanic clast-rich composition that is similar to that of their “lower Mystic assemblage.” The other sample (FSC-02 of Malkowski and Hampton, 2014) comes from rocks mapped by Bundtzen et al. (1997) as Sheep Creek Formation in the central McGrath quadrangle (Fig. 4). The sample consists of fine- to medium-grained sandstone for which no petrographic details are available (B. Hampton, 2014, personal commun.). It was taken 12 m below the top of a 180-m-thick measured section made up mostly of rhythmically interbedded siltstone and fine-grained sandstone in tabular beds 2–15 cm thick, intercalated with bedded chert, siliceous to tuffaceous mudstone, tuff, and mafic volcanic rocks in layers 20 cm to 15 m thick (Malkowski, 2010). Beds of chert and volcanic rocks do not occur in any of the Sheep Creek sections we studied and are not mentioned in the definition of the formation by Bundtzen et al. (1997). The two samples grouped in the “upper Mystic assemblage” by Malkowski and Hampton (2014) yielded a bimodal Paleozoic age distribution with prominent Silurian and Permian age populations. The composite age spectrum is shown in Figure 15, and it is notably different from other spectra described so far. If youngest detrital zircon age populations from “Mystic assemblage” samples represent depositional ages, then the succession was deposited in at least two pulses during Carboniferous to Permian time. If so, only the younger Permian pulse appears to have reached the McGrath quadrangle. The MDS plot in Figure 16 shows that the upper Mystic assemblage (UMA) is more similar to other Permian successions than to the lower Mystic assemblage, suggesting the presence of diverse sediment sources during the late Paleozoic within the Mystic subterrane.

Both petrographic and detrital zircon data from Permian strata in the Medfra quadrangle differ from those of upper Paleozoic strata in the Mystic assemblage. The Permian age population of the Medfra sample is considerably younger than those of the two upper Mystic assemblage samples of Malkowski and Hampton (2014). Abundant metamorphic lithic clasts and micas in the Medfra strata—absent from the Mystic assemblage—could have been derived from the metamorphic basement of the Nixon Fork subterrane that locally underlies the Permian rocks (Patton et al., 1980). Neoproterozoic age populations in the detrital zircon age spectra from both Medfra samples could reflect input from Nixon Fork basement rocks and/or Neoproterozoic siliciclastic strata like those at the base of the Nixon Fork succession at Lone Mountain (Figs. 2, 15; Bradley et al., 2014). Clasts in the limestone conglomerate resemble various parts of the Nixon Fork carbonates; clasts of peloidal grainstone with abundant quartz andfeldspar silt correspond particularly well to a common lithofacies of the Ordovician Novi Mountain Formation (Dumoulin et al., 2002).

Limy beds in the Medfra quadrangle Permian section contain a fauna of brachiopods, bryoanoids, pelecypods, corals, trilobites, and echinoderms that is grossly comparable to that of coeval or slightly older rocks at White Mountain (area C, Figs. 2, 3; J.T. Dutro, 1982, personal commun.; Hahn et al., 1985; Hahn and Hahn, 1985) and Lime Lakes (area D, Figs. 2, 3; J.T. Dutro, 1982, 1983, personal commun.; C. Stevens, 1985, 2016, personal commun.; Hahn and Hahn, 1985). A detailed comparison of the faunas from these three localities, and an analysis of their biogeographic implications, would be very useful.

**Triassic Conglomerate**

D detrital zircon, fossil, and petrographic data suggest that carbonate- and chert-clast conglomerate in the east-central and southeastern McGrath quadrangle was derived in part from older rocks of the Farewell terrane. Detrital zircon spectra are generally similar to those from the Sheep Creek Formation,
Barren Ridge Limestone, and Terra Cotta Mountains Sandstone (Fig. 15), and the MDS plot shows spatial clustering of the composite data sets for all of these units (Fig. 16). Lime mudstone is a common lithology in both the Barren Ridge Limestone and Terra Cotta Mountains Sandstone, and a subordinated part of the underlying Post River Formation. Conodont ages from the composite sample at locality 12 (Table 1) are consistent with a Dillinger subterrane source. Chert (including radiolarian chert) is present in Dillinger units and in Devonian strata of the Mystic subterrane. Although Triassic zircons could conceivably have been derived from Triassic igneous rocks of the Mystic subterrane, the predominantly mafic composition of these rocks suggests that a source outside the Farewell terrane is more likely; possible sources are discussed below.

Upper Triassic strata in the Medfra quadrangle (area A) include intervals of carbonate-clast conglomerate and intraclastic breccia (Patton et al., 1980; Silberling et al., 1997) that have some similarities to the McGrath quadrangle conglomerates of presumed Triassic age. Clasts in the Medfra samples that we examined are mostly fine-grained carbonate, and many are dolomitic and/or phosphatic. Less-common coarser-grained lithologies include peloid and ooid-bioclast grainstones that are strikingly similar to, and may have been derived from, lower Paleozoic limestones of the Nixon Fork subterrane. Non-carbonate clasts include monocrystalline quartz, chert, and dark brown mudstone. The presence of dolomitic and phosphatic clasts in the Medfra section provides an intriguing compositional link with the McGrath conglomerate at locality 13 (Fig. 4).

**Jurassic and Cretaceous Strata**

Lower Jurassic sections in areas E and F sampled for this study are mainly quartz-carbonate sandstone and sandy fossiliferous limestone. Partly (?) coeval rocks elsewhere in the Mystic subterrane are fine-grained siliceous strata that gradationally overlie Upper Triassic carbonate successions in the Medfra and Taylor Mountains quadrangles, and overlie Triassic mafic igneous rocks in the central Lime Hills quadrangle (areas A–C, Figs. 2, 3; Patton et al., 1980; Reed et al., 1985; Silberling et al., 1997; LePain et al., 2000; Karl et al., 2011). Radiolarian and spiculitic chert is the main lithology in all three areas, interbedded with siltstone, sandstone, and—in the Lime Hills section—tuff. Early Jurassic belemnoid cephalopods and bivalves occur in the Taylor Mountains strata (McRoberts and Blodgett, 2002; Karl et al., 2011), and Pliensbachian (middle Early Jurassic) radiolarians are found in the central Lime Hills quadrangle (Reed et al., 1985). Lithofacies and faunas of the Jurassic sections in areas A–C indicate a deeper-water setting than correlative rocks in areas E and F, but phosphate nodules reported from area B (Karl et al., 2011) provide a link with phosphate occurrences in areas E and F.

Cretaceous strata have not been identified within the Farewell terrane outside of the strata discussed above in areas A, E, and F. These rocks have potential correlative effects in other parts of Alaska that are discussed below.

**Correlations and Potential Clastic Sources Outside the Farewell Terrane**

Detrital zircon and petrographic data imply that sources outside the Farewell terrane must have contributed detritus to most of the Mystic subterrane units described above. In particular, sources are needed for zircons of Late Devonian, Carboniferous, Permian, Late Triassic, and Early Jurassic age. MALKOWSKI and HAMPTON (2014) proposed that during Carboniferous–Early Permian time, the Farewell terrane was situated in the Panthalassic Ocean, along the western margin of the Slide Mountain Ocean (Fig. 17B), receiving material from arc and recycled orogen sources of the Alexander and Wrangellia insular terranes. In their reconstruction, and those of Nelson et al. (2013) and Beranek et al. (2014), the Yukon-Tanana and related peri-Laurentian terranes are also positioned along the western margin of the Slide Mountain Ocean at this time. In this section, we summarize potential magmatic sources in insular and peri-Laurentian terranes, as well as oceanic terranes to the west, that could have contributed detrital zircons to Mystic units. We also consider potential correlations between the uppermost part of the Farewell terrane and the Kahiltna assemblage, and between Farewell and the White Mountains and Livengood terranes.

**Alexander-Wrangellia-Peninsular Composite Terrane**

The Alexander terrane in southeastern Alaska and western Canada (Fig. 1) is a Neoproterozoic–Jurassic crustal fragment made up of the Craig, Admiralty, and northern Alexander subterranes (Nelson et al., 2013; Beranek et al., 2014). Wrangellia extends from southcentral Alaska (Fig. 1) and the Yukon to at least Vancouver Island (Canada) and is characterized by Triassic flood basalts (Jones et al., 1977). The Peninsular terrane (Fig. 1) underlies the Alaskan Peninsula and consists chiefly of Triassic–Jurassic magmatic rocks (e.g., Rioux et al., 2010). Both Wrangellia and the Peninsular terrane have Paleozoic basement complexes that include late Paleozoic igneous rocks (Beranek et al., 2014). Beranek et al. (2014) proposed that assembly of the Alexander-Wrangellia-Peninsular composite terrane began in the Middle–Late Pennsylvanian and was completed by the early–middle Permian.

Silurian–Middle Devonian faunas in the Craig subterrane have some similarities to those of Farewell (e.g., Blodgett et al., 2002; although cf. Antoshkina and Soja, 2016), and detrital zircon spectra from lower Paleozoic rocks in the two areas are also similar (Dumoulin et al., 2018b). Silurian–Lower Devonian turbidites in the Dillinger subterrane of Farewell contain abundant Silurian and Early Devonian detrital zircons that have no known local (within Farewell) source but that may have been derived from the Alexander terrane and/or from a common Caledonide source (Dumoulin et al., 2018b), suggesting relative proximity of the two terranes during the early Paleozoic. Recent work suggests that this proximity may have continued into (or recurred during) the late Paleozoic. Malkowski and Hampton (2014) argued that...
Detrital zircon U-Pb and Hf isotope analyses from their Mystic assemblage matched most closely with magmatic source areas of the Alexander terrane and Wrangellia. Igneous rocks of Late Devonian, Mississippian, and Early–Middle Pennsylvanian age, summarized by Beranek et al. (2014), are found mainly in Wrangellia, although Late Devonian gabbro (363 Ma) occurs in the northern Alexander, and Tochilin et al. (2014) reported an orthogneiss of latest Devonian age (359 Ma) in their Banks Island assemblage, which may be part of the Alexander terrane. Plutonic suites of Late Pennsylvanian–Permian age are documented in both Wrangellia and Alexander: the Skolai arc and related rocks (320–285 Ma) in the former (Malkowski and Hampton, 2014), and the Barnard Glacier suite (307–301 Ma) and Donjek Glacier suite (291–284 Ma) in the northern Alexander terrane (Beranek et al., 2014).

As noted above, Mesozoic igneous rocks are widespread in the Alexander-Wrangellia-Peninsular composite terrane. Triassic flood basalts in Wrangellia (middle Ladinian to Norian; ca. 239–225 Ma) are partly coeval with Norian rifting in the Alexander terrane (Nelson et al., 2013). A magmatic arc of Late Triassic–Middle Jurassic age was then established in southern Wrangellia, roughly correlative with the ca. 212–153 Ma Talkeetna arc in the Peninsular terrane (Rioux et al., 2010; Nelson et al., 2013).

Detrital zircon data from upper Paleozoic–Triassic strata of the Alexander terrane may be compared with Mystic subterrane age spectra (Figs. 15, 16). Pebbly sandstone from the Permian Halleck Formation in southern Alexander (Craig subterrane) and possibly coeval metasedimentary rocks from the Banks Island assemblage (Tochilin et al., 2014) yielded age spectra (Fig. 15).
with similarities to those from the upper Mystic assemblage (Maikowski and Hampton, 2014) and the Mount Dall conglomerate (Fig. 16). Early Permian, Late Devonian (Famennian), and Silurian detrital zircon age populations occur in the Halleck spectra, and Late Pennsylvanian, Famennian, and Early Devonian age peaks occur in the Permian (?) Banks Island composite spectrum (Fig. 15). Spectra reported from other upper Paleozoic–Triassic rocks in the Alexander terrane are less similar to those of coeval Farewell samples. Unpublished data from five samples of the uppermost Cannery Formation (Upper Devonian–Permian) in the Admiralty subterrane yielded a single age cluster ranging from 350 to 300 Ma and no older grains (Ward et al., 2014). The Triassic Nehenta Formation produced a single peak age of Early Devonian (417 Ma) and no other grains (Fig. 15; Tochilin et al., 2014). Unpublished data from two samples of the Triassic Burnt Island Conglomerate yielded a 220–250 Ma population with older grains ranging from 295 to 370 Ma (Ward et al., 2014).

Yukon-Tanana Terrane

The Yukon-Tanana terrane of east-central Alaska (Fig. 1) includes overlapping arc successions of Late Devonian to middle Permian age, which developed above a pre-Devonian metasedimentary basement of probable western Laurentian affinity (Colpron et al., 2015). Two main pulses of felsic magmatism at 365–330 Ma and 264–252 Ma are documented (Nelson et al., 2006; Beranek and Mortensen, 2011), and the terrane was intruded by Late Triassic–Early Jurassic plutons (ca. 220–178 Ma; Colpron et al., 2015). These igneous ages overlap the ages of Late Devonian–Jurassic detrital zircons in many of the Mystic subterrane units discussed above.

Tikchik-Togiak Terranes

The Tikchik and Togiak terranes of southwestern Alaska (Decker et al., 1994) are potential sources of detrital zircons of Late Devonian, Carboniferous, Permian, Late Triassic, and Early Jurassic age, although rocks composing these terranes have only been mapped and studied at a reconnaissance level. An arc volcanic sequence in the Tikchik terrane has interbedded carbonates that yielded Late Devonian–Early Mississippian conodonts (Box et al., 1993). A dacite from higher in that sequence yielded an unpublished U-Pb zircon age of ca. 318 Ma (Carboniferous) with an oceanic neodymium isotopic composition (Box et al., 2015b). This arc is interpreted to have collided with the present southwestern edge of the Farewell terrane in Pennsylvanian–Early Permian time, and much of the Tikchik terrane is composed of a structural complex of boudinaged rocks that include sandstones with Silurian and older detrital zircon signatures (Box et al., 2007; Kari et al., 2007) similar to those from strata of the Dillinger subterrane of the Farewell terrane (Dumoulin et al., 2014b). Permian detrital zircons are abundant in Permian and Triassic post-collisional basin strata that form part of the Tikchik terrane. Late Triassic and Early Jurassic arc volcanic and plutonic rocks occur in the Togiak terrane, interpreted to depositionally overlie the Tikchik terrane, and Triassic and Jurassic detrital zircons occur in Upper Triassic and Lower Jurassic strata of that overlapping terrane.

Kahiltna Assemblage

Aptian and older Cretaceous strata in the Farewell terrane are at least partly coeval with the older portion of the Kahiltna assemblage (Ridgway et al., 2002), which is exposed along the southern margin of the Farewell terrane throughout the central and western Alaska Range. Parts of the Kahiltna and correlative strata contain sparse fossils of Late Jurassic–early Cretaceous (Kimmeridgian to Valanginian) age (Wallace et al., 1989; Ridgway et al., 2002) and yield youngest detrital zircon age populations ranging from Late Jurassic to early Late Cretaceous (Kalbas et al., 2007; Hampton et al., 2010; Hults et al., 2013). The Kahiltna consists mainly of siliciclastic flysch; limestone is rare and found by Kalbas et al. (2007) only north of the Denali fault in the northwestern Talkeetna quadrangle, chiefly near the base of their section EF1, where graded fossil hash grainstone, fossiliferous siltstone, and micrite contain belemnites and inoceramid bivalves. Blodgett and Clautice (2000) documented similar lenses of shell-rich Valangian limestone in the Kahiltna in the Healy quadrangle to the northeast. Valanginian limestones of the Mystic subterrane resemble the shelly limestones in the Kahiltna, but are not interbedded with siliciclastic turbidites.

Hauterivian–Barremian inoceramid limestone in the Lime Hills quadrangle may be coeval with Kahiltna assemblage strata in the McGrath A-2 1:63,360-scale quadrangle (southeastern part of the McGrath 1:250,000-scale quadrangle) that contain Inoceramus sp. of possible Hauterivian age (Bundtzen et al., 1987, their fossil loc. 32). Lime Hills inoceramid limestone is faunally and lithologically similar to coeval units in the Peninsular terrane such as the Nelchina Limestone and the Herendeen Formation (e.g., Nokleberg et al., 1994). Rocks of this age in the Medfra quadrangle are richer in siliciclastics than the Lime Hills strata, but limier than most of the Kahiltna. No lithologic and faunal match for the Aptian mudstone unit in the Medfra quadrangle has been identified in adjacent Alaskan terranes.

As noted above, the Albian or younger strata found within the Farewell terrane at localities 3 (Fig. 2) and 16 (Fig. 4) are lithologically similar to part of the Kahiltna assemblage, and may represent outliers of that unit or related rocks. The petrographic composition and detrital zircon spectra of sandstone at both Farewell localities match well with those of Kahiltna strata from the north side of the basin that were largely derived from older, northern source terranes such as Farewell and Yukon-Tanana (Hults et al., 2013; Karl et al., 2013). Siliciclastic flysch of the Cretaceous Kuskokwim Group, which is broadly similar to and partly correlative with the Kahiltna assemblage, crops out along the northwestern boundary of the Farewell terrane in the Medfra quadrangle (Wilson et al., 2015). No detailed petrographic or detrital zircon data have been published.
Research Paper

from the Kuskokwim in this area, but it is reasonable to assume that the Albion or younger rocks at locality 3 (Fig. 2) may be a fault sliver of this unit.

Livengood and White Mountains Terranes

Detrital zircon data from mid-Paleozoic strata in the Livengood and White Mountains terranes have similarities with spectra from coeval (and younger?) rocks in the Mystic subterrane and argue against a previously proposed correlation with rocks in the Yukon. Spectra from the Cascade Ridge and Globe units have similar detrital zircon age populations despite the much greater number of Early Devonian grains in the Cascade Ridge. Spectra from these two samples also have some similarities with many of our Mystic subterrane spectra (Fig. 15). The MDS plot in Figure 16 shows that the Globe unit is more similar to the composite Sheep Creek Formation data set (and most similar to the Terra Cotta Mountains Sandstone data set), whereas the Cascade Ridge sample is more similar to the Mystic assemblage data sets described above. The Cascade Ridge sample is most similar to the Upper Triassic composite data set (Fig. 16), reflecting similarly high proportions of Early Devonian– and Silurian-age grains in both spectra. Comparative detrital zircon data (Table S3 [footnote 1]) from the Globe unit and the Keno Hill quartzite in the Yukon (Beranek et al., 2010) argue against the proposed correlation of these two units by Weber et al. (1992), as do faunal data that suggest a non-Laurentian origin for lower Paleozoic strata of the White Mountains terrane (Dumoulin et al., 2014).

Upper Paleozoic and lower Mesozoic rocks in the Livengood and White Mountains terranes are limited in extent, but several units could profitably be targeted for future research to clarify the affinities of these terranes. Permian rocks in the Livengood terrane (map unit Ps of Weber et al., 1992, 1994) include sandstone and quartz and chert granule to pebble conglomerate that contain brachiopods, foraminifers, and conodonts; detrital zircon data and detailed faunal analyses from these strata would be very useful. Geochemistry of Late Triassic (Carnian?) mafic igneous rocks (map unit Trm of Weber et al., 1992) that intrude the Globe unit could be compared to that of Triassic–Jurassic mafic igneous rocks in Farewell.

IMPLICATIONS FOR TECTONIC EVOLUTION OF THE FARpwell TERRANE

U-Pb zircon, fossil, and lithofacies data suggest that the Farewell, Arctic Alaska-Chukotka, and Alexander terranes had a shared early Paleozoic history in a paleo-Arctic setting (Blodgett et al., 2002; Dumoulin et al., 2002, 2014, 2015b; Nelson et al., 2013). By the Devonian, connections between the three terranes had weakened and their histories diverge. In the tectonic scenario of Nelson et al. (2013), Farewell remained near Siberia at a latitude of ~60° during middle through late Paleozone time, whereas Arctic Alaska-Chukotka adjoined northern Laurentia and the Alexander terrane moved from the paleo-Arctic into the paleo-Pacific. Recent studies (Beranek et al., 2014; Malzkowski and Hampton, 2014) have proposed that Farewell was proximal to the Alexander-Wrangellia-Peninsular composite terrane by the late Paleozoic. Our new data from Mystic subterrane strata illuminate the Devonian through Mesozoic evolution of the Farewell terrane, suggest connections with other Alaskan terranes, and raise questions for further research.

Devonian

Devonian rocks in the Mystic subterrane include shallow-water carbonate and siliciclastie strata and a variety of deep-water lithologies (Fig. 3). Fossiliferous limestones of Early to Middle Devonian age that overlie deep-water rocks of the Dillinger subterrane in areas D–F are coeval with, and likely depositional or tectonic outliers of, the youngest part of the Nixon Fork platform. Post–MidDevonian shallow-water carbonate rocks in the Farewell terrane are limited in spatial and temporal extent (Fig. 3). If they were ever part of a carbonate platform comparable in size to the Nixon Fork platform, most of this edifice has been removed by erosion. Alternatively, their widely dispersed distribution is consistent with deposition on a series of islands that were only periodically within the photic zone and habitable by neritic fauna.

Shallow-water fossiliferous limestone of Frasnian age is the thickest (up to 500 m; Bundtzen et al., 1994) and most widespread (areas C, D, and F, Figs. 2, 3) Mystic carbonate unit. It contains a diverse biota that includes corals, brachiopods, pelecypods, and gastropods, as well as algae and foraminifers, most similar to coeval biotas from western Canada (Alberta) and Eurasia (Russian platform and the Urals; Mamet and Plafker, 1982; Bundtzen et al., 1994, 1997). Faunal and lithologic data suggest a very shallow, open marine environment with local patch reefs (Mamet and Plafker, 1982).

Mystic siliciclastie strata known to be Devonian are scarce. An interval ~100 m thick of siltstone and shale in area E contains a Frasnian fauna and flora suggestive of a shallow-water, nearshore setting (Blodgett and Gilbert, 1992). Turbidites of the Sheep Creek Formation (areas D, E) could be, in part, of Frasnian or Famennian age (based on constraints from underlying strata), but they have produced no Devonian fossils. Thick, Lower Devonian arkose redbeds like those typical of the Alexander terrane (Gehrels and Saleeby, 1987; Bazard et al., 1995; Soja and White, 2016) and extensive Upper Devonian quartz-rich fluvial strata like those widespread in Arctic Alaska (e.g., Moore and Nilsen, 1984) have no equivalents in the Farewell terrane.

The most distinctive Devonian lithofacies in the Mystic subterrane are deep-water strata (barite and black shale, calcareous radiolarite, chert with phosphorite nodules) in areas E and F. These lithologies typically form in highly productive oceanographic environments such as coastal zones with upwelling currents—for example, in Carboniferous strata that host the Red Dog deposit in Arctic Alaska (Dumoulin et al., 2004). Barite or phosphorite deposits of Late Devonian age are unknown in any other Alaskan terrane. They are ~25–35 m.y.
older than Middle Mississippian phosphorites in Arctic Alaska (Dumoulin et al., 2004, 2011). Barite deposits similar to and approximately coeval with the Gagaryah deposit have been found in the Selwyn Basin of western Laurentia (Goodfellow and Jonasson, 1984).

Thus, available paleontologic and lithologic data provide no clear links between Farewell and other Alaskan terranes during the Late Devonian. Paleozoic faunal similarities between Farewell and Alexander are not documented for Farewell on the southern (Laurentian) side of the Uralian Sea is more consistent with these constraints than is the more northerly location, adjacent to Siberia, that was previously proposed (e.g., Nelson et al., 2013; Antoshkina and Soja, 2016) (Fig. 17A). Our preferred position for the Farewell terrane is also in agreement with faunal and lithologic data that indicate ties to Arctic Alaska and Alexander during early Paleozoic time.

Carboniferous–Permian

Early Permian (284–285 Ma) metamorphic ages in northern Farewell have been interpreted as dating a collisional event—the Browns Fork orogeny—between Farewell and an unknown object (Bradley et al., 2003). Possible collisional “objects” include the Innoko terrane northwest of Farewell (Bradley et al., 2003) and an arc in the Tichik terrane southwest of Farewell (Box et al., 2015b) (Fig. 1). Alexander and/or Wrangellia may also (or alternatively) have been involved in this collision (Beranek et al., 2014; Małkowski and Hampton, 2014). Mystic rocks of late Paleozoic age are chiefly siliciclastic strata (Fig. 3), and U-Pb detrital zircon data from these rocks suggest connections with several Alaskan terranes during late Paleozoic time. These data shed new light on which sedimentary strata in the Farewell terrane may have accumulated during the Browns Fork orogeny, but raise additional questions as well.

Our data from upper Paleozoic units of southern Farewell are consistent with those of Małkowski and Hampton (2014) in implicating the Alexander-Wrangellia-Peninsular composite terrane as a potential source of detritus for some Mystic units and as a possible causative collisional agent for the Browns Fork orogeny. In particular, Late Devonian, Carboniferous, and early Permian detrital zircons that are found in parts of the Sheep Creek Formation, the Mystic assemblage, and the Mount Dall conglomerate, as well as the abundant mafic volcanic clasts in the Mystic assemblage, may have this provenance. Igneous rocks of the Yukon-Tanana terrane are an alternate source for Late Devonian and Mississippian zircons but not for the Pennsylvanian–early Permian zircons found in the upper Mystic assemblage (Małkowski and Hampton, 2014) and the Mount Dall (Fig. 8). The Tichik terrane (Box et al., 2015b) could also have supplied Late Devonian, Carboniferous, and early Permian detrital zircons. Early Paleozoic and Proterozoic zircons in the southern Farewell units could be derived from older parts of the Alexander terrane, or could be reworked from older parts of Farewell (e.g., Dillertertert subterrane). Matches between Dillertert lithofacies and specific Mystic clast lithologies described above support the latter conclusion. Virtually all of the Sheep Creek could have had such a recycled Dillertert provenance. The data outlined above support a late Paleozoic position for the Farewell terrane proximal to parts of the Alexander and Wrangellia terranes, as suggested by Małkowski and Hampton (2014), rather than a locality along the Siberian margin, as proposed by Nelson et al. (2013) (Fig. 17B).

But the early late Permian (ca. 256 Ma) peak age of detrital zircons in rocks of the Medfra quadrangle (Fig. 8) is younger by >25 m.y. than peak zircon ages of the upper Mystic assemblage (ca. 282–298 Ma; Małkowski and Hampton, 2014), metamorphic ages in northern Farewell (284–285 Ma; Bradley et al., 2003), and the latest documented ages of Permian igneous activity in Alexander and Wrangellia (ca. 284–285 Ma; Beranek et al., 2014). This implies that Permian strata in northern Farewell were not deposited as part of the Browns Fork orogeny and that their middle to late Permian zircons were not derived from Alexander or Wrangellia. The Medfra peak zircon age coincides instead with the 264–252 Ma pulse of magmatism in the Yukon-Tanana terrane (Nelson et al., 2006). Abundant Late Devonian detrital zircons in both of our Medfra samples (Fig. 8) could also have been sourced by Yukon-Tanana. Parts of the Tichik terrane (Box et al., 2015b) contain detrital zircons of ca. 260–255 Ma, but the depositional age of these strata (at least latest Permian and younger; S.E. Box, unpublished data) suggest that they may be too young to have been a source for the middle to early late Permian Medfra rocks.

As noted above, recent paleogeographic reconstructions (Nelson et al., 2013; Beranek et al., 2014) have positioned both insular terranes (Alexander, Wrangellia) and peri-Laurentian terranes (Yukon-Tanana) along the western margin of the Slide Mountain Ocean during late Paleozoic time. If, as proposed by Małkowski and Hampton (2014), Farewell was near (colliding with?) the insular terranes by the early Permian, subsequent (middle to late Permian) interaction between Farewell and Yukon-Tanana is possible.

Questions remain concerning Farewell’s late Paleozoic sedimentary record and history. How much of unit Pzus (Mystic assemblage)—and the Sheep Creek Formation—accumulated in the early Carboniferous? Youngest zircon age populations in the lower Mystic assemblage (Fig. 8) are consistent with a Mississippian to Early Pennsylvanian depositional age, which in turn might suggest proximity of Farewell to Alexander and/or Wrangellia (or Yukon-Tanana?) during early to middle Carboniferous time. Alternatively, if the lower Mystic and much of the Sheep Creek were deposited along with the upper Mystic and Mount Dall conglomerate as part of the Browns Fork orogeny, then a variety of sediment sources with several different detrital zircon profiles were being eroded during this orogeny. Unit Pzus was thought (Reed and Nelson, 1980) to depositionally underlie the Mount Dall, but detrital zircon data (Małkowski and Hampton, 2014; Figs. 3, 8) suggest that the two units
are at least partly coeval. Further study may reveal why their detrital zircon spectra are similar (Fig. 8) but their clast compositions are not.

Upper Paleozoic carbonate strata occur in areas A and C–F (Figs. 2, 3) as isolated outcrops or thin layers within siliciclastic sequences. Biotas in these strata have generally not been described in detail or closely compared to each other or to coeval assemblages in other Alaskan terranes. Trilobites are an exception. Specimens of latest Pennsylvanian–Permian age from areas A, C, and D were documented by Hahn and Hahn (1985, 1993); the area C fauna is the most diverse and has affinities with coeval assemblages from Wrangellia (Rainbow Mountain area) as well as the Yukon, Spitsbergen, and Slovenia. As noted above, preliminary studies suggest a temperate climate during deposition of Permian rocks in area A and of Pennsylvanian–Permian strata in area D (C. Stevens, 2016, personal commun.) Tethyan (warm-water) foraminifers, which occur in Carboniferous rocks of the Alexander terrane (Mamet et al., 1993) and Permian strata of Wrangellia and peri-Laurentian terranes such as Stikinia (e.g., Beranek et al., 2014), have not been found in Farewell. Paleofloral assemblages from the Mount Dall conglomerate have mixed phytogeographic affinities that suggest a mid-latitude setting (Sunderlin, 2008). Limestone and siliciclastic strata of the Tikhchik terrane yielded middle Permian faunas, including brachiopods and fusulinid foraminifers (Karl et al., 2011), that are approximately coeval with some Mystic faunas, but no detailed information is available on the Tikhchik fossils. Additional study of the biogeographic affinities of Paleozoic Mystic biotas should clarify ties between Farewell and other terranes during the late Paleozoic.

Mesozoic

In the paleogeographic reconstruction of Nelson et al. (2013), Farewell was an isolated crustal fragment that moved from the paleo-Arctic into the paleo-Pacific during late Permian to Jurassic (Figs. 17C, 17D). However, the detrital zircon data outlined above suggest that Farewell was already in the paleo-Pacific by the late Paleozoic and was receiving detritus from Alexander, Wrangellia, and, perhaps, the Yukon-Tanana terrane. Zircon data—and other lines of evidence—indicate continued interaction between Farewell and one or more of these terranes during the Mesozoic.

Definitively uppermost Permian–Middle Triassic rocks have not been found in the Farewell terrane, so Upper Triassic sedimentary strata and mafic igneous rocks of Late Triassic–Early Jurassic age provide the earliest constraints on Farewell’s Mesozoic history. Upper Triassic (Norian) neritic carbonate rocks occur in areas A and B. Successions in both areas deepen upward, but strata in area B are thicker, have a more diverse fauna, and were deposited in somewhat shallower and/or warmer water (Sillierling et al., 1997; McRoberts and Blodgett, 2002). The association of temperate-water monotid species with the tropical to subtropical hydrozoan Heterastridium in area A suggests a low- to mid-latitude setting (Sillierling et al., 1997; Mackay et al., 2003). Diverse corals, bivalves, and gastropods in area B have closest affinities to low-latitude biotas of the Alexander terrane and Chulitna (Fig. 1; McRoberts and Blodgett, 2002), a small terrane southeast of Farewell that includes Triassic limestone and pillow basalt (Sillierling et al., 1994). Layers of coralline limestone intercalated with altered vesicular basalt at locality 14 (Fig. 4) provide a tie between the carbonate successions in areas A and B and coeval mafic igneous rocks of areas C–F (Fig. 2). Although ammonites, halobid and monotid bivalves, and radiolarians are found in shale and chert interlayered with basalt in areas C–E (Gilbert, 1981; Bundtzen et al., 1994, 1997), biogeographic affinities have not been determined for these faunas.

Phosphate occurs in both Triassic and Jurassic strata in Farewell, as discussed above, but is particularly notable in Lower Jurassic rocks in areas E and F, where it is associated at several localities with Sinemurian fossils. Lower Jurassic phosphatic rocks are unknown in other Alaskan terranes, but phosphate occurs in Sinemurian strata in southeastern British Columbia and adjacent Alberta, Canada (Poulton and Atikten, 1989), and in northern Yukon (Poulton, 1997). No faunal or other features are known to link Farewell to western Laurentian strata in Canada during the Jurassic, so the coeval phosphates may reflect similar oceanographic settings rather than proximity. As was suggested for Devonian phosphatic strata of the Mystic, Lower Jurassic phosphatic rocks in Farewell likely formed in middle or lower paleolatitudes.

Detrital zircon spectra from Upper Triassic (?) and Lower Jurassic rocks in areas E and F are generally similar to those from other Farewell strata such as the Sheep Creek Formation and Silurian–Devonian units of the Dillingler subterrane, with Early Devonian–Silurian probability peaks and an array of Proterozoic grains (Fig. 15). Early Paleozoic and older grains could be reworked from underlying older units. Few zircons of Carboniferous–Permian age were found in our Mesozoic samples, although one Triassic (?) spectra (sample 11ADw119A) has a small Permian probability peak.

Norian (226–208 Ma) detrital zircon age populations in four samples and Early Jurassic (195–184 Ma) grains in four others were likely derived from outside the Farewell terrane, as Mystic mafic igneous rocks of this age contain little zircon. Late Triassic–Early Jurassic arc rocks in the Alexander-Wrangellia-Peninsular composite terrane, similar arc rocks in the Tikhchik-Togiak terrane, and partly coeval plutons in the Yukon-Tanana terrane are all potential sources for the Mesozoic zircons in our samples, but several lines of evidence lead us to favor Mesozoic proximity between Farewell and the Alexander-Wrangellia-Peninsular composite terrane (Figs. 17C, 17D). Triassic faunal ties between Farewell and Alexander were noted above. Jurassic faunas in Farewell suggest a relatively warm-water, low- to mid-latitude setting, compatible with the Jurassic position proposed for the Alexander-Wrangellia-Peninsular terrane at this time (e.g., Nelson et al., 2013). In addition, Yukon-Tanana was affected by Jurassic and Early Cretaceous metatamorphic events that have no counterparts in Farewell (Bradley et al., 2003).

Late Triassic to Early Jurassic mafic igneous rocks in the Mystic subterrane have chemical compositions characteristic of a rift setting and are broadly similar to Late Triassic basaltic in the Chulitna region to the southeast (Cl autice et al., 2001; Gilman et al., 2009). Extensive Late Triassic basaltic of
Wrangellia are geochemically similar as well (Lassiter et al., 1995; Greene et al., 2008), but the Wrangellia basalts have more primitive (i.e., higher) \( \epsilon_{Nd} \) values (+5.3 to +7.4) and are interlayered with a lower section of subduction-related igneous rocks. Middle and Late Triassic mafic rocks in the Alexander terrane of southeastern Alaska are considered to be rift related (Taylor et al., 2008; Steeves et al., 2016), but they also have more primitive \( \epsilon_{Nd} \) values (+4 to +9.5) and are associated with rhyolitic rocks. Late Triassic basalts are known from the Tojigak terrane to the southwest (Box et al., 1993), but these rocks have subduction-related geochemistry. Late Triassic and Early Jurassic basalts from the Angayucham and Tozitna terranes in northern Alaska are generally similar to Mystic mafic igneous rocks (Barker et al., 1988; Pallister et al., 1989), but are interbedded with radiolarian chert, suggesting an oceanic plate seamount setting. In summary, the Late Triassic–Early Jurassic mafic igneous rocks of the Mystic sequence are geochemically similar to mafic rocks of comparable age in other Alaskan terranes, but they differ in detail from most of these by their more “continental” isotopic composition or by their association with more continental derived sedimentary rocks.

The presence of similar Late Triassic rift-type mafic rocks in the Farewell, Wrangellia, and Alexander terranes, with differences outlined above attributed to local contrasts in their crustal underpinnings, may indicate these terranes shared a Late Triassic rift event and became separated at that time (Fig. 17C). Although the composite Wrangellia-Peninsular-Alexander terrane was clearly separated from the Farewell terrane during Cretaceous sedimentation in the Kahiltna basin (Ridgway et al., 2002; Hampton et al., 2010; Hults et al., 2013), it might have been adjacent to the Farewell terrane in late Paleozoic time as suggested by our detrital zircon data and the data of Malkowski and Hampton (2014) discussed above.

The Lower Cretaceous limestones that unconformably overlie Lower Jurassic rocks in northern and southeastern Farewell are partly coeval with older parts of the Kahiltna assemblage, an overlap succession that covers the inferred suture zone between Wrangellia and Farewell. Faunal and lithologic data suggest that Cretaceous strata in the Farewell terrane could represent shallow-water, marginal facies of the northern Kahiltna basin. These strata are also partly coeval with volcaniclastic rocks (e.g., Koksetna River sequence of Wallace et al. (1988)) deposited on the southern side of the Kahiltna basin along the margin of the Peninsula-Wrangellia-Alexander composite terrane. Lower Cretaceous marginal components of the Kahiltna succession give way to thicker, more widespread Upper Cretaceous strata toward the center of the basin. These younger strata indicate increased rates of subsidence and sediment accumulation and changing sediment provenance (e.g., Kalbas et al., 2007; Hults et al., 2013) during the final accretion of the Peninsula-Wrangellia-Alexander composite terrane along the southern Alaska margin.

## CONCLUSIONS

Detrital zircon, faunal, geochemical, and lithologic data from rocks of the Farewell terrane (Mystic subterrane) illuminate its Late Devonian through Early Cretaceous history. Petrographic and detrital zircon analyses imply that Devonian–Permian and Triassic–Jurassic clastic strata of the Mystic were derived at least in part from older Farewell rocks, but sources outside Farewell are needed for zircons of Late Devonian, Carboniferous, Permian, Late Triassic, and Early Jurassic age. Potential sources for zircons of these ages include the Alexander-Wrangellia-Peninsular composite terrane, the Yukon-Tanana terrane, and the Tikchik and Tojigak terranes.

Available data fit best with paleogeographic models in which the Farewell and Alexander terranes were in relative proximity through much of Paleozoic and early Mesozoic time (Fig. 17). The presence of phosphorite nodules in Upper Devonian strata of the Mystic subterrane imply a setting within 40° of the paleoequator, and support a middle Paleozoic position for Farewell on the southern (Laurentian) side of the Uralian Sea, rather than the northern (Siberian) side as was previously proposed (Fig. 17A). The Alexander-Wrangellia-Peninsular composite terrane is a likely source for Late Devonian, Carboniferous, early Permian, and early Mesozoic zircons found in clastic units of the southern Farewell terrane (Figs. 17B–17D). Middle to late Permian zircons in northern Farewell may have a provenance in the Yukon-Tanana terrane. Late Triassic to Early Jurassic mafic igneous rocks in the Mystic subterrane are similar to broadly coeval igneous rocks in the Wrangellia and Alexander terranes, and are possible evidence of a shared rifting event during the early Mesozoic (Fig. 17C). Faunal data and the presence of phosphatic strata suggest a relatively warm-water, low- to mid-latitude setting for Farewell in the Early Jurassic (Fig. 17D). Lower Cretaceous limestones and related strata that crop out sparsely but widely in the Mystic subterrane may be marginal facies that formed early in the development of the Kahiltna overlap assemblage.

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REFERENCES CITED


