Geological Society of America
3300 Penrose Place
P.O. Box 9140
Boulder, CO 80301
(303) 447-2020 • fax 303-357-1073
www.geosociety.org

Chapter 12: "The restricted Gemuk Group: ATriassic to Lower Cretaceous succession in southwestern Alaska" (Miller et al.), *in* Ridgway, K.D., Trop, J.M., Glen, J.M.G., and O'Neill, J.M., eds., Tectonic Growth of a Collisional Continental Margin: Crustal Evolution of Southern Alaska: Geological Society of America Special Paper 431.

This PDF file is subject to the following conditions and restrictions:

Copyright © 2007, The Geological Society of America, Inc. (GSA). All rights reserved. Copyright not claimed on content prepared wholly by U.S. government employees within scope of their employment. Individual scientists are hereby granted permission, without fees or further requests to GSA, to use a single figure, a single table, and/or a brief paragraph of text in other subsequent works and to make unlimited copies for noncommercial use in classrooms to further education and science. For any other use, contact Copyright Permissions, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA, fax 303-357-1073, editing@geosociety.org. GSA provides this and other forums for the presentation of diverse opinions and positions by scientists worldwide, regardless of their race, citizenship, gender, religion, or political viewpoint. Opinions presented in this publication do not reflect official positions of the Society.

The Geological Society of America
Special Paper 431
2007

The restricted Gemuk Group: A Triassic to Lower Cretaceous succession in southwestern Alaska

Marti L. Miller
Dwight C. Bradley
U.S. Geological Survey, 4200 University Drive, Anchorage, Alaska 99508, USA

Thomas K. Bundtzen
Pacific Rim Geological Consulting, Fairbanks, Alaska, USA

Robert B. Blodgett
629 O St., Anchorage, Alaska, USA

Emile A. Pessagno, Jr.
University of Texas, Dallas, Texas, USA

Robert D. Tucker
Washington University, St. Louis, Missouri, USA

Anita G. Harris
U.S. Geological Survey, Denver, Colorado, USA

ABSTRACT

New data from an Upper Triassic to Lower Cretaceous deep marine succession—the herein reinstated and restricted Gemuk Group—provide a vital piece of the puzzle for unraveling southwestern Alaska's tectonic history. First defined by Cady et al. in 1955, the Gemuk Group soon became a regional catchall unit that ended up as part of at least four different terranes. In this paper we provide the first new data in nearly half a century from the Gemuk Group in the original type area in Taylor Mountains quadrangle and from contiguous rocks to the north in Sleetmute quadrangle. Discontinuous exposure, hints of complex structure, the reconnaissance level of our mapping, and spotty age constraints together permit definition of only a rough stratigraphy. The restricted Gemuk Group is at least 2250 m thick, and could easily be at least twice as thick. The age range of the restricted Gemuk Group is tightened on the basis of ten radiolarian ages, two new bivalve ages, one conodont age, two U-Pb zircon ages on tuff, and U-Pb ages of 110 detrital zircons from two sandstones. The Triassic part of the restricted Gemuk Group, which consists of intermediate pillow lavas interbedded with siltstone, chert, and rare limestone, produced radiolarians, bivalves, and conodonts of Carnian and Norian ages. The Jurassic part appears to be mostly siltstone and chert, and yielded radiolarians of Hettangian-Sinemurian, Pliensbachian-Toarcian, and Oxfordian ages. Two tuffs near the Jurassic-Cretaceous boundary record nearby arc volcanism: one at 146 Ma is interbedded with red and green

Miller, M.L., Bradley, D.C., Bundtzen, T.K., Blodgett, R.B., Pessagno, E.A., Jr., Tucker, R.D., and Harris, A.G., 2007, The restricted Gemuk Group: A Triassic to Lower Cretaceous succession in southwestern Alaska, *in* Ridgway, K.D., Trop, J.M., Glen, J.M.G., and O'Neill, J.M., eds., Tectonic Growth of a Collisional Continental Margin: Crustal Evolution of Southern Alaska: Geological Society of America Special Paper 431, p. 273–305, doi: 10.1130/2007.2431(12). For permission to copy, contact editing@geosociety.org. ©2007 The Geological Society of America. All rights reserved.

siltstone, and a second at ca. 137 Ma is interbedded with graywacke turbidites. Graywacke appears to be the dominant rock type in the Lower Cretaceous part of the restricted Gemuk Group. Detrital zircon analyses were performed on two sandstone samples using SHRIMP. One sandstone yielded a dominant age cluster of 133–180 Ma; the oldest grain is only 316 Ma. The second sample is dominated by zircons of 130–154 Ma; the oldest grain is 292 Ma. The youngest zircons are probably not much older than the sandstone itself. Point counts of restricted Gemuk Group sandstones yield average ratios of 24/29/47 for Q/F/L, 15/83/2 for Ls/Lv/Lm, and 41/48/11 for Qm/P/K. In the field, sandstones of the restricted Gemuk Group are not easily distinguished from sandstones of the overlying Upper Cretaceous turbidite-dominated Kuskokwim Group. Petrographically, however, the restricted Gemuk Group has modal K-feldspar, whereas the Kuskokwim Group generally does not (average Qm/P/K of 64/36/0). Some K-feldspar-bearing graywacke that was previously mapped as Kuskokwim Group (Cady et al., 1955) is here reassigned to the restricted Gemuk Group. Major- and trace-element geochemistry of shales from the restricted Gemuk Group and the Kuskokwim Group show distinct differences. The chemical index of alteration (CIA) is distinctly higher for shales of the Kuskokwim Group than for those of the restricted Gemuk Group, suggesting more intense weathering during deposition of the Kuskokwim Group.

The restricted Gemuk Group represents an estimated 90–100 m.y. of deep-water sedimentation, first accompanied by submarine volcanism and later by nearby explosive arc activity. Two hypotheses are presented for the tectonic setting. One model that needs additional testing is that the restricted Gemuk Group consists of imbricated oceanic plate stratigraphy. Based on available information, our preferred model is that it was deposited in a back-arc, intra-arc, or forearc basin that was subsequently deformed. The terrane affinity of the restricted Gemuk Group is uncertain. The rocks of this area were formerly assigned to the Hagemeister subterrane of the Togiak terrane—a Late Triassic to Early Cretaceous arc—but our data show this to be a poor match. None of the other possibilities (e.g., Nukluk and Tikchik subterranes of the Goodnews terrane) is viable; hence, the terrane subdivision and distribution in southwestern Alaska may need to be revisited. The geologic history revealed by our study of the *restricted* Gemuk Group gives us a solid toehold in unraveling the Mesozoic paleogeography of this part of the northern Cordillera.

Keywords: Gemuk Group, Southwestern Alaska, Mesozoic stratigraphy, regional geology.

INTRODUCTION

Southwestern Alaska is a geologically complex region that includes magmatic arcs, accretionary complexes, continental fragments, and problematic sedimentary basins. Meaningful stratigraphy is a fundamental requirement for unraveling the tectonic evolution of any region as complex as this. Deciphering this region's geologic history is made even more difficult by factors including remoteness, lack of detailed geologic mapping, spotty outcrop, and misinterpretations embedded in the literature.

In this paper, we revisit a unit that was once thought to cover a large part of southwestern Alaska—the Gemuk Group. This unit, originally named for rocks in the Sleetmute and Taylor Mountains quadrangles, was defined as consisting of siltstone, chert, volcanic rocks, sandstone, and limestone ranging from Carboniferous(?) to Early Cretaceous in age (Cady et al., 1955). Soon after definition, the term degenerated into a regional catchall unit that eventually ended up as part of at least four different terranes. Over the past 13 years, our research in this part of Alaska has clarified the age, stratigraphic succession, and field relations of the original Gemuk Group. Our study has also brought to light misconceptions about the unit's age and regional distribution that took hold during the days of geosyncline theory and now need to be corrected. As will be discussed in a later section, Wilson and Coonrad (2005) proposed that the name *Gemuk Group* be abandoned. We propose instead to restrict the term to the rocks for which it was originally defined and to remove the huge expanses of real estate added to the Gemuk Group that should never have been included.

In this paper we describe the "restricted Gemuk Group" of Late Triassic to Early Cretaceous age. We provide new fossil and U-Pb age control, lithologic details, sedimentary geochemistry, some sense of the overall stratigraphic succession, and a revision of the upper boundary. We hereafter refer to the regionally extensive, broadly overapplied Gemuk Group of the older literature as the "overextended Gemuk Group."

REGIONAL GEOLOGY

The tectonic framework of southwestern Alaska was synthesized by Decker et al. (1994) (Fig. 1A). In the eight-quadrangle region in which the overextended Gemuk Group was once shown on published or unpublished USGS maps (Fig. 1B), Decker et al. (1994) recognized at least four tectonostratigraphic terranes and a multitude of subterranes, plus a widespread Cretaceous flysch sequence (Kuskokwim Group) that they regarded as an overlap assemblage.

The Togiak terrane, first identified by Jones and Silberling (1979), represents a Mesozoic arc. Box (1985) divided the Togiak terrane into two subterranes: the Kulukak subterrane (predominantly Jurassic volcaniclastic turbidites) and the Hagemeister subterrane (Upper Triassic, Jurassic, and Lower Cretaceous volcanic and volcaniclastic rocks built on a Triassic ophiolitic basement). Most of the interpretations of the Togiak terrane (and the adjacent Goodnews terrane) were based on coastal exposures along the north shore of Bristol Bay (Box, 1985). Decker et al. (1994) extrapolated these terranes and subterranes inland as far as the Taylor Mountains and Sleetmute quadrangles but acknowledged possible problems. Decker et al. (1994) assigned all of the rocks that belong in our restricted Gemuk Group to the Hagemeister subterrane—an error in our view. Both the Hagemeister and Kulukak subterranes include rocks from the overextended Gemuk Group.

The Goodnews terrane of Decker et al. (1994) consists of four subterranes, one on the east side of the Togiak terrane and three on the west. On the east side of the Togiak terrane is the Tikchik subterrane, which has been characterized as a mélange that includes radiolarian chert of Ordovician, Triassic, Jurassic, and Early Cretaceous ages, Permian limestone, Permian or Triassic pillow basalt and graywacke, and Upper Triassic clastic and mafic volcanic rocks (Decker et al., 1994). Some rocks in this subterrane are structurally coherent and kilometers long. On the west side of the Togiak terrane, the Cape Peirce subterrane is a belt of Jurassic blueschists, consisting largely of mafic protoliths thought to be of Permian and Triassic ages (Decker et al., 1994). The Platinum subterrane consists of Jurassic mafic and ultramafic rocks. The Nukluk subterrane is a mélange that includes Ordovician, Devonian, and Permian limestone, Mississippian, Triassic, and Jurassic chert, Permian basalt, and undated mudstone (Decker et al., 1994). The Cape Peirce, Platinum, Nukluk, and Tikchik subterranes all include rocks that at some point had been mapped as (overextended) Gemuk Group.

The Nyac terrane is a Jurassic to Lower Cretaceous(?) arc-related volcanic and volcaniclastic assemblage (Decker et al., 1994; Box et al., 1993). Associated sedimentary rocks include graywacke, siltstone, and conglomerate (Box et al., 1993). The Nyac terrane also includes rocks that were previously mapped as (overextended) Gemuk Group.

The three other terranes shown in the area of Figure 1A, the Farewell, Kilbuck, and Kahiltna, are beyond the scope of the present paper. The Farewell terrane, in eastern Sleetmute and Taylor Mountains quadrangles (Fig. 1A), is a Neoproterozoic to Jurassic succession deposited on the margin of a microcontinent that is now thought to have originated near Siberia (Blodgett and Boucot, 1999; Blodgett et al., 2002; Dumoulin et al., 2002). The Upper Triassic–Lower Jurassic stratigraphic succession of the Farewell terrane exposed in the northeastern Taylor Mountains quadrangle (Blodgett et al., 2000; McRoberts and Blodgett, 2002) differs from that of the restricted Gemuk Group in being composed chiefly of shallow-water limestone and siliciclastic rocks, as well as slightly deeper water cherts deposited in a continental margin setting. The Kilbuck terrane consists of Paleoproterozoic (ca. 2050 Ma) basement (Box et al., 1990; Moll-Stalcup et al., 1996). The Kahiltna terrane is a Jurassic to Cretaceous turbidite basin of the Alaska Range that barely extends into the area of Figure 1A; these rocks were shown as overextended Gemuk Group on an USGS compilation (J.M. Platt and E.H. Mueller, unpub. map compilation, 1957, summarized in Wilson and Coonrad, 2005).

Upper Cretaceous sandstone and mudstone of the Kuskokwim Group overlap the older terranes (Fig. 1A). The Kuskokwim Group will be discussed in more detail in sections on sandstone petrography and sedimentary geochemistry to shed light on mapping problems involving restricted Gemuk Group versus Kuskokwim Group.

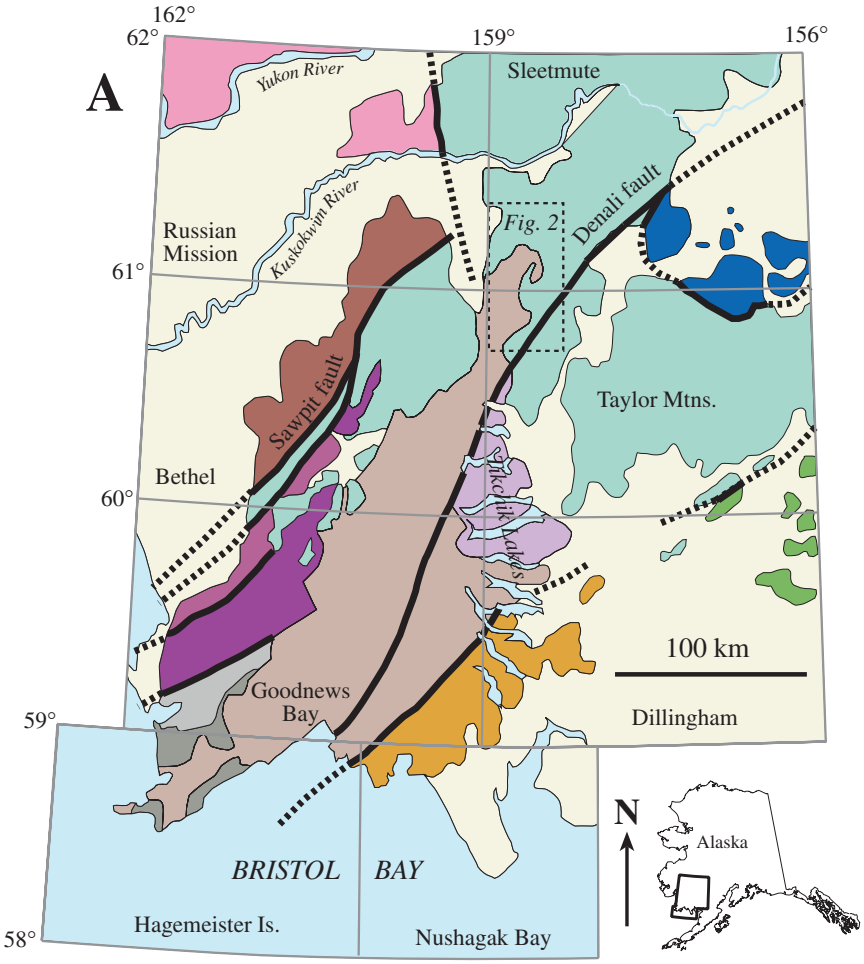
STRATIGRAPHIC NOMENCLATURE OF THE GEMUK GROUP

When originally named, the Gemuk[1] Group was envisioned as a "marine geosynclinal" sequence (Cady et al., 1955). Within this pre–plate-tectonic paradigm, it was thought that across much of Alaska broad geanticlines exposed older rocks (mainly Precambrian crystalline basement) creating "primary" and "secondary geosynclinal" basins "in which bedded rocks accumulated unconformably on the older formations" (Cady et al., 1955, p. 18). Rocks deposited during the primary geosynclinal subsidence were understood to be Paleozoic to Early Cretaceous in age and to correlate across vast areas. This preconception led Cady et al. (1955) and subsequent workers to apply the name Gemuk Group to rocks far beyond the type area, including some thought to be as old as Carboniferous. In our opinion, these extrapolations of the unit's age and distribution were not supported by the data.

Original Definition

As originally mapped, the Gemuk Group consisted of three separated outcrop areas in northwestern Taylor Mountains and southwestern Sleetmute quadrangles (Cady et al., 1955, pl. 1; Fig. 2A). Cady et al. (1955) defined the unit as "dense dark massive siltstone, with which are interbedded smaller amounts of chert

[1] The name *Gemuk* comes from the Yup'ik word *qemiq,* meaning "hill, especially part of a ridge of hills" (*The Yup'ik Eskimo Dictionary,* compiled by S.A. Jacobson, 1984; J. McAtee, 2005, personal commun.); a similar sounding Yup'ik word *kemek,* which means meat, was inadvertently misreported as the translation by Wilson and Coonrad (2005).



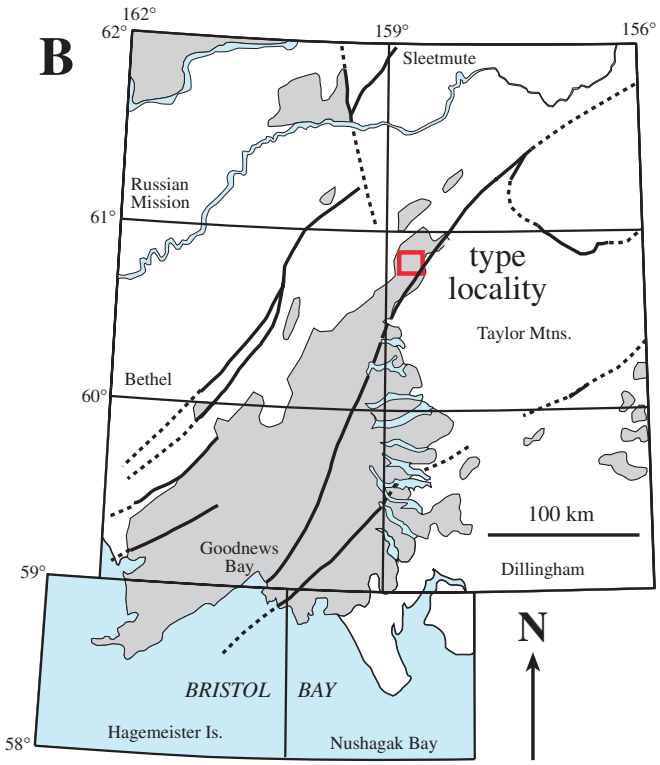
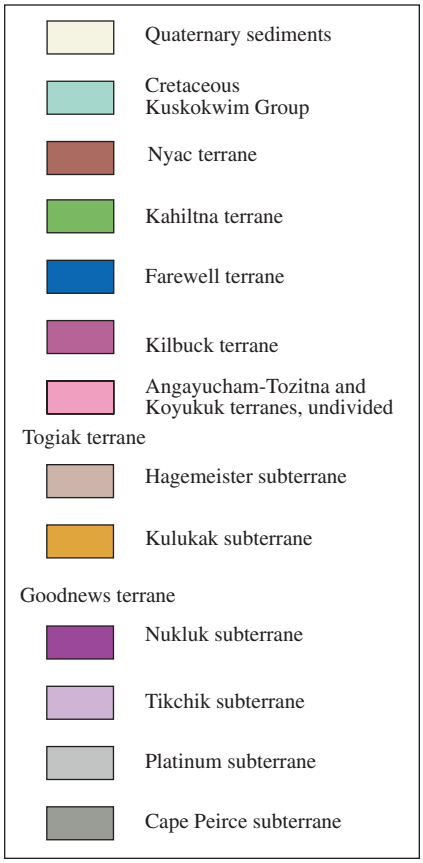


Figure 1. (A) Tectonostratigraphic terrane map of southwestern Alaska, modified from Decker et al. (1994) and Silberling et al. (1994). (B) Gray shading indicates general distribution of rocks previously shown as Gemuk Group on published or unpublished USGS geologic maps (modified from Wilson and Coonrad, 2005, their Fig. 2); original type locality of Cady et al. (1955) is indicated.



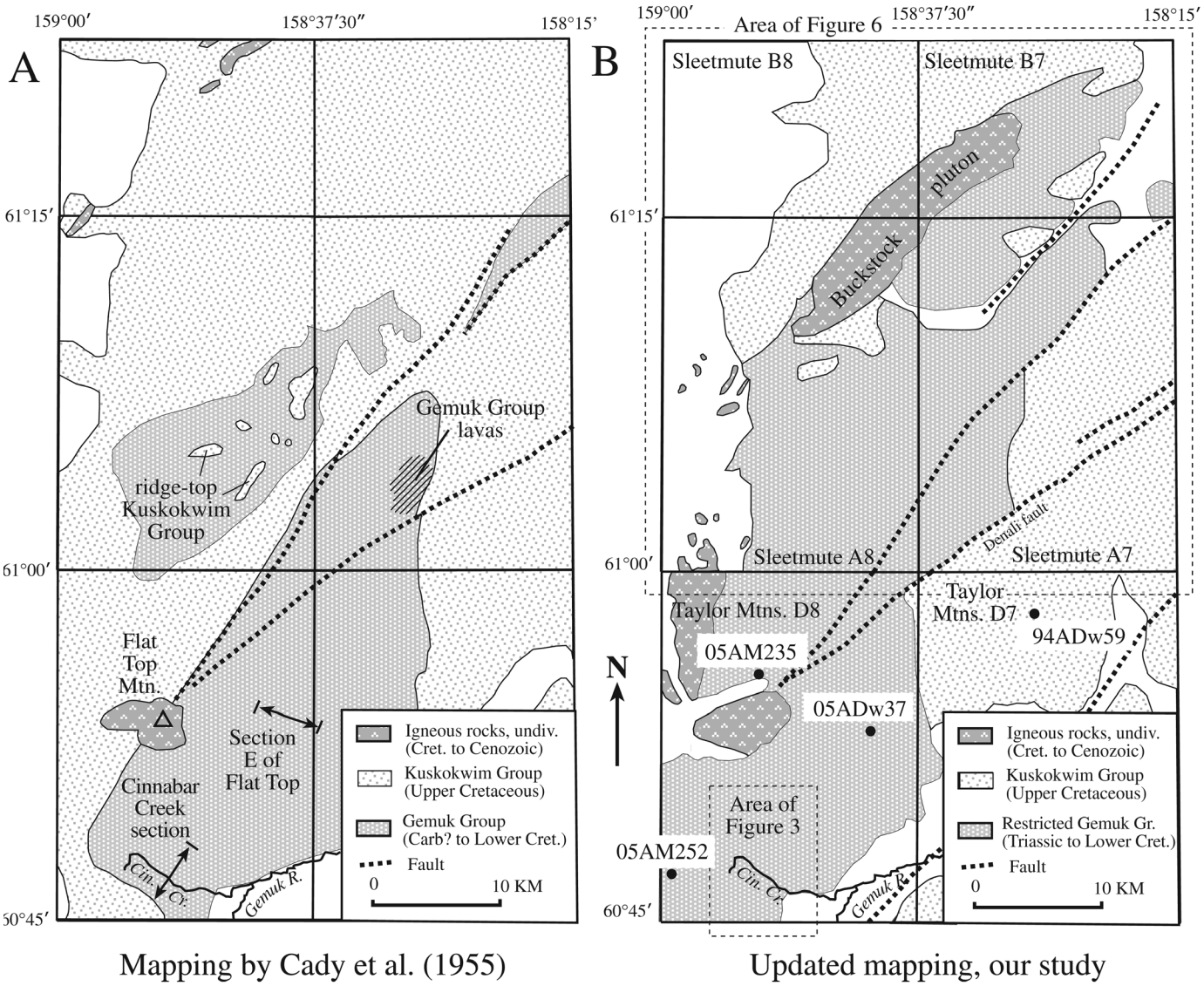


Figure 2. (A) Map showing the three separate outcrop belts of the Gemuk Group as originally defined by Cady et al. (1955). (B) Map showing the restricted Gemuk Group based on our new work. Also shown are field localities referred to in the text. See Figure 1A for location of map area.

and volcanic rock, and thin interbeds of limestone, graywacke, and breccia." Megafossils of Late Triassic age were found in the southernmost of the three outcrop belts (from the Cinnabar Creek section, Fig. 2A); the northeasternmost of the three exposure belts yielded Early Cretaceous fossils. Cady et al. (1955) designated the area lying "north of the lower middle course of the Gemuk River" as the type locality, which consisted of partial stratigraphic sections in two areas: the Cinnabar Creek area and an upland area east of Flat Top Mountain (Fig. 2A). They estimated the combined stratigraphic thickness of these two partial sections to be 15,000–25,000 ft (~4600–7600 m). Cady et al. (1955) interpreted the Cinnabar Creek area to be a homocline exposing 10,000–15,000 feet (~3000–4600 m) of Upper Triassic rocks. This interpretation led them to speculate that "rocks below the Cinnabar Creek section [i.e., the section east of Flat Top Mountain, Fig. 2A] . . . may be older than Upper Triassic, because they are lithologically different. If so, they are probably of Carboniferous or Permian age, or both" (Cady et al., 1955, p. 33–34). There are two problems with this interpretation. First, the structure is not as simple as Cady et al. (1955) believed. Sainsbury and MacKevett (1965) showed that the Cinnabar Creek section is folded and does not represent a homocline at all. Thus it cannot be assumed that the partial section east of Flat Top Mountain is older. The second problem is that, in fact, the rocks east of Flat Top Mountain (black, red, and green siltstone, and silty chert) are not "lithologically different" but to us seem completely consistent with Triassic through Lower Cretaceous Gemuk Group (Cady et al., 1955; this study). Because only Late Triassic and Early Cretaceous fossils were found, Cady et al. (1955, p. 22) queried the older ages but still listed the Gemuk Group as a "Carboniferous(?)-Permian(?)-Upper Triassic-Upper

Jurassic(?)-Lower Cretaceous succession"; however, they made correlations as if the older ages were accepted, not queried.

Problematic Correlations (Overextended Gemuk Group)

Since correlations far and wide were expected, the extent of the Gemuk Group was immediately expanded beyond its original borders—even within the publication wherein the unit was originally named. Cady et al. (1955) looked ~65 km south to the Tikchik Lakes area, which had been mapped by Mertie (1938) as containing "Carboniferous" strata (actually Permian, as discussed below). Cady et al. (1955) believed the rock types there were similar enough in age, lithology, and perceived structural position to warrant correlation with the Gemuk Group. This correlation is where the Carboniferous age call first became entrenched in the Gemuk-related literature, but on closer examination, we realized that a leap of logic had inadvertently been made. In the Tikchik Lakes area, Mertie (1938, p. 37) described a Carboniferous map unit as containing Permian limestone and Mississippian(?) "chert, cherty grit, and conglomerate; quartzite and quartzitic sandstone, . . . shale, slate, and argillite; and limestone and calcareous sandstones and shales" that are locally sheared and semischistose. Whereas some of the lithologies are similar to the type Gemuk Group, taken as a whole the lithologic argument is not compelling enough for suggesting correlation, particularly in light of the significant age difference. The age of Mertie's Tikchik Lake "Carboniferous" rocks is also part of the problem. At the time of Mertie's 1938 report, the Permian series was considered by the USGS to be the uppermost division of the Carboniferous (Mertie, 1938, pl. 2), so a "definitive" Carboniferous call was based on a *Permian* fossil. The Mississippian(?) age call wasn't even based on fossil evidence but only on perceptions and assumptions that can no longer be supported. First, Mertie (1938) interpreted a structural unconformity between fossil-bearing Permian limestone and underlying rocks, which he then reasoned to be "definitely pre-Permian" (Mertie, 1938, p. 42.). Second, because these rocks did "not appear to be of terrigenous origin and that marine Pennsylvanian rocks are practically unknown in Alaska" (Mertie, 1938, p. 42), he assigned to them a Mississippian(?) age. Later workers (Hoare and Coonrad, 1959a) found no evidence for this unconformity but did not alter the Mississippian(?) age assignment, which had been based entirely on the supposed unconformity. In fact, the rocks mapped by Mertie (1938) are not correlative with the Gemuk Group in the type area but are part of what was later recognized as a mélange of the Tikchik subterrane (Decker et al., 1994; Box et al., 1993).

Other areas where rocks were mapped as Gemuk Group include the Russian Mission, Goodnews Bay, Hagemeister Island, and Bethel quadrangles. These correlations, which were made on the basis of perceived similarity of age and lithology, no longer hold up. For instance, Cady et al. (1955) and Hoare and Coonrad (1959b) considered a unit of volcanic and interbedded sedimentary rocks that lay north of the Kuskokwim River in the Russian Mission quadrangle (Fig. 1) to be correlative with the Gemuk Group[2]. Whereas there is some similarity in rock types (mixed volcanic flows, graywacke, and minor interbedded limestone), the Permian fossil age for the limestone (Smith, 1939) is notably older than the Late Triassic age of the Gemuk Group in the type area. Other rocks to the south of the Gemuk Group type area that Cady et al. (1955) suggested were of "equivalent age and lithologic character" lay in the eastern part of the Bethel quadrangle (Fig. 1B). These were later depicted by Hoare and Coonrad (1959a) to be part of a broad belt of "Gemuk Group" that continued many miles south into the Goodnews Bay and Hagemeister Island quadrangles (Hoare and Coonrad, 1961a, 1961b). Without any new fossil control, Hoare and Coonrad (1959a) assigned a Mississippian(?) to Early Cretaceous age to their Gemuk Group unit based on Cady et al. (1955) and Mertie (1938), thus perpetuating the inappropriately older age range. By the early 1960s, the term *Gemuk Group* had been applied so widely that it was used across an irregular area some 400 km by 200 km (Fig. 1B). With the advent of plate tectonics, workers in southwestern Alaska apparently recognized correlations derived from geosynclinal theory were problematic. Hoare and Coonrad (1978) dropped the name Gemuk Group from a regional compilation and remapped their former Gemuk Group rocks into about half a dozen units, lumping Mertie's (1938) supposed Carboniferous rocks into an undifferentiated "MzPz" unit. Similarly, Box et al. (1993) did not use the term *Gemuk Group* when remapping the Bethel quadrangle but instead depicted these rocks as part of several different tectonostratigraphic terranes. These workers quietly quit using the term *Gemuk Group,* but did so for rocks that we believe did not belong in the Gemuk Group in the first place.

Proposed Abandonment by Wilson and Coonrad (2005)

Although a number of workers had quit using the term *Gemuk Group,* its status as a formal stratigraphic name was unchanged until 2004. In that year Miller et al. first proposed restriction of the Gemuk Group to rocks in and near the type area (see next heading). In 2005, Wilson and Coonrad proposed to abandon the name altogether. Contending that the term had already been implicitly abandoned and was no longer useful for mapping, they proposed to replace *Gemuk Group,* with *Togiak-Tikchik Complex.* The Togiak-Tikchik Complex of Wilson and Coonrad (2005) was conceived to be a "structural juxtaposition of diverse stratigraphic units" or, as characterized elsewhere in their paper, a "tectonic assemblage or collage," parts of which "clearly represent mélange." The Togiak-Tikchik Complex comprises the type Gemuk Group plus all of the other rocks ever shown as Gemuk Group on any published or unpublished USGS geologic map. This includes rocks that we contend didn't belong in the Gemuk Group in the first place, the "overextended Gemuk Group."

[2] Indeed, Cady et al. (1955) even showed these rocks as Gemuk Group on their geologic map, but in the text they described this as a correlation made on the basis of similar age and lithology.

Recommendation to Reinstate and Restrict

Based on reconnaissance mapping and follow-up studies (1993–2005), we recommend reinstating the name Gemuk Group but restricting it to rocks of the type area in Taylor Mountains quadrangle plus the contiguous rocks to the north in the Sleetmute quadrangle (as proposed by Miller et al., 2004, 2005). Restricting the Gemuk Group eliminates rocks that were inappropriately included. The restricted Gemuk Group of our usage is a stratigraphic sequence, definable and separate from the "structural collage" envisioned by Wilson and Coonrad (2005). It is an Upper Triassic to Lower Cretaceous stratigraphic succession, which though folded and faulted, is structurally tractable. As more data are collected, designation of formations within the restricted Gemuk Group will be possible. Pending future work, the rocks that we exclude from the restricted Gemuk Group can be called by their various informal map unit designations.

RESTRICTED GEMUK GROUP IN THE TAYLOR MOUNTAINS QUADRANGLE

As previously discussed, the original Gemuk Group type locality designated by Cady et al. (1955) consisted of two partial sections: (1) Cinnabar Creek and (2) the upland area east of Flat Top Mountain (Fig. 2A). Cady et al. (1955) believed that these two areas together comprised a 15,000–25,000-foot-thick (~4600–7600 m) homoclinal succession of Gemuk Group that was broadly conformable with overlying Kuskokwim Group strata. We here present an updated view of the Cinnabar Creek part of the original type area of Cady et al. (1955), based on revisions by Sainsbury and MacKevett (1965), and our own recent work. The Cinnabar Creek section is not a homocline, as was also recognized by Sainsbury and MacKevett (1965). We divide the succession near Cinnabar Creek into three informal subunits (A, B, and C, from older to younger, Fig. 3), which are not in chronologic order on the map. We also present new age control for the partial section Cady et al. (1955) called the "upland area east of Flat Top Mountain" and for two other localities in Taylor Mountains D8 quadrangle (05AM235 and 05AM252, Fig. 2B).

Subunit A is the oldest and the best understood part of the Cinnabar Creek section. It is a generally south-dipping package that lies between Cinnabar Creek and an unnamed tributary of Beaver Creek, a distance of ~1 km. Bedding dips range from 30 to 85 degrees and average ~60 degrees. Neither overturned strata nor thrust repetitions have been recognized within subunit A. This part of the type Gemuk Group is dominated by resistant intermediate pillow lavas (Figs. 4A and 4B) interbedded with marine sedimentary rocks. Cady et al. (1955) recognized at least five volcanic horizons ranging in thickness up to 60 m. These largely andesitic lavas (Cady et al., 1955) are plagioclase porphyritic in a finer groundmass of subophitic-textured plagioclase, clinopyroxene, and accessory opaque groundmass. Secondary chlorite and calcite are ubiquitous. That the lavas were locally vesicular is shown by the now chlorite filled amygdules (Fig. 5A). Interbedded and poorly exposed sedimentary rocks include siltstone, chert, and limestone. Gray, black, and green chert in 1–3 cm thick layers is found as rubble. Some of the chert yielded Triassic radiolarians as described later in the Paleontology section. Limestone occurs in outcrop (Fig. 4C) in conspicuous, light gray fossil-rich horizons up to 20 cm thick interbedded with siltstone. Conodont and megafossil data from these limestones are discussed in the Paleontology section. We mapped the boundary between subunits A and C as a fault (Figs. 3 and 4A). This is different than the equivalent boundary shown by Sainsbury and MacKevett (1965), who recognized the flow-bearing part of the Gemuk Group as distinct but thought the southern contact with mainly sedimentary rocks was gradational. Detrital zircon data coupled with petrographic data (both discussed later) at locality 04AM51 (Fig. 3) suggest that

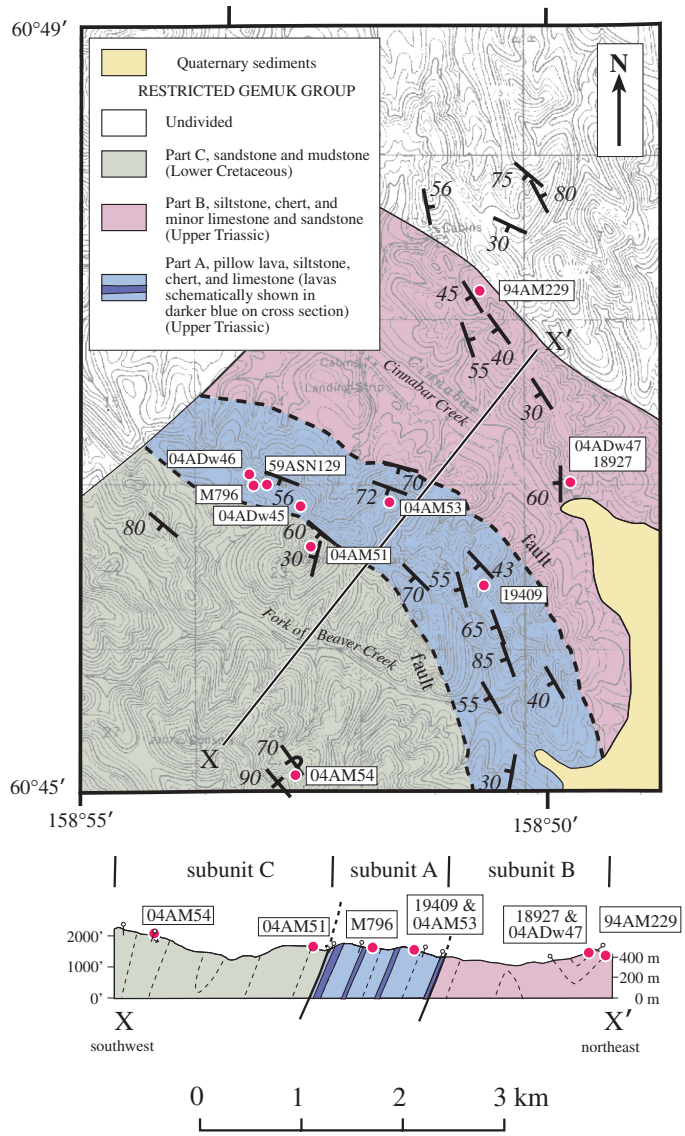


Figure 3. Geologic map and cross section of the Cinnabar Creek area in the Taylor Mountains D8 quadrangle showing fossil, sandstone point count, and detrital zircon sample locations. See Figure 2B for location of map.

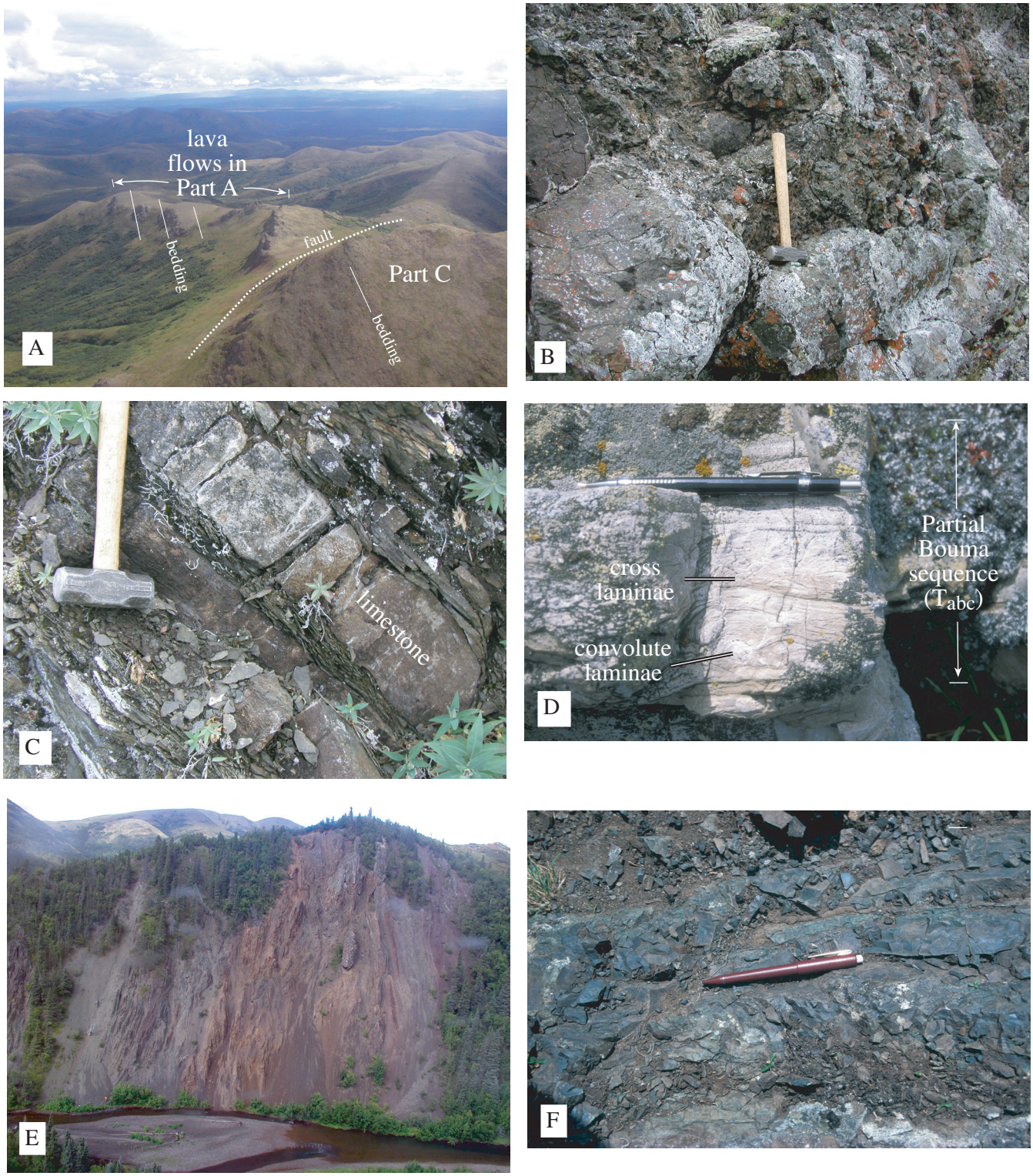


Figure 4. Photographs of the restricted Gemuk Group: (A) Aerial view of subunit A showing resistant lava flows and fault contact with subunit C; (B) Upper Triassic pillow lavas of subunit A; (C) bed of bivalve-bearing Upper Triassic limestone associated with siltstone and pillowed andesite (locality 04ADw46, Fig. 3), bedding dips to the right; (D) graded bed of Lower Cretaceous sandstone in our subunit C of the type Gemuk Group (locality 04AM54, Fig. 3); (E) folded section of interbedded brown limey mudstone, green mudstone, and chert exposed along Atsaksovluk Creek (locality 05AM235, Fig. 2B); (F) green mudstone of the restricted Gemuk Group displaying typical hackly fracture; (G) bed of green chert, Sleetmute quadrangle (arrow indicates pencil for scale); (H) distant view of tuff-rich upper division of the restricted Gemuk Group (see Fig. 7) in Sleetmute A8 quadrangle (see Fig. 2B) showing nearly flat lying beds of tuffaceous mudstone, chert, local tuff, and ridge-top sandstone. Arrow indicates exposure of ridge-top sandstone, which was mapped by Cady et al. (1955) as Kuskokwim Group but which we now include as restricted Gemuk Group. Relief from ridge-top sandstone to valley bottom is ~600 m.

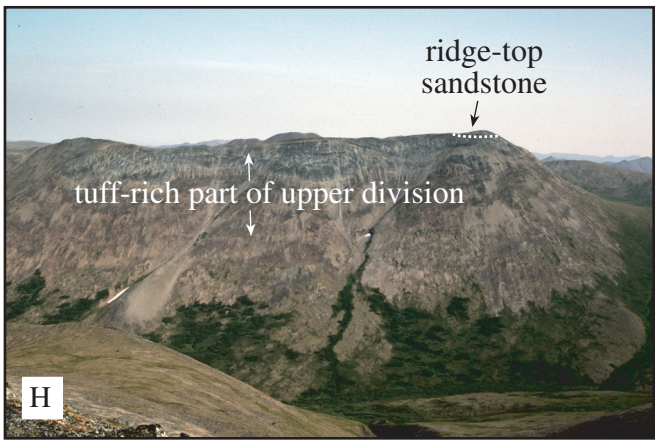


Figure 4. (*continued*)

these sedimentary rocks (subunit C) are Early Cretaceous and not Triassic in age. Hence, the juxtaposition of subunits A and C requires either the presence of a fault or a major disconformity. The latest Triassic section (subunit B) is missing here, despite being present a kilometer to the north; this, coupled with local disrupted cherts and argillites, supports the fault interpretation. Based on the cross section, this fault would be a flat-on-flat thrust, and it limits the thickness of homoclinal strata in section A to ~800 m.

Subunit C, immediately to the southwest of subunit A, consists of alternating graywacke and mudstone. Cady et al. (1955) interpreted the rocks we call subunit C as being stratigraphically above subunit A and assigned these strata to the Upper Cretaceous Kuskokwim Group. Sainsbury and MacKevett (1965) reassigned subunit C to the Gemuk Group and implied a Triassic age for this part of the section. We concur that it belongs in the (restricted) Gemuk Group, but as previously mentioned, our zircon and petrographic data suggest an Early Cretaceous age. Within subunit C, inverted beds are present that preclude an accurate thickness estimate. The sandstone beds of subunit C range from 15 to 30 cm thick and are generally gray to greenish gray but locally are light tan; the generally brown mudstones range from 15 to 25 cm in thickness. Whereas few clean exposures of sedimentary structures are found, partial Bouma sequences are consistent with a turbidite origin (Fig. 4D). Medium-grained sandstones are siliciclastic, containing quartz (22%–32%), plagioclase feldspar (21%–24%), potassium feldspar (3%–4%), lithic grains (32%–48%), and miscellaneous clasts (6%–7%) including mica, chlorite, epidote, and opaques (n = 2, samples 04AM51A[3] and 54A, Table 1; Fig. 3). Sandstone petrography is discussed in more detail later.

Subunit B lies north of subunit A; the contact between them is not exposed but is likely a fault because subunit A youngs away from the contact but is older. Cady et al. (1955) considered these rocks to be older than subunit A because they thought of them as part of the same homocline. However, Sainsbury and MacKevett (1965) mapped a syncline in subunit B, leading them to realize it was not homoclinal. Further, fossil evidence shows that subunit B, although also Triassic, is slightly younger than subunit A (see Paleontology section). Rocks in this subunit consist of siltstone, chert, limestone, and minor sandstone. The siltstone is closely fractured and hence crumbly, even in outcrop. Green and gray chert occurs in 5- to 15-cm-thick beds separated by thin shaley interbeds. Limestone occurs both as fossil-rich horizons, like that in subunit A, and as silty lime mudstone in 5 by 10 cm lenses. Sandstone is found locally in 10-cm-thick layers. The sandstone is fine-grained, dark gray green, and lithic-rich, containing abundant limestone and volcanic lithic clasts.

In addition to the rocks of the Cinnabar Creek area (our subunits A and B), Cady et al. (1955) broadly included rocks that crop out "in the upland area east of Flat Top Mountain" as part of the Gemuk Group type locality (Fig. 2A). They described a purportedly homoclinal 5,000–10,000-foot- (~1500–3000 m) thick section of massive, interbedded red, green, and black siltstone. They believed that this section lay stratigraphically below the northernmost beds of the Cinnabar Creek section (our subunit B), and because it was lithologically different they thought it was older than Late Triassic and speculated it could even be Carboniferous or Permian. The structural complications at Cinnabar Creek negate all of this reasoning. Also, our reconnaissance mapping east of Flat Top Mountain revealed not a simple homocline but rather folds, overturned beds, and widely divergent bedding strikes. Moreover, a chert sample from ~10 km east of Flat Top Mountain (locality 05ADw37, Fig. 2B) yielded radiolarians whose age range is Early Jurassic to Early Cretaceous (see Paleontology section).

In summary, the original type area of the Gemuk Group consists of two rock successions (the Cinnabar Creek area and the upland area east of Flat Top Mountain), whose relationship was thought by Cady et al. (1955) to be straightforward. We divide the

[3] Note that throughout this paper, we follow the conventions that the station number denotes a single locality and that multiple samples taken at that single locality are lettered A, B, C, etc.

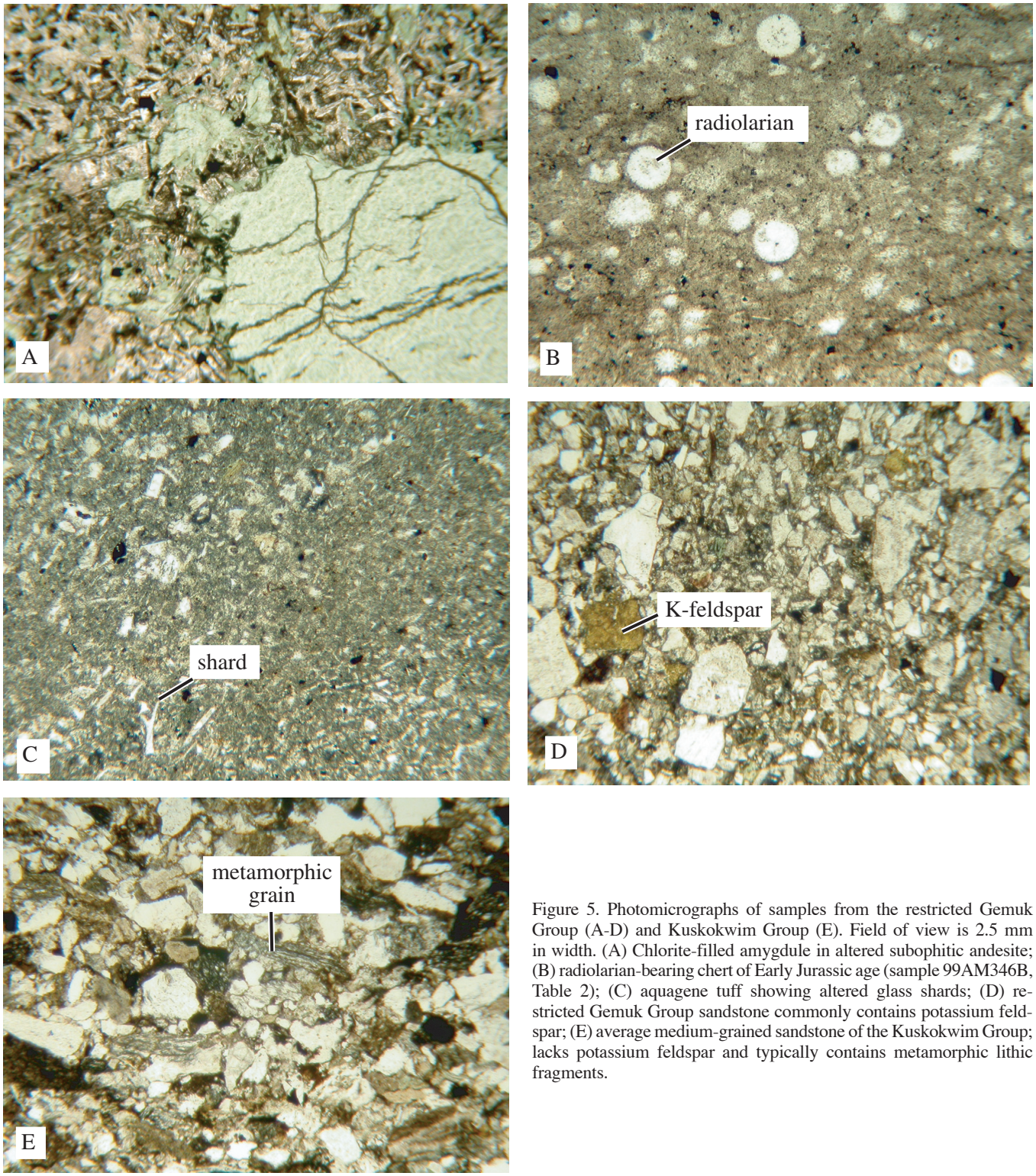


Figure 5. Photomicrographs of samples from the restricted Gemuk Group (A-D) and Kuskokwim Group (E). Field of view is 2.5 mm in width. (A) Chlorite-filled amygdule in altered subophitic andesite; (B) radiolarian-bearing chert of Early Jurassic age (sample 99AM346B, Table 2); (C) aquagene tuff showing altered glass shards; (D) restricted Gemuk Group sandstone commonly contains potassium feldspar; (E) average medium-grained sandstone of the Kuskokwim Group; lacks potassium feldspar and typically contains metamorphic lithic fragments.

TABLE 1. PETROGRAPHIC POINT-COUNT DATA FOR SANDSTONES FROM THE RESTRICTED GEMUK GROUP AND THE KUSKOKWIM GROUP

			F		Ls					Lv										
Sample	Qm	Qp	pl	ksp	ss	md	ms	ct	ls	fel	und	subv	Lm	mi	chl	ep	sph	op	x	mat
Restricted Gemuk Group																				
04AM51A[1]	80	9	85	12	40	0	0	0	0	85	9	59	3	8	10	3	0	4	1	12
04AM54A[1]	132	0	98	18	8	0	0	1	1	34	65	22	0	9	12	3	0	4	0	17
94AM362A[2]	95	10	120	23	0	2	0	0	14	5	41	75	4	15	7	8	9	4	0	24
99AM360A[2]	89	13	104	36	0	5	7	0	2	10	41	78	6	5	4	12	0	1	0	15
99ADw44C[2]	24	6	49	14	0	0	0	0	86	42	20	148	0	2	9	2	3	2	0	12
Kuskokwim Group																				
94ADw52B[2]	83	9	42	0	0	0	28	0	0	23	69	106	28	2	10	0	0	8	2	15
98AM78B[2]	66	11	83	0	0	10	10	0	0	12	100	57	35	12	4	3	12	1	1	24
97ADw008[3]	52	9	73	0	0	0	13	0	0	8	100	73	46	13	13	1	0	4	1	3
98ADw17A[3]	68	76	18	0	28	17	9	0	28	12	33	68	26	2	15	0	0	8	0	19
98AM06A[3]	73	40	7	0	0	37	27	4	0	10	42	33	112	12	3	1	0	4	0	19

Category abbreviations: Qm, monocrystalline quartz; Qp, polycrystalline quartz; F, feldspar; pl, plagioclase; ksp, potassium feldspar; Ls, sedimentary lithic grains; ss, sandstone; md, mudstone; ms, metasandstone; ct, chert; ls, limestone; Lv, volcanic lithic grains; fel, felsic; und, undifferentiated; subv, subvolcanic or intrusive; Lm, foliated metamorphic lithic grains; mi, mica; chl, chlorite; ep, epidote; sph, sphene; op, opaque; x, other; mat, matrix. At least 400 framework grains were counted per sample. Modal data are presented in Table 6.

[1] Sample location shown on Figure 3

[2] Sample location shown on Figure 6

[3] Sample locations as follows: 97ADw008, 61°53′37″, 157°31′27″; 98ADw17A, 61°32′37″, 158°35′30″; 98AM06A, 61°44′23″, 157°58′41″

Cinnabar Creek area into subunits. Subunit A is a partial section of an Upper Triassic, volcanic-dominated part of the restricted Gemuk Group. Subunit B provides additional information about slightly younger Triassic chert-rich strata. Subunit C is part of the restricted Gemuk Group and not part of the Upper Cretaceous Kuskokwim Group (per Cady et al., 1955) and is probably Lower Cretaceous. Cady et al. (1955) included the rocks east of Flat Top Mountain in their original thickness estimate, believing them to be stratigraphically below the Cinnabar Creek succession. New evidence does not support Cady et al.'s (1955) inference; the area east of Flat Top Mountain is now known to include Jurassic or Lower Cretaceous rocks. Finally, we emphasize that although these rocks are folded and faulted they are not intractable. Careful mapping and thorough sampling for fossils and datable tuffs could better establish the stratigraphy.

Outside of the original type area, two other localities in Taylor Mountains D8 quadrangle have yielded Late Triassic fossil ages (details in the Paleontology section) for the restricted Gemuk Group. One of these, a spectacular river cut exposure (locality 05AM235, Fig. 2B; Fig. 4E) consists of a folded section of interbedded brown limey mudstone, green mudstone, and chert that yielded micro- and megafossils of Late Triassic age. The second locality (05AM252, Fig. 2B) has rubble of brown mudstone, green chert, and black chert, and outcrop of medium-grained sandstone; the green chert yielded Late Triassic radiolarians. How these additional Upper Triassic rocks fit into the subunits defined for the Cinnabar Creek area is not certain, but they would appear to roughly correlate with subunit B. Nowhere outside of the Cinnabar Creek area have we observed pillow lavas interbedded with restricted Gemuk Group strata as is characteristic of subunit A.

The lower contact of the restricted Gemuk Group is not exposed in the Taylor Mountains D8 quadrangle; the oldest known rocks are in subunit A. The upper contact with the Upper Cretaceous Kuskokwim Group is also not exposed, and its nature is unknown.

RESTRICTED GEMUK GROUP IN THE SLEETMUTE QUADRANGLE

Cady et al. (1955) traced the Gemuk Group northward into southwestern Sleetmute quadrangle (Fig. 2A). They recognized three outcrop belts of Gemuk Group, one of which included the type area; the other two were shown as inliers within strata of the younger Kuskokwim Group (Cady et al., 1955, their pl. 1; Fig. 2A). Our new mapping connects all three of these outcrop belts into a single tract that includes the type area (Fig. 2B). A summary of our new mapping in Sleetmute quadrangle is shown in Figure 6. Several vertical faults cut through the restricted Gemuk Group but do not show major offset. The contact with overlying Upper Cretaceous Kuskokwim Group is not exposed and could either be a disconformity or a minor angular unconformity.

The dominant lithologies of the restricted Gemuk Group in the Sleetmute quadrangle are dark mudstone, less abundant (but distinctive) maroon and green mudstone (Fig. 4F), chert (Fig. 5B), cherty tuff, tuff (Fig. 5C), and turbiditic sandstone (Fig. 5D), plus rare limestone. There are similarities and differences between the restricted Gemuk Group in the type area and the exposures in the

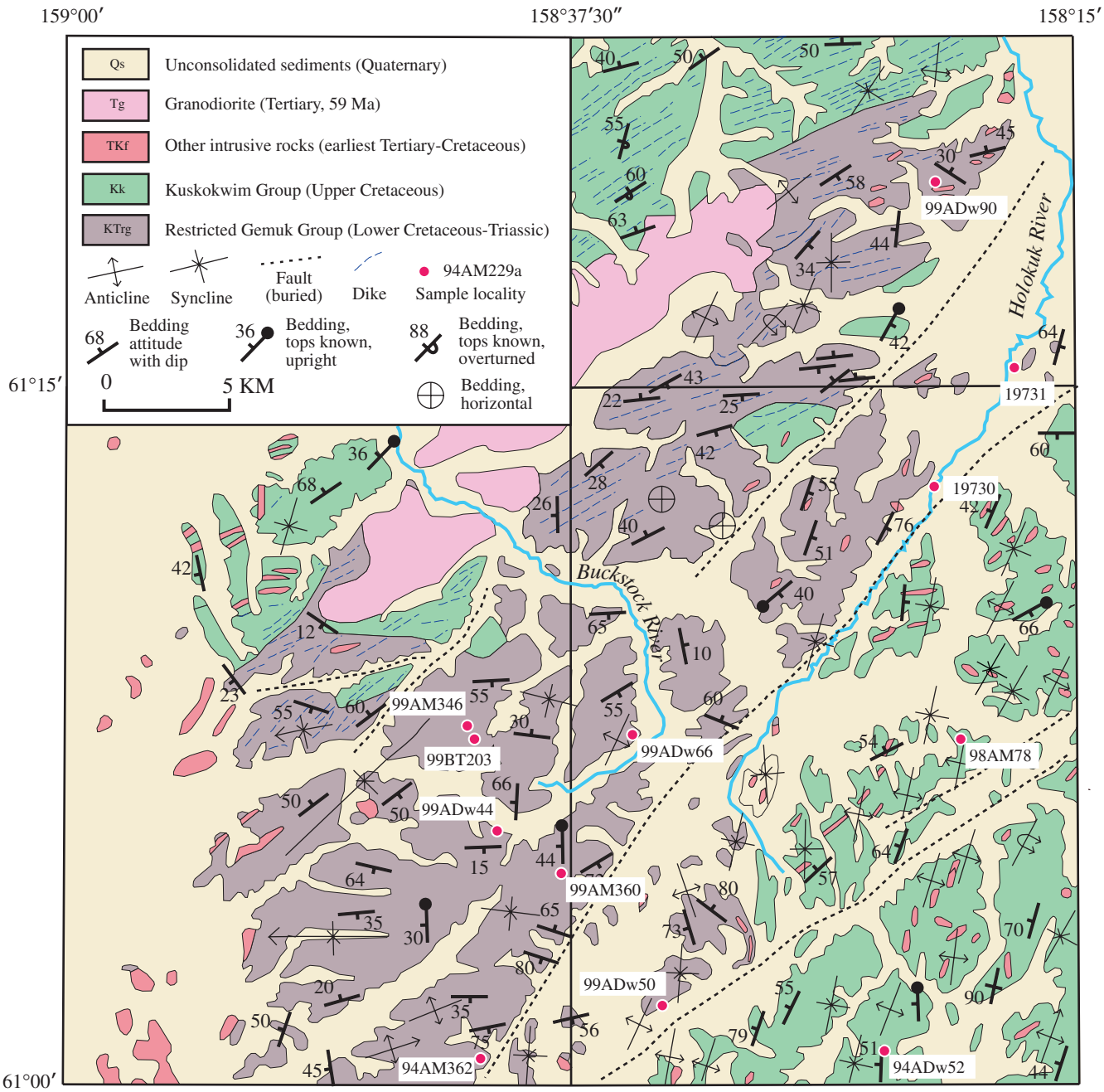


Figure 6. Geologic map of the restricted Gemuk Group in the southwestern corner of the Sleetmute quadrangle based on our new work. Also shown are fossil and point count sample localities. See Figure 2B for location of map.

Sleetmute quadrangle. In the Sleetmute quadrangle, Triassic rocks have not been recognized, and there are no pillow lavas. On the other hand, Jurassic rocks are abundant and, as in the type area, Lower Cretaceous sandstones are an important component.

Overall we have a broad understanding of the stratigraphic succession, but given the relatively poor exposure and the reconnaissance level of our mapping, we can provide no more than a schematic presentation of it. Locally we have been able to define continuous stratigraphy for short homoclinal sections (between 225 and 850 m thick), but these isolated sections cannot be tied together. However, the fossil and lithologic data from Sleetmute and Taylor Mountains quadrangles are sufficient basis for constructing the schematic section shown on Figure 7.

The Jurassic section is mostly siltstone and chert but may also include sandstone. The dominant rock type is black and dark brown siltstone that forms resistant outcrops, but crumbles when struck with a hammer. Thin layers of locally maroon, green, or olive colored mudstone are notable but volumetrically minor.

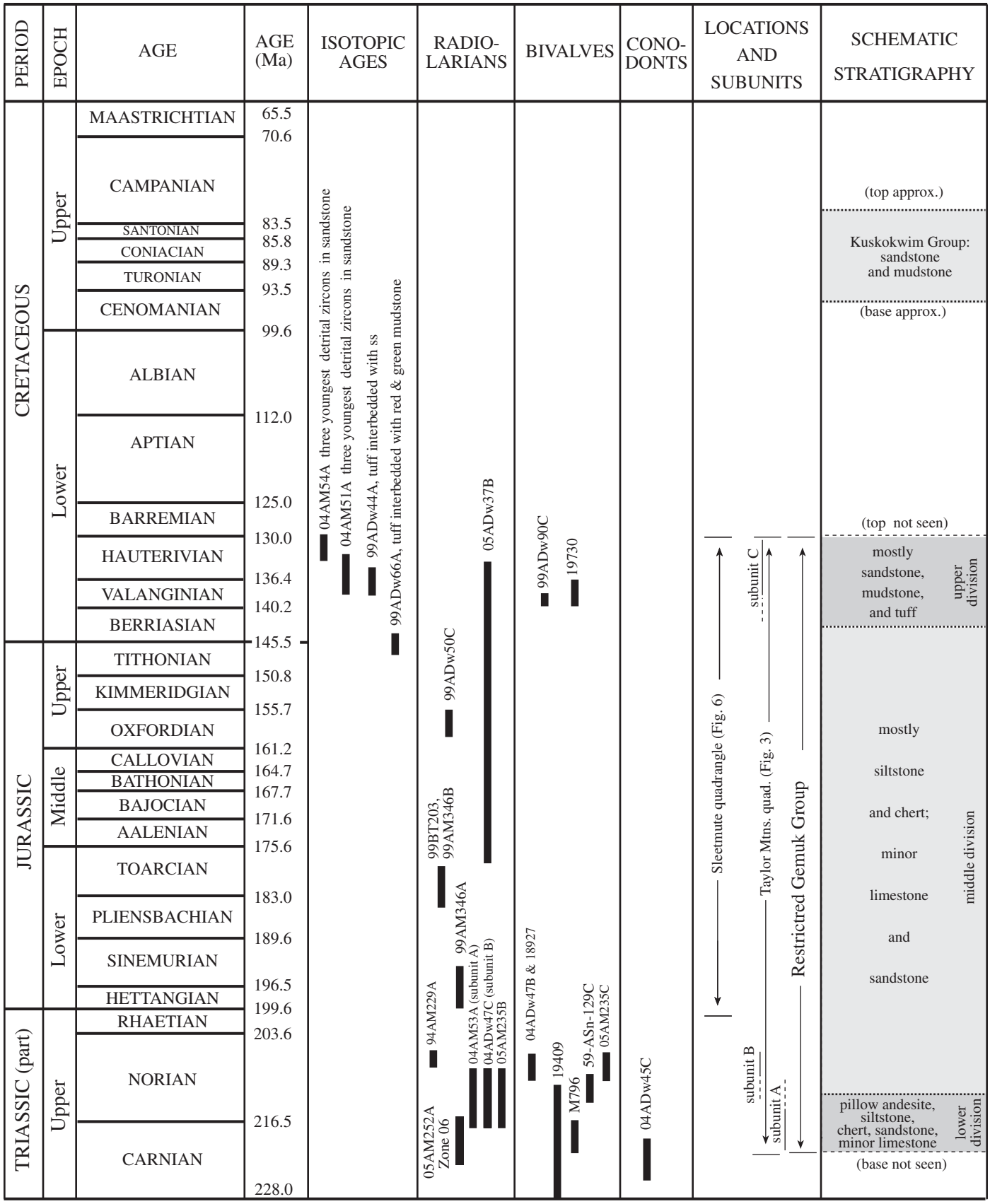


Figure 7. Composite stratigraphic section of the restricted Gemuk Group in northwestern Taylor Mountains and southwestern Sleetmute quadrangles showing age control and generalized, informal lithologic divisions. For fossils the bars show the age range of each collection; for isotopic ages the bars show the age plus or minus the error. Numerical calibration of the time scale is from Gradstein et al. (2004).

Chert, which occurs in beds a few to 20 cm thick, varies in color including black, gray, tan, and green varieties (Fig. 4G). Volumetrically minor limestone is found locally interbedded with siltstone and consists of dark gray micrite in beds up to 15 cm thick. None of the limestone has yielded diagnostic microfossils, and hence, the specific stratigraphic position of limestone in Figure 7 is unclear. Four radiolarian cherts yielded age diagnostic Jurassic fossils. As shown in Figure 7, these represent two ages of the Early Jurassic (99AM346A, 99BT203, and 99AM346B), and one of the Late Jurassic (99ADw50C). Middle Jurassic fossils have not been found in the Sleetmute quadrangle. This could possibly be due to nondeposition but more likely to sparse sampling. Fossil age control will be discussed in more detail in the Paleontology section. The presence of sandstone in the Jurassic part of the section is not proven but suggested by occurrences of sandstone near rubble crops of Jurassic chert.

The uppermost Jurassic and lowermost Cretaceous part of the section is marked by abundant felsic to intermediate tuffs (Fig. 5C). The tuffs are interbedded with siltstone, cherty mudstone, tuffaceous chert, and sandstone. Bed thicknesses are quite variable from a few centimeters to several meters. Variable colors are also characteristic, including buff, tan, and greenish gray (Fig. 4H). Age control for this part of the section is based on two U-Pb tuff ages and two bivalve collections. In the four places where we have age control, the lithology is extremely varied. Specifically, (1) a 146 Ma tuff is interbedded with maroon and green mudstone in a section that also includes green sandstone, (2) a 137 Ma tuff is interbedded with graywacke turbidites, (3) an early Valanginian coquina (99ADw90C) is in tan siltstone near chert, and (4) a Valanginian bivalve (collection 19730, Cady et al., 1955) is associated with relatively clean sandstone. More details on these data are provided in the Isotope Geochronology and Paleontology sections.

The youngest part of the restricted Gemuk Group consists mostly of turbiditic, feldspathic sandstone. That these sandstones belong with the restricted Gemuk Group is shown by local interbeds of distinctive Gemuk Group lithologies including maroon and green siltstone and a few tuffs. The stratigraphic thickness of the turbiditic rocks is probably significant; in one place we know that the turbidites represent at least 900 m of section. These sandstones are generally greenish gray and interbedded with mudstone. Partial Bouma sequences are consistent with a turbidite origin. Medium-grained sandstones are siliciclastic, containing quartz (~25%), plagioclase feldspar (25%–28%), potassium feldspar (5%–9%), lithic grains (33%–36%), and miscellaneous clasts (5%–10%) including mica, chlorite, epidote, and opaques (n = 2, samples 94AM362A and 99AM360A, Table 1; Fig. 6). One sandstone sample from an interbedded sandstone, shale, and tuff sequence (99ADw44C, Table 1; Fig. 6) is unusually lithic rich. Framework grains in this sample are quartz (8%), plagioclase feldspar (12%), potassium feldspar (3%), lithic clasts (73%), and miscellaneous trace clasts (4%). Two out of three of the lithic clasts are volcanic; the remaining clasts are limestone and shell fragments.

Cady et al. (1955) did not recognize the abundance of sandstone in their original definition of the Gemuk Group. In southwestern Sleetmute quadrangle Cady et al. (1955) had mapped several ridge-top sandstones as Kuskokwim Group above Gemuk Group (Figs. 2A and 4H). We reassign these sandstones to restricted Gemuk Group. These beds are conformable with underlying cherty and tuffaceous mudstones and as we now recognize, the restricted Gemuk Group has abundant sandstone. This situation parallels what happened with subunit C (Fig. 3) in the type area that Cady et al. (1955) had originally assigned to the Kuskokwim Group and that we reassign to the Lower Cretaceous part of the restricted Gemuk Group.

Another revision we have made to Cady et al.'s (1955) original mapping involves their report of lava in Gemuk Group of the Sleetmute quadrangle (Fig. 2A). In this area they reported lava interbedded with siltstone and suggested this was a similar occurrence to flows in the Cinnabar Creek type area. In our new mapping we have reassigned this area to the Kuskokwim Group and note that the referred to flows are instead sills[4]. A $^{40}Ar/^{39}Ar$ age of 70 Ma was obtained from one such sill nearby (94ADw59B, Fig. 2B).

The lower contact of the restricted Gemuk Group is not exposed in Sleetmute quadrangle. While also not exposed, the upper contact with the Upper Cretaceous Kuskokwim Group can be located within a few hundred meters (along the east side of the restricted Gemuk Group outcrop belt in Sleetmute A7 quadrangle, Figs. 2B and 6). A substantial age gap may exist between the youngest known restricted Gemuk Group (ca. 130 Ma or younger) and oldest known Kuskokwim Group (ca. 95 Ma; Miller et al., 2002). The nature of the contact is unknown but most likely is a disconformity. Both the restricted Gemuk Group and the Kuskokwim Group appear to share the same deformational history, and the few bedding strikes near the contact are subparallel.

STRUCTURE AND METAMORPHISM

The restricted Gemuk Group has been subjected to folding of varying intensity and is cut by high-angle faults including strands of the Denali strike-slip fault (Figs. 1A and 2B). Cleavage is generally lacking. Folds are largely open to tight and upright. Despite this evidence for relatively mild tectonism, there are hints of structural complexities. A local zone of graywacke turbidites in the upper part of the restricted Gemuk Group shows disrupted bedding and web structure, perhaps representing a bedding parallel fault zone. Recumbent fold hinges have been observed at outcrop scale in Sleetmute quadrangle. Hence, apparently homoclinal sections may be deformed by undetected folds and/or bedding parallel faults. A good case in point is the type area, which turns out to be more deformed than either Cady et al. (1955) or Sainsbury and MacKevett (1965) thought.

The restricted Gemuk Group is essentially unmetamorphosed except near plutons, where biotite hornfels is developed at intrusive contacts. In the type area, the amygdaloidal intermediate lavas show chlorite and calcite alteration but are not regionally meta-

[4] Interestingly, in his original 1945 field notes, J.M. Hoare reported these to be sills.

morphosed. Similarly, the sandstones show no more than minor secondary clay development between clasts. Conodont alteration indices (CAI) from the type area are 2.5–3, indicating a temperature of 100 to 200 °C. At a geothermal gradient of 30 °C per km, this would imply 3.3–6.6 km burial (Epstein et al., 1977).

PALEONTOLOGY

Paleontologic data support a Late Triassic to Early Cretaceous age range for the restricted Gemuk Group. We present new fossil data for radiolarians, conodonts, and bivalves. We also review and update ages from previous bivalve collections.

Radiolarians

Ten chert samples yielded age-diagnostic radiolarian collections (Table 2; Fig. 7). Three samples from the Cinnabar Creek section of the type area are Late Triassic, but they represent two radiolarian zones. One chert from subunit A (04AM53A, Fig. 3) and one from subunit B (04ADw47C, Fig. 3) are in the *Capnodoce* Zone of Pessagno (1979), which spans the latest Carnian through middle Norian. Another sample from subunit B (94AM229A) is younger because it contains radiolaria of the *Betraccium* Zone of the late Norian. One sample (05ADw37B, Fig. 2B) from the "upland area east of Flat Top Mountain" (of Cady et al., 1955; Fig. 2A) yielded a younger age span of late Toarcian (Late Jurassic) to late Hauterivian (Early Cretaceous). Two samples from outside of the original type area also yielded radiolarians of Late Triassic age. One of these (05AM235B, Fig. 2B) indicates a Carnian to late middle Norian age. The other (05AM252A, Fig. 2B) indicates a Carnian to Norian age.

The remaining four samples are from the Sleetmute quadrangle (Fig. 6), representing the Jurassic part of the section. One sample (99AM346A) indicates Zone 04–05 of Pessagno et al. (1987), which spans the Hettangian to lower Sinemurian of the Early Jurassic. Two samples (99BT203 and 99AM346B) indicate Zone 01 of Pessagno et al. (1987) or upper Pliensbachian to middle Toarcian in the Early Jurassic. The last sample (99ADw50c) indicates Subzone 2 gamma to the lower part of Subzone 2 beta: middle to upper Oxfordian of the Late Jurassic (of Pessagno et al., 1987). Samples 99AM346A and B are from rubble in the same saddle.

Conodonts

Although volumetrically minor, the limestones of the restricted Gemuk Group were considered a promising target for age control. Eight large (5–10 kg) samples, however, yielded only two "collections," one of which (04ADw45C) consisted of a single conodont. This single conodont (*Metapolygnathus polygnathiformis*) was from subunit A of the type area and is diagnostic of late Carnian age. Another collection (04ADw47B) from a limestone interbedded with chert in subunit B is not age diagnostic but does provide some environmental information. It consists of 445 elements of a single, long-ranging cosmopolitan species (*Neogondolella navicula*), typical of deeper and (or) cooler water conodont biofacies. Almost all of the conodonts are juvenile Pa elements (Table 3); the near absence of other conodont elements from this sample indicates their postmortem winnowing into the deeper-water basin in which radiolarian oozes accumulated.

Megafossils

Bivalves provided the initial age determinations, Late Triassic and Early Cretaceous, for strata of the Gemuk Group (Cady et al., 1955; Sainsbury and MacKevett, 1965). Two Late Triassic fossil collections were listed by Cady et al. (1955) from the Cinnabar Creek area. One of these (USGS Mesozoic locality 18927; Fig. 3) consists of a monospecific accumulation of *Monotis* (*Pacimonotis*) *subcircularis* Gabb (listed therein as *Monotis subcircularis*) in a coquinoid limestone. This species is indicative of an early late Norian age and is widespread throughout the eastern margin of Panthalassa (paleo-Pacific Ocean), occurring on both the western margins of North and South America, as well as in the Koryak terrane of northeastern Siberia. Its occurrence at Cinnabar Creek was noted in the recent monographic treatment of Alaskan monotid bivalves by Silberling et al. (1997). We resampled this locality (04ADw47B, Fig. 3); the new collection, like the earlier collection, consists of a monospecific accumulation of *M.* (*P.*) *subcircularis* Gabb (R.B. Blodgett, personal observation, 2004). Most of the rock was subsequently digested for conodont analysis yielding positive results (see section on Conodonts). The second Late Triassic fossil locality reported by Cady et al. (1955; USGS Mesozoic locality 19409, Fig. 3) consisted of float fragments that contained three bivalve species: *Halobia* sp. indet., *Myophoria* aff. *M. vestita* Albert, and *Mysidioptera?* sp., indicative of a Late Triassic age. Based on current knowledge of the genus *Halobia* (McRoberts, 1997), a revised age range of Carnian to middle Norian is indicated.

Sainsbury and MacKevett (1965) discovered two additional Late Triassic megafossil localities in the Cinnabar Creek area. The first (USGS Mesozoic locality M796, Fig. 3) contains fragmentary *Halobia* resembling *H. ornatissima* Smith and terebratuloid and spiriferid (?*Psioidea*) brachiopods. A Late Triassic, probably late Carnian (Viarnian *sic* therein) age was reported by these authors. The present age distribution of *H. ornatissima* Smith is still considered to be late Carnian (McRoberts, 1997). The second locality (Sainsbury field locality 59ASN129, Fig. 3) contained fragments of *Halobia* and a more coarsely ribbed bivalve that may be *Monotis*. Only a general age assignment of Late Triassic was suggested in Sainsbury and MacKevett (1965). However, if the identification of the *Monotis* could be proved true, our present knowledge suggests a middle Norian age because this is the only time interval in which these two genera have overlapping stratigraphic ranges.

Field work in 2005 resulted in discovery of additional examples of *Monotis* (*Pacimonotis*) *subcircularis* Gabb from 17 km north of the Cinnabar Creek area (05AM235C, Fig. 2B; Table 2). This collection came from green mudstone, part of a large river cut exposure of limey mudstone, green mudstone, and chert (Fig. 4E).

TABLE 2. FOSSIL AGE DETERMINATIONS OF SAMPLES FROM THE RESTRICTED GEMUK GROUP

Field no.	Location	Lithology	Fauna	Age	Comments
99ADw90C	See Fig. 6. Sleetmute B7; 61°19′15″, 158°20′57″	Coquina horizon in discontinuous section of tan siltstone and black chert	Bivalve: *Buchia sublaevis* Keyserling	early Valanginian	Sample looks similar to the coquinoid limestone developed across much of northern Alaska, although the density of shell material is a bit less than typical of that unit.
99ADw50C	See Fig. 6. Sleetmute A7; 61°01′42″, 158°33′08″	Calcareous nodules	Radiolarians: *Orbiculiforma* sp. cf. *O. quadrata* Pessagno; *Praeparvicingula deadhorsensis* Pessagno, Blome, and Hull; *Praeparvicingula packsaddlensis* Pessagno, Blome, and Hull; *Archaeodictyomitra* sp. aff. *A. rigida* Pessagno	Zone 2, Subzone 2 gamma to lower part of Subzone 2 beta (Pessagno et al., 1993). Late Jurassic: middle Oxfordian to late Oxfordian	Northern Boreal assemblage (sensu Pessagno et al., 1993, 1999). Note that *Praeparvicingula deadhorsensis* is only known to date from the middle Oxfordian Southern Boreal assemblage of the Galice Formation s.l., Smith River subterrane, northwestern California and from the Northern Austral assemblage (Sula Islands, Indonesia Displaced Gondwana terrane; Pessagno and Hull, 2001). *P. packsaddlensis* is only known from the Galice Formation s.l., Smith River subterrane.
05ADw37B	See Fig. 2B. Taylor Mts. D8; 60°53.271′, 158°40.894′	Radiolarian chert, dark on fresh surface, weathers chalky	Radiolarians: *Archaeocenosphaera* sp., *Praeconocaryomma* sp., *Praeparvicingula* sp.	Superzone 1, Zone 1A, Subzone 1A2 to Zone 5, Subzone 5C. Late Jurassic (upper Toarcian) to Early Cretaceous (lower Hauterivian)	
99BT203	See Fig. 6. Sleetmute A8; 61°07′30″, 158°41′56″	Light- to medium-gray banded radiolarian chert; chert section ~90 m thick	Radiolarians: *Canoptum anulatum* Pessagno and Poisson; *Orbicuuliforma* spp.	Zone 01 of Pessagno et al. (1987). Early Jurassic: late Pliensbachian to middle Toarcian	Abundant poorly preserved Radiolaria
99AM346B	See Fig. 6. Sleetmute A8; 61°08′01″, 158°42′24″	Radiolarian chert, white and black banded	Radiolarians: *Canoptum anulatum* Poorly preserved indeterminate Spumellaria	Zone 01 of Pessagno et al. (1987). Early Jurassic: late Pliensbachian to middle Toarcian	
99AM346A	See Fig. 6. Sleetmute A8; 61°08′01″, 158°42′24″	Gray radiolarian chert	Radiolarians: *Canoptum* spp.; *Archaeocenosphaera* spp.; *Pantanellium tanuense* Pessagno and Blome; *Protopsium* spp; Numerous poorly preserved Spongodiscacea	Zone 05 to Zone 04 of Pessagno et al. (1987). Early Jurassic: Hettangian to early Sinemurian	Fauna lacks Upper Triassic elements such as *Betraccium* Pessagno and lacks upper Sinemurian elements such as first true hagiastrids. In the Queen Charlotte Islands *Pantanellium tanuense* is restricted to Zone 05.
94AM229A	See Fig. 3. Taylor Mts. D8; 60°47′38″, 158°50′43″	Green radiolarian chert	Radiolarians: *Canoptum* spp.; *Capnuchospaera* spp.; *Pantanellium* sp. Aff. P. *silberlingi* Pessagno; *Crucella?* Sp.	early late Norian	Assemblage totally lacks Capnodoce De Wever and other members of the Capnodocinae Pessagno. Hence, this horizon is above the top of the underlying Capnodoce Zone (Pessagno, 1979; Blome, 1984).

(*continued*)

TABLE 2. FOSSIL AGE DETERMINATIONS OF SAMPLES FROM THE RESTRICTED GEMUK GROUP (*continued*)

Field no.	Location	Lithology	Fauna	Age	Comments
05AM235C	See Fig. 2B. Taylor Mts. D8; 60°55.865′, 158°50.947′	Green mudstone	Bivalve: *Monotis (Pacimonotis) subcircularis* Gabb	early late Norian	
04ADw47B	See Fig. 3. Taylor Mts. D8; 60°46.585′, 158°49.688′	Limestone	Bivalve: *Monotis (Pacimonotis) subcircularis* Gabb	early late Norian	Resampled USGS Mesozoic locality 18927 of Cady et al. (1955)
04ADw47C	See Fig. 3. Taylor Mts. D8; 60°46.585′, 158°49.688′	Black radiolarian chert	Radiolarians: *Capnodoce* sp., Spumellaria, abundant casts Common siliceous sponge spicules	*Capnodoce* Zone of Pessagno (1979), Blome (1984). Late Triassic: late Carnian(?); early Norian to late middle Norian	Preservation poor
04AM53A	See Fig. 3. Taylor Mts. D8, 60°46′31″, 158°51′46″	Radiolarian chert, local gray, black, and green	Radiolarians: *Capnodoce* sp.; *Canoptum farawayense* Blome; *Canoptum* sp. aff. *C. laxum* Blome; Indeterminate Spumellaria with spines displaying torsion of ridges and grooves (typical of Triassic) Siliceous sponge spicules	*Capnodoce* Zone of Pessagno (1979), Blome (1984). Late Triassic: late Carnian(?); early Norian to late middle Norian	Preservation fair
05AM235B	See Fig. 2B. Taylor Mts. D8; 60°55.865′, 158°50.947′	Red radiolarian chert	Radiolarians: *Capnodoce* sp., *Hagiastrum* sp., *Pseudoheliodiscus* sp. fragment	Zone 07. Late Triassic: Carnian to late middle Norian	
05AM252A	See Fig. 2B. Taylor Mts. D8; 60°46.777′, 158°59.094′	Green radiolarian chert	Radiolarians: Indeterminate multicyrtid Nassellariina, *Canoptum* sp., *Sarla* sp. aff. S. vetusta Pessagno	Zone 06. Late Triassic: Carnian to Norian	

Radiolarians identified by E.A. Pessagno, Jr.; bivalves identified by William P. Elder (99ADw90C) and Robert B. Blodgett (04ADw46A, 05AM235B).

TABLE 3. CONODONT DATA FROM THE RESTRICTED GEMUK GROUP, TAYLOR MOUNTAINS QUADRANGLE

Field no. (USGS collection no.)	Location	Lithology	Conodont Fauna	Age	CAI	Conodont Biofacies and Depositional Environment	Remarks
04ADw45C (Mes. 35055)	See Fig. 3. Taylor Mts. D-8 60°46.45′, 158°52.63′	Limestone from a well-defined band of rubble in saddle between pillow basalt flows. Sample is a few tens of meters higher in the section than 04ADw46A.	1 juvenile Pa element *Metapolygnathus polygnathiformis* (Budurov and Stefanov); 83 smooth conical ichthyoliths with central, narrow and relatively shallow basal cavity limited to lower 1/4 of element	late early–earliest late Carnian (middle early Late Triassic)	2.5 to 3.0	Indeterminate (only one conodont was recovered)	6.0 kg of rock was processed; 2.36 kg +20 mesh and 329 g 20–140 mesh insoluble residue. Heavy-mineral concentrate consists chiefly of recrystallized, composite white carbonate grains, subordinate ichthyoliths, and one conodont.
04ADw46A	See Fig. 3. Taylor Mts. D-8, 60°46.63′, 158°52.81′	Partly silicified limestone containing a few siliciclastic grains. Limestone bed is ~15 cm thick and interbedded with argillite.	No conodonts were found; 24 smooth conical ichthyoliths having a central, narrow, and relatively shallow basal cavity limited to lower 1/4 of element	*Monotis (Pacimonotis) subcircularis* Gabb in this sample indicates a Late Triassic, early late Norian age			6.0 kg of rock was processed; 2.84 kg +20 mesh and 402 g 20–140 mesh insoluble residue. Heavy-mineral concentrate consists chiefly of abundant phosphatic shell fragments and lesser carbonate grains.
04ADw47B (Mes. 35062)	See Fig. 3. Taylor Mts. D-8, 60°46.585′, 158°49.688′	The sample is from a single rubble band of *Monotis*-bearing limestone (~10–15 cm thick) in a section of radiolarian chert.	*Neogondolella navicula* (Huckeide) 445 mainly incomplete Pa elements and 12 M and S element fragments	Conodonts indicate a late Early Permian to Late Triassic age, and most likely Late Triassic, probably Norian. Note, age refined by radiolarians from interbedded chert sample 04ADw47C (Table 2) to Late Triassic: late Carnian(?); early Norian to late middle Norian	2.5 to 3.0	Postmortem transport within or from the neogondolellid biofacies. Nearly all conodont elements are incomplete and nearly all are Pa elements suggesting the more abundant, fragile, and lighter weight ramiform elements (bar and blade elements and fragments) were likely hydraulically winnowed into deeper water (probably into the nearby siliceous ooze that would become chert).	1.95 kg of rock was processed; 175 g +20 mesh and 163 g 20–140 mesh insoluble residue. Heavy-mineral concentrate consists chiefly of white carbonate grains, conodonts (almost all Pa elements), lesser hexagonal tan mica flakes and books and 72 fish teeth, plates, and otoliths, minor composite ferruginous grains, and rare composite glauconite grains.

Conodonts identified by Anita G. Harris.

This species denotes a very narrow stratigraphic range of early late Norian (Late Triassic). Chert from this same locality (05AM235B, Table 2) yielded a Carnian to late middle Norian radiolarian age.

Two Early Cretaceous megafossil localities were reported from strata assigned to the Gemuk Group by Cady et al. (1955). The first locality (USGS Mesozoic locality 19730, Fig. 6) is from a cut-bank of the Holokuk River and consists of a float fragment (thought to be locally derived) of *Aucella crassicollis* Keyersling, considered to be indicative of an early Early Cretaceous age. The genus *Aucella* is now recognized to be a junior synonym of the genus *Buchia,* and this species is now commonly thought to be indicative of a Valanginian age. Their second locality (USGS Mesozoic locality 19731, Fig. 6) was collected from a bluff on the east side of the Holokuk River and contained *Inoceramus* sp. (fragment of a large species) and *Serpula* sp. indet. (a worm tube). Only a generalized Cretaceous age was indicated in Cady et al. (1955). We have added a new megafossil locality (99ADw90C, Fig. 6) from a coquina horizon in a discontinuous section of tan siltstone and black chert west of Holokuk River. The coquina was examined and identified by William P. Elder as consisting of a monospecific accumulation of the bivalve *Buchia sublaevis* Keyserling, which he considered indicative of an early Valanginian age.

ISOTOPE GEOCHRONOLOGY

Tuffs

Intermediate to felsic tuffs are common in the upper part of the restricted Gemuk Group in the Sleetmute quadrangle. Among seven that were sampled for geochronology, two yielded zircons suitable for U-Pb geochronology.

The older of the two tuffs (99ADw66A, Fig. 6) is interbedded with maroon and green mudstone. Eight zircon fractions were dated by the TIMS method. The analyses were done at Washington University using methods described in Miller et al. (2000). All eight fractions are concordant and show a spread of $^{207}Pb/^{206}Pb$ ages from 130 to 149 Ma (Table 4; Fig. 8A). The age is interpreted to be 145.9 ± 1.4 Ma on the assumption that the younger concordant grains have suffered minor lead loss.

A slightly younger tuff (99ADw44A, Fig. 6) is interbedded with graywacke turbidites and yielded a SHRIMP age of 136.5 +2.2/−1.0 Ma (Table 5; Fig. 8B). This age is based on a coherent group of the youngest four (out of six) individual zircons (Fig. 8B, inset). This age estimate is based on the assumption that the older grains are xenocrystic, hence derived from an older part of the volcanic pile. Alternatively, it is possible that the younger grains have experienced minor lead loss and that the older grains better reflect the age of the tuff; in this case, the age could be as old as 140 Ma. Either way, the tuff is Early Cretaceous in age.

Detrital Zircons

Detrital zircon populations were dated from two sandstone samples from subunit C of the restricted Gemuk Group type area.

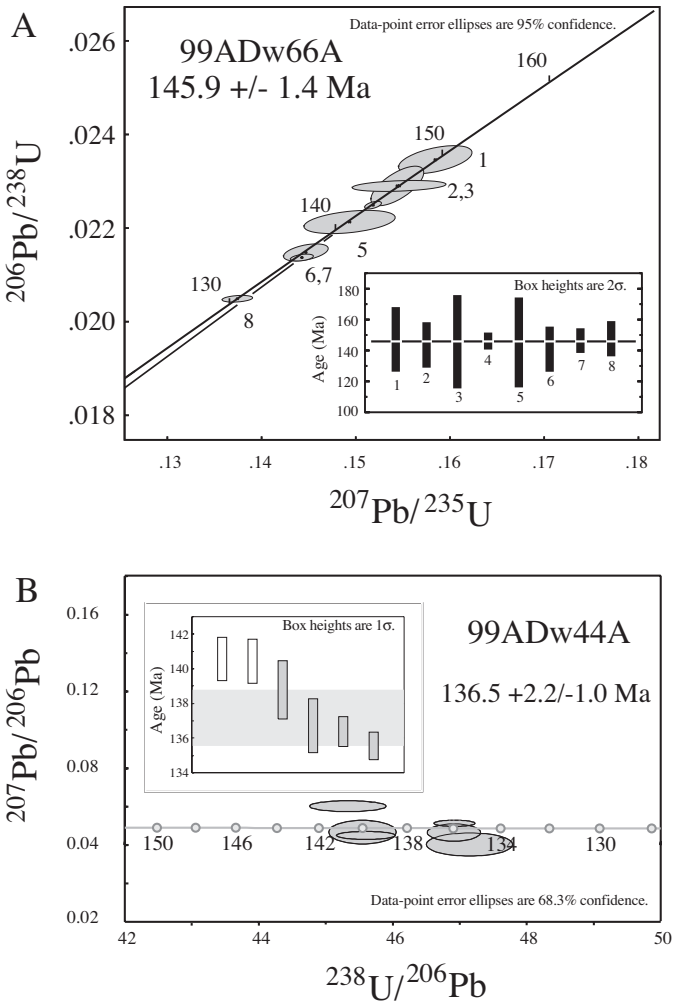


Figure 8. U-Pb concordia diagrams for two tuffs from the restricted Gemuk Group. (A) Standard concordia diagram based on TIMS data for sample 99ADw66A (see Figure 6 for location). As discussed in text, an age of 145.9 ± 1.4 Ma is interpreted. (B) Tera-Wasserburg diagram based on SHRIMP data for sample 99ADw44a (see Figure 6 for location). As discussed in text, an age of 136.5 + 2.2/−1.0 Ma is interpreted.

Mineral separates were done by A to Z, Inc., and single-crystal age determinations were done on the SHRIMP-RG at Stanford University in November 2004. Methods are described in Bradley et al. (this volume). Both samples (04AM51A and 04AM54A) yielded remarkably fresh, angular zircons, and the zircon populations are similar to each other. Locations are shown in Figure 3; the data are shown in Table 5 and plotted in Figure 9.

Fifty-five detrital zircons were dated from sample 04AM51A (Figs. 9A and 9B). The data show a major uninterrupted age cluster between 180 and 133 Ma (Toarcian to Hauterivian). Minor age clusters occur between 209 and 203 Ma (Norian) and also between 230 and 216 Ma (Ladian to Norian). The oldest grain is 316 Ma (Early Pennsylvanian). The three youngest grains average 135 Ma.

Fifty-five detrital zircons were also dated from sample 04AM54A (Figs. 9C and 9D). These data show an even stronger

TABLE 4. U-Pb ISOTOPE DILUTION ANALYSES, TUFF FROM THE RESTRICTED GEMUK GROUP, SLEETMUTE QUADRANGLE

FRACTIONS		CONCENTRATIONS					ATOMIC RATIOS							AGE [Ma]	
No.	Properties (1)	Wt. (μg) (2)	Pb rad (ppm) (2)	U (ppm) (2)	Pb com (pg) (3)	Th/U (4)	$^{206}Pb/^{204}Pb$ (5)	$^{207}Pb/^{206}Pb$ (6)	±	$^{207}Pb/^{235}U$ (6)	±	$^{206}Pb/^{238}U$ (6)	±	$^{206}Pb/^{238}U$ (6)	±
Gemuk tuff, 99ADW66A (Fig. 6) (60°07′28″, 158°35′19″)															
1	5 gr, –200,cl,c,l-p	18	2.5	103	11	0.577	275.4	0.04899	42	0.1584	15	0.02346	12	147.2	20.2
2	1 gr, +200,cl,c,l-p	9	3.2	126	3	0.815	554.1	0.04891	29	0.1544	11	0.02290	17	143.6	14.0
3	1 gr, +200,cl,c,l-p	10	2.9	114	4	0.764	398.3	0.04895	62	0.1546	20	0.02290	5	145.7	29.5
4	10 gr, +200,cl,c,l-p	68	3.4	135	11	0.724	1,189	0.04896	10	0.1518	3	0.02249	3	146.1	4.8
5	8 gr, +200,cl,c,l-p	20	1.3	53.3	3	0.681	462.1	0.04895	60	0.1493	19	0.02213	10	145.5	28.4
6	9 gr, +200,cl,c,l-p	31	4.1	172	31	0.759	333.9	0.04885	29	0.1447	9	0.02148	7	140.8	13.9
7	10 gr, +200,cl,c,l-p	60	1.9	85.6	10	0.634	686.7	0.04897	15	0.1443	5	0.02137	3	146.4	7.3
8	6 gr, +200,cl,c,l-p	26	3.0	144	15	0.438	353.2	0.04900	23	0.1384	6	0.02049	3	147.6	10.7

Notes:

1. Cardinal number indicates the number of zircon grains analyzed (e.g., 35 grains); all grains were selected from nonparamagnetic separates at 0° tilt at full magnetic field in Frantz Magnetic Separator; +200 = size in mesh (>75Fm); c = colorless; cl = clear; l-p = long prismatic. All grains were air-abraded following Krogh (1982).
2. Concentrations are known to ± 30% for sample weights of about 20 μg and ± 50% for samples >5 μg.
3. Corrected for 0.0215 mole fraction common-Pb in the ^{205}Pb-^{235}U spike.
4. Calculated Th/U ratio assuming that all ^{208}Pb in excess of blank, common-Pb, and spike is radiogenic ($\lambda\ ^{232}Th = 4.9475 \times 10^{-11}\ y^{-1}$).
5. Measured, uncorrected ratio.
6. Ratio corrected for fractionation, spike, blank, and initial common-Pb (at the determined age from Stacey and Kramers (1975)). Pb fractionation correction = 0.094%/amu (±0.025% 1σ); U fractionation correction = 0.111%/amu (″ 0.02% 1σ). U blank = 0.2 pg; Pb blank # 10 pg. Absolute uncertainties (1σ) in the Pb/U and $^{207}Pb/^{206}Pb$ ratios calculated following Ludwig (1980). U and Pb half-lives and isotopic abundance ratios from Jaffey et al. (1971).

age cluster, between 154 and 130 Ma (Kimmeridgian to Hauterivian). A lesser age cluster falls between 188 and 161 Ma (Pliensbachian to Oxfordian). The oldest grains are 266, 280, and 292 Ma (Permian). The three youngest grains average 132 Ma.

The detrital zircon data provide the youngest age constraint so far for the restricted Gemuk Group (Fig. 7). Rocks of ca. 132 Ma (Hauterivian) age contributed detritus to the sandstone. Although the sandstone could be younger than this, it is lithologically distinct from Upper Cretaceous Kuskokwim Group sandstone (see below). This, coupled with its similarity to other restricted Gemuk Group sandstones for which tuffs provide age control, leads us to believe that the youngest rocks in the restricted Gemuk Group are Early Cretaceous in age.

The detrital zircon data suggest some conclusions about the sediment source. The absence of early Paleozoic or Precambrian zircons is striking in comparison to most Alaskan sandstones (Bradley et al., this volume), and suggests that no old continental source areas contributed sediment. The most likely source is an arc (perhaps intraoceanic) that was active more or less continuously from 230 to 130 Ma (Middle Triassic to Early Cretaceous). The greater proportion of young grains in sample 04AM54A than in sample 04AM51A could be interpreted in terms of progressive unroofing of this arc. As for the exact identity of the source terrane, the detrital zircons are not particularly diagnostic. The Early Cretaceous detrital zircons are broadly coeval with the two interbedded tuffs we've dated from the restricted Gemuk Group sandstones; hence, tuffs and sandstones could have been derived from the same arc. The Jurassic detrital zircons could have come from 187 to 159 Ma plutons in the Togiak terrane of Hagemeister Island and Goodnews Bay quadrangles (Hoare and Coonrad, 1978). The Togiak arc's basement is Triassic in age, and its cover includes Lower Cretaceous tuff. Thus the Togiak terrane is a plausible source for both the older and younger zircons. Looking beyond the closest likely sources, the Koyukuk arc and the combined Wrangellia and Peninsular terranes could also account for the detrital zircon populations (Patton et al., 1994; Plafker and Berg, 1994), but being the closest source, the Togiak seems most straightforward.

SANDSTONE PETROGRAPHY

Sandstones of turbidite origin are found in both the Kuskokwim Group and the restricted Gemuk Group. Although of different age (Late Cretaceous and Early Cretaceous, respectively), these sandstones are not easily distinguished in the field. However, analysis of stained thin sections reveals several differences between the two, most notably that the restricted Gemuk Group has K-spar, whereas the Kuskokwim Group has little or none (Figs. 5D and 5E, respectively). Modal analysis of ten medium-grained sandstone samples, five from each unit (Table 6; Fig. 10), revealed other provenance differences as well.

Two of the five restricted Gemuk Group samples selected for modal analysis come from the type area in Taylor Mountains quadrangle (Fig. 3), and the remaining three are from the Sleetmute

TABLE 5. U-Pb SHRIMP ANALYSES FOR TWO DETRITAL ZIRCON POPULATIONS (FIG. 9) AND ONE TUFF (FIG. 8) FROM THE RESTRICTED GEMUK GROUP

Sample no. (spot no.)	ppm U	ppm Th	207r/ 235	% error	206r/ 238	% error	$^{206}Pb/^{238}U$ Age in Ma (207 cor)	1σ err	$^{207}Pb/^{206}Pb$ Age in Ma (204 cor)	1σ err	% Discordant
04AM51A (Fig. 3), Gemuk sandstone											
(30)	627	308	0.16	2.7	.0209	0.7	132.5	0.9	413	59	210
(31)	120	43	0.25	15.0	.0222	2.1	135.8	2.1	1210	292	756
(7)	168	62	0.12	10.3	.0214	1.2	138.0	1.6	–301	261	–320
(39)	153	51	0.18	14.1	.0223	1.6	140.8	1.9	529	307	272
(45)	127	32	0.18	5.2	.0225	1.4	141.5	2.1	546	110	281
(40)	232	59	0.19	11.2	.0225	1.5	141.6	1.8	624	239	334
(36)	172	90	0.15	6.6	.0223	1.3	141.8	1.8	196	150	38
(19)	772	332	0.14	4.7	.0224	0.6	143.5	0.8	–101	115	–171
(29)	132	49	0.14	12.4	.0226	1.5	144.5	2.0	–51	299	–135
(3)	232	65	0.19	14.3	.0233	1.5	146.4	1.5	562	310	279
(48)	369	143	0.17	8.4	.0236	1.0	149.8	1.2	329	189	118
(14)	662	145	0.16	8.9	.0240	0.8	152.7	0.9	176	208	15
(1)	103	37	0.18	6.3	.0243	1.7	153.7	2.6	390	137	152
(11)	71	29	0.23	21.9	.0248	2.9	154.3	3.5	857	451	442
(15)	145	74	0.17	19.1	.0243	1.7	154.5	2.0	240	439	55
(16)	255	105	0.24	12.6	.0250	1.4	155.3	1.6	885	258	456
(17)	85	41	0.16	9.2	.0245	2.0	156.3	3.2	127	211	–19
(55)	118	34	0.21	4.9	.0250	1.4	156.9	2.3	640	101	302
(35)	99	32	0.20	5.6	.0250	1.6	157.2	2.5	563	117	254
(28)	892	585	0.17	2.1	.0247	0.6	157.2	1.0	176	47	12
(26)	115	12	0.20	5.2	.0252	1.4	158.4	2.3	549	109	242
(27)	111	40	0.16	6.8	.0256	1.5	163.8	2.5	–38	161	–124
(49)	649	103	0.18	2.8	.0259	0.6	164.8	1.1	153	64	–7
(32)	290	86	0.15	6.6	.0257	1.0	165.0	1.6	–233	164	–243
(44)	74	22	0.26	6.4	.0266	1.8	165.0	3.0	921	126	444
(5)	384	57	0.20	7.7	.0262	0.9	165.6	1.3	373	172	124
(53)	325	140	0.19	5.5	.0262	0.9	166.0	1.4	279	125	68
(38)	890	427	0.18	2.0	.0261	0.5	166.0	0.9	160	45	–4
(10)	146	35	0.22	4.6	.0270	1.3	169.3	2.2	584	95	241
(23)	402	47	0.20	11.8	.0269	1.1	169.7	1.3	393	264	130
(9)	291	92	0.22	9.9	.0272	1.2	170.9	1.6	599	213	246
(42)	76	20	0.26	5.8	.0277	1.7	171.9	3.0	892	116	406
(46)	104	34	0.23	13.6	.0275	1.8	172.3	2.6	616	292	253
(54)	918	307	0.19	3.2	.0271	0.5	172.4	0.9	205	73	19
(43)	209	29	0.20	278.9	.0273	18.3	173.2	1.8	291	6357	67
(8)	542	223	0.19	2.8	.0273	0.7	173.8	1.2	197	62	13
(21)	252	127	0.19	6.0	.0275	1.0	174.7	1.7	159	137	–9
(20)	417	215	0.20	7.9	.0277	0.9	175.6	1.3	301	180	71
(33)	202	63	0.25	11.5	.0282	1.4	176.2	1.9	724	243	304
(12)	84	22	0.23	6.8	.0285	1.7	178.8	3.0	573	144	217
(52)	203	75	0.25	10.4	.0287	1.3	179.7	1.9	692	219	279
(37)	269	145	0.23	3.2	.0296	0.9	186.7	1.7	460	69	144
(2)	206	60	0.20	9.1	.0301	1.2	191.7	2.1	142	211	–26
(4)	1192	757	0.22	1.6	.0317	0.4	201.4	0.8	200	35	–1
(18)	150	56	0.28	13.5	.0324	1.5	202.1	2.3	727	285	254
(6)	1038	427	0.21	1.4	.0318	0.4	202.1	0.9	104	33	–48
(25)	195	73	0.22	3.8	.0324	1.0	205.4	2.1	211	86	3
(51)	492	133	0.23	4.6	.0324	0.7	205.5	1.3	252	105	22
(41)	297	133	0.28	8.4	.0332	1.0	207.8	1.7	620	181	195
(50)	373	222	0.23	2.8	.0339	0.7	215.5	1.6	117	64	–46
(47)	794	328	0.25	2.6	.0345	0.5	218.5	1.1	267	58	22
(13)	462	206	0.27	5.3	.0354	0.7	223.1	1.5	411	118	83
(24)	814	299	0.25	2.0	.0357	0.5	226.0	1.1	247	45	9
(34)	72	20	0.32	13.6	.0368	2.0	229.7	4.1	708	285	203
(22)	485	222	0.36	2.0	.0502	0.6	316.3	1.8	267	43	–16
04AM54A (Fig. 3), Gemuk sandstone											
(4)	259	112	0.10	13.1	.0200	1.5	129.9	1.8	–584	352	–557
(40)	327	179	0.13	4.0	.0206	1.0	132.2	1.4	–83	94	–163
(27)	105	46	0.12	14.4	.0208	1.9	133.6	2.5	–154	354	–216

(*continued*)

TABLE 5. U-Pb SHRIMP ANALYSES FOR TWO DETRITAL ZIRCON POPULATIONS (FIG. 9) AND ONE TUFF (FIG. 8) FROM THE RESTRICTED GEMUK GROUP (*continued*)

Sample no. (spot no.)	ppm U	ppm Th	207r/ 235	% error	206r/ 238	% error	$^{206}Pb/^{238}U$ Age in Ma (207 cor)	1σ err	$^{207}Pb/^{206}Pb$ Age in Ma (204 cor)	1σ err	% Discordant
(18)	207	88	0.14	7.8	.0210	1.3	134.5	1.8	71	183	–47
(48)	124	30	0.17	16.4	.0216	2.0	136.0	2.3	538	356	291
(6)	283	147	0.14	4.7	.0214	1.1	136.9	1.5	91	108	–33
(53)	237	92	0.18	12.4	.0220	1.4	138.2	1.5	588	268	320
(41)	268	133	0.14	4.2	.0216	1.1	138.2	1.6	71	96	–48
(19)	242	97	0.12	17.4	.0215	1.4	138.6	1.6	–396	452	–389
(2)	262	104	0.16	5.9	.0218	1.2	138.7	1.6	287	132	106
(17)	255	104	0.11	20.3	.0215	1.5	139.3	1.6	–527	541	–483
(42)	250	84	0.17	4.0	.0220	1.2	139.3	1.7	434	85	209
(10)	150	47	0.15	10.6	.0219	1.6	139.3	2.1	161	245	15
(44)	294	171	0.16	5.7	.0220	1.1	139.4	1.5	382	126	172
(38)	325	152	0.15	4.0	.0219	1.0	139.4	1.5	227	88	62
(9)	174	64	0.14	9.6	.0219	1.5	139.6	2.0	96	224	–31
(12)	326	178	0.17	3.5	.0220	1.0	139.6	1.4	388	74	176
(29)	86	42	0.19	41.7	.0223	3.8	139.6	2.8	657	890	363
(8)	163	69	0.19	12.1	.0224	1.7	140.4	2.1	685	256	380
(23)	266	123	0.17	3.8	.0222	1.1	140.6	1.6	416	82	193
(46)	335	184	0.15	4.4	.0221	1.3	140.8	1.8	174	98	24
(16)	293	106	0.16	5.1	.0222	1.1	140.8	1.5	266	114	88
(25)	178	60	0.22	15.0	.0227	2.1	141.1	2.4	920	305	535
(13)	214	79	0.15	36.3	.0223	2.5	141.9	1.9	146	850	3
(32)	168	76	0.11	11.7	.0221	1.5	142.7	2.1	–511	310	–463
(43)	393	150	0.15	3.6	.0225	0.9	143.3	1.4	174	82	22
(21)	492	171	0.16	12.2	.0228	1.1	144.8	1.2	280	279	93
(24)	160	92	0.20	24.1	.0233	2.5	146.3	2.6	655	514	341
(20)	179	65	0.16	5.2	.0230	1.4	146.5	2.1	152	116	4
(28)	108	73	0.13	13.7	.0233	1.8	150.6	2.6	–406	355	–373
(3)	116	23	0.10	12.5	.0232	1.8	151.2	2.7	–1027	370	–794
(22)	81	28	0.09	38.1	.0232	2.3	151.5	3.0	–1395	1235	–1045
(11)	83	50	0.23	30.0	.0245	3.2	151.9	2.9	900	616	478
(52)	194	129	0.17	5.3	.0240	1.1	152.2	1.7	255	118	67
(5)	318	92	0.14	13.9	.0238	1.3	152.4	1.6	–134	342	–189
(31)	809	328	0.17	3.0	.0242	0.6	153.9	1.0	183	69	19
(7)	145	73	0.21	13.4	.0246	1.8	154.2	2.4	624	287	299
(1)	165	72	0.18	5.5	.0253	1.4	160.6	2.2	212	124	32
(37)	288	242	0.15	11.0	.0251	1.2	161.1	1.7	–91	269	–157
(51)	548	196	0.17	2.9	.0260	0.7	165.9	1.1	127	67	–24
(45)	97	63	0.15	20.5	.0258	2.1	165.9	3.1	–262	517	–260
(30)	1007	308	0.18	2.0	.0264	0.6	167.5	0.9	227	44	35
(55)	242	179	0.14	11.2	.0269	1.2	173.9	2.1	–582	302	–440
(50)	107	41	0.17	22.9	.0275	2.1	175.6	3.2	–51	555	–129
(49)	754	148	0.18	4.3	.0276	0.7	176.3	1.1	35	101	–80
(33)	332	185	0.18	5.8	.0278	1.0	177.0	1.7	89	136	–50
(56)	178	70	0.17	8.2	.0280	1.2	179.2	2.1	–138	201	–178
(35)	372	205	0.19	12.0	.0288	1.1	183.5	1.7	92	282	–50
(15)	210	85	0.25	9.5	.0296	1.3	185.7	2.2	608	204	223
(34)	252	144	0.20	4.3	.0293	1.1	186.2	2.0	221	96	19
(54)	888	263	0.22	2.7	.0297	0.5	187.7	1.0	320	61	70
(47)	445	184	0.20	4.6	.0307	0.9	195.5	1.7	45	109	–77
(39)	116	35	0.27	6.9	.0419	1.5	265.9	4.0	34	162	–87
(14)	447	172	0.31	2.5	.0440	0.7	277.9	2.1	226	54	–19
(57)	597	478	0.32	1.7	.0463	0.6	292.2	1.6	208	37	–29
99ADw44A (Fig. 6), Gemuk tuff (61°05′20″, 158°41′00″)											
(2)	422	97	0.23	60.6	.0217	3.0	133.3	7.6	1144	1202	728
(6)	1049	332	0.15	2.1	.0213	0.4	135.5	0.6	254	47	87
(3)	944	327	0.14	6.6	.0213	0.6	136.4	0.6	24	159	-83
(1)	275	147	0.12	9.6	.0212	0.9	136.7	1.1	–327	245	–342
(8)	323	69	0.18	3.2	.0221	0.8	138.8	1.2	610	67	333
(9)	651	162	0.14	8.8	.0220	0.7	140.4	0.9	32	209	–77
(7)	553	134	0.14	3.4	.0219	0.6	140.5	0.9	–58	81	–141
(4)	177	88	0.18	21.3	.0239	1.6	151.6	2.0	366	479	140

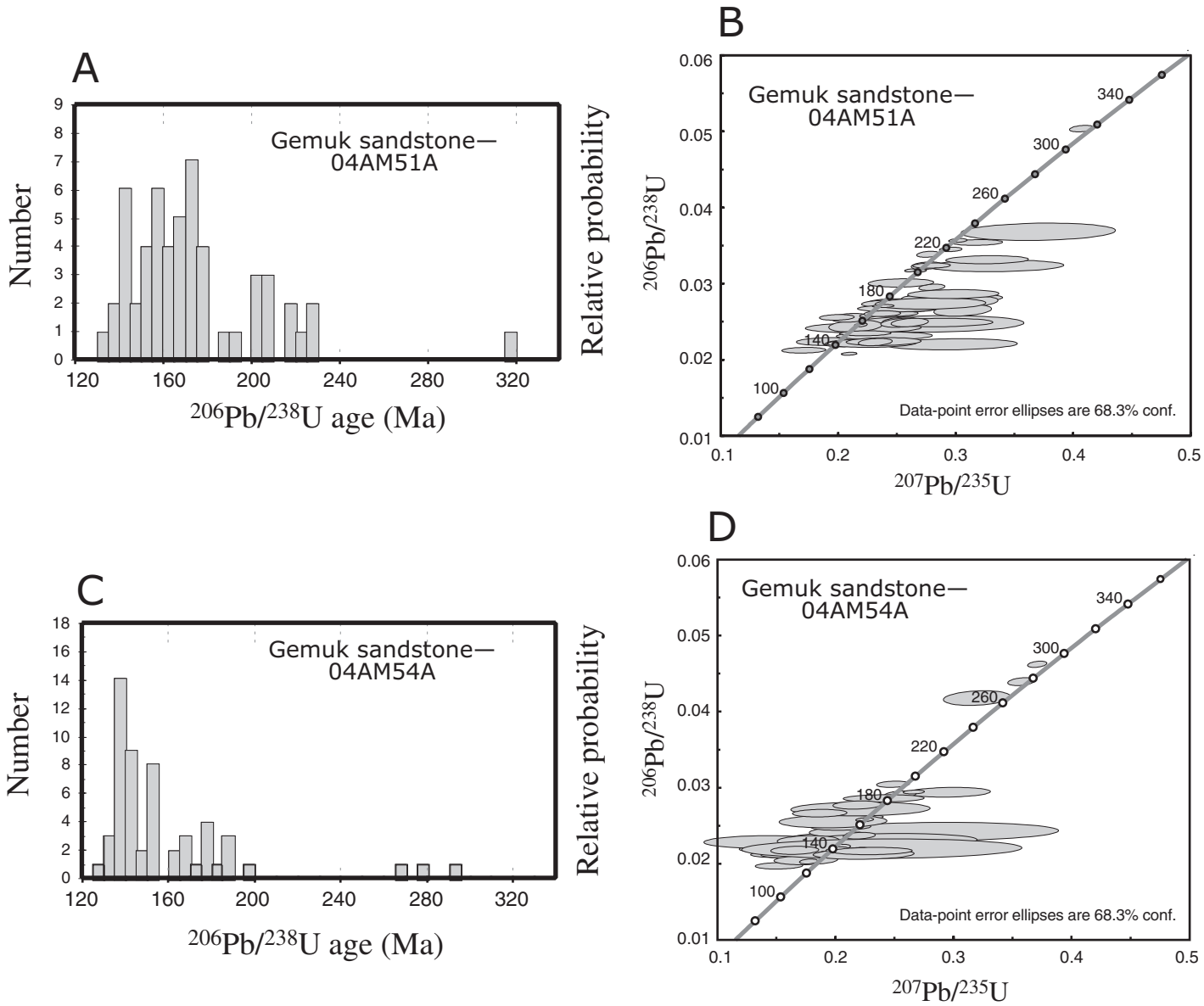


Figure 9. Detrital zircon data for two Lower Cretaceous sandstones of the restricted Gemuk Group (see Table 5). (A) and (B) are a histogram and Concordia diagram for sample 04AM51A. (C) and (D) are a histogram and Concordia diagram for sample 04AM54A. The histograms are based entirely on ^{206}Pb/^{238}U age picks. See Figure 3 for location of samples.

quadrangle (Fig. 6). These sandstones are moderately to poorly sorted and contain subangular to subrounded clasts of mostly medium- to fine-grained size (Fig. 5D). They generally classify as lithic wackes, but some verge on arkosic wacke (classification of Williams et al., 1954). On average, the restricted Gemuk Group sandstones have Q/F/L ratios of ~24/29/47 (Table 6). Volcanic lithic clasts, especially felsic varieties, are the most common rock fragments. Detrital metamorphic clasts are rare to absent (Ls/Lv/Lm averages 15/83/2, Table 6). The most notable feature of the restricted Gemuk Group sandstones is the presence of potassium feldspar (Qm/P/K averages 41/48/11). All five of the restricted Gemuk Group sandstones plot in the magmatic arc provenance field of Dickinson (1985); three plot in the dissected arc subfield, and two plot in the undissected arc subfield (Fig. 10A). One restricted Gemuk Group sample that plots in the undissected arc field was interbedded with 137 Ma tuff (99ADw44C). This sample has an especially high volcanic-lithic content, is rich in limestone clasts (including shell fragments), and is relatively poorer in quartz framework grains.

All five samples of Kuskokwim Group selected for modal analysis are from the Sleetmute quadrangle. Two come from relatively near the restricted Gemuk Group exposures, but to better represent the range of this vast unit, three are more distant (as much as 70 km from the nearest restricted Gemuk Group). The

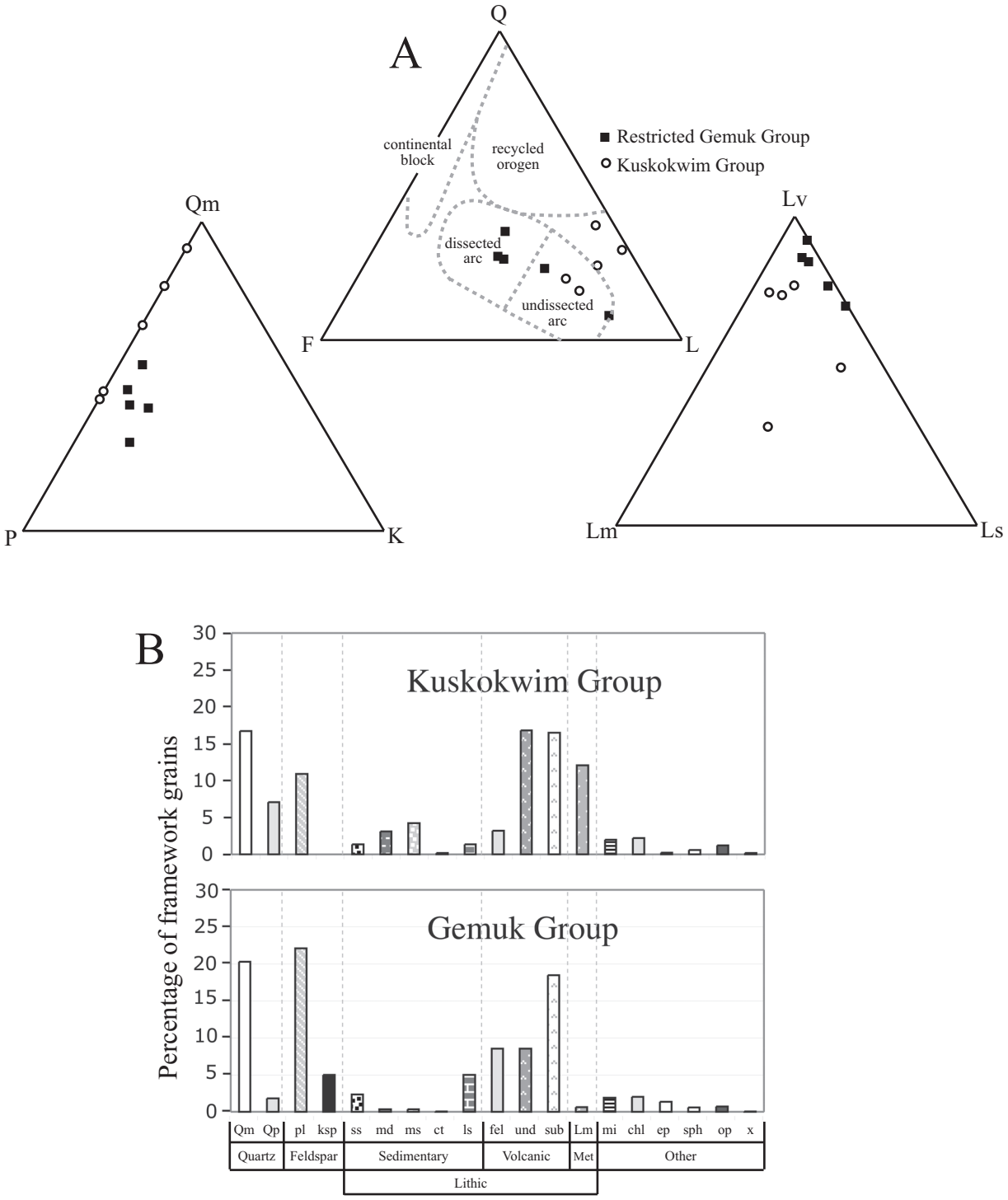


Figure 10. (A) Ternary plots of modal sandstone grain compositions for restricted Gemuk Group and Kuskokwim Group (Table 6). Provenance associations on the QFL plot are after Dickinson (1985). (B) Histograms comparing average modal composition values for restricted Gemuk Group and Kuskokwim Group sandstones. The restricted Gemuk Group has notable potassium feldspar and sandstone lithic clasts, whereas the Kuskokwim Group has abundant metamorphic lithics and no potassium feldspar. Abbreviations are explained in Table 1.

TABLE 6. RECALCULATED MODAL POINT-COUNT DATA

Sample	% Q	% F	% L	% Qm	% P	% K	% Ls	% Lv	% Lm
Restricted Gemuk Group									
04AM51A	23	26	51	45	48	7	20	78	2
04AM54A	35	31	34	53	40	7	7	93	0
94AM362A	27	37	36	40	50	10	11	86	3
99AM360A	26	36	38	39	45	16	9	87	4
99ADw44C	8	16	76	28	56	16	29	71	0
Average	**24**	**29**	**47**	**41**	**48**	**11**	**15**	**83**	**2**
Kuskokwim Group									
94ADw52B	24	11	65	66	34	0	11	78	11
98AM78B	20	22	58	44	56	0	9	75	16
97ADw008	16	20	64	42	58	0	5	76	19
98ADw17A	37	5	58	79	21	0	37	51	12
98AM06A	29	2	69	91	9	0	26	32	42
Average	**25**	**12**	**63**	**64**	**36**	**0**	**18**	**62**	**20**

Abbreviations: Q, total quartz; F, total feldspar; L, total lithic clasts; Qm, monocrystalline quartz; P, plagioclase; K, potassium feldspar; Ls, sedimentary lithic clasts; Lv, volcanic lithic clasts; Lm, metamorphic lithic clasts. Refer to Table 1 for raw data and sample locations.

sandstones are poorly sorted, containing mostly medium-grained angular to subrounded clasts but ranging from coarse grained to very fine grained (Fig. 5E). They classify as lithic wackes. The average Q/F/L is 25/12/63 (Table 6), making them more lithic rich and less feldspar rich than the average sandstone from the restricted Gemuk Group. Similar to the restricted Gemuk Group, volcanic lithics are dominant (Ls/Lv/Lm averages 18/62/20), but felsic varieties are of less significance in the samples of the Kuskokwim Group. In contrast to the restricted Gemuk Group, detrital metamorphic fragments (mostly schist, lesser metasandstone, and metasiltstone) are an important and persistent component of the Kuskokwim Group (Fig. 10B). The most obvious difference, however, is in the total absence of potassium feldspar in the five Kuskokwim Group sandstones (Qm/P/K averages 64/36/0). This is consistent with the previous description of Kuskokwim Group sandstone (Miller and Bundtzen, 1994), where it was noted potassium feldspar clasts were extremely rare. The five samples from the Kuskokwim Group (Fig. 10A) plot in and near the undissected arc provenance field of Dickinson (1985).

Except in the rare places where the distinctive maroon or green mudstone of the restricted Gemuk Group is also present, it is difficult to distinguish Kuskokwim Group sandstone from restricted Gemuk Group sandstone in the field. Petrographic analysis however shows distinct differences. Restricted Gemuk Group sandstone commonly has potassium feldspar, felsic volcanic lithics and few metamorphic lithics. Sandstone of the Kuskokwim Group is overall more lithic rich, has abundant nonfelsic volcanic clasts, common metamorphic lithics, and little to no potassium feldspar. These differences are consistent with the general provenance fields of dissected arc for the restricted Gemuk Group and undissected arc for the Kuskokwim Group.

SHALE GEOCHEMISTRY

We report the results of major- and trace-element whole-rock analyses of sedimentary rocks from Sleetmute quadrangle. The main purpose is simply to characterize the geochemistry of the restricted Gemuk Group. In addition, we provide comparable data for the Kuskokwim Group that reinforce the petrographic evidence that significant differences exist between siliciclastic rocks of these two groups. These geochemical data also provide some constraints on the weathering regime of the restricted Gemuk Group source region.

Whole-rock geochemical samples were collected as part of our mapping project in the Sleetmute quadrangle as background information for mineral resource assessment. Samples were collected in 1993, 1994, 1997, 1998, and 1999, years that spanned the time of a serious reorganization of the USGS analytical geochemistry group. Hence, not all the rocks underwent the same set of analyses by the same labs. The most uniform and complete set of analyses is a 40–element ICP-AES package for major, minor, and trace elements. All samples were collected as pairs, one sandstone and one shale, from the same graded bed. In all, 27 pairs of restricted Gemuk Group and 49 pairs of Kuskokwim Group were analyzed. Rare-earth-element (REE) analyses were done by neutron activation on a small subset of samples. Analytical data are shown in Table 7; analytical methods are described in Lichte et al. (1987) for ICP-AES, and in Baedecker and McKown (1987) for neutron activation.

Major- and trace-element abundances for shales of the restricted Gemuk Group and Kuskokwim Group are summarized in the spidergram in Figure 11A. Abundances are normalized to Post-Archean Average Shale of Taylor and McLennan (1985, their Table 2.9, column 1). Both major and trace elements are arrayed in order of their residence time in seawater (from Table 2.3 of Taylor and McLennan, 1985). From left to right on the spidergram, the elements are increasingly mobile in the surface environment. Thus, elements toward the left end of the diagram are more likely to have abundances that reflect source-rock composition, and those to the right are more likely to have been modified in the near-surface environment.

Shales of the restricted Gemuk Group have particularly low abundances of K, Th, Ce, Pb, La, Nd, Ni, and Cr, and high Mn, Na, Sc, and V. Shales of the Kuskokwim Group have low Th, Ce, La, Y, and Sr, and high Zn, Ba, V, and P. On average the Kuskokwim Group shales vary less from average shale than does restricted Gemuk Group shale. Compared to Kuskokwim Group shales, restricted Gemuk Group shales are markedly lower in Ni and higher in Na.

Rare-earth-element (REE) patterns (Fig. 11B) are broadly similar for restricted Gemuk Group and Kuskokwim Group shales; both show LREE enrichment and negative Eu anomalies. Restricted Gemuk Group shales have lower overall REE abundances. One restricted Gemuk Group shale has a minor positive Ce anomaly.

The chemical index of alteration, or CIA (Nesbitt and Young, 1982), is generally interpreted as a measure of the intensity of weathering of a sediment's source area. CIA is $100*Al_2O_3/(Al_2O_3 + CaO + Na_2O + K_2O)$. For noncalcareous shales it varies between

TABLE 7. MAJOR- AND TRACE-ELEMENT GEOCHEMICAL DATA FOR SANDSTONE-SHALE PAIRS FROM RESTRICTED GEMUK GROUP AND KUSKOKWIM GROUP

Sample No.	Location Lat/Long degrees	Rock type	Si %	Al %	Ca %	Fe %	K %	Mg %	Na %	P %	Ti %	Mn ppm	Ba ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	La ppm	Li ppm	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Sc ppm	Sr ppm	Th ppm	V ppm	W ppm	Y ppm	Zn ppm	Zr ppm
Restricted Gemuk Group																																
94ADW66B	61.113/158.502	ss	28.89	8.00	0.37	4.10	1.00	1.00	2.40	0.06	0.48	2000	540	29	20	60	23	12	12	36	8	18	36	2	23	130	2	170	0.1	22	97	122
94ADW66A	61.113/158.502	sh	28.89	8.30	0.28	4.80	1.80	1.30	1.70	0.07	0.50	1300	770	38	17	120	52	18	19	41	13	17	47	2	20	83	4	230		17	120	146
94ADW7A	61.151/158.533	ss	30.25	8.40	1.20	3.70	0.57	1.20	3.40	0.05	0.31	2300	200	29	14	58	23	14	14	43	5	14	21	2	14	250	2	120	1.2	8	63	128
94ADW7B	61.151/158.533	sh	28.52	8.20	0.30	5.30	1.50	1.80	2.30	0.06	0.42	4500	410	81	55	65	110	14	33	52	11	29	74	18	21	180	6	200		21	200	144
94ADW80D	61.023/158.580	ss	32.96	6.20	0.47	3.90	1.50	0.94	2.10	0.07	0.36	1100	590	28	11	46	37	18	13	23	6	13	18	12	12	200	2	120	0.2	14	86	120
94ADW80E	61.023/158.580	sh	30.39	7.70	0.43	4.00	2.20	1.10	2.10	0.10	0.56	910	730	46	13	59	73	24	21	23	11	20	23	6	21	180	2	180		18	98	176
94AM226A	61.234/158.528	ss		7.40	0.38	4.70	1.60	1.60	2.30	0.04	0.43	2400	1500	24	17	47	64	16	13	110	12		31	2	21	200	2	130		7	84	
94AM226C	61.234/158.528	sh		8.20	0.92	5.20	0.39	1.70	3.70	0.04	0.52	10000	470	27	12	32	33	22	13	73	13		27	2	27	250	2	190		17	110	
94AM239A	61.137/158.596	ss	25.71	8.70	3.10	6.00	1.40	1.80	2.30	0.08	0.54	950	320	16	26	47	59	15	9	31	5	9	20	8	20	260	2	170	0.5	14	100	106
94AM239B	61.137/158.596	sh	27.54	9.80	1.80	4.20	2.40	1.20	2.10	0.15	0.71	520	440	33	20	38	120	14	17	22	7	22	17	2	31	180	2	210	0.5	21	83	172
99ADW020A	61.251/158.516	ss		5.95	0.68	1.73	0.32	0.27	3.43	0.05	0.18	896	288	35	3	14	10	12	14	15	11	27	8	9	10	194	3	97	3.4	36	108	
99ADW020B	61.251/158.516	sh		10.80	0.21	3.70	2.65	0.95	3.54	0.09	0.53	1320	1440	130	1	35	18	46	67	40	20	77	2	17	36	161	10	702	4.6	34	55	
99ADW022A	61.243/158.507	ss		10.80	1.67	4.69	1.91	1.28	2.47	0.07	0.4	612	687	52	11	24	17	26	23	81	19	23	13	14	17	281	3	125	1.8	21	102	
99ADW022B	61.243/158.507	sh		10.10	0.17	4.11	2.49	1.20	1.31	0.07	0.58	130	863	45	8	39	47	29	22	67	19	24	29	7	25	97	3	287	2.4	21	94	
99ADW026A	61.203/158.449	ss		8.20	1.42	3.97	1.49	1.52	3.13	0.07	0.446	548	476	27	13	19	33	19	14	74	15	5	17	5	15	388	3	139	1.5	15	62	
99ADW026B	61.203/158.449	sh		8.81	0.94	5.98	1.73	2.08	2.06	0.08	0.56	741	552	36	21	33	70	26	17	80	19	9	33	16	21	275	6	196	2.3	21	112	
99ADW028A	61.197/158.449	ss		7.36	1.42	3.86	0.93	1.50	2.82	0.055	0.347	567	263	42	14	17	20	16	22	57	10	15	19	5	14	338	3	136	3.2	13	56	
99ADW028B	61.197/158.449	sh		8.89	0.54	5.44	1.45	2.05	2.69	0.08	0.44	628	344	32	16	29	38	24	17	75	13	15	16	5	17	307	3	178	2.8	22	93	
99ADW036A	61.168/158.451	ss		7.76	1.46	4.34	1.19	1.76	2.65	0.07	0.446	599	438	30	18	36	32	19	14	46	14	11	35	4	16	457	3	150	4.1	16	67	
99ADW036B	61.168/158.451	sh		9.16	1.89	5.64	1.84	2.63	2.14	0.09	0.60	841	508	38	18	82	83	25	19	58	18	17	37	10	24	378	3	212	2.5	21	106	
99ADW037A	61.178/158.481	ss		6.85	2.33	3.92	1.13	1.30	2.09	0.055	0.363	737	237	29	16	35	29	17	14	63	12	13	27	7	16	353	3	140	2.3	10	66	
99ADW037B	61.178/158.481	sh		9.61	0.36	5.31	2.37	1.82	1.60	0.09	0.57	591	475	40	17	36	67	29	19	80	20	17	24	5	26	208	3	221	0.3	15	121	
99ADW038A	61.174/158.481	ss		7.75	1.66	3.81	0.92	1.43	3.03	0.055	0.308	852	306	27	12	15	28	16	14	64	10	14	13	7	14	462	3	134	2.3	11	59	
99ADW038B	61.174/158.481	sh		8.73	0.45	6.11	1.44	2.27	2.14	0.07	0.40	772	391	34	17	31	71	27	17	96	11	17	27	6	23	282	3	205	1.9	15	101	
99ADW039A	61.085/158.644	ss		7.92	1.52	3.81	1.20	1.43	3.10	0.06	0.479	515	556	26	9	24	26	17	13	70	15	9	23	7	16	322	3	139	1.1	16	58	
99ADW039B	61.085/158.644	sh		8.81	1.14	5.65	1.87	1.94	2.50	0.08	0.50	631	632	29	11	35	36	26	13	103	17	15	23	6	17	373	3	183	1.0	17	86	
99ADW044D	61.090/158.683	ss		7.33	8.10	3.70	1.08	1.22	2.67	0.075	0.429	1430	385	38	14	16	27	17	19	46	13	18	11	12	14	463	3	121	3.1	16	66	
99ADW044E	61.090/158.683	sh		8.35	0.68	4.63	1.93	1.41	2.30	0.06	0.51	840	1010	49	15	19	75	26	28	60	21	27	30	9	21	365	3	183	3.1	25	120	
99ADW045A	61.089/158.680	ss		8.93	1.47	4.66	1.34	1.73	4.09	0.09	0.402	777	913	29	16	18	24	21	14	54	11	11	3	2	17	361	3	172	3.4	17	70	
99ADW045B	61.089/158.680	sh		9.02	1.52	4.74	1.06	2.54	3.52	0.08	0.27	1180	597	27	15	16	21	19	13	79	5	17	2	6	19	495	3	179	3.0	16	67	
99ADW050A	61.028/169.552	ss		5.50	0.46	1.54	0.65	0.17	2.90	0.145	0.132	407	337	37	11	39	56	9	19	25	6	24	46	5	12	180	3	161	3.8	37	243	
99ADW050B	61.028/169.552	sh		7.20	0.10	2.85	2.55	0.88	0.79	0.06	0.29	579	995	20	8	47	33	28	11	17	9	5	20	8	18	40	3	368	1.6	12	73	
99ADW060A	61.017/158.693	ss		8.50	2.66	4.29	1.23	1.99	2.54	0.075	0.495	589	654	34	17	32	37	25	16	51	16	11	34	8	17	681	3	165	1.0	16	61	
99ADW060B	61.017/158.693	sh		9.03	0.86	5.35	2.64	2.02	1.64	0.10	0.62	468	671	41	13	34	108	27	20	53	20	17	16	6	26	275	3	241	2.4	27	113	
99ADW061A	61.132/158.607	ss		8.88	3.02	6.22	0.60	2.22	2.48	0.08	0.699	850	213	28	19	35	43	25	11	41	16	17	4	5	23	399	3	252	1.6	20	79	
99ADW061B	61.132/158.607	sh		9.08	2.79	4.79	1.55	1.59	2.02	0.09	0.58	628	378	25	14	19	66	24	11	30	16	15	4	9	23	420	3	177	1.7	25	87	
99ADW064A	61.123/158.599	ss		8.79	2.51	4.80	1.12	1.72	3.32	0.08	0.539	776	288	23	19	19	45	21	10	28	16	11	7	7	22	265	3	186	0.8	22	70	
99ADW064B	61.123/158.599	sh		9.01	2.81	4.81	1.40	1.66	2.32	0.09	0.61	638	435	31	17	14	68	23	14	30	18	13	3	7	24	473	3	188	1.6	28	75	
99ADW077A	61.130/158.853	ss		9.88	0.70	5.80	1.82	1.65	1.94	0.08	0.638	3090	665	34	11	37	57	23	15	120	21	16	65	2	16	135	3	189	1.0	18	104	
99ADW077B	61.130/158.853	sh		8.94	0.91	4.49	2.19	1.42	1.20	0.09	0.57	3070	768	65	13	54	37	24	32	80	22	30	56	2	25	176	6	249	0.5	24	103	
99ADW096A	61.337/158.317	ss		5.59	0.10	3.00	2.01	0.52	1.71	0.055	0.369	574	1040	32	10	17	45	15	13	17	14	11	38	16	17	111	3	190	1.2	14	87	
99ADW096B	61.337/158.317	sh		4.42	0.18	2.91	1.68	0.87	1.00	0.06	0.26	2270	1050	25	23	14	52	15	10	24	6	10	38	7	16	80	3	131	1.7	18	109	
99AM336A	61.257/158.440	ss		9.77	0.66	5.38	1.30	1.90	2.78	0.055	0.468	303	403	27	10	25	26	23	13	77	13	5	16	8	17	216	3	156	7.1	13	86	
99AM336B	61.257/158.440	sh		11.80	0.34	5.68	3.12	1.23	1.12	0.06	0.74	387	955	43	19	64	80	35	24	45	27	11	24	19	30	127	7	341	3.5	15	128	
99AM341A	61.204/158.419	ss		7.51	1.39	3.97	1.50	1.51	2.60	0.065	0.413	495	507	27	13	32	29	18	12	51	14	12	24	6	14	386	3	128	2.0	14	57	
99AM341B	61.204/158.419	sh		9.22	1.18	5.63	2.15	2.08	2.13	0.10	0.64	555	676	44	16	81	69	26	22	67	21	22	30	6	23	358	7	215	5.9	26	111	
99AM351A	61.060/158.673	ss		7.19	4.23	2.42	2.39	0.87	1.02	0.105	0.347	1610	752	78	9	5	22	17	37	26	9	39	2	15	11	199	3	70	1.4	51	66	
99AM351C	61.060/158.673	sh		8.17	1.33	2.86	2.93	1.03	1.32	0.04	0.34	1110	661	34	12	5	24	20	21	26	15	21	2	10	11	91	3	72	2.0	27	81	
99AM354A	61.051/158.663	ss		8.33	1.40	4.48	1.54	1.76	2.62	0.06	0.435	519	633	29	14	28	37	21	13	75	16	13	23	5	15	410	3	144	3.9	16	66	
99AM354B	61.051/158.663	sh		9.49	1.12	5.82	2.47	2.12	2.02	0.08	0.62	544	762	32	15	24	91	29	15	78	21	12	26	8	25	248	3	221	2.5	18	124	
99AM363A	61.176/158.680	ss		8.05	1.48	3.85	1.44	1.68	2.74	0.065	0.424	511	682	29	13	20	30	18	15	50	12	10	15	2	15	440	3	137	1.9	16	57	
99AM363B	61.176/158.680	sh		9.53	1.26	5.63	2.50	2.43	2.05	0.10	0.62	655	728	38	18	46	96	27	21	62	20	16	34	7	26	316	3	225	1.0	23	119	
99AM364A	61.009/158.707	ss		8.21	1.14	3.58	1.80	1.25	2.71	0.06	0.363	365	597	29	9	13	27	19	15	41	11	14	5	6	13	308	3	128	3.2	11	54	
99AM364B	61.009/158.707	sh		9.69	0.67	5.89	2.67	2.09	1.80	0.11	0.67	445	530	43	13	32	80	28	19	55	21	21	15	8	27	197	3	245	2.0	20	109	

(*continued*)

TABLE 7. MAJOR- AND TRACE-ELEMENT GEOCHEMICAL DATA FOR SANDSTONE-SHALE PAIRS FROM RESTRICTED GEMUK GROUP AND KUSKOKWIM GROUP (*continued*)

Sample No.	Location Lat/Long degrees	Rock type	Si %	Al %	Ca %	Fe %	K %	Mg %	Na %	P %	Ti %	Mn ppm	Ba ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	La ppm	Li ppm	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Sc ppm	Sr ppm	Th ppm	V ppm	W ppm	Y ppm	Zn ppm	Zr ppm
Kuskokwim Group																																
94ADW13B	61.081/158.457	ss	28.61	8.00	0.38	5.80	1.20	1.40	1.60	0.09	0.44	550	530	66	19	99	28	15	31	67	10	35	71	19	16	100	6	120	0.1	38	130	164
94ADW13A	61.081/158.457	sh	26.32	10.00	0.25	5.10	2.10	1.50	0.84	0.09	0.54	540	650	52	19	150	75	21	30	64	14	21	59	24	25	72	10	190		31	120	198
94ADW18C	61.086/158.264	ss	35.53	4.40	0.65	4.10	0.90	0.94	0.97	0.11	0.2	860	500	21	16	130	20	11	10	44	6	9	63	14	7	80	2	110	0.9	10	110	210
94ADW18D	61.086/158.264	sh	29.41	6.50	0.34	7.40	2.00	0.97	0.83	0.16	0.35	2900	990	42	17	160	37	16	23	34	13	19	70	19	13	73	7	200		16	130	128
94ADW30A	61.027/158.355	ss	35.34	4.70	0.22	4.20	0.86	1.10	1.10	0.1	0.24	490	520	21	18	95	24	10	11	64	8	10	66	11	8	69	2	130	0.1	9	110	104
94ADW30B	61.027/158.355	sh	27.40	11.00	0.33	3.90	3.10	1.40	0.76	0.15	0.50	370	2100	79	14	230	52	28	44	56	23	34	69	18	23	99	8	300		19	130	156
94ADW52B	61.007/158.401	ss	28.99	8.00	0.50	6.10	0.90	1.70	2.80	0.07	0.44	550	490	19	23	79	22	16	10	73	6	11	48	13	13	110	2	130	0.3	12	100	134
94ADW52A	61.007/158.401	sh	29.36	7.70	0.26	5.20	2.00	1.70	0.91	0.10	0.42	410	820	31	20	190	58	18	17	58	16	15	80	11	17	50	5	240		15	130	142
94ADW56B	61.019/158.398	ss	30.81	6.40	1.70	5.10	1.40	1.40	1.00	0.1	0.33	1200	540	23	17	160	60	16	11	58	10	10	73	11	13	91	5	170	1.6	14	140	148
94ADW56A	61.019/158.398	sh	29.27	8.00	0.29	4.80	2.20	1.50	0.75	0.10	0.43	370	790	31	15	200	64	22	17	56	17	13	70	5	19	47	5	250		13	130	144
94ADW5B	61.036/158.375	ss	30.71	5.60	2.00	5.80	0.93	1.40	0.94	0.77	0.26	1100	440	69	15	120	21	14	31	74	6	48	52	16	13	200	2	140	0.9	82	160	160
94ADW5A	61.036/158.375	sh	26.79	9.60	0.22	5.40	2.00	1.40	1.20	0.11	0.49	680	830	54	17	130	59	21	31	67	14	24	52	15	21	86	7	190		14	93	172
94ADW61A	61.056/158.403	ss	30.01	7.50	0.22	5.40	1.80	1.60	1.10	0.09	0.44	760	690	37	28	200	66	23	19	38	12	17	93	28	17	52	4	220	0.0	12	130	142
94ADW61B	61.056/158.403	sh	29.78	7.30	0.45	5.50	1.80	1.60	1.00	0.09	0.40	980	670	36	25	180	72	18	19	36	12	16	84	12	17	60	4	220	0.6	13	150	150
94ADW67D	61.163/158.427	ss	25.10	6.30	4.50	4.50	1.50	1.70	2.10	0.1	0.34	13000	720	34	18	81	23	12	22	33	5	13	39	8	14	290	5	130	8.9	18	89	146
94ADW67C	61.163/158.427	sh	30.71	6.80	0.26	4.80	2.00	1.30	1.40	0.08	0.39	3200	740	32	29	150	73	18	17	41	14	15	75	15	17	72	5	300	0.5	14	160	126
94AKW212A	61.056/158.289	ss		3.70	0.12	2.20	0.78	0.29	1.20	0.08	0.16	280	450	11	11	110	15	7	5	21	2		45	7	7	58	2	86		3	70	
94AKW212C	61.056/158.289	sh		10.00	0.34	5.80	2.30	1.80	1.40	0.15	0.52	720	1200	61	19	130	57	22	31	84	9		75	17	21	94	8	220		11	120	
94AM272B	61.066/158.330	ss	33.05	6.00	0.19	5.20	1.20	1.20	1.20	0.11	0.27	1800	610	26	23	110	31	11	14	56	11	11	72	17	12	74	5	150	1.0	10	140	176
94AM272A	61.066/158.330	sh	27.86	10.00	0.24	5.00	3.00	1.50	1.10	0.12	0.55	840	1300	59	23	160	69	23	30	50	17	24	79	7	23	88	8	310	1.6	11	150	160
94AM348A	61.478/158.712	ss	27.68	10.00	2.70	5.10	1.80	1.30	0.93	0.12	0.62	1000	950	61	24	84	41	20	34	40	13	27	50	16	21	370	8	180	1.4	30	130	188
94AM348B	61.478/158.712	sh	27.91	10.00	0.90	5.70	2.60	1.30	0.68	0.12	0.63	620	970	62	24	88	51	21	32	36	12	25	56	12	21	220	9	180	1.3	25	130	192
97ADW001A	61.688/157.179	ss		4.60	2.00	3.70	1.20	1.00	0.61	0.13	0.21	401	682	35	12	33	24	8	17	43	12	15	44	12	9	72	3	122	3.2	17	98	
97ADW001B	61.688/157.179	sh		8.20	1.70	4.40	2.70	1.20	0.34	0.09	0.37	499	1170	53	15	78	74	16	25	74	15	23	71	25	19	86	8	257	5.3	16	153	
97ADW006A	61.904/157.527	ss		8.10	0.24	4.70	1.30	1.30	2.00	0.05	0.4	417	380	36	15	34	26	13	15	64	9	17	50	17	15	87	7	137	2.3	13	88	
97ADW006B	61.904/157.527	sh		10.00	0.23	5.30	2.80	1.50	0.84	0.05	0.53	367	748	52	20	34	68	23	23	61	14	23	78	26	24	75	13	203	3.7	18	116	
97ADW011A	61.909/157.736	ss		5.20	4.10	3.10	1.40	1.90	0.83	0.08	0.24	364	713	39	10	49	22	15	19	49	8	18	49	11	11	160	3	128	2.7	14	78	
97ADW011B	61.909/157.736	sh		6.20	3.80	3.10	1.90	2.20	0.71	0.08	0.27	400	826	41	14	49	44	20	18	43	10	18	51	12	13	139	3	157	3.1	15	98	
97ADW023A	61.883/156.321	ss		4.20	1.50	2.50	1.30	0.92	0.03	0.08	0.19	460	813	34	12	12	27	11	16	69	12	14	52	14	9	38	3	131	2.9	13	109	
97ADW023B	61.883/156.321	sh		7.10	2.10	3.10	2.40	0.88	0.05	0.10	0.33	763	1180	50	17	15	50	16	23	104	17	25	54	19	14	61	6	198	4.2	17	177	
97ADW028A	61.897/156.403	ss		5.30	0.15	4.60	1.10	1.20	0.60	0.07	0.19	440	771	37	14	34	22	11	17	47	10	16	84	13	11	40	3	138	3.8	13	114	
97ADW028B	61.897/156.403	sh		7.90	0.14	4.60	2.20	1.50	0.70	0.09	0.34	335	1200	54	14	69	59	19	25	52	9	23	86	21	15	42	9	201	3.3	15	154	
97ADW029A	61.848/156.372	ss		4.30	0.12	3.80	0.85	0.96	0.59	0.04	0.17	187	560	34	8	13	13	14	17	28	11	16	51	13	8	40	3	112	2.4	9	98	
97ADW029B	61.848/156.372	sh		10.00	0.32	5.50	3.00	1.50	0.54	0.05	0.46	392	1500	59	22	71	99	24	29	46	13	29	90	27	25	88	11	270	2.9	21	162	
97ADW030A	61.694/157.183	ss		4.90	2.90	3.10	1.40	1.30	0.87	0.09	0.2	399	711	43	10	14	24	14	21	31	10	18	41	11	12	89	3	131	3.9	15	84	
97ADW030B	61.694/157.183	sh		8.60	1.20	4.90	3.30	1.00	0.51	0.07	0.38	403	1380	59	17	65	77	21	28	56	16	26	79	22	22	77	10	273	2.8	16	177	
97ADW035A	61.898/157.817	ss		5.60	1.60	3.90	1.40	1.60	0.82	0.08	0.23	756	822	42	12	44	30	17	19	44	9	18	53	12	12	78	3	141	2.9	15	103	
97ADW035B	61.898/157.817	sh		8.40	0.48	4.80	2.40	1.90	0.73	0.09	0.40	708	1400	63	35	90	95	21	30	67	12	29	101	24	20	74	12	234	4.2	19	165	
97ADW038A	61.889/157.842	ss		6.10	2.30	4.50	1.20	2.10	1.10	0.07	0.28	424	788	32	13	50	38	14	15	64	9	15	77	11	14	113	3	157	3.2	14	110	
97ADW038B	61.889/157.842	sh		9.70	0.77	4.40	3.30	2.40	0.58	0.07	0.56	387	2080	68	20	110	134	31	32	71	17	33	83	24	29	67	10	321	4.3	18	145	
97AM052A	61.601/158.311	ss		4.90	0.13	3.10	1.30	1.00	0.38	0.07	0.22	532	664	38	10	60	12	7	19	28	4	17	44	12	10	26	7	130	2.0	8	86	
97AM052B	61.601/158.311	sh		4.60	0.60	4.10	1.10	0.93	0.55	0.10	0.26	2990	610	37	10	62	16	7	18	27	2	19	46	12	9	34	7	115	4.0	16	77	
97AM053C	61.488/158.135	ss		7.40	8.50	4.40	0.52	1.40	1.50	0.22	0.46	1520	1290	34	15	31	1	7	17	42	8	19	40	12	16	497	3	147	5.0	27	98	
97AM053D	61.488/158.135	sh		8.70	1.10	4.70	1.90	1.30	1.10	0.07	0.61	373	738	53	13	50	50	10	27	60	15	28	53	22	21	196	7	223	3.0	18	131	
97ARJ001B	61.933/157.550	ss		5.70	0.22	4.00	0.87	0.92	1.40	0.07	0.43	516	890	35	15	40	16	9	17	26	12	16	48	12	13	61	3	143	2.0	11	89	
97ARJ001C	61.933/157.550	sh		7.30	0.13	4.40	1.60	1.20	0.76	0.10	0.32	495	960	47	15	71	43	17	23	36	11	20	71	18	15	47	8	191	2.9	14	137	
97ARJ008A	61.865/157.583	ss		6.10	0.16	3.50	1.60	1.30	1.00	0.07	0.32	317	1010	50	13	60	27	18	24	41	12	21	57	15	13	44	8	163	2.3	15	108	
97ARJ008B	61.865/157.583	sh		6.40	0.15	4.40	1.80	1.40	0.88	0.08	0.29	303	808	40	12	34	41	13	19	41	10	16	64	15	13	39	8	165	3.3	9	110	
97ARJ011B	61.939/156.355	ss		5.40	1.60	3.30	1.50	1.30	0.73	0.07	0.23	376	887	42	12	17	24	18	22	40	11	19	57	11	12	72	3	147	3.3	19	93	
97ARJ011A	61.939/156.355	sh		6.10	0.18	3.60	1.60	1.20	0.76	0.08	0.25	231	974	46	10	19	36	14	22	38	12	20	60	14	12	40	8	164	2.0	14	108	
98ADW027A	61.307/157.520	ss		3.88	0.05	3.42	0.70	0.83	0.79	0.05	0.09	143	409	15	3	34	28	8	8	39	2	11	46	16	7	45	3	86		2	68	
98ADW027B	61.307/157.520	sh		6.25	0.12	3.51	1.83	0.87	0.87	0.10	0.20	120	1020	39	3	57	22	11	21	30	6	21	47	8	12	80	7	169		6	64	
98ADW033A	61.891/158.050	ss		6.07	0.20	4.51	0.76	0.21	0.04	0.07	0.252	516	550	42	15	38	25	2	22	36	8	26	60	2	15	16	3	159		15	97	
98ADW033B	61.891/158.050	sh		7.94	0.05	5.53	1.79	0.45	0.07	0.08	0.36	300	1010	45	16	132	65	13	25	40	7	27	72	9	16	36	7	217		13	139	

(*continued*)

TABLE 7. MAJOR- AND TRACE-ELEMENT GEOCHEMICAL DATA FOR SANDSTONE-SHALE PAIRS FROM RESTRICTED GEMUK GROUP AND KUSKOKWIM GROUP (*continued*)

Sample No.	Location Lat/Long degrees	Rock type	Si %	Al %	Ca %	Fe %	K %	Mg %	Na %	P %	Ti %	Mn ppm	Ba ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	La ppm	Li ppm	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Sc ppm	Sr ppm	Th ppm	V ppm	W ppm	Y ppm	Zn ppm	Zr ppm
98ADW055A	61.849/157.601	ss		5.37	0.87	4.58	1.33	1.34	0.74	0.09	0.33	1270	1010	40	13	57	31	2	20	39	5	23	59	2	11	57	8	137		16	102	
98ADW055B	61.849/157.601	sh		8.92	0.41	9.10	2.55	1.21	0.62	0.09	0.40	7460	2310	54	14	96	100	2	28	55	6	32	86	14	23	74	13	232		29	166	
98ADW056A	61.851/157.611	ss		4.69	3.44	7.71	1.17	0.90	0.66	1.47	0.162	4120	1010	32	9	120	23	2	15	31	5	20	44	5	9	125	3	122		19	90	
98ADW056B	61.851/157.611	sh		7.79	0.37	5.78	2.05	1.28	0.69	0.10	0.41	1060	1360	59	18	161	80	2	28	53	9	33	83	27	17	72	11	216		27	176	
98ADW062C	61.745/157.231	ss		7.67	1.72	2.97	0.77	0.79	1.33	0.055	0.432	723	475	44	12	32	14	8	21	33	5	13	37	2	12	116	3	113		14	78	
98ADW062B	61.745/157.231	sh		11.20	0.21	4.73	3.11	1.62	0.47	0.04	0.52	208	1610	43	8	95	72	24	23	65	11	24	79	7	25	67	9	297		15	128	
98AM007A	61.731/157.931	ss		6.00	1.43	4.34	0.92	1.58	1.68	0.11	0.42	389	685	46	13	26	24	6	20	46	7	21	55	2	12	89	7	138	0.8	17	103	
98AM007B	61.731/157.931	sh		5.27	2.20	3.54	1.40	1.36	0.81	0.10	0.23	399	792	44	13	17	25	5	17	37	9	18	56	2	10	105	3	139	0.8	14	101	
98AM018A	61.873/158.169	ss		5.66	0.14	4.47	0.85	1.07	1.19	0.055	0.468	669	549	44	16	25	17	2	19	36	8	20	59	2	13	51	7	139		11	83	
98AM018B	61.873/158.169	sh		6.17	0.16	3.80	1.51	1.24	0.76	0.09	0.31	243	777	49	13	28	30	18	23	37	7	23	62	4	14	48	8	167		13	102	
98AM049C	61.778/157.859	ss		4.95	0.96	9.65	1.24	0.94	0.43	0.625	0.186	6140	1270	46	11	109	25	2	17	32	8	15	51	8	10	46	8	130	0.3	16	99	
98AM049B	61.778/157.859	sh		5.13	0.09	13.10	1.22	1.02	0.51	0.23	0.21	5110	824	38	11	90	17	2	18	33	10	13	49	11	10	31	9	133	0.8	17	99	
98AM107A	61.916/158.045	ss		5.38	0.03	3.38	1.34	0.27	0.05	0.055	0.216	444	941	54	13	101	18	2	24	37	8	23	65	2	11	67	8	143	0.8	13	127	
98AM107B	61.916/158.045	sh		7.80	0.08	8.07	2.23	0.54	0.34	0.13	0.40	3970	1270	81	19	69	91	2	33	58	10	27	119	26	20	55	15	244		24	186	
98ARJ080C	61.696/157.182	ss		6.99	2.19	4.18	2.34	1.27	0.83	0.085	0.252	460	1080	45	14	130	45	7	23	56	9	23	67	8	16	79	9	190		16	133	
98ARJ080B	61.696/157.182	sh		8.43	1.83	4.47	3.18	1.23	0.61	0.08	0.31	382	1460	67	14	158	74	21	32	72	6	33	54	11	19	97	12	252		17	139	
98ARJ084A	61.744/157.899	ss		5.65	0.76	3.66	1.45	1.20	0.88	0.07	0.234	379	851	46	12	74	25	11	23	46	5	23	64	2	11	53	7	141		14	105	
98ARJ084B	61.744/157.899	sh		5.33	0.16	3.36	1.50	0.90	0.72	0.08	0.25	295	1350	49	8	52	22	10	22	49	8	22	59	9	11	42	10	139		14	104	
99ADW008A	61.479/158.710	ss		9.08	1.47	3.91	1.62	1.15	2.00	0.105	0.622	951	1070	46	17	18	4	26	24	38	21	25	15	10	18	326	3	152	3.4	21	61	
99ADW008B	61.479/158.710	sh		9.38	0.86	5.98	2.38	1.59	0.64	0.15	0.65	583	802	70	21	67	36	30	34	46	25	33	48	14	20	165	12	199	6.9	28	127	
99ADW015A	61.397/158.307	ss		5.67	1.56	8.74	0.08	1.95	0.30	0.31	0.26	847	80	44	8	37	4	26	19	144	5	33	44	14	15	86	7	163	1.5	47	91	
99ADW015B	61.397/158.307	sh		9.80	0.78	6.29	1.96	1.46	0.90	0.11	0.67	498	935	54	13	66	61	29	30	92	23	35	47	13	22	101	9	235	1.1	25	105	
99ADW016A	61.409/158.414	ss		11.90	3.07	3.65	1.29	0.85	2.98	0.44	0.52	424	476	71	34	22	23	20	35	94	17	50	46	19	19	420	8	137	0.3	48	141	
99ADW016B	61.409/158.414	sh		9.96	0.53	5.92	2.44	1.51	0.98	0.11	0.53	544	809	63	28	66	66	29	30	112	15	33	64	19	22	95	12	250	0.6	21	147	
99ADW017A	61.419/158.437	ss		5.70	2.10	5.29	0.05	2.36	0.77	0.12	0.47	1900	76	38	21	30	7	8	20	82	17	27	72	56	14	156	8	151	0.6	27	214	
99ADW017B	61.419/158.437	sh		12.40	1.64	4.79	3.39	1.41	1.43	0.09	0.85	1010	1500	90	27	64	71	38	47	78	32	47	67	15	27	278	13	311	2.6	23	114	
99ADW018A	61.428/158.455	ss		7.85	1.29	4.97	1.05	1.40	1.46	0.19	0.55	391	411	49	20	33	28	21	24	99	14	24	41	17	16	147	8	142	1.4	21	100	
99ADW018B	61.428/158.455	sh		10.10	1.38	5.23	2.19	1.41	1.34	0.21	0.58	492	929	52	31	55	49	27	26	88	23	31	75	27	21	186	10	229	1.8	25	120	
99ADW019A	61.430/158.492	ss		5.32	0.16	4.53	0.76	1.12	0.93	0.13	0.29	756	475	22	9	39	7	14	9	55	11	13	57	8	11	38	7	132	1.8	12	65	
99ADW019B	61.430/158.492	sh		8.96	0.13	5.00	2.12	1.61	0.78	0.09	0.45	554	1150	58	21	122	59	23	32	48	14	29	88	15	23	43	8	243	1.2	18	117	
99ADW024A	61.236/158.297	ss		9.54	1.26	3.25	1.55	0.99	2.64	0.07	0.44	362	560	37	4	11	14	21	18	57	16	21	12	12	16	259	3	113	3.0	20	70	
99ADW024B	61.236/158.297	sh		9.81	0.36	4.33	2.19	1.20	1.63	0.07	0.56	198	690	40	11	33	45	28	18	62	25	18	27	7	22	173	3	221	1.6	16	148	
99ADW101A	61.297/158.731	ss		10.70	0.38	5.19	2.91	1.49	0.67	0.07	0.68	663	841	54	24	49	52	33	30	89	27	22	55	17	25	169	12	210	2.4	21	106	
99ADW101B	61.297/158.731	sh		7.46	1.25	4.55	1.02	1.20	1.59	0.07	0.48	457	355	41	16	19	14	19	21	73	16	15	36	10	14	221	7	129	0.6	17	61	
99AM324A	61.198/158.829	ss		12.00	0.75	5.42	1.85	1.48	2.79	0.08	0.72	1630	618	47	13	26	47	28	23	135	24	26	31	15	27	257	7	231	0.3	10	96	
99AM324B	61.198/158.829	sh		12.40	0.30	4.52	2.64	1.21	1.31	0.07	0.81	746	951	47	14	60	44	30	22	80	30	27	25	11	32	146	7	280	2.9	12	61	
99AM328A	61.392/158.354	ss		9.00	1.70	4.45	0.71	1.37	3.00	0.08	0.622	1180	366	42	17	21	12	24	24	128	19	22	20	5	18	259	7	171	4.1	24	45	
99AM328B	61.392/158.354	sh		9.73	0.86	5.35	0.46	1.51	3.30	0.07	0.63	971	242	28	16	23	29	23	14	270	19	21	14	19	19	220	3	166	1.2	13	150	
99AM331A	61.442/158.444	ss		4.83	2.39	5.79	0.19	2.04	0.13	0.145	0.429	713	249	43	19	48	21	14	21	83	14	21	61	12	13	187	3	153	3.5	18	89	
99AM331B	61.442/158.444	sh		9.57	1.49	5.53	1.11	1.37	2.09	0.08	0.60	800	534	43	19	30	13	25	19	99	17	25	35	13	18	391	7	177	4.8	15	84	
99AM382A	61.206/158.844	ss		5.47	0.33	4.00	1.05	1.19	0.92	0.11	0.363	1120	469	42	12	80	12	15	22	63	15	13	50	8	11	76	8	152	3.2	15	117	
99AM382B	61.206/158.844	sh		10.00	0.20	4.04	3.18	1.41	0.69	0.10	0.66	772	1170	73	9	103	53	26	39	65	32	29	58	8	26	56	11	307	3.6	18	119	
99AM443C	61.206/158.844	ss		4.48	4.34	3.02	1.24	1.62	0.52	0.095	0.215	330	622	36	9	24	24	14	16	46	9	16	43	13	9	93	3	126	2.7	18	100	
99AM443D	61.206/158.844	sh		5.66	3.71	3.23	1.67	1.50	0.51	0.10	0.25	330	897	40	10	37	37	15	19	53	10	19	41	17	11	78	6	157	1.2	19	121	

Note: Each sandstone sample has a corresponding shale sample (same sample number, different suffix letter). All analyses were by ICP-AES following procedures in Lichte et al. (1987), except as follows. Silica was determined by LX X050, zirconium was determined by MX X010 and tungsten was determined by LQ E010 or by RT Z000. Abbreviations: sh, shale; ss, sandstone.

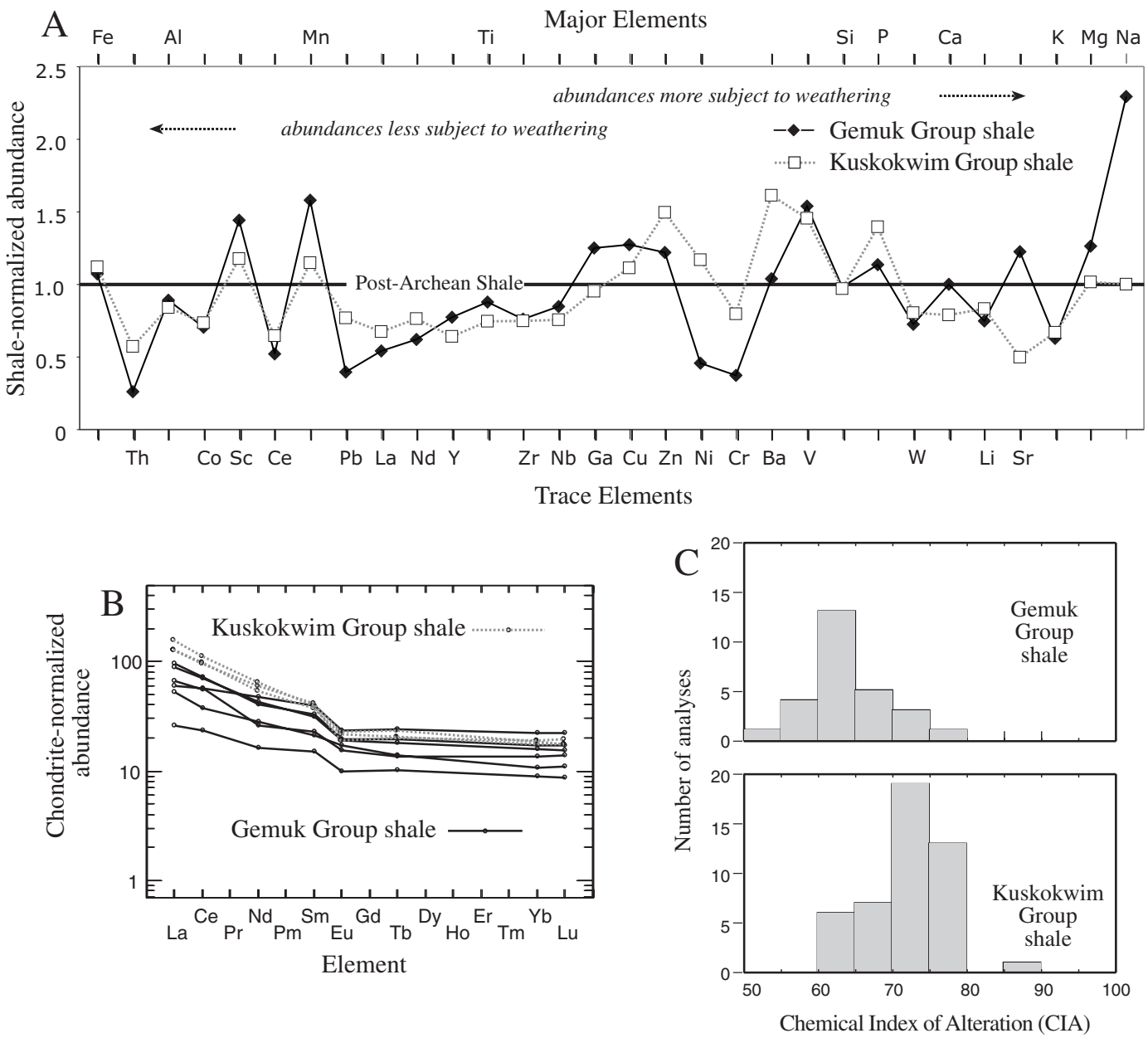


Figure 11. Geochemical plots comparing shales of the restricted Gemuk Group with those of the Kuskokwim Group. (A) Spidergram showing normalized major-element abundances for shales. Elements are arrayed from left to right according to seawater residence time, which is a proxy for stability in the weathering environment. (B) REE diagram, normalized to chondrites following Sun and McDonough (1989). Restricted Gemuk Group shales are enriched in LREE and have negative Eu anomalies. (C) Histograms of calculated chemical index of alteration (CIA of Nesbitt and Young, 1982). Note that the shales of the Kuskokwim Group have a higher CIA than those of the restricted Gemuk Group.

50 for unweathered rocks and 100 for rocks that have been so intensely weathered that nothing remains but kaolinite. The CIA of restricted Gemuk Group samples has a mean of ~60 (Fig. 11C), ~10 points lower than Kuskokwim Group shales. On this basis, the source of the restricted Gemuk Group shales would appear to have been less intensely weathered than the source of the Kuskokwim Group shales. This difference could be due to changing paleoclimates, the Late Cretaceous having been a particularly hot time (Frakes et al., 1992, p. 194). However, an additional factor is the change in source area as evidenced by the influx of metamorphic lithic fragments in the Kuskokwim Group (discussed in previous section).

COMPOSITE STRATIGRAPHIC SECTION OF THE RESTRICTED GEMUK GROUP

Combining the existing lithologic, paleontologic, and isotopic data from the Taylor Mountains and Sleetmute quadrangles

allows us to construct a rough stratigraphy for the restricted Gemuk Group (Fig. 7). The Upper Triassic part of the section is known from three areas in Taylor Mountains D8 quadrangle; correlative rocks have not yet been recognized in the Sleetmute quadrangle. Jurassic parts of the section are confirmed in the Sleetmute quadrangle and may also be present in the Taylor Mountains quadrangle. Lower Cretaceous strata are now known from both quadrangles.

As summarized in Figure 7, we recognize three lithologic divisions. The lowest division, corresponding to subunit A of the type area, consists of andesitic pillowed lavas interbedded with chert, siltstone, and limestone ranging in age from late Carnian to mid-Norian (Late Triassic). The middle division is largely siltstone and chert ranging in age from mid-Norian to at least Oxfordian (Late Jurassic). Definitive Middle Jurassic fossils have not been found, probably due to incomplete sampling. The upper division is mostly siliciclastic turbidites and tuffs; the highest beds in the upper unit are nearly entirely sandstone. The upper unit ranges in age from latest Jurassic (Tithonian) to Early Cretaceous (Hauterivian or maybe a little younger).

Stratigraphic thickness is difficult to estimate. The thickness given by Cady et al. (1955) of 15,000–25,000 feet (4600–7600 m) was based on incorrect assumptions and is no longer valid. The lower unit (subunit A) is ~800 m thick. The thickness of the middle unit is largely unconstrained, but the uppermost part of this unit is ~600 m thick based on relatively flat-lying strata in mountainside exposures in the southwestern corner of the Sleetmute quadrangle (Fig. 4H). The thickness of the upper unit is also largely unconstrained, but a partial homoclinal section in Sleetmute quadrangle is 850 m. In all, the restricted Gemuk Group is at least 2250 m thick and could easily be at least twice as thick.

DISCUSSION

Depositional Setting

The turbidites and radiolarian cherts that together form perhaps half the thickness of the restricted Gemuk Group were deposited below storm wave base. The siltstones that make up most of the remainder show no evidence of shallow-water deposition (e.g., bioturbation, wave ripples, or hummocky cross-stratification). The amygdaloidal pillow lavas were erupted under water, although probably not at depths greater than 700 m, as suggested by the presence of vesicles (Moore and Schilling, 1973). The only rocks that might be argued to have been deposited in shallow water are the rare Triassic and Lower Cretaceous limestones containing the bivalves *Monotis* and *Buchia,* respectively. These limestones are interbedded with radiolarian cherts in two cases and with pillow lavas in another case; they are coquinas that we interpret to have been transported downslope into their site of deposition. The conodonts of sample 04ADw47B also indicate postmortem transport. Accordingly, we believe that most if not all of the restricted Gemuk Group was deposited in relatively deep water, probably at least 100 m depth. These conditions prevailed for at least 80 million years.

Terrane Affinity

Using the terrane framework established (along the coast) by Box (1985), the type Gemuk Group was included by Decker et al. (1994) in the Hagemeister subterrane of the Togiak terrane. As noted in a previous section, the Hagemeister subterrane is interpreted to be a Late Triassic to Early Cretaceous arc built on Triassic ophiolite (Decker et al., 1994). This is a debatable subterrane assignment for the restricted Gemuk Group. The Triassic intermediate pillow lavas of the restricted Gemuk Group are unlikely to represent even the top of an ophiolite, though they could represent a submarine arc. In the Jurassic part of the restricted Gemuk Group succession, our limited data show evidence for igneous activity only in the uppermost Jurassic. In contrast, the Hagemeister subterrane includes 159 Ma and 187 Ma gabbros, as well as Lower Jurassic pillow lavas, volcanic breccias, and volcaniclastic sediments (Hoare and Coonrad, 1978). So far, Lower or Middle Jurassic volcanic rocks or tuffs have not been identified in the restricted Gemuk Group, and Jurassic plutonic rocks are totally lacking. The uppermost Jurassic and Lower Cretaceous tuffs of the restricted Gemuk Group were likely derived from an arc, and the abundance of tuffs suggests that such an arc would have been relatively close by.

Among the other subterranes in the Decker et al. (1994) scheme, the Kulukak subterrane of the Togiak terrane is interpreted as a Jurassic back-arc basin that received voluminous volcaniclastic sediment from the arc. The subduction zone is thought to have dipped to the east, and its surface trace would have lain to the west of the Togiak arc (Fig. 5 *in* Decker et al., 1994). Available age control for the restricted Gemuk Group suggests that radiolarian cherts and siltstones were being deposited during the Jurassic. The Nukluk and Tikchik subterranes of the Goodnews terrane are belts of mélange, both of which include cherts whose Triassic, Jurassic, and Early Cretaceous radiolarian ages partly correspond to chert ages in the restricted Gemuk Group. Thus it is possible that one or the other of these mélange belts includes (among many other rocks) dismembered equivalents of strata that are preserved in a relatively intact form in the outcrop belt of the restricted Gemuk Group.

In summary, as currently defined, none of the terranes of Decker et al. (1994) are a perfect home for the restricted Gemuk Group. However, an equivalent of each of the components of the restricted Gemuk Group is represented in either the Goodnews or Togiak terrane. The extrapolations that Decker et al. (1994) made far inland are quite possibly flawed; perhaps the subterrane scheme needs revision, or maybe more terranes exist than have been recognized. Until we can better define the tectonic setting of the restricted Gemuk Group, we will not be able to resolve this issue.

Tectonic Setting

Any model must account for the lithologies and ages summarized in Figure 7 and must also account for the other oceanic and arc rocks in southwestern Alaska. At our present level of under-

standing, two plate tectonic settings for the restricted Gemuk Group seem viable.

Scenario 1, oceanic-plate stratigraphy. The concept of oceanic plate stratigraphy was developed by Berger and Winterer (1974). As plate motion conveys a piece of seafloor from its origin at a ridge, across an abyssal plain, and into a trench, a predictable stratigraphy will develop. From base to top, the idealized sequence would be: (1) pillow basalt, (2) pelagic carbonate, (3) pelagic chert and mudstone, (4) hemipelagic siltstone, and (5) turbidites, often accompanied by tuffs. The conveyor-belt effect makes each of these rock types time transgressive. If this stratigraphy gets offscraped into a series of fault-bounded panels, then individual panels could end up with the same rock succession but different ages. Oceanic-plate stratigraphy is widely recognized in many orogenic belts, including the Mesozoic of Japan (Matsuda and Isozaki, 1991), the Mesozoic McHugh Complex of Alaska (Connelly, 1978; Bradley and Kusky, 1992), and the Mesozoic Franciscan Complex of California (Isozaki and Blake, 1994). Could this model apply to the restricted Gemuk Group? On the whole, the rocks present in the restricted Gemuk Group are broadly compatible with this model, although some problems are apparent: (1) pillow lavas only occur at one stratigraphic level, the Triassic; (2) these lavas are andesite, not basalt; (3) the lavas cannot represent the top of an ophiolitic basement because they occur within a sedimentary section; (4) vesicles (now amygdules) in the pillow lavas suggest water depth less than ~700 m; and (5) significant graywacke sections are only known from the Upper Jurassic and Lower Cretaceous. None of these problems is necessarily fatal to the model, and most can be rationalized. The pillowed andesites, for example, might represent part of an intra-oceanic arc caught up in a subduction complex. The cherts from several stratigraphic levels in our composite section (Fig. 7) might actually be from different offscraped panels that have been juxtaposed along unrecognized thrust faults. Detailed mapping, supported by intensive sampling of radiolarian cherts and tuffs, would enable us to test the ocean-plate stratigraphy idea.

Scenario 2, back-arc basin. Perhaps a more plausible scenario for the restricted Gemuk Group involves deposition in a back-arc basin east of the Togiak terrane. During Early Triassic to Early Cretaceous time, the Togiak arc is thought to have developed over an east-dipping (present directions) subduction zone (Fig. 5 of Decker et al., 1994). The Triassic pillow lavas in this model could be related to back-arc spreading. The Jurassic cherts and siltstones would represent deep-water sedimentation in the back-arc basin. The uppermost Jurassic to Lower Cretaceous tuffs and graywackes would have been derived from the Togiak arc source.

CONCLUSIONS

We restrict the Gemuk Group of southwestern Alaska to its type area in Taylor Mountains quadrangle and contiguous rocks to the north in Sleetmute quadrangle. The restricted Gemuk Group is an Upper Triassic to Lower Cretaceous marine succession of pillow lavas, siltstone, chert, limestone, tuff, and graywacke. The age range of the restricted Gemuk Group is tightened on the basis of ten radiolarian ages on chert, two new bivalve ages, one conodont age on limestone, two U-Pb zircon ages on tuff, and U-Pb ages of 110 detrital zircons from two sandstones. Discontinuous exposure, hints of complex structure, the reconnaissance level of our mapping, and spotty age constraints together permit definition of only a rough stratigraphy. The Triassic part of the section features intermediate pillow lavas interbedded with siltstone, chert, and rare limestone. The Jurassic part of the section appears to be mostly siltstone and chert. Two tuffs near the Jurassic-Cretaceous boundary record nearby arc volcanism; one at 146 Ma is interbedded with red and green siltstone, and a second at ca. 137 Ma is interbedded with turbiditic graywacke. Graywacke and shale appear to be the dominant rock types in the Lower Cretaceous part of the section. Although superficially similar, these strata contrast compositionally with the sandstones and shales of the overlying Upper Cretaceous Kuskokwim Group. Major- and trace-element geochemistry of shales from the restricted Gemuk Group and the Kuskokwim Group show distinct differences. The chemical index of alteration (CIA) is distinctly higher for Kuskokwim Group than for restricted Gemuk Group shales, suggesting either more intense weathering during Kuskokwim Group deposition or a change in source area (or some combination thereof). Sandstone point counts from both groups show that restricted Gemuk Group has K-feldspar clasts whereas none are found in the Kuskokwim Group. Some K-feldspar-bearing graywacke that was previously mapped as Kuskokwim Group (Cady et al., 1955) is here reassigned to the restricted Gemuk Group.

Based on a composite section of the restricted Gemuk Group, we draw the following broader conclusions. The restricted Gemuk Group represents an estimated 90–100 m.y. of deep-water sedimentation, first accompanied by submarine volcanism and later by nearby explosive arc activity. Two hypotheses for the tectonic setting are viable. One model is that the restricted Gemuk Group consists of imbricated oceanic plate stratigraphy, in which case it would represent a subduction complex. Our preferred model is that it was deposited in a back-arc basin. As for terrane assignment, southwestern Alaska was largely subdivided on the basis of coastal exposures far to the south of our study area. Extrapolations inboard are problematic, and the terrane affinity of the restricted Gemuk Group is uncertain. The rocks of this area were formerly assigned to the Hagemeister subterrane of the Togiak terrane—a Late Triassic to Early Cretaceous arc—but our data show this to be a poor match. None of the other possibilities fit well either. As for stratigraphic nomenclature, we reject a recent proposal that the Gemuk Group be abandoned as a stratigraphic entity and be replaced by the newly proposed "Togiak-Tikchik Complex." This amounts to a new name for the old regional catch-all unit. We recommend reinstating but restricting the Gemuk Group. Geochronologic, paleontologic, stratigraphic, and compositional studies of the *restricted* Gemuk Group provide key information about the Late Triassic to Early Cretaceous history of

this complex region. Comparable modern studies on the Permian and older rocks that have been removed from the restricted Gemuk Group are needed to unravel this region's earlier tectonic history.

ACKNOWLEDGMENTS

Dork Sahagian helped with depth interpretation of the vesicular lavas. William P. Elder identified a bivalve collection. Joe Wooden provided technical support making the SHRIMP analyses possible. Julie Dumoulin's careful review clarified and improved the entire manuscript. William Patton, Jr.'s broad regional perspective helped us clarify the interpretive aspects of this paper. Tom Judkins provided his expert advice on complicated issues of stratigraphic nomenclature. Ken Ridgway provided astute comments that clarified the paper's focus.

REFERENCES CITED

Baedecker, P.A., and McKown, D.M., 1987, Instrumental neutron activation analysis of geochemical samples, *in,* Baedecker, P.A., ed., Methods for Geochemical Analysis: U.S. Geological Survey Bulletin 1770, p. H1–H14.

Berger, W.H., and Winterer, E.L., 1974, Plate stratigraphy and the fluctuating carbonate line: Special Publications of the International Association of Sedimentologists, v. 1, p. 11–48.

Blodgett, R.B., and Boucot, A.J., 1999, Late Early Devonian (late Emsian) eospiriferinid brachiopods from Shellabarger Pass, Talkeetna C-6 quadrangle, south-central Alaska and their biogeographic importance: Further evidence for a Siberian origin of the Farewell and allied Alaskan accreted terranes: Senckenbergiana lethaea, v. 72, no. 1, p. 209–221.

Blodgett, R.B., Wilson, F.H., Stanley, G.D., Jr., McRoberts, C.A., and Sandy, M.R., 2000, Upper Triassic stratigraphy and fauna of the Taylor Mountains D-2 and D-3 quadrangles (SW part of the Farewell terrane), southwest Alaska: Geological Society of America Abstracts with Programs, v. 32, no. 6, p. A-4.

Blodgett, R.B., Rohr, D.M., and Boucot, A.J., 2002, Paleozoic links among some Alaskan accreted terranes and Siberia based on megafossils, *in* Miller, E.L., Grantz, A., and Klemperer, S.L., eds., Tectonic Evolution of the Bering Shelf-Chukchi Sea-Arctic Margin and Adjacent Landmasses: Geological Society of America Special Paper 360, p. 273–290.

Blome, C.D., 1984, Upper Triassic Radiolaria and Radiolarian Zonation from western North America: Bulletins of American Paleontology, v. 85, no. 318, p. 1–88, 17 pls.

Box, S.E., 1985, Terrane analysis of the northern Bristol Bay region, southwestern Alaska: U.S. Geological Survey Circular 967, p. 32–37.

Box, S.E., Moll-Stalcup, E.J., Wooden, J.L., and Bradshaw, J.Y., 1990, Kilbuck terrane: Oldest known rocks in Alaska: Geology, v. 18, p. 1219–1222, doi: 10.1130/0091-7613(1990)018<1219:KTOKRI>2.3.CO;2.

Box, S.E., Moll-Stalcup, E.J., Frost, T.P., and Murphy, J.M., 1993, Preliminary geologic map of the Bethel and southern Russian Mission quadrangles, southwestern Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-2226-A, scale 1:250,000, 20 p.

Bradley, D.C., and Kusky, T.M., 1992, Deformation history of the McHugh Complex, Seldovia quadrangle, south-central Alaska, *in* Bradley, D.C., and Ford, A.B., eds., Geologic Studies in Alaska by the U.S. Geological Survey, 1990: U.S. Geological Survey Bulletin 1999, p. 17–32.

Bradley, D.C., McClelland, W.C., Wooden, J.L., Till, A.B., Roeske, S.M., Miller, M.L., Karl, S.M., and Abbott, J.G., 2007, this volume, Detrital zircon geochronology of some Neoproterozoic to Triassic rocks in interior Alaska, *in* Ridgway, K.D., Trop, J.M., Glen, J.M.G., and O'Neill, J.M., eds., Tectonic Growth of a Collisional Continental Margin: Crustal Evolution of Southern Alaska: Geological Society of America Special Paper 431, doi: 10.1130/2007.2431(07).

Cady, W.M., Wallace, R.E., Hoare, J.M., and Webber, E.J., 1955, The Central Kuskokwim Region, Alaska: U.S. Geological Survey Professional Paper 268, 132 p.

Connelly, W., 1978, Uyak Complex, Kodiak Islands, Alaska: A Cretaceous subduction complex: Geological Society of America Bulletin, v. 89, p. 755–769, doi: 10.1130/0016-7606(1978)89<755:UCKIAA>2.0.CO;2.

Decker, J., Bergman, S.C., Blodgett, R.B., Box, S.E., Bundtzen, T.K., Clough, J.G., Coonrad, W.L., Gilbert, W.G., Miller, M.L., Murphy, J.M., Robinson, M.S., and Wallace, W.K., 1994, The geology of southwestern Alaska, *in* Plafker, G., and Berg, H.C., eds., The Geology of Alaska: Geological Society of America, Geology of North America, v. G-1, p. 285–310.

Dickinson, W.R., 1985, Interpreting provenance relations from detrital modes of sandstones, *in* Zuffa, G.G., ed., Provenance of Arenites: Boston, D. Reidel, p. 333–362.

Dumoulin, J.A., Harris, A.G., Gagiev, M., Bradley, D.C., and Repetski, J.E., 2002, Lithostratigraphic, conodont, and other faunal links between lower Paleozoic strata in northern and central Alaska and northeastern Russia, *in* Miller, E.L., Grantz, A., and Klemperer, S.L., eds., Tectonic Evolution of the Bering Shelf-Chukchi Sea-Arctic Margin and Adjacent Landmasses: Geological Society of America Special Paper 360, p. 291–312.

Epstein, A.G., Epstein, J.B., and Harris, L.D., 1977, Conodont Color Alteration: An Index to Organic Metamorphism: U.S. Geological Survey Professional Paper 995, 27 p.

Frakes, L.A., Francis, J.E., and Syktus, J.I., 1992, Climate Modes of the Phanerozoic: Cambridge University Press, 274 p.

Gradstein, F.M., Ogg, J.G., and Smith, A.G., eds., 2004, A Geologic Time Scale 2004: Cambridge University Press, 384 p.

Hoare, J.M., and Coonrad, W.L., 1959a, Geology of the Bethel quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-285, scale 1:250,000.

Hoare, J.M., and Coonrad, W.L., 1959b, Geology of the Russian Mission quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-292, scale 1:250,000.

Hoare, J.M., and Coonrad, W.L., 1961a, Geologic map of the Goodnews quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-339, scale 1:250,000.

Hoare, J.M., and Coonrad, W.L., 1961b, Geologic map of the Hagemeister Island quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-321, scale 1:250,000.

Hoare, J.M., and Coonrad, W.L., 1978, Geologic map of the Goodnews and Hagemeister Island quadrangles region, southwestern Alaska: U.S. Geological Survey Open-File Report 78-9-B, scale 1:250,000, 2 sheets.

Isozaki, Y., and Blake, M.C., 1994, Biostratigraphic constraints on formation and timing of accretion in a subduction complex: An example from the Franciscan Complex in northern California: The Journal of Geology, v. 102, p. 283–296.

Jacobson, S.A., 1984, compiler, The Yup'ik Eskimo Dictionary: Fairbanks, Alaska Native Language Center, University of Alaska, 757 p.

Jaffey, A.H., Flynn, K.F., Glendenin, L.E., Bentley, W.C., and Essling, A.M., 1971, Precision measurement of half-lives and specific activities of ^{235}U and ^{238}U: Physical Review C: Nuclear Physics, v. 4, p. 1889–1906, doi: 10.1103/PhysRevC.4.1889.

Jones, D.L., and Silberling, N.J., 1979, Mesozoic stratigraphy: The key to tectonic analysis of southern and central Alaska: U.S. Geological Survey Open-File Report 79-1200, 41 p.

Krogh, T.E., 1982, Improved accuracy of U-Pb zircon dating by the creation of more concordant systems using air abrasion techniques: Geochimica et Cosmochimica Acta, v. 46, p. 637–649, doi: 10.1016/0016-7037(82)90165-X.

Lichte, F.E., Golightly, D.W., and Lamothe, P.J., 1987, Inductively coupled plasma-atomic emission spectrometry, *in,* Baedecker, P.A., ed., Methods for Geochemical Analysis: U.S. Geological Survey Bulletin 1770, p. B1–B10.

Ludwig, K.R., 1980, Calculation of uncertainties of U-Pb isotope data: Earth and Planetary Science Letters, v. 46, p. 212–220, doi: 10.1016/0012-821X(80)90007-2.

McRoberts, C.A., 1997, Late Triassic halobiid bivalves: Diversity trends and circum-Pacific correlations, p. 198–208, *in* Dickins, J.M., Yang Zunyi, Yin Hongfu, Lucas, S.G., and Acharyya, S.K., eds., Late Palaeozoic and Early Mesozoic Circum-Pacific Events and Their Global Correlation: Cambridge, Cambridge University Press, 245 p.

McRoberts, C.A., and Blodgett, R.B., 2002, Late Triassic (Norian) mollusks from the Taylor Mountains quadrangle, southwestern Alaska, *in* Wilson, F.H., and Galloway, J.P., eds., Geologic Studies in Alaska by the U.S. Geological Survey, 2000: U.S. Geological Survey Professional Paper 1662, p. 55–75.

Matsuda, T., and Isozaki, Y., 1991, Well-documented travel history of Mesozoic pelagic chert in Japan: From remote ocean to subduction zone: Tectonics, v. 10, p. 475–499.

Mertie, J.B., Jr., 1938, The Nushagak District Alaska: U.S. Geological Survey Bulletin 903, 96 p.

Miller, M.L., and Bundtzen, T.K., 1994, Generalized geologic map of the Iditarod quadrangle, Alaska showing potassium-argon, major oxide, trace element, fossil, paleocurrent, and archaeologic sample localities: U.S. Geological Survey Miscellaneous Field Studies Map MF-2219-A, 48 p., interpretive text and tables, scale 1:250,000.

Miller, M.L., Tucker, R.D., Layer, P.W., and Bundtzen, T.K., 2000, Isotopic ages from intrusive rocks near the Stuyahok gold placer deposits, south-central Holy Cross quadrangle, Alaska, *in* Kelley, K.D., and Gough, L.P., eds., Geologic Studies in Alaska by the U.S. Geological Survey, 1998: U.S. Geological Professional Paper 1615, p. 179–188.

Miller, M.L., Bradley, D.C., Bundtzen, T.K., and McClelland, W., 2002, Late Cretaceous through Cenozoic strike-slip tectonics of southwestern Alaska: The Journal of Geology, v. 110, p. 247–270, doi: 10.1086/339531.

Miller, M.L., Bradley, D.C., Bundtzen, T.K., Pessagno, E.A., Jr., Blodgett, R.B., Tucker, R., and Wooden, J., 2004, Reevaluating the Triassic to Cretaceous "Gemuk Group": Evidence from the Sleetmute quadrangle, southwest Alaska: Alaska Geological Society 2004 Technical Conference, Abstracts and Program, p. 17.

Miller, M.L., Bradley, D.C., Bundtzen, T.K., Blodgett, R.B., Pessagno, E.A., Jr., Tucker, R.D., and Harris, A.G., 2005, Age and provenance of the restricted Gemuk Group (Triassic to Lower Cretaceous), southwest Alaska: Geological Society of America, Abstracts with Programs, v. 37, no. 7, p. 81.

Moll-Stalcup, E., Wooden, J.L., Bradshaw, J., and Aleinikoff, J., 1996, Elemental and isotopic evidence for 2.1-Ga arc magmatism in the Kilbuck terrane, southwestern Alaska: U.S. Geological Survey Bulletin 2152, p. 111–130.

Moore, J.G., and Schilling, J.-G., 1973, Vesicles, water, and sulfur in Reykjanes Ridge basalts: Contributions to Mineralogy and Petrology, v. 41, p. 105–118, doi: 10.1007/BF00375036.

Nesbitt, H.W., and Young, G.M., 1982, Early Proterozoic climate and plate motions inferred from major element chemistry of lutites: Nature, v. 299, p. 715–717, doi: 10.1038/299715a0.

Patton, W.W., Jr., Box, S.E., Moll-Stalcup, E.J., and Miller, T.P., 1994, Geology of west-central Alaska, *in* Plafker, George, and Berg, H.C., eds., The Geology of Alaska: Geological Society of America, Geology of North America, v. G-1, p. 241–269.

Pessagno, E.A., Jr., 1979, Systematic paleontology, *in* Pessagno, E.A., Jr., Finch, W., and Abbott, P.L., Upper Triassic Radiolaria from the San Hipólito Formation, Baja, California: Micropaleontology, 25(2), 160–197, pls. 1–9.

Pessagno, E.A., Jr., and Hull, D.M., 2001, Upper Jurassic (middle Oxfordian) radiolaria from the Sula Islands (East Indies): Their taxonomic, biostratigraphic, chronostratigraphic, and paleobiogeographic significance: Micropaleontology, v. 48, no. 3, p. 229–256, pls. 1–4.

Pessagno, E.A., Jr., Blome, C.D., Carter, E.S., Macleod, N., Whalen, P.A., and Yeh, K-Y., 1987, Studies of North American Jurassic Radiolaria: Part 2, Preliminary Radiolarian Zonation for the Jurassic of North America: Cushman Foundation for Foraminiferal Research Special Publication, 23 (Part 2), p. 1–18, Figs. 1–7.

Pessagno, E.A., Jr., Blome, C.D., Hull, D., and Six, W.M., Jr., 1993, Middle and Upper Jurassic radiolaria from the Western Klamath terrane, Smith River subterrane, northwestern California: Their biostratigraphic, chronostratigraphic, geochronologic, and paleolatitudinal significance: Micropaleontology, v. 39, no. 2, p. 93–166, doi: 10.2307/1485837.

Pessagno, E.A., Jr., Hull, D.M., Martin, C.B., Meng, X., Montgomery, H., Ogg, J.G., and Urrutia-Fucugauchi, J., 1999, Stratigraphic evidence for northwest to southeast tectonic transport of Jurassic terranes in Central Mexico and the Caribbean (western Cuba), *in* Mann, P., ed., Caribbean Sedimentary Basins: Sedimentary Basins of the World, v. 4, 699 p., chapter 5, p. 123–150.

Plafker, G., and Berg, H.C., 1994, Overview of the geology and tectonic evolution of Alaska, *in* Plafker, G., and Berg, H.C., eds., The Geology of Alaska: Geological Society of America, Geology of North America, v. G-1, p. 989–1021.

Sainsbury, C.L., and MacKevett, E.M., Jr., 1965, Quicksilver deposits of southwestern Alaska: U.S. Geological Survey Bulletin 1187, 89 p.

Silberling, N.J., Jones, D.L., Monger, J.W.H., Coney, P.J., Berg, H.C., and Plafker, G., 1994, Lithotectonic terrane map of Alaska and adjacent parts of Canada, *in* Plafker, G., and Berg, H.C., eds., The Geology of Alaska: Geological Society of America, Geology of North America, v. G-1, Plate 3, scale 1:2,500,000.

Silberling, N.J., Grant-Mackie, J.A., and Nichols, K.M., 1997, The Late Triassic bivalve *Monotis* in accreted terranes of Alaska: U.S. Geological Survey Bulletin 2151, 21 p.

Smith, P.S., 1939, Areal Geology of Alaska: U.S. Geological Survey Professional Paper 192, 100 p.

Stacey, J.S., and Kramers, J.D., 1975, Approximation of terrestrial lead isotope evolution by a two-stage model: Earth and Planetary Science Letters, v. 26, p. 207–221, doi: 10.1016/0012-821X(75)90088-6.

Sun, S.-s., and McDonough, W.F., 1989, Chemical and isotopic systematics of oceanic basalts: Implications for mantle composition and processes, *in,* Saunders, A.D., and Norry, M.J., eds., Magamatism in the Ocean Basins: Geological Society [London], Special Publication 42, p. 313–345.

Taylor, S.R., and McLennan, S.M., 1985, The Continental Crust: Its Composition and Evolution: Oxford, Blackwell Scientific Publications, 312 p.

Williams, H., Turner, F.J., and Gilbert, C.M., 1954, Petrography: San Francisco, W.H. Freeman and Co., 406 p.

Wilson, F.H., and Coonrad, W.L., 2005, The Togiak-Tikchik Complex of southwestern Alaska: A replacement for the Gemuk Group: Stratigraphic nomenclature that has outlived its time: U.S. Geological Survey Scientific Investigations Report 2005-5019, 8 p., (http://pubs.usgs.gov/sir/2005/5019/).

Manuscript Accepted by the Society 31 January 2007