To Jeff –
We're slow, but sure!
Marti

ARTICLES

Late Cretaceous through Cenozoic Strike-Slip Tectonics of Southwestern Alaska

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ABSTRACT

New geologic mapping and geochronology show that margin-parallel strike-slip faults on the western limb of the southern Alaska orocline have experienced multiple episodes of dextral motion since ~100 Ma. These faults are on the upper plate of a subduction zone ~350–450 km inboard of the paleotrench. In southwestern Alaska, dextral displacement is 134 km on the Denali fault, at least 88–94 km on the Iditarod–Nixon Fork fault, and perhaps tens of kilometers on the Dishna River fault. The strike-slip regime coincided with Late Cretaceous sedimentation and then folding in the Kuskokwim basin, and with episodes of magmatism and mineralization at ~70, ~60, and ~30 Ma. No single driving mechanism can explain all of the ~95 million-year history of strike-slip faulting. Since ~40 Ma, the observed dextral sense of strike slip has run contrary to the sense of subduction obliquity. This may be explained by northward motion of the Pacific Plate driving continental margin slivers into and/or around the oroclinal bend. From 44 to 66 Ma, oroclinal rotation, perhaps involving large-scale flexural slip, may have been accompanied by westward escape of crustal blocks along strike-slip faults. However, reconstructions of this period involve unproven assumptions about the identity of the subducting plate, the position of subducting ridges, and the exact timing of oroclinal bending, thus obscuring the driving mechanisms of strike slip. Prior to 66 Ma, oblique subduction is the most plausible driving mechanism for dextral strike slip. Cumulative displacement on all faults of the western limb of the orocline is at least 400 km, about half that on the eastern limb; this discrepancy might be explained by a combination of thrusting and unrecognized strike-slip faulting.

Introduction

Major strike-slip fault zones have long been recognized in western interior Alaska (Grantz 1966; figs. 1, 2). The Denali and Iditarod–Nixon Fork faults, in particular, are linear, through-going structures that have well-defined topographic expressions and are comparable in scale to the San Andreas and Alpine fault systems. They occur in the continental back-arc region of the present-day Aleutian subduction zone and strike roughly parallel to the curved continental margin. A number of studies have addressed the sense, timing, and amount of motion on the major margin-parallel strike-slip faults on the eastern limb of the southern Alaska orocline (e.g., Eisbacher 1976; Gabrielse 1985; Dover 1994; Lowey 1998) and in the hinge area of the orocline (Cole et al. 1999). Strike-slip faulting on the western limb has not been as thoroughly documented in the literature, and an up-to-date synthesis has been lacking. Approximately 88–94 km of dextral offset was documented for the Iditarod–Nixon Fork fault (Miller and Bundtzen 1988), and 145–153 km of dextral offset (revised herein to ~134 km) has been suggested for the Denali fault (Blodgett and Clough 1985). However, Csejtey et al. (1996) argued that Cenozoic dextral displacement across the Denali fault in the area of the Cantwell Basin (fig. 1) cannot exceed a few tens of kilometers, and Redfield and Fitzgerald (1993) suggested that, at least since the Miocene, the sense of motion in this area has been sinistral, not dex-

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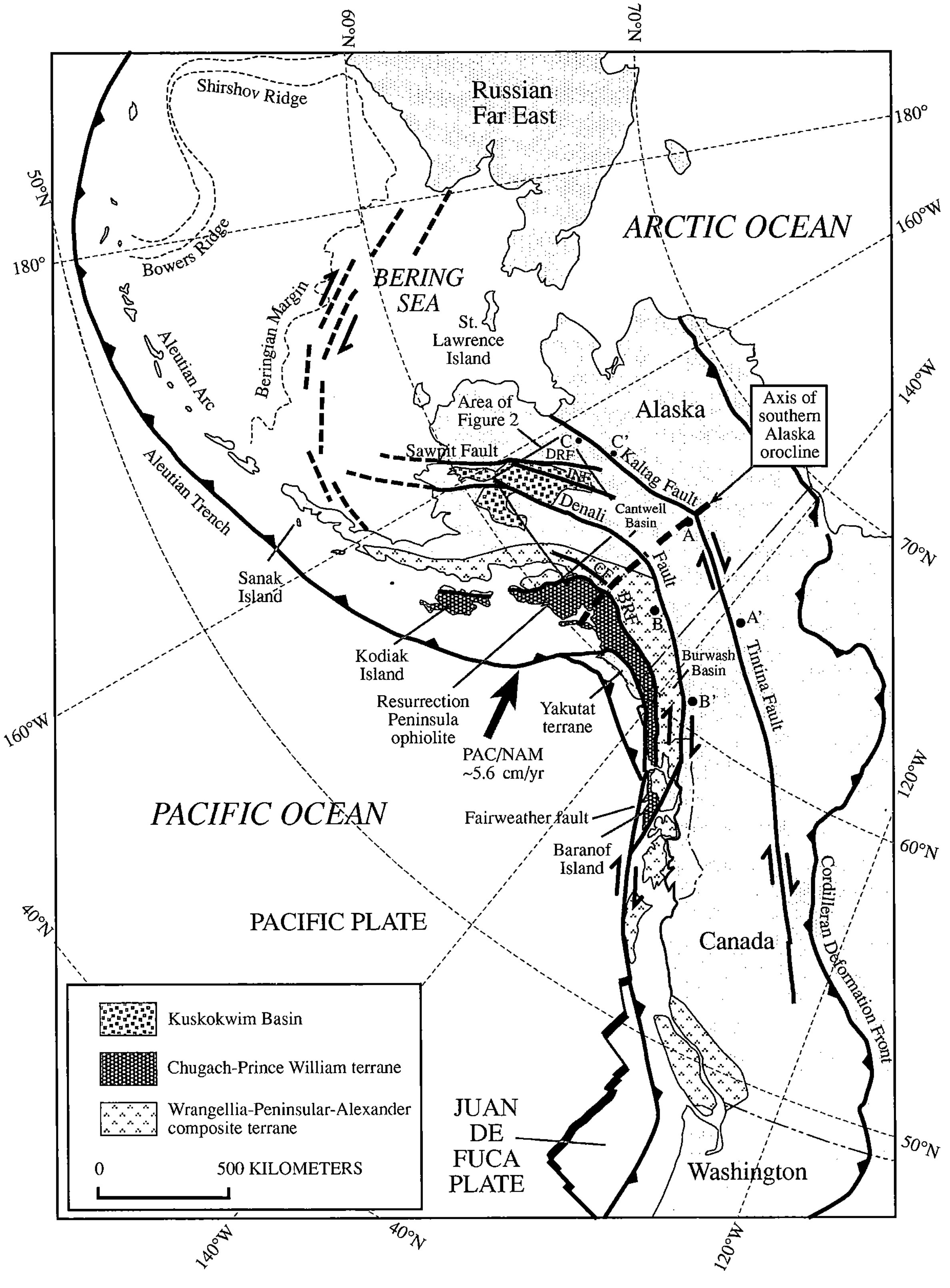

Figure 1. Map of Alaska, the northeastern Pacific, and parts of Canada and the Russian Far East showing key features mentioned in text. Geologic offsets *A* and *A'* (Tintina fault), *B* and *B'* (Denali fault), and *C* and *C'* (Kaltag fault) are indicated. *BRF*, Border Ranges fault; *CF*, Castle Mountain fault. Strike-slip faults of Beringian margin after Worrall (1991).

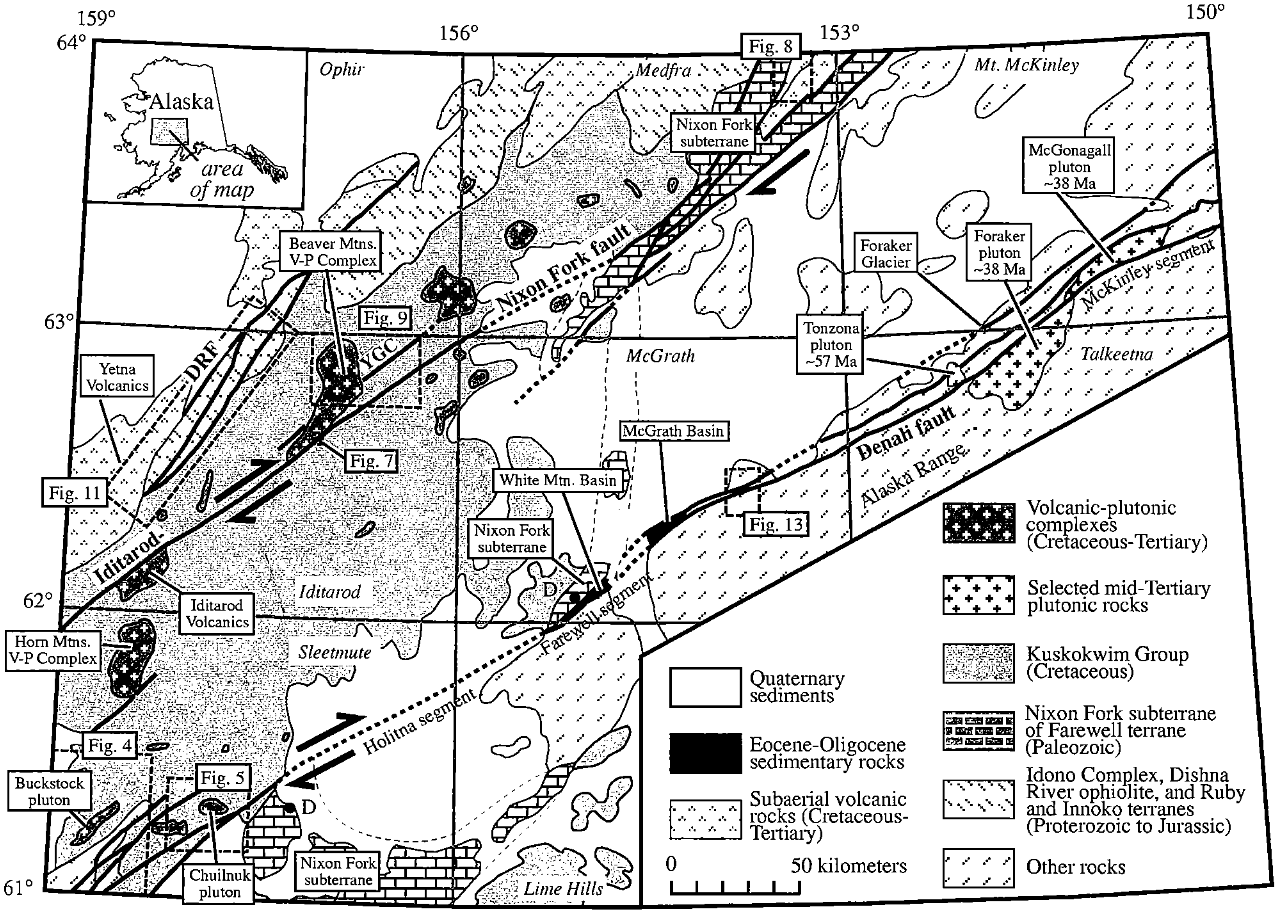

Figure 2. Generalized geologic map of part of southwestern Alaska emphasizing strike-slip faults and key features that bear on their interpretation. *YGC,* Yankee-Ganes Creek fault; *DRF,* Dishna River fault. Area of the Kuskokwim basin is delineated by the Kuskokwim Group. *D* and *D′* mark offset Silurian reefs (R. Blodgett, written communication, 1999).

tral. In light of these controversies, the main purpose of this article is to document the sense, timing, and amount of motion on these margin-parallel strike-slip faults—potentially valuable geologic constraints that might be brought to bear on plate reconstructions in the Pacific and on the history of terrane transport. The history of strike-slip faulting is also important for economic geology reasons: a number of gold and mercury deposits are spatially associated with the major strike-slip faults (fig. 3), one major gold trend is offset 90 km across the Iditarod–Nixon Fork fault, and, as we suggest here, mineralization during three time intervals (~70, ~60, and ~30 Ma) was coeval with strike-slip movements.

Our conclusions are regional in scope, but the data we describe in detail are based primarily on new mapping in the Iditarod, McGrath, and Sleetmute 1 : 250,000-scale quadrangles (fig. 2), performed by the U.S. Geological Survey and the Alaska Division of Geological and Geophysical Surveys (see, e.g., Miller and Bundtzen 1994; Decker et al. 1995; Bundtzen et al. 1997, 1999; and U.S. Geological Survey unpublished mapping).

Regional Geology

This article focuses on the Kuskokwim Mountains region of southwestern interior Alaska, a largely unglaciated area, characterized by rolling hills as high as 900 m that separate wide, sediment-filled valleys. Bedrock is poorly exposed due to extensive vegetation, local loess cover, and the antiquity of the landscape. The dominant bedrock unit is the Upper Cretaceous Kuskokwim Group (Cady et al. 1955) that is largely composed of turbiditic sand-

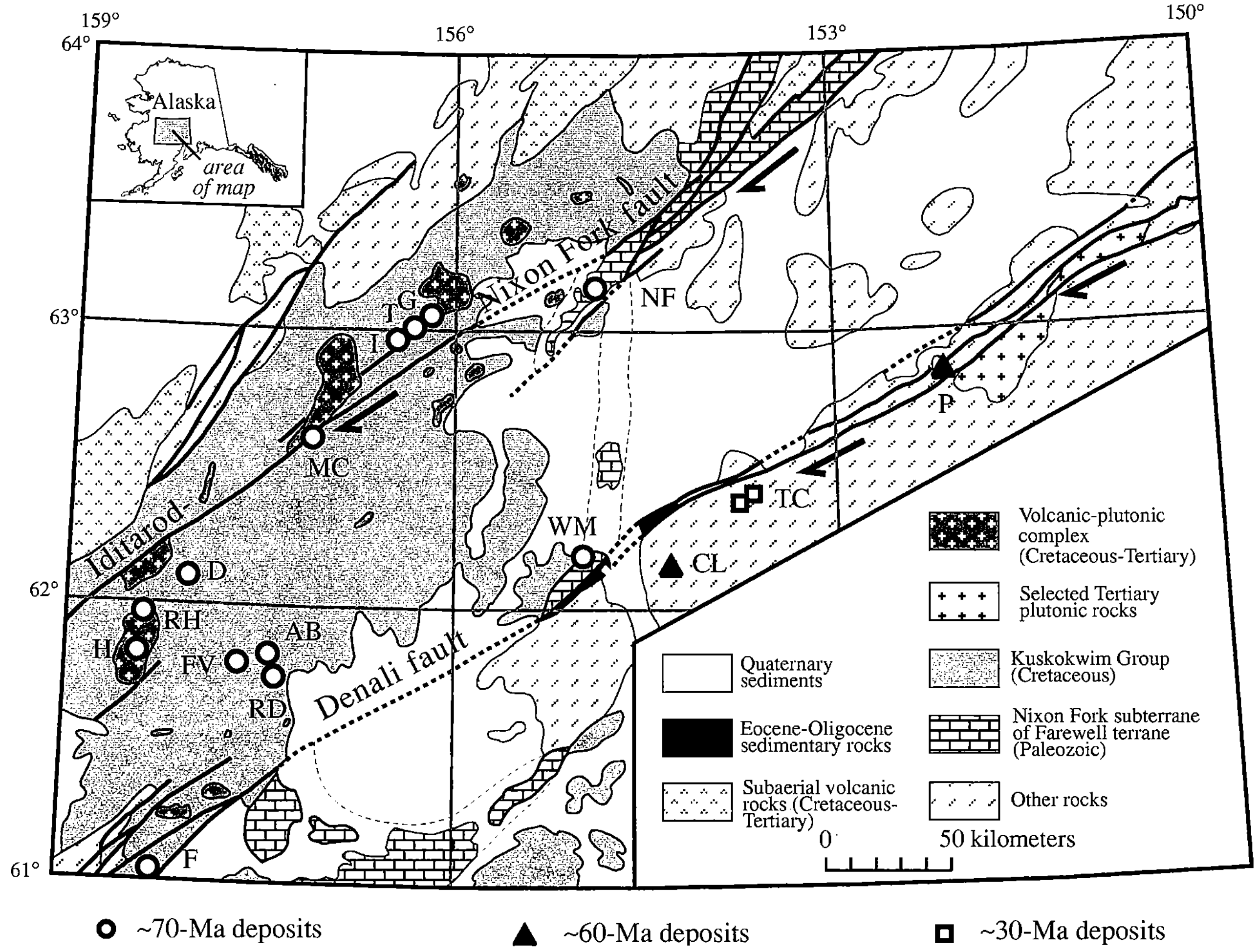

Figure 3. Same area as figure 2 showing key mineral deposits that have some bearing on the Late Cretaceous to Tertiary tectonic history. Symbols correspond to ages as shown. Abbreviations for deposits are as follows: *AB,* Alice and Bessie; *CL,* Chip Loy; *D,* Donlin Creek; *F,* Fortyseven Creek; *FV,* Fairview; *G,* Goss Gulch; *H,* Horn Mountains; *I,* Independence; *MC,* Moore Creek; *NF,* Nixon Fork; *P,* Purkeypile; *RD,* Red Devil; *RH,* Rhyolite; *T,* Telephone Hill; *WM,* White Mountain.

stone and shale (fig. 2). This basin-fill sequence overlies a number of older basement terranes of varied origin that were amalgamated by mid-Cretaceous time (Decker et al. 1994; Patton et al. 1994). The waning stages of Kuskokwim Group deposition were accompanied by regional volcanism and intrusion (Miller and Bundtzen 1994). A number of volcanic-plutonic complexes of Late Cretaceous and early Tertiary age partly intrude and partly overlie the Kuskokwim Group; approximately coeval felsic and intermediate dikes also cut the sedimentary rocks. In the eastern part of figure 2, two younger units bear on the displacement history of the Denali fault: mid-Tertiary plutons of the Alaska Range and Eocene to Oligocene nonmarine sedimentary rocks of the McGrath and White Mountain basins.

Pre-Mid-Cretaceous Rocks. Older bedrock of the Kuskokwim region includes Proterozoic to Lower Cretaceous units of various types. West of the Kuskokwim basin, the oldest rocks are assigned to the Early Proterozoic Idono Complex (Miller et al. 1991) and the Late(?) Proterozoic to Paleozoic Ruby terrane (Jones et al. 1987; Patton et al. 1994). The fault-bounded Idono Complex consists of amphibolite-grade granitic to dioritic orthogneiss, amphibolite, and metasedimentary rocks. Rocks of the Ruby terrane in the area of interest are also fault bounded and consist of greenschist facies meta-igneous and metasedimentary rocks (Chapman et al. 1985; Miller and Bundtzen 1994). Paleozoic-Mesozoic oceanic crust and subduction zone assemblages also crop out on the west side of the Kuskokwim basin (fig. 2). These include slivers of dismembered Jurassic ophiolite (Dishna River mafic-ultramafic rocks of Miller [1990]) and volcanic and sedimentary rocks of the Mississippian to Triassic Innoko terrane (of Jones et al. [1987]).

Basement rocks on the east side of the Kuskokwim basin consist of parts of the Nixon Fork, Dillinger, and Mystic subterranes. Depositional relationships between the three suggest that they are facies of a single terrane, referred to as the "Farewell terrane" by Decker et al. (1994). The Nixon Fork subterrane, which is a platformal carbonate succession of Late Proterozoic to Devonian age, provides the best evidence for offset across the Denali fault in the study area; accordingly, the Nixon Fork subterrane is indicated in figure 2 by a special pattern, whereas the rest of the Farewell terrane is included with "other rocks."

Kuskokwim Basin Fill. Upper Cretaceous sedimentary and minor volcanic rocks of the Kuskokwim Group depositionally overlie structural slivers of the pre-Cretaceous bedrock units (fig. 2). The Kuskokwim Group was deposited primarily by turbidity currents into an elongate, probably strike-slip basin beginning in Late Cretaceous time (Miller and Bundtzen 1992, 1994). Cady et al. (1955) estimated a minimum thickness of 7.5 km. The basinal sequence is successively overlapped by shoreline facies, suggesting that shallow-water strata were deposited when the sedimentation rate exceeded the subsidence rate. Fossils from the Kuskokwim Group are mainly Turonian but range in age from Cenomanian to Campanian or Maastrichtian. The youngest fossils are poorly diagnostic spores. Better control is provided by tuff, interbedded with shoreline facies rocks near the top of the Kuskokwim Group, that has yielded a 77-Ma K/Ar age on biotite (Miller and Bundtzen 1994). For the purposes of this article, we will take this as the approximate upper age limit of the Kuskokwim Group, which accordingly would have an age range from about 95 to 77 Ma.

Late Cretaceous and Tertiary Igneous Rocks. In the Kuskokwim region, Late Cretaceous and Tertiary igneous rocks are of four main types: (1) volcanic-plutonic complexes; (2) subaerial volcanic fields; (3) felsic to intermediate dikes, sills, and stocks; and (4) volumetrically minor altered intermediate to mafic dikes (Miller and Bundtzen 1994; Bundtzen and Miller 1997). Only the first two types are of sufficient aerial extent to show on figure 2. The volcanic-plutonic complexes are important to the strike-slip history because they provide evidence for timing and amount of movement.

Calc-alkaline volcanic-plutonic complexes of Late Cretaceous and early Tertiary age intrude and locally overlie strata of the Kuskokwim Group (Bundtzen et al. 1988; Miller and Bundtzen 1994). About 20 of these complexes, which range from as small as 8 km^2 to as large as 650 km^2, crop out in a broad, 450-km-long, northeast-trending belt (Miller et al. 1989; Moll-Stalcup 1994; Bundtzen and Miller 1997). The majority of the volcanic-plutonic complexes lie in the focus area of this report (fig. 2); three additional complexes are located to the southwest. These complexes generally consist of intermediate to mafic, and locally rhyolitic, tuffs and flows and comagmatic monzonite to quartz monzonite composite plutons. Hornfels aureoles, as wide as 2 km, surround most of the larger plutons and developed in both the clastic sedimentary and overlying volcanic rocks. Conventional K/Ar and a limited number of ^{40}Ar/^{39}Ar ages of volcanic rocks range from about 76 to 63 Ma (Moll et al. 1981; Miller and Bundtzen 1994; Decker et al. 1995; Bundtzen et al. 1999). The comagmatic plutons yield ages ranging from about 71 to 67 Ma, although some younger ages (to 60 Ma) have been reported (Moll et al. 1981; Miller and Bundtzen 1994; Decker et al. 1995; Bundtzen et al. 1999). There is no significant time break between deposition of the uppermost Kuskokwim Group (Campanian) and initial volcanism associated with the volcanic-plutonic complexes. Indeed, the volcanic rocks are locally conformable and disconformable with the Kuskokwim Group (Miller and Bundtzen 1994).

Volcanic rocks of similar Late Cretaceous and early Tertiary age, but which do not have associated comagmatic plutons, form locally extensive fields in the Kuskokwim region. These volcanic sequences are largely andesitic in composition but commonly have dacite, rhyolite, and minor basalt. Subaerial volcanic flows, tuffs, and locally domes compose the fields, which individually cover areas as large as 5000 km^2. Conventional K/Ar ages range from about 71 to 54 Ma, and, like the volcanic-plutonic complexes, major- and trace-element geochemistry indicates broad calc-alkaline trends.

Hypabyssal felsic to intermediate dikes, sills, and stocks of Late Cretaceous and early Tertiary age crop out discontinuously across the Kuskokwim region. Although of similar age, they are probably not directly related to the volcanic-plutonic complexes. The hypabyssal rocks are characterized by a distinctly peraluminous chemistry and commonly contain garnet phenocrysts, suggesting they represent melted continental crust (Miller and