TECTONICS, VOL. 1, NO. 4, PAGES 343-368, AUGUST 1982

ORIGIN AND AGE OF THE BORDER RANGES FAULT OF SOUTHERN ALASKA AND ITS BEARING ON THE LATE MESOZOIC TECTONIC EVOLUTION OF ALASKA

Terry L. Pavlis

Department of Geological Sciences, Lehigh University, Bethlehem, Pennsylvania 18015

Abstract. Local geologic relationships in the western Chugach Mountains, together with regional considerations, suggest that in the Early Cretaceous a subduction zone was formed along the southern edge of the Wrangellia-Peninsular-Alexander composite terrane (Talkeetna superterrane of Csejtey et al., 1982) of southern Alaska. The effects of this event include (1) a shattering of older (pre-Cretaceous) crystalline rocks along a complex fault system, (2) emplacement of a tectonic melange beneath the shattered crystalline rocks, and (3) a subgreenschist facies prograde metamorphism of the melange and retrograde metamorphism of the older crystalline rocks. This event created a regionally mappable structural contact between broken crystalline rocks and the melange; the Border Ranges fault of MacKevett and Plafker (1974). Regional stratigraphy as well as radiometric ages of rocks predating and postdating the Border Ranges fault appear to bracket the age of the Border Ranges fault and its associated deformational effects to the interval between about 135 and 120 Ma. Further regional tectonostratigraphic associations suggest that the deformation along the Border Ranges fault represents the nucleation of a north and (or) east dipping subduction zone beneath the Talkeetna superterrane and that the magmatic arc associated with this juvenile subduction zone is the Gravina-Nutzotin belt of southeast Alaska. Mismatches in the distribution of different elements of this Early Cretaceous arc-trench system are probably a result of Late Cretaceous or early Tertiary strike slip motion, but Early Cretaceous ridge-trench interaction (suggested by the occurrence of Early Cretaceous near-trench plutons) may have played a role as well. The Talkeetna superterrane is generally thought to be an exotic block that collided with the Cordillera in the middle Cretaceous (Coney et al., 1980). The age data commonly cited as evidence for a middle Cretaceous age for the collision are, however, misleading. A model is proposed here in which the initiation of convergence along the trailing edge of the Talkeetna superterrane records the time of initial impingement of two irregular margins whereas intense middle Cretaceous deformation recognized along the leading edge of the Talkeetna superterrane (Csejtey et al., 1982) records destruction of a syncollisional flysch basin during the final phase of the collision.

INTRODUCTION

Accretion in deep sea trenches resulting from subduction of oceanic lithosphere is now a recognized tectonic process. This process is thought to proceed by the stacking of underthrust wedges within the trench [Seely et al., 1974; Karig, 1974] and results in

Copyright 1982 by the American Geophysical Union.
Paper number 2T1202. 0278-7407/82/002T-1202 $10.00

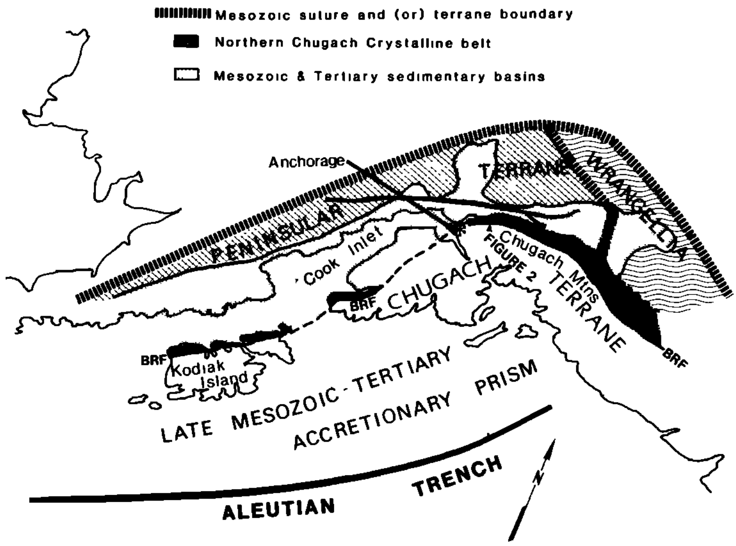


Figure 1. Generalized map of southern Alaska illustrating the position of the northern Chugach crystalline belt relative to major Late Mesozoic tectono-stratigraphic terranes and sedimentary basins. BRF = Border Ranges fault.

the building of an accretionary prism with its characteristic trenchward younging sequence. Because the sequence records the history of accretion, it is theoretically possible to trace the accretionary history through the thrust wedges to some fundamental break between younger accreted rocks and crystalline rocks of the arc massif. Ideally, rocks along this fundamental break should carry a record of the earliest history of convergence. Realistically, however, structural studies along this arc-forearc break are handicapped by both poor exposure (cover by forearc basin deposits) and extreme structural complexity. The second problem is unavoidable, but in the eastern Aleutian arc, late Tertiary uplift of a broad forearc ridge (Figure 1) has exposed the fundamental break between a late Mesozoic subduction complex and older crystalline rocks [MacKevett and Plafker, 1974]. This structural contact is known as the Border Ranges fault [MacKevett and Plafker, 1974].

The purpose of this paper is to describe a complex shattering of rocks along the Border Ranges fault and to present evidence that this brittle deformation was a result of the main period of underthrusting along the Border Ranges fault. In addition, I present evidence that the age for initiation of subduction is Early Cretaceous and is closely tied to coeval collisional events. This relationship places important constraints on allowable tectonic models. These constraints are discussed in the latter part of the paper, and a preliminary tectonic model is presented.

REGIONAL TECTONIC SETTING AND GENERAL GEOLOGY

The Pacific Border Ranges (Kodiak, Kenai, Chugach, and St. Elias Mountains) of Alaska separate the Cook Inlet basin system from a Neogene forearc basin/accretionary prism complex [Dickinson and Seely, 1979]. Most of the rocks exposed in the Border Ranges are the oldest tectonic units of the Alaskan-Aleutian subduction complex (Figure 1), the Chugach terrane of Berg et al. [1972] and

Jones and Silberling [1979]. Intermittently exposed along the northern flank of the ranges, however, are a complex group of crystalline rocks that form the southern edge of three older terranes, the Peninsular terrane, Wrangellia, and the Alexander terrane (Figure 1). The boundary between the Chugach terrane and the older terranes is the Border Ranges fault [MacKevett and Plafker, 1974].

In uppermost Cook Inlet (Figure 1) the Border Ranges fault and structurally overlying crystalline rocks emerge from Neogene cover and are well exposed in the western Chugach Mountains just east of Palmer, Alaska. A geologic investigation involving a 30 km traverse across structure was conducted in this area during 1979 and 1980. The results of the mapping are generalized in Figure 2.

Rocks of the Chugach terrane have been described regionally by numerous workers [e.g. Clark, 1972a, b; 1973; Moore, 1973a, b,; Jones and Clark, 1973; Plafker et al., 1977; Connelly, 1978; Cowan and Boss, 1978; Moore and Wheeler, 1978; and Nilsen and Moore, 1979] and consist of two major units: (1) a chaotic assemblage exposed intermittently along the Border Ranges fault and (2) a deformed flysch sequence lying structurally beneath the chaotic assemblage and constituting the bulk of the terrane. In the western Chugach Mountains (Figure 2) the chaotic assemblage, the flysch, and the structural contact between them are called the McHugh Complex, the Valdez Group, and the Eagle River fault, respectively [Clark, 1972a]. The McHugh Complex has yielded fossils from Permian to middle Cretaceous (Albian) in age [Plafker, et al., 1977; Connelly, 1978; Karl, et al., 1979; and G. Winkler, personal communications, 1981]. The flysch appears to have been deposited entirely in latest Cretaceous time [Tysdal and Plafker, 1978].

Regionally, the northern limit of the Chugach terrane defines the Border Ranges fault [MacKevett and Plafker, 1974]. The structurally overlying rocks carry an older, pre-latest Mesozoic record that varies along strike, hence the division into the three terranes (Figure 1): Peninsular terrane, Wrangellia, and Alexander terrane [Jones and Silberling, 1979]. Despite this lateral variability it is clear from stratigraphic relationships that these three older terranes were a composite terrane by the end of Middle Jurassic time [Jones and Silberling, 1979]. This composite terrane (Talkeetna superterrane of Csejtey, et al., 1982) apparently collided with North America during the Cretaceous [Coney, et al., 1980], thus the Border Ranges fault is both the northern limit of the subduction complex and the trailing edge of an accreted terrane.

The trailing edge of the composite terrane is represented by the narrow belt of crystalline rocks along the northern flank of the Border Ranges (northern Chugach crystalline belt, Figure 1). Regionally, this crystalline belt contains sporadic occurrences of blueschist and alpine peridotite [Rose, 1966; Forbes and Lanphere, 1973; Metz, 1976; Carden, et al., 1977; Winkler, et al., 1981], but in much of the belt Early to Middle Jurassic plutonic rocks and associated metamorphic rocks are the dominant lithology [Clark, 1972a; Winkler, et al., 1981; Pessel, et al., 1981; Pavlis, 1982, manuscript in preparation, 1982]. The blueschist facies metamorphism probably predates the Jurassic plutonic event [Plafker, et al., 1976; Pavlis, 1982].

In the mapped area the crystalline belt is divisible into three structural-lithologic belts (Figure 2): a southern belt of predominantly metamorphic rocks; a plutonic complex occupying the central one-third of the crystalline complex; and a northern belt composed of diverse cataclastic rocks as well as volcaniclastic rocks. The latter are exposures of the Upper Triassic-Lower

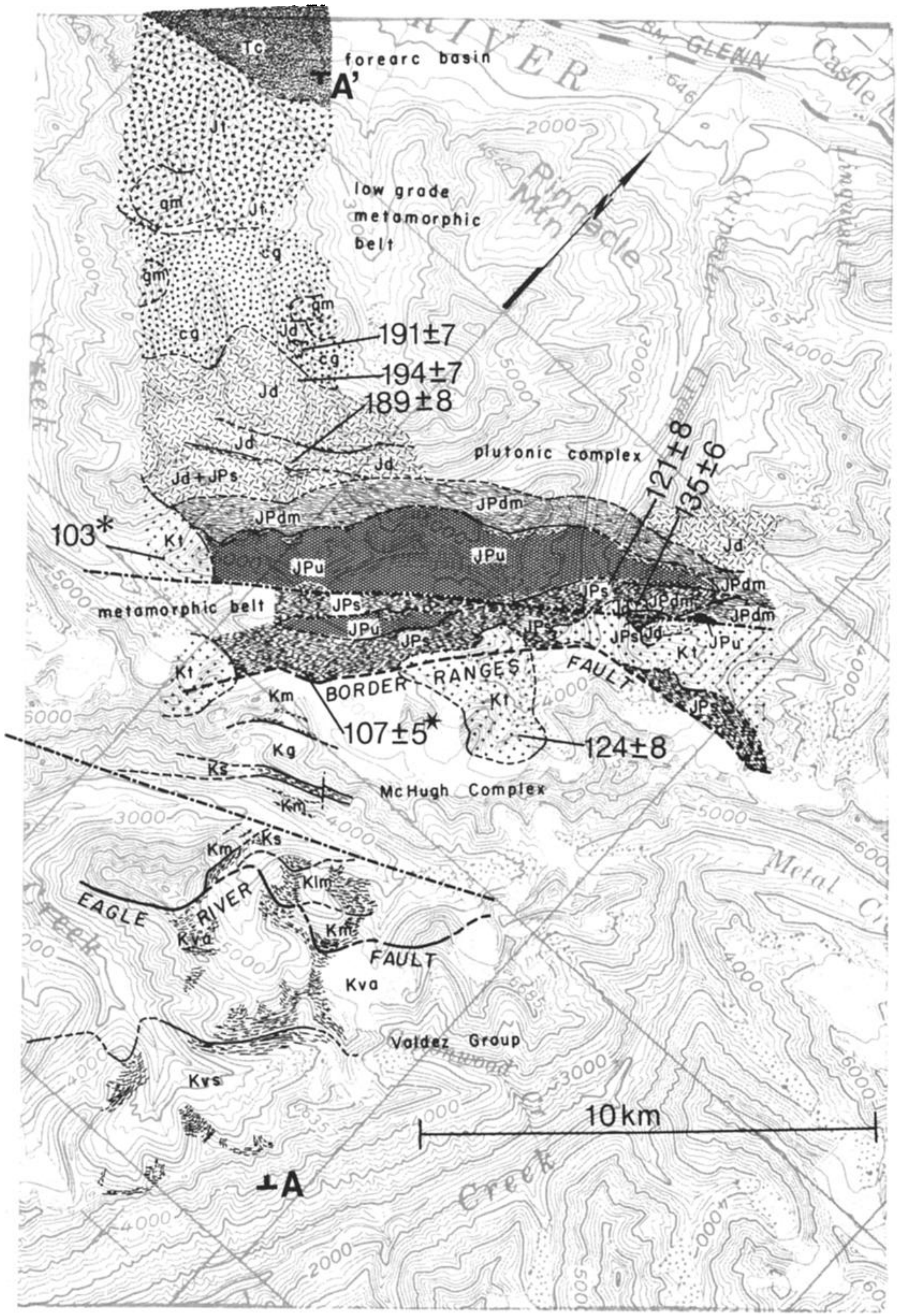

Tc
forearc basin
A'
Jf
gm
Jf
low grade
metamorphic
belt
cg
gm
gm
Jd
cg
191±7
cg
194±7
Jd
189±8
Jd
Jd
plutonic complex
Jd+JPs
121±8
135±6
JPdm
JPdm
103*
Kt
JPu
JPu
Jd
metamorphic belt
JPs
JPs
JPdm
JPdm
JPu
JPs
JPs
Jd
JPu
Kt
Kt
BORDER RANGES FAULT
Km
JPs
107±5*
Kt
124±8
Kg
Ks
Km
McHugh Complex
Ks
Km
Klm
EAGLE RIVER FAULT
Kva
Km
Kva
Valdez Group
Kvs
10km
A

Fig. 2a

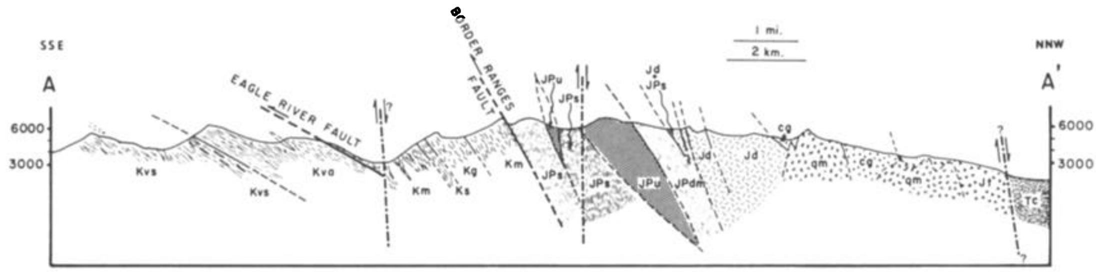


Fig. 2b

EXPLANATION

LITHOLOGIC UNITS

Upper Plate of the Border Ranges Fault

Intrusive Rocks

- **Kt** trondhjemite
- **qm** quartz monzonite
- **Jd** diorite & quartz diorite

Metamorphic Rocks (low grade belt)

- **cg** cataclastic rocks: locally includes volcanic rocks of uncertain age
- **Jt** Talkeetna Formation

Metamorphic Rocks (southern belt)

- **JPdm** disrupted metamorphic rocks: upper plate disrupted zone
- **JPs** foliated metamorphic rocks
- **JPu** ultramafic rocks

Lower Plate Units (Cretaceous Subduction Complex)

Valdez Group

- **Kva** argillaceous rocks: dark phyllite w/fine grained greywacke; locally lensoidal
- **Kvs** greywacke-argillite semischists

McHugh Complex

- **Km** massive rocks undivided: mostly greywacke&greenstone; disrupted near BRF
- **Klm** lensoidal melange: mesoscopically foliated, lensoidal rocks
- **Ks** schistose rocks: mostly mylonitic greenschist
- **Kg** greywacke broken formation: massive greywacke, locally conglomeratic

Forearc Basin Deposits

- **Tc** Chickaloon Formation

SYMBOLS

- younger fault
- Lithologic Contact*: solid where exposed, dashed where inferred
- surface trace of main phase structural fabric

*Heavy lines are major faults Upper plate contacts are faults except 1 margins of Kt and qm which are intrusive contacts. 2 JPs-Jd contacts are intrusive in the southern metamorphic belt. and 3 the northern margin of the plutonic complex which may be a faulted intrusive contact

Fig. 2c

Figure 2. Generalized geologic map (2a) and cross section (2b) of part of the western Chugach Mountains. Figure 2c is an explanation for 2a and 2b. Line of cross section A-A' (2b) is indicated on 2a. Numbers on Figure 2a are radiometric ages in millions of years. All ages are K-Ar ages on hornblende separates except ages indicated with a star and an asterisk. The former is a K-Ar age on an impure hornblende separate (separate contained sericite). The latter is a U-Pb zircon age obtained by J. Arth and T. Hudson (personal communications, 1981). Analytical data for the K-Ar ages can be found in Pavlis (1982, manuscript in preparation, 1982).

Jurassic Talkeetna Formation, a volcanic sequence recognizable throughout the Cook Inlet area [Kirshner and Lyon, 1973; Fisher and Magoon, 1978]. At the northern edge of the belt volcanic rocks are in probable fault contact with mildly deformed Tertiary and Cretaceous sedimentary rocks. These sedimentary rocks are deposits of the Cook Inlet forearc basin system [Fisher and Magoon, 1978] and have been described elsewhere [e.g. Barnes, 1962; Grantz, 1960, 1964; Jones and Grantz, 1967; Kirshner and Lyon, 1973; Detterman, et al., 1976].

In the following sections I describe geologic relationships along the Border Ranges fault (Figure 2) that relate critically to its movement history. The emphasis is on the recognition and characterization of structures which appear to be of the same age as the main period of motion on the Border Ranges fault. Thus because the McHugh Complex is generally thought to have been deformed within a subduction zone [Clark, 1973 and MacKevett and Plafker, 1974] the Border Ranges fault and structures related to it carry the only history of this convergence 'event'. Structural relationships in the Valdez Group (Figure 2) are not described in this paper because they are apparently younger than and unrelated to, the major period of motion along the Border Ranges fault. The reader is referred to the work of Pavlis [1982] for detailed descriptions of the Valdez Group in the area of Figure 2.

LOWER PLATE OF THE BORDER RANGES FAULT: McHUGH COMPLEX

General Characteristics and Lithology

Between the Eagle River fault and the Border Ranges fault is a complex structural unit that constitutes the McHugh Complex of Clark [1973]. In the mapped area the McHugh Complex is a broken unit in which greywacke with lesser amounts of metavolcanic rocks (greenstones) are the dominant lithologies. The complex locally contains abundant argillite and chert as well as sporadic 'exotic' blocks of epidote amphibolite, limestone, and metavolcanic rocks of higher metamorphic grade (greenschist facies) than the bulk of the complex. These lithologies become 'mixed' from microscopic to macroscopic scales to form a variety of structural lithologic associations. As such, the McHugh Complex as a whole can be considered a melange; specifically, a greywacke-greenstone melange which generally lacks an argillite matrix.

In the mapped area the McHugh Complex has been regionally metamorphosed at sub-greenschist facies conditions. Prehnite and pumpellyite are recognizable in a variety of rocks throughout the complex but the paragenesis prehnite + pumpellyite + chlorite + quartz diagnostic of the prehnite pumpellyite facies proper [Winkler, 1979], has not been observed. Amphibole was observed in a few blocks of mafic rock, however, these rocks appear to have been metamorphosed prior to emplacement, thus their relationship to the regional metamorphism is unclear. These observations suggest a sub-greenschist facies metamorphism but a clear distinction into a characteristic subfacies cannot yet be made.

The metaclastic rocks of the McHugh Complex consist of a wide variety of poorly sorted sedimentary rocks but fine to medium grained greywacke is characteristic. The greywackes are locally conglomeratic with pebbles and cobbles of black argillite; plutonic rocks (mostly hornblende diorite); a variety of volcanic rocks; and minor clasts of chert and metamorphic rock. Aside from the argillite chips these clasts can all be considered to have been derived from the crystalline terrane north of the Border Ranges fault. Argillites locally are abundant, and although argillites

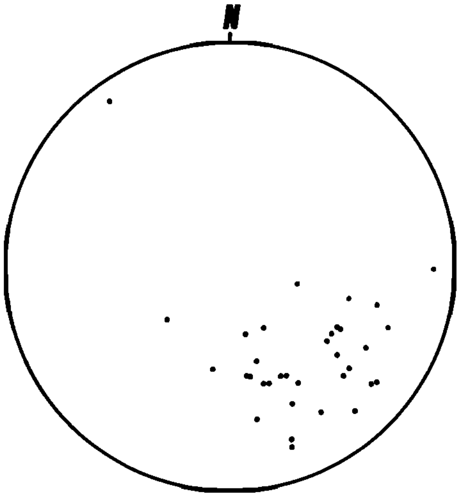


Figure 3. Equal area, stereographic projection showing 34 poles to mesoscopic foliation in the McHugh Complex.

are usually associated with cherts, they locally occur with greywackes as massive welded units. Their original relationship to the greywackes is unknown.

Metavolcanic rocks, although subordinate to greywacke, constitute a significant proportion of the complex. The metavolcanic rocks occur in a variety of associations including: (1) massive greenstone units and (or) blocks that presumably represent flows or hypabyssal intrusives; and (2) fine grained, probably tuffaceous material commonly intercalated on a fine scale with chert and argillite but locally occurring alone as thicker units. In the field the latter are, in many cases, difficult to distinguish from fine grained metagreywackes.

Cherts and carbonates are never abundant but occur at many localities throughout the complex. Cherts are almost invariably associated with, and generally occur as lenses within, either dark foliated argillite and (or) green tuffaceous rocks. Carbonates are always rare and occur exclusively as fault-bounded slabs. The chert-argillite-tuffaceous greenstone association is similar to rocks described on Kodiak Island by Connelly [1978] and are presumably a hemi-pelagic sedimentary association [Connelly, 1978].

The complex as a whole is characterized by a brittle structural style encompassing all scales. Ductile and transitional brittle-ductile structural fabrics are also recognizable and, together with anastomosing fault systems, impart a mesoscopic to macroscopic, mappable foliation to much of the McHugh Complex (Figure 2a). Where this foliation is penetrative at mesoscopic and smaller scales, it is characterized by moderate northwest dips (Figure 3). The strike of the foliation is variable, however, due to an open warping by steeply plunging second-phase folds.

Character of Structural-Lithologic Units

On the basis of structural style and lithologic association, the McHugh Complex was divided into four major structural-lithologic units (Figure 2): (1) massive McHugh (Km), (2) a unit composed entirely of metaclastic rocks (Kg), (3) lensoidal rocks (Klm), and (4) foliated, primarily mylonitic rocks (Ks).

The first is the most abundant and can be considered 'typical McHugh Complex'. The characteristic mappable feature of this unit (Km) is a mixed association of greywacke and greenstone along with a chaotic structural style in which the fracture systems associated with disruption show no obvious preferred orientation on a mesoscopic scale. Discrete ductile shear zones locally cut rocks of this type, producing distinct foliated zones within more massive rocks. Lithologically, greywacke is dominant overall, but greenstones locally make up much or all of the unit. In parts of the unit tuffaceous rocks may constitute a 'matrix' but generally no matrix is evident and mesoscopic lithologic boundaries are simply faults. The scale of the disruption is generally just beyond mesoscopic observations, but because of difficulties in distinguishing green greywackes and greenstones from a distance, this observation should be considered tentative. Additional complications are recognizable in rocks at the structural top of the McHugh Complex. These rocks, although lumped together as the massive unit (Km), are extremely complex near the Border Ranges fault and include a variety of lithologies, many of which are foliated. These rocks may be somewhat higher grade (greenschist facies) than the bulk of the complex, but there are insufficient data to firmly establish this relationship. Large 'exotic' blocks are also locally incorporated near the Border Ranges fault. Many of these blocks are metamorphic rocks derived from the upper plate, but others have no obvious local correlative.

The second structural unit (Kg) is simply a variation of the massive unit (Km), in that it is characterized by similar structural styles but appears to be devoid of metavolcanic rocks. That is, the unit is basically a broken formation of greywackes and conglomeratic greywackes.

The lensoidal unit (Klm) and the schistose unit (Ks) are the most distinctive rocks of the McHugh Complex and are mappable because they are mesoscopically foliated and can be readily traced along strike. The lensoidal rocks generally lack an argillaceous matrix and are dominated by a brittle structural style reflected in a mesoscopic lensoidal fabric defined by tight anastomosing fault networks. Individual phacoids rarely exceed 2 m in strike length throughout the unit. Lithologically, the lensoidal rocks are dominantly greywacke with minor argillite and occasional 'exotic' blocks of greenstone, grey chert, and (or) limestone. The schistose rocks (Ks), in contrast, are penetratively deformed mylonitic or blastomylonitic rocks. The foliation is produced by both lithologic layering and alignment of very fine grained micaceous minerals, primarily chlorite.

Significance of Structural Observations

Clearly, the McHugh Complex is characterized by extreme structural complexity, and considerable work remains before details of the deformational history are revealed. From the available data, however, two major features stand out. First, although ductilely deformed rocks are present within the McHugh Complex, the bulk of the deformation within the complex appears to have been accommodated by brittle structures. Second, the mapped distribution of structural units (Figure 2a) suggests that the deformation of the McHugh Complex predates the formation of its lower structural contact, the Eagle River fault. This age relationship is evidenced by the local truncation of foliated units (Klm and Ks) by the Eagle River fault, yet laterally, structural fabrics in the same units become conformable to the Eagle River fault (Figure 2a). These lateral variabilities could be due to variations in strain, but this interpretation seems unlikely because variation from concordance to discordance can be related to mappable open folds of main phase fabrics in the McHugh, yet similar macroscopic structures do not extend below the Eagle River fault. Indeed, structural fabrics below the Eagle River fault closely parallel the fault trace (Figure 2a). It is difficult to reconcile this disparity between upper and lower plate fabric orientations by a single deformational event, thus the simplest interpretation is that the structural fabrics of the McHugh Complex, as well as the second phase folding of these fabrics, predate the Eagle River fault.

DEFORMATION IN THE UPPER PLATE OF THE BORDER RANGES FAULT

Lithologic Units

In the area of Figure 2 the upper plate of the Border Ranges fault is composed of four distinct groups of igneous and metamorphic rocks. Three of these rock sequences are clearly older than the Border Ranges fault and a complex system of faults that parallel it (Figure 2). These older rock sequences include (Figure 2): upper greenschist metamorphic rocks (JPu, JPs, and rocks within a disrupted zone (JPdm)), intermediate plutonic rocks (Jd), and volcaniclastic rocks (Jtk).

Upper greenschist facies rocks occur throughout the southern two-thirds of the crystalline belt. Most occur in the southern one-third of the belt, however, where they form a narrow belt (the metamorphic belt in Figure 2) which aside from a younger group of plutons (Kt, Figure 2) and a few small bodies of diorite (Jd in Figure 2) is composed entirely of metamorphic rocks. Similar upper greenschist facies rocks occur as roof pendants along both the southern and northern limits of the plutonic complex occupying the center of the crystalline belt (Figure 2). The metamorphic rocks are divisible into three structural-lithologic associations: (1) internally undeformed, metamorphosed ultramafic bodies containing interlayered ultramafic and mafic rocks (JPu, Figure 2); (2) isoclinally folded, commonly polyphased deformed, foliated metamorphic rocks including quartzites, marbles, amphibolites, and quartz-rich mica schists (lumped together as JPs in Figure 2), and (3) a metamorphosed, argillite matrix melange containing blocks of metamorphosed chert, gabbro, basalt, and ultramafic rocks (JPdm, Figure 2). These units correspond, respectively, to the Wolverine Complex (MzPzum) of Clark [1972b], undifferentiated metamorphic rocks (JPu), and undifferentiated mafic complexes (MzPzm) shown on the regional map of Magoon, et al. [1976].

The second group of older rocks is intermediate plutonic rocks (Jd, Figure 2); predominantly hornblende diorites and quartz diorites. Intermediate plutonic rocks occur throughout the crystalline belt, but in the mapped area they are only abundant in the central one-third of the belt where, despite internal imbrication, they form a continuous 3-5 km wide plutonic complex (Figure 2). Plutonic rocks of this group yielded Early Jurassic ages (189-194 Ma) within the plutonic complex but gave younger K-Ar ages in the metamorphic belt (135 Ma), probably due to Cretaceous resetting [Pavlis, 1982, manuscript in preparation, 1982]. Where contact relationships were observed, these rocks generally intrude foliated upper greenschist facies rocks, although north of the main plutonic complex rocks of this type also appear to invade volcaniclastic rocks.

The third group of rocks is volcaniclastic rocks tentatively considered as the Talkeetna Formation. In the mapped area, these rocks are massive volcaniclastics that are extensively invaded by fine grained plutonic rocks of uncertain age. These fine-grained plutonic rocks vary in composition from diorite to quartz monzonite, but the dominant lithology is quartz diorite. The volcaniclastic rocks were subjected to a very low grade metamorphism at prehnite-pumpellite or lower greenschist facies [Pavlis, 1982, and manuscript in preparation, 1982]. Scattered throughout the crystalline belt are a series of younger plutons that represent the fourth group of crystalline rocks (Kt, Figure 2). These plutons are unaffected by the major faulting that characterizes the older sequences, and most or all of them are younger than the Border Ranges fault; i.e., they clearly cut the Border Ranges fault at two localities (Figure 2).

The younger plutons are a distinctive group of leucocratic igneous rocks scattered throughout the southern half of the crystalline belt (Kt, Figure 2). All of these rocks are characterized by color indices less than about 15, high quartz contents, and plagioclase (near end member albite) as the only feldspar. The major mafic phase is biotite, although a few rocks carry amphibole as well. White mica (muscovite?) is ubiquitous, but the rocks are generally altered and it is not clear if the white mica is primary or secondary; e.g. the white mica could be hydrothermal and (or) a product of the subsolidus breakdown of K-feldspar in a peraluminous rock. These rocks were first recognized by Clark [1972b] who described them as 'Tertiary albite granite.' They are probably more appropriately called trondhjemites (see definition of Barker [1979]), although they are not trondhjemites sensostricto, as many have color indices greater than 10 and the abundance of white mica in the rocks implies that many may be more potassic than a 'typical' trondhjemite.

A hornblende K-Ar age of 124 $\pm$ 8 Ma was obtained from one of these younger plutons (Figure 2a) suggesting an Early Cretaceous or older age for the plutons. The accuracy of this single age is strengthened by two other ages that have been obtained nearby: (1) R. Bruhn and S. Evans (personal communication, 1982) obtained a slightly discordant K-Ar age on biotite (113 $\pm$ 5 Ma) and hornblende (126 $\pm$ 6 Ma) collected from a young granodiorite pluton along the Border Ranges fault, just southwest of Figure 2a and (2) T. Hudson and J. Arth (personal communications, 1981) obtained a concordant U-Pb zircon age of 103 Ma for the pluton that cuts JPdm in Figure 2a. Clearly, these ages scatter between about 100 and 125 Ma, and thus the younger plutons may span a period of time. Nonetheless, the plutons are no younger than mid-Early Cretaceous in age; i.e., certainly pre-100 Ma and probably pre-125 Ma.

Structural Relationships

The distribution of the older rock sequences in the upper plate of the Border Ranges fault is controlled by a complex system of discrete faults and wide fault zones. This fault system is the product of at least two generations of faulting: (1) an older generation of major N-NE striking, moderate northwest dipping faults and fault zones that parallel the Border Ranges fault and, like the Border Ranges fault, are cut by the younger plutons; and (2) a younger generation of minor, E-NE striking, vertical faults that postdate the younger plutons. The younger group is represented by three faults (Figure 2), and although only one cuts the younger plutons, they all cut younger rocks (Tc or structural fabrics in the McHugh Complex), thus they are presumably of the same generation. Since this paper is concerned largely with structures related to the Border Ranges fault, the younger faults are not significant here except as an indicator of younger structure complicating the older history.

Most of the northwest dipping faults are discrete zones of cataclasis and low-grade alteration and vary in width depending largely on the rock type affected. The widest discrete fault zones are in ultramafic rocks in which serpentinization and shearing locally extends 200 m away from the fault contact. Closely spaced and anastomosing microfaults usually extend about 50 m into the serpentinized zone, but widely spaced faults and associated serpentinization often affect a wider zone. Faults within more silicic rocks are generally less than 50 m in width, and, like the ultramafic rocks, they usually contain a narrow cataclastic core with a wider alteration halo. Where the faults juxtapose ultramafics and more silicic rocks, the effects of the faulting on silicic rocks are negligible or restricted to a zone less than 10 m wide, while the deformation is concentrated in the serpentinites. The latter relationship is undoubtedly due to the relative fracture strengths between serpentinite and the crystalline metamorphic rocks.

Two major disrupted zones, like the discrete faults, parallel the Border Ranges fault. The first is a 1-1.5 km wide zone of disrupted rocks immediately north of the largest ultramafic body (JPdm, Figure 2). This disrupted zone contains a polyphase 'mixing' history, as many of the rocks within the zone are an argillite matrix melange in which the melange fabric predates the regional metamorphism (T. L. Pavlis, manuscript in preparation, 1982]. These older disrupted rocks are structurally interleaved with a variety of other rocks along a mesoscopic anastomosing fault system. These faults, like the other faults of the crystalline belt, are associated with a pronounced retrograde alteration. This alteration is not limited to the zone itself and affects a belt up to 100 m wide in the structurally overlying metamorphic and plutonic complex (Jd and JPs, Figure 2).

A second disrupted zone occurs along the northern edge of the plutonic complex within the undifferentiated unit cg (Figure 2). Distinguishing volcaniclastic and cataclastic lithologies within this unit is difficult, and because of these problems the extent of the disrupted zone cannot yet be determined. The character of the northern zone is, however, similar to the southern disrupted zone in that a wide zone of sheared and altered rocks is recognizable; yet large, fault-bounded, intact bodies occur within the altered sequence. Many of these fault bounded bodies contain internal crosscutting relationships indicative of their older, prefaulting history, i.e., diorites intruding either foliated upper greenschist facies rocks or volcaniclastics. Clearly, more mapping will be required to fully elucidate the extent and character of this 'northern disrupted zone.' Nonetheless, it records, like the southern zone, a major postplutonic brittle deformational event.

The alteration associated with the upper plate fault system clearly occurred at markedly lower temperatures than the regional metamorphism of the upper greenschist facies rocks. The retrograde relationship is clearly indicated by growth of the new phases: prehnite ± quartz, epidote + quartz, and scapolite in veins and cataclastic zones; chlorite and sericite as ubiquitous secondary phases after biotite and plagioclase, respectively; and serpentine in ultramafic rocks. The serpentinization is particularly significant because the primary upper greenschist facies paragenesis in the ultramafic rocks appears to be serpentine-free and the slickensided serpentinites are therefore related to the younger faulting. These secondary assemblages, specifically, the ubiquitous presence of prehnite, requires that the retrograde metamorphism occurred at temperatures less than about 400°C [Kuniyoshi and Liou, 1976]. Thus the retrograde metamorphism during faulting was a sub-greenschist-facies event and is indistinguishable from the metamorphism of the structurally adjacent McHugh Complex. This relationship, together with the observation that the northwest dipping fault system and the Border Ranges fault are of the same relative age, implies that the upper plate faults and the Border Ranges fault were produced during the same event. That is, the faults probably represent a macroscopic Border Ranges fault system produced during emplacement of the McHugh Complex.

Local Age Estimate for the Border Ranges Fault

The crosscutting relationships described above are important regionally because the age of the Border Ranges fault is clearly bracketed as younger than the Early Jurassic plutons (189-194 Ma) but older than the younger plutons (between about 100 and 125 Ma in age). The minimum age, in particular, is significant because it requires that in the western Chugach Mountains the McHugh Complex and the Border Ranges fault are no younger than mid-Early Cretaceous. That is, depending on one's choice of a Cretaceous time scale and the interpretation of available ages, the Border Ranges fault is no younger than Albian and is probably pre-Albian in age. The maximum age estimate from the mapped area, 189-194 Ma, is not particularly informative, however, and a more precise estimate would be useful. In the mapped area, younger ages (i.e. post-189 Ma), were obtained from rocks which predate the Border Ranges fault, yet these ages are not unequivocal as maximum age indicators because the younger ages (Figure 2) appear to be reset. The younger ages (135-107 Ma) occur exclusively in the metamorphic belt between the plutonic complex and the Border Ranges fault (Figure 2a). This implies that the southern belt could be a distinctly younger metamorphic terrane juxtaposed by faulting against an older Jurassic sequence. However, three lines of evidence argue against this hypothesis: (1) the metamorphic rocks on both sides of JPdm (Figure 2a) are lithologically indistinguishable from those to the north and the latter are clearly invaded by Early Jurassic diorites, (2) paradoxical age relationships can be recognized in the southern belt, i.e., the oldest K-Ar age from the belt (135 Ma) was obtained from a pluton that clearly intrudes adjacent amphibolites, yet the amphibolites yielded a younger age (121 Ma), and (3) there are two potential thermal sources that may have produced a resetting, the retrograde metamorphism during faulting and the Cretaceous plutonism.

Taken together, these age data are most easily interpreted as indicating that the ages in the southern one-third of the crystalline belt were reset during the Cretaceous and that the younger ages are not useful as maximum age indicators. Indeed, the simplest interpretation is that all of the crystalline rocks are part of the same original crystalline complex. This interpretation is significant because it implies that the brittle deformation in the crystalline belt probably represents a single event; the shattering of an older crystalline terrane during the major period of motion on the Border Ranges fault. This interpretation of a single event is strengthened by a consideration of regional relationships.

DISCUSSION AND CONCLUSIONS

Age and Origin of the Border Ranges Fault: The Formation of an Early Cretaceous Arc-Trench System

The McHugh Complex of the western Chugach Mountains is only part of a regional 'melange facies' (or subterrane) of the Chugach terrane that occurs sporadically along the Border Ranges fault

[Plafker, et al., 1977; Nilsen, 1982]. The melange has long been recognized as of probable subduction origin [e.g., Berg, et al. 1972; Clark, 1973; MacKevett and Plafker, 1974; Moore and Connelly, 1977; Connelly, 1978], thus it and the Border Ranges fault are presumably the oldest clearly recognizable products of the north directed underthrusting of Pacific ocean floor. Because the intense brittle deformation affecting crystalline rocks of the western Chugach Mountains appears to be of the same age as the Border Ranges fault, the deformation would appear to be the result of initiation (or renewal) of underthrusting. This close relationship between the McHugh Complex and the Border Ranges fault places major regional significance on the age of the Border Ranges fault, because this event should be recognizable regionally and presumably is related to other regional tectonic events.

The age of the melange facies of the Chugach terrane has, however, been much debated. The age controversy exists largely because (1) fossil ages obtained from rocks incorporated into the melange span a long period of time (Permian-Early Cretaceous), (2) the melange does not form a continuous belt adjacent to the Border Ranges fault but instead consists of scattered packets that lie structurally above the Late Cretaceous Chugach terrane flysch, and (3) there is a general paucity of pre-Tertiary minimum age indicators. Because of these regional relationships a variety of ages and tectonic models have been applied to the melange facies. These models range from polygenetic models in which the rocks are in part Lower Jurassic and in part Lower Cretaceous [Moore and Connelly, 1977] to suggestions by Plafker, et al.[1977], Connelly [1978], and Nilsen [1982] that the melange facies is a seperate phase or facies of the Chugach terrane flysch.

The structural relationships in the western Chugach Mountains are clearly at odds with the second hypothesis. Indeed, the truncation of McHugh structural fabrics by the Eagle River fault requires that the McHugh Complex is an older unit, and the cutting of the Border Ranges fault by Early Cretaceous plutons requires that the fault and at least part of the McHugh Complex are no younger than mid-Early Cretaceous. Decker [1980] reached a similar conclusion on the basis of 100 Ma K-Ar metamorphic ages from the Kelp Bay Group on Chichagof Island, a sequence generally included in the Chugach terrane [Berg, et al., 1972 and Plafker, et al., 1977]. Thus in the two cases where a minimum age could be established rocks of the melange facies give pre-100 Ma ages, implying that much (and probably all) of the complex is pre-middle Cretaceous in age. An important corollary of this conclusion, however, is the requirement that either the melange facies is not subduction-related, or an Early Cretaceous (or older) subduction event occurred along what is now the southern Alaskan margin. The evidence for a subduction origin is abundant [Plaker, et al., 1977; Connelly, 1978; Moore and Wheeler, 1978]; thus, presumably, the key problem is the true age of the melange.

Three data bear on this maximum age question: (1) fossil ages from the melange, (2) radiometric ages from rocks cut by the Border Ranges fault, and (3) analysis of regional tectonostratigraphic associations (e.g., searching for coeval volcanic arc and forearc basin systems). Ideally, all of these age indicators should point to the same age if the melange facies represent a single subduction 'event', yet in reality each of the maximum age indicators suffers from ambiguities.

<u>Fossil ages from the melange.</u> The use of fossil ages could be applied unequivocally to the age of the McHugh Complex if fossils had been found in the area where the McHugh Complex is cut by Cretaceous plutons. However, no fossils have yet been found in this critical area, and fossil ages must be extrapolated by

lithologic correlation from adjacent areas. Such a correlation is inherently ambiguous for two reasons: (1) as yet there is no way of knowing if the melange facies of the Chugach terrane was produced by a single episode of subduction accretion or occurred during two or more separate periods, and (2) subduction accretion represents a continuum of events and can span an extended period of time, thus recognition of a relatively young fossil at one locality can only be applied as an age indicator at that locality, not to the age of the melange as a whole. Finally, an additional factor must be considered: a maximum age for accretion of the oldest tectonic unit of a subduction complex is not necessarily a maximum age for convergence (e.g., the age of the Border Ranges fault). Therefore, fossil ages from the McHugh Complex and other rocks of the melange facies are equivocal age indicators. Indeed, they only hint at the age of the melange and provide no information on the maximum age for the convergence 'event.'

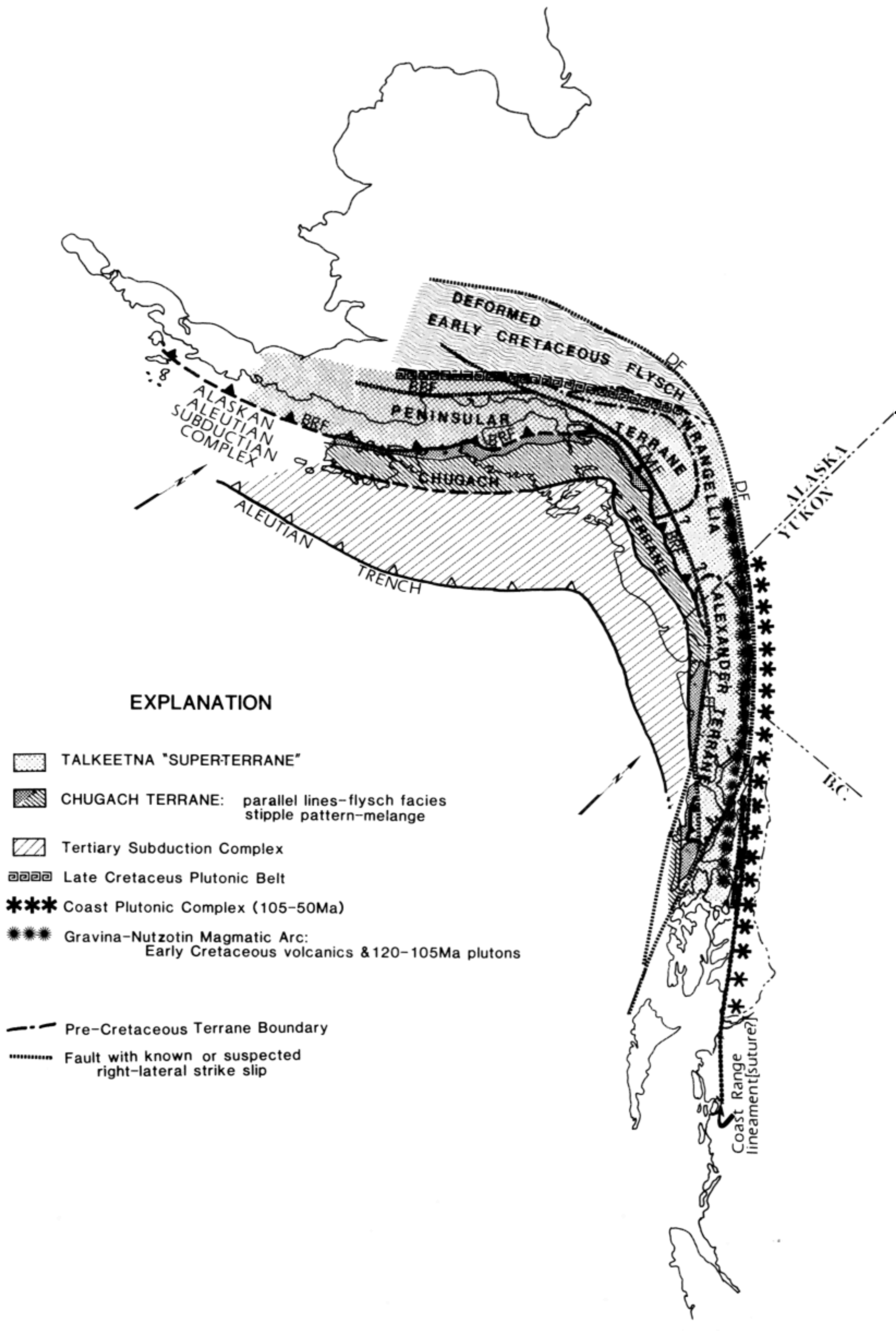
Fossil ages from the melange facies of the Chugach terrane vary from Permian to Early Cretaceous [Plafker, et al., 1977]. Fossils as young as Valanginian are common [Plafker, et al., 1977] and have been recognized in the western Chugach Mountains near Anchorage [Karl, et al., 1979]. These ages are significant because the rocks near Anchorage can be traced laterally to the area of Figure 2 [Magoon, et al., 1976] implying that Valanginian probably represents a maximum age for the McHugh Complex. Fossils as young as Albian have been recovered from the Uyak Complex on Kodiak Island [Connelly, 1978] and the McHugh Complex in the central Chugach Mountains (G. Winkler, personal communication, 1981); thus accretion of the McHugh Complex must have continued at least until the Albian. Note that the Albian fossils illustrate the ambiguity of regional fossil ages because they are of the same age (or younger) than the minimum age indicators in the western Chugach Mountains.

Radiometric ages of crystalline rocks. Radiometric ages of rocks cut by the Border Ranges fault should be a valid maximum age for convergence, but two problems prevent a simple interpretation: (1) it is possible that some pre-Early Cretaceous ductile deformation preceded the emplacement of the McHugh Complex (e.g., deformational fabrics in some of the rocks north of the Border Ranges fault may represent a ductile 'proto-Border Ranges fault') and (2) available radiometric ages are all K-Ar ages [Clark, 1972a, Forbes and Lanphere, 1973; Carden, et al., 1977, Carden and Decker, 1977, Winkler, et al., 1981; this study], which are easily reset, hence many ages could be reset ages. These problems are not easily evaluated, and each is highly dependent on locality. Resetting, for example, is probably not a significant problem except in areas of significant younger plutonism and (or) intense faulting. Thus because many K-Ar ages between about 160 and 190 Ma have been reported from plutonic rocks along the Border Ranges fault [Clark, 1972a, Carden, et al., 1977, Carden and Decker, 1977, and Winkler, et al., 1981], it seems unlikely that the Border Ranges fault is older than Middle Jurassic. The problem of deformation predating emplacement of the McHugh Complex, however, is more difficult to evaluate. Resetting seems highly unlikely except at two localities: the metamorphic belt of the western Chugach Mountains (Figure 2) and the Haley Creek terrane (Winkler, et al., 1981] of the central Chugach Mountains. In both of these areas anomalously young (148-100 Ma) K-Ar ages are recognizable. In the western Chugach Mountains these ages can be attributed to resetting by Cretaceous plutonism, yet in the Haley Creek terrane the ages apparently record the effects of mylonitic deformation during a retrograde greenschist facies metamorphic event [Winkler, et al., 1981]. It is of note, however, that this mylonitic deformation overprinted older, higher grade (epidote amphibolite facies) metamorphic fabrics [Winkler, et al., 1981], a relationship equivalent to the cataclasis and retrograde metamorphic effects associated with the major faulting event in the western Chugach Mountains. This implies that the mylonitic fabrics in the Haley Creek terrane may have been produced during the same period as the faulting in the western Chugach Mountains. If this correlation is true, then the scatter in ages from the Haley Creek terrane may be of great significance in that they probably reflect partial to complete resetting of the K-Ar system. That is, the older ages (140-150 Ma) may reflect partial resetting during Cretaceous movement on the Border Ranges fault, and therefore they may be a legitimate maximum age indicator. Obviously, more geochronology is needed to substantiate these suggestions. Nonetheless, the scatter in K-Ar ages from both the Haley Creek terrane and the western Chugach Mountains seems too similar to be purely a coincidence. Thus on the basis of radiometric age data, it is unlikely that the Border Ranges fault is older than about 150 Ma (middle Late Jurassic) and it is likely that the younger ages in the Haley Creek terrane (120-130 Ma) approximate the true age of motion.

Tectono-stratigraphic associations. The Late Jurassic and earliest Cretaceous have long been recognized as a major period of quiescence throughout southern Alaska [Fisher and Magoon, 1978; Moore and Connelly, 1979]. This quiescence is evidenced by a scarcity of radiometric ages between about 125 and 145 Ma [Hudson, 1979] and by a style of sedimentation in the Cook Inlet basin system that reflected a successive denundation of an older (Early to Middle Jurassic) volcanic arc in the Alaska Range and Talkeetna Mountains [Kirschner and Lyon, 1973; Fisher and Magoon, 1978; and Moore and Connelly, 1979]. This quiescence culminated in the deposition of Lower Cretaceous (Neocomian) shallow marine carbonates (Figure 5) at several localities in the basin [Jones, 1976; Fisher and Magoon, 1978]. The quiescence ended abruptly in the late Early Cretaceous, however, with the deposition of Albian flysch-like rocks (Lower Matanuska and Kennicott Formations) from upper Cook Inlet to the Wrangell Mountains [Grantz, 1964, Jones and Grantz, 1967, Kirshner and Lyon, 1973, Jones, 1976, Fisher and Magoon, 1978; Moore and Connelly, 1979]. During this same time interval an extensive volcanic pile and associated Early Cretaceous plutons (120-105 Ma), the Gravina-Nutzotin belt (Figure 4), were emplaced in a narrow belt in southeast Alaska [Berg, et al., 1972; Hudson, 1979]. Ages are poorly constrained in much of the Gravina-Nutzotin belt, but where ages are known the onset of volcanism occurred at about the end of Neocomian time [Berg, et al., 1972].

Clearly, relationships in both the Gravina-Nutzotin belt and Cook Inlet basin suggest that a major tectonic transition occurred at about the end of Neocomian time. Berg, et al. [1972] first suggested that this transition marked the development of an arc-trench system, the products of which are now represented by the Gravina-Nutzotin belt and the Chugach terrane. The evidence presented above for the age of the Border Ranges fault (an age bracket of 150-120 Ma and probably 130-120 Ma) appears to confirm this hypothesis. However, in detail the event is complicated by ambiguities in the Early Cretaceous time scale (Figure 5).

A discussion of Early Cretaceous events is complicated in North America by poor constraints on the absolute age of Lower Cretaceous stages [Lanphere and Jones, 1978]. That is, although worldwide correlations lead to the classical time scale of Van Hinte [1976], data from North America [Lanphere and Jones, 1978] are at odds with this time scale (Figure 5). This ambiguity is important because it leads to problems in correlating relative and absolute ages (Figure


DEFORMED
EARLY CRETACEOUS FLYSCH
DF
BRF
PENINSULAR
TERRANE
WRANGELLIA
CHUGACH
TERRANE
ALASKAN ALEUTIAN SUBDUCTIAN COMPLEX
ALEUTIAN
TRENCH
ALEXANDER TERRANE
ALASKA
YUKON
B.C.
Coast Range lineament[suture?]
EXPLANATION
TALKEETNA "SUPERTERRANE"
CHUGACH TERRANE: parallel lines–flysch facies
stipple pattern–melange
Tertiary Subduction Complex
Late Cretaceus Plutonic Belt
Coast Plutonic Complex (105–50Ma)
Gravina–Nutzotin Magmatic Arc:
Early Cretaceous volcanics & 120–105Ma plutons
Pre-Cretaceous Terrane Boundary
Fault with known or suspected
right-lateral strike slip

5). By using Lanphere and Jones' [1978] time scale, the stratigraphic transitions in Cook Inlet and the Gravina-Nutzotin belt occur at about 135 Ma (end of the Neocomian), and K-Ar cooling ages of Gravina-Nutzotin belt plutons as well as the plutons cutting the Border Ranges fault (about 120 Ma) both follow the transition in time; a reasonable age relationship. In contrast, application of Van Hinte's [1976] time scale places both the stratigraphic transitions and the K-Ar ages in the same time window (about 120-125 Ma). Although possible, it seems unlikely that this concordance is real.

Clearly, this time problem will remain until more age data are available and (or) the Early Cretaceous time scale is better constrained. Regardless of ones choice of time scale, however, the stratigraphic transitions in both the Cook Inlet basin system and the Gravina-Nutzotin belt correspond in age [Van Hinte, 1976] or are older than [Lanphere and Jones, 1978] my minimum age estimate (about 120 Ma) for the Border Ranges fault (Figure 5). Thus it would appear that a major tectonic transition occurred in southern Alaska in Early Cretaceous (probably Neocomian) time, the formation of a north and (or) east dipping subduction zone. That event shattered an older sequence of crystalline rocks forming the Border Ranges fault system. Simultaneously, oceanic rocks (melange facies of the Chugach terrane) were deformed and emplaced beneath the juvenile subduction zone. The region immediately north of the juvenile subduction zone apparently was uplifted during this period (Figure 5) since a regional disconformity separates Neocomian carbonates from overlying Albian rocks [Jones, 1976]. Simultaneously with the formation of the convergent margin, extensive volcanism began in the Gravina-Nutzotin belt, and by Albian time the arc-trench system was fully developed. That is, the classic tripartite arc (Gravina-Nutzotin belt), forearc basin (upper Cook Inlet basin), and trench (Chugach terrane melange) can be readily recognized (Figure 4).

Complexities of the Early Cretaceous Arc-Trench System: Near Trench Plutonism

The emplacement of Early Cretaceous granitic plutons in the western Chugach Mountains is significant, not only because of the

Figure 4 (opposite). Tectonic map of part of southern Alaska, southwest Yukon Territories, and western British Columbia. Figure shows the present distribution of major late Mesozoic tectonic elements lying south and west of the Denali fault (DF) and Coast plutonic complex. The Cretaceous suture zone inferred by Coney and others (1980), Monger and others (1982), and Csejtay and others (1982) is generally thought to extend from the belt of deformed early Cretaceous flysch (top center) to along the Denali fault (eastern Alaska and southwest Yukon territories) and into the Coast Range lineament (Southeast Alaska and British Columbia). Map also shows major late Mesozoic tectonostratigraphic terranes (after Coney and others, 1980); known or suspected zones of right-lateral strike-slip faulting (CMF Castle Mountain fault, DF-Denali fault. FF-Fairweather fault, and CSF-Chatham Strait fault); Major thrusts bounding the Alaska-Aleutian subduction complex--Border Ranges fault (labeled BRF and indicated by solid barbed lines) and the active subduction zone in the Aleutian trench (indicated by open barbed lines); and major Cretaceous magmatic belts lying either within the Talkeetna superterrane or along the suture zone at its leading edge. Map is compiled from Jones and Silberling (1979), Hudson (1979), Berg and others (1972), Monger and Price (1979), Plafker and others (1977), and Crawford and Hollister (1982).

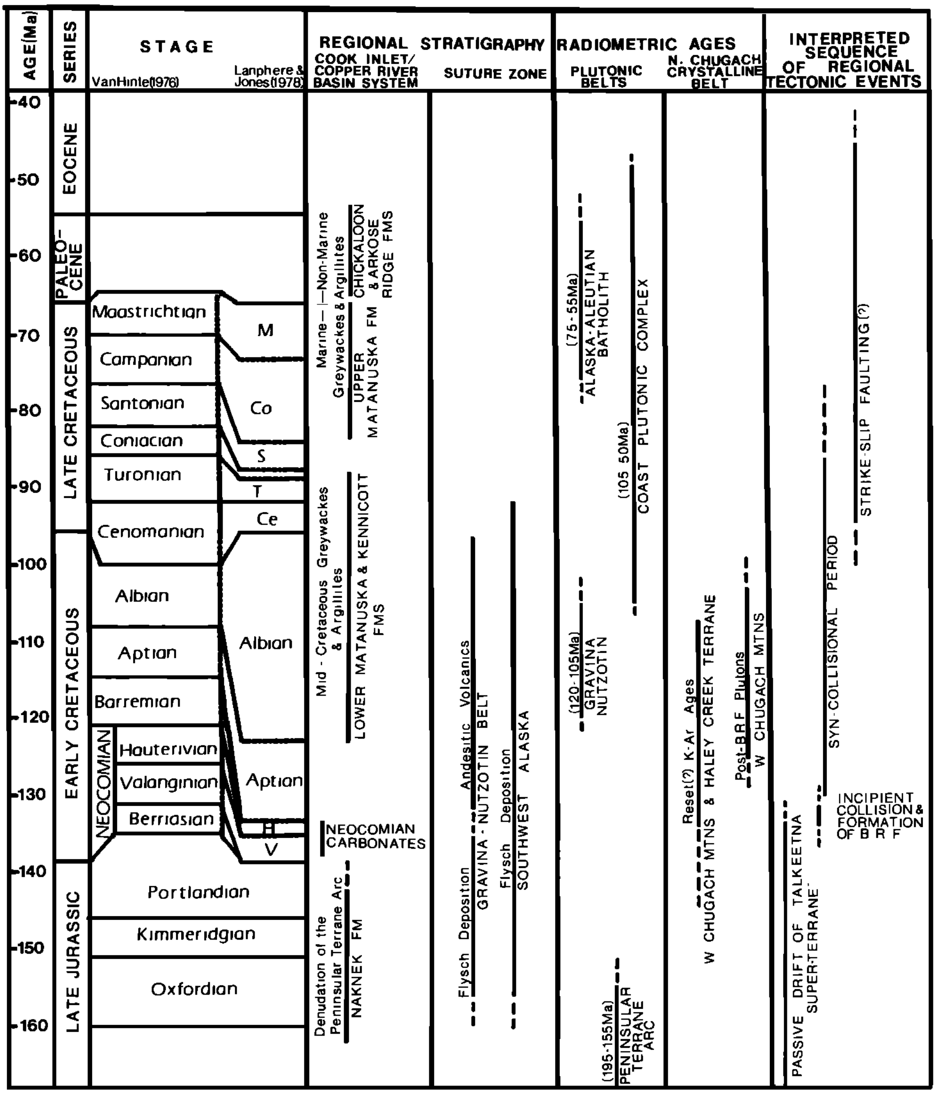


Figure 5. Summary of stratigraphic sequences on the trailing edge (Cook Inlet/Copper River basin system) and leading edge (suture zone) of the Talkeetna superterrane. Figure is a compilation of data from Berg and others (1972), Jones (1976), Magoon and others (1976), Fisher and Magoon (1978), Hudson (1979), Monger and Price (1979), and Pavlis (1982 and manuscript in preparation, 1982).

chronological constraints they provide, but also because their presence implies an anomalous event: an episode of near-trench plutonism. Near-trench plutonism is commonly attributed to ridge-trench interactions [Marshak and Karig, 1977]. This mechanism for the Cretaceous plutons, however, suggests that two successive events may have occurred within a geologically short time interval, i.e., the initiation of subduction and emplacement of the McHugh Complex followed by a period of interaction between the juvenile convergent margin and an oceanic spreading center. Clearly, this origin for the near-trench plutonism, if true, is of major significance to microplate/plate reconstructions for the period, but an alternate mechanism could account for the 'anomalous plutonism'. At the onset of subduction older crystalline rocks may have been dragged into the juvenile subduction zone, where they may have been subjected to temperatures high enough for partial melting. If this mechanism were operative, then the age of the near-trench plutons is particularly significant because they should approximate the true age of the initiation of convergence.

As yet, there is insufficient evidence to clearly resolve an origin for the anomalous plutonism. Detailed geochronological studies and (or) geochemical studies might allow differentiation of a ridge-trench versus subduction origin. The latter, for example, should represent an 'instantaneous' event with a wholly anatectic magma source, whereas the former may span a period of time and some mafic magma input might be anticipated [Hill, et al., 1981].

Complications by Strike Slip Faulting (?)

The implied genetic link between the Chugach terrane and the Gravina-Nutzotin belt is appealing because of coincident ages. Nonetheless, a second problem arises from this interpretation, in that the present distribution of the Early Cretaceous melange is not precisely coincident with the distribution of the arc. That is, the melange occurs sporadically along the entire northern edge of the Chugach terrane, but the Gravina-Nutzotin belt crops out only in eastern Alaska (Figure 4). Clearly, there are a number of possible explanations for the distributions of Early Cretaceous tectonic elements. Assuming the basic genetic relationship is true, however, two possibilities are likely: (1) a period of ridge trench interaction led to arc quiescence in western Alaska (Figure 4), and (2(younger strike slip faults have altered the original distribution of Early Cretaceous tectonic elements.

Neither of these possibilities can be discounted, and each is supported by some data. Ridge-trench interaction is supported by two observations: (1) near-trench plutonism (suggestive of ridge-trench interaction [Marshak and Karig, 1977]) in the western Chugach Mountains, and (2) observations by Grantz [1964] that middle Cretaceous sedimentary rocks in the Matanuska Valley are characterized by numerous unconformities and complex facies patterns; possibly reflecting a migrating triple junction.

However, strike slip faulting is also consistent with regional observations. It has long been recognized that major strike slip faulting has occurred in southern Alaska. Right lateral, strike slip faulting is obvious in southeast Alaska (Figure 4), but major strike slip has also been suggested in south-central Alaska [Grantz, 1964, 1966; Fuchs, 1980], notably along the Castle Mountain and Bruin Bay fault systems (Figure 4). Admittedly, the connection between strike slip faults of south central Alaska and southeast Alaska is unclear. Nonetheless, observations of relatively young high angle faulting in the central and eastern Chugach Mountains [Grantz, 1961; Pessel, et al., 1981; Winkler, et al., 1981) are not inconsistent with significant Tertiary strike slip faulting. Further evidence for significant strike-slip comes from paleomagnetic data [e.g., Stone and Packer, 1977, 1979; Stone, et al., 1982] which suggest that much of southwest Alaska may have been as much as 15^{o} south of its present position as recently as Paleocene. Since there is little geologic evidence for Tertiary collision in Alaska [Coney, et al., 1980], the apparent displacements probably were taken up on strike slip faults [Irving, et al., 1980]. Perhaps part of that motion occurred along the Castle Mountain fault. Indeed, Grantz [1964] has noted that the complexity of middle Cretaceous stratigraphy in the Matanuska Valley can easily be attributed to a middle Cretaceous (or younger) period of strike slip faulting along the Castle Mountain fault.

Clearly, problems remain but a redistribution by right lateral strike slip faulting probably best explains the present distributions of Early Cretaceous tectonic elements in southern Alaska. Thus during the Early Cretaceous a north and (or) east dipping subduction zone probably existed beneath what is now southern Alaska, but the products of that arc trench system have been redistributed by younger strike slip faulting. If true, strike slip displacements as large as 800 km are allowable (Figure 4).

Plate Tectonic/Micro-Plate Tectonic Model for Southern Alaska

The tectonic relationships discussed above lead to a number of intriguing tectonic questions because the Early Cretaceous age for initiation of subduction corresponds to the early phase of a major deformational period throughout the northern Cordillera. It has become increasingly apparent in recent years that this deformational period is the product of the collision between the 'Talkeetna superterrane' (Figure 4) and terranes previously accreted to North America [e.g., Jones, et al., 1977. 1982; Csejtey, et al., 1978; Jones and Silberling, 1979; Coney, et al., 1980; Irving, et al., 1980; and Monger, et al., 1982].

The time of the collision is generally thought to be middle Cretaceous with the age bracketed between Early Cretaceous flysch deformed within the suture (Figures 4 and 5) and crosscutting, undeformed middle Cretaceous (50-104 Ma) plutons of the Coast Plutonic Complex and the Alaskan-Aleutian batholith [Monger and Price, 1979; Csejtey, et al., 1978, 1982; Coney, et al., 1980; and Monger, et al., 1982]. It is of note, however, that this commonly cited middle Cretaceous age bracket is misleading because the deformation of flysch along a suture is not a valid maximum age for a collision. Dewey [1977], for example, has noted that in general collisions will be oblique events and (or) irregularities will extend from the opposed margins. Thus sutures should be characterized by high strain areas of initial impingement bounded along strike by laterally time transgressive, syncollisional flysch basins [Dewey, 1977]. The age of flysch deformed along a suture thus records, at best, a syncollisional period.

Dewey's [1977] arguments can be applied to the apparent collision of the Talkeetna 'superterrane' because the terrane boundary in most of Alaska is now marked by deformed supracrustal sequences [Jones and Silberling, 1979; Jones and others, 1982; and Csejtey, et al., 1982]. These sequences are now well exposed in two belts (Figure 4): (1) a broad belt of Late Jurassic through Early Cretaceous flysch in southwest Alaska [Jones and Silberling, 1979] and (2) Late Jurassic-Early Cretaceous flysch in the Gravina-Nutzotin belt [Berg, et al., 1972]. To the south, however, deformation and metamorphism increase and in British Columbia (Figure 4) the suture is marked by a high grade metamorphic belt [Monger, et al., 1982]. The main metamorphism is of a Barrovian type suggesting a syncollisional metamorphism [Monger, et al., 1982] and metamorphism may have been continuous from Jurassic through middle Cretaceous (170-108 Ma) time [Crawford and Hollister, 1982]. Thus the suture between the Talkeetna superterrane and the inner Cordillera varies along strike from a highly deformed zone of Jurassic or Early Cretaceous Barrovian metamorphism (in British Columbia) to a deformed flysch belt which contains rocks as young as Cenomanian (90 Ma) at it northern end. Ages are admittedly loosely constrained; nonetheless, these relationships are clearly in line with an oblique or irregular collisional model, that is, an event which began in British Columbia and progressively consumed a syncollisional flysch basin.

This argument leads to an important question, however, as to when the collision actually began. The best answer, I believe, comes not from the suture but from events that occurred away from the suture along the trailing edge of the Talkeetna superterrane.

As noted above, a north and (or) eastward dipping subduction zone appears to have formed along the trailing edge at about the end of Neocomian (135-120 Ma) time and its magmatic products (upper, volcanic part of the Gravina-Nutzotin assemblage) were deposited in the site of the suture. Coney, et al. [1980] suggested that, since rocks of the Gravina-Nutzotin belt are all at least mildly deformed, the Talkeetna superterrane must have arrived bearing an existing arc-trench system. This interpretation suggests that the subduction zone (Border Ranges fault) formed spontaneously prior to collision. Although this is possible, I believe that a more plausible explanation is that the subduction zone formed as a response to the collision. That is, the formation of a subduction zone along the trailing edge of the collided block would be required as initial impingement abruptly halted passive north and (or) eastward drift.

This argument leads to a model for the collisional event illustrated in Figure 6. The model calls for a simple collision of two irregular margins (Figure 6) with initial impingement occurring in about central British Columbia; the area of intense deformation and high grade metamorphism described by Crawford and Hollister [1982]. As an immediate result of initial impingement, a northeast (?) dipping subduction zone formed on the trailing edge; probably in latest Neocomian time; and the earliest magmatic products were shed into the future suture zone to form the upper (volcanic) part of the Gravina-Nutzotin assemblage. At this stage (Figure 6b) the colliding block is detached from the motion of Pacific plates (Farallon?). Assuming the collided block was interacting with Farallon plate, approximately 8 cm/yr of E-NE directed, North American/Farallon relative motion [Coney, 1978] must be shared by the juvenile subduction zone and continued closing of the trapped ocean basin (Figure 6b). Note that if this motion were shared equally by the two subduction zones, about 25 Ma would be required before an initial mismatch of 1000 km would be comsumed. Gradually, the collisional suturing must have progressed northward, deforming the earliest products of the Gravina- Nutzotin arc while flysch continued to be deposited in southwest Alaska (Figures 6b and 6c). The collision continued at least into the early Late Cretaceous in southwest Alaska because flysch as young as Cenomanian have been recognized there [Jones, et al., 1982]. Late Cretaceous plutons in that area demonstrate, however, that the collision was complete by about 80 Ma [Csejtey et al., 1982]. The suturing may have progressed southward as well (Figure 6b), although critical age relationships in southern British Columbia are debated (see Davis, et al. [1978] for discussion of this problem). These arguments depend heavily on correlation of the Seven Devils terrane with Wrangellia and the sedimentation history of the Tyaughton-Methow trough (e.g., see Dickinson [1976] and Hillhouse, et al., [1982]) and are not discussed in detail here. Thus although Figure 6b illustrates a southward age progression, other models (e.g., oblique collision) are allowable.

From the above it would appear that the actual collision probably spanned a 40 Ma (130-90 Ma) or longer time interval and the final welding of blocks may have progressed over an even longer interval. In addition, actual terrane boundaries in much of southeast Alaska are clearly complicated by younger strike slip motions, thus final 'accretion of allochthonous terranes' into their present positions may not have occurred until the present [Irving, et al., 1980]. Indeed, the latter is virtually required

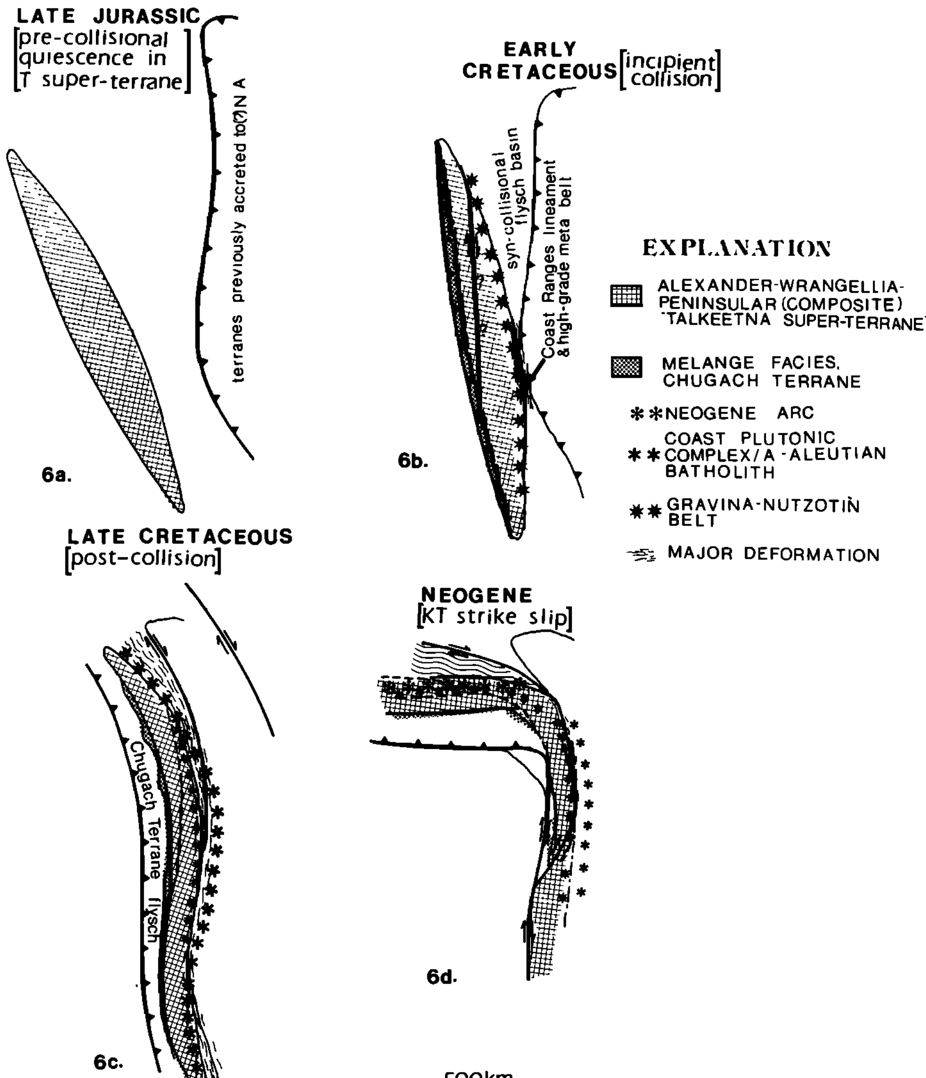


Figure 6. Tectonic cartoon illustrating the inferred irregular collision between the Talkeetna superterrane and the interior Cordilleran terranes. Individual figures are time slices at about 140 Ma (6a), 120 Ma (6b), 70 Ma (6c), and today (6d). See text for discussion.

by the paleomagnetic data [Irving and others, 1980] of Stone and Packer [1977, 1979] which suggest southern Alaska was still not in its present position as recently as Paleocene.

Acknowledgements. This paper arose from the author's Ph.D. work at the University of Utah under the direction of R. L. Bruhn. Logistical expenses for this study were provided by grants from Union Oil Company, ARCO Oil and Gas Company, Amoco Production Company, and Geology Special Funds at the University of Utah. Additional support was provided through a University of Utah Fellowship and NSF grant EAR-8020468. I thank the State of Alaska Division of Geological and Geophysical Surveys for allowing me to participate in their 1979 Central Chugach mapping project, and along with the U.S. Geological Survey for helicopter assistance in field checking critical relationships in 1981. R. L. Bruhn, J. R. Bowman, D. R. Currey, P. H. Roth, and R. B. Smith reviewed an early version of the manuscript. J. Casey Moore and an anonymous reviewer are thanked for pointing out an error in the first draft of this paper. Maura Weathers provided a valuable review of the revised manuscript.

REFERENCES

Barker, F., Trondhjemite: Definition, environment, and hypotheses of origin, in Trondhjemites, Dacites and Related Rocks, edited by F. Barker, Elsevier, New York, 1979.

Barnes, F. F., Geologic map of lower Matanuska Valley, Alaska, scale 1:63,360, U.S. Geol. Surv. Misc. Geol. Invest. Ser. Map I-359, 1962.

Berg, H. C., D. L. Jones, and D. J. Richter, Gravina-Nutzotin belt-Tectonic significance of an upper Mesozoic sedimentary and volcanic sequence in southern and southeastern Alaska, U. S. Geol. Surv. Prof. Pap., 800-D, D1 D24, 1972.

Carden, J. R. and J. E. Decker, Tectonic significance of the Knik River Schist Terrane, south-central Alaska, Alaska Div. Geol. Geophys. Surv., Geol. Rep., 55, 7-9, 1977.

Carden, J. R., W. Connelly, R. B. Forbes, and R. L. Turner, Blueschists of the Kodiak Islands, Alaska: An extension of the Seldovia schist terrane, Geology, 5, 529-535, 1977.

Clark, S. H. B., Reconnaissance bedrock geologic map of the Chugach Mountains near Anchorage, Alaska, scale 1:250,000, U.S. Geol. Surv. Misc. Field Stud. Map, MF 350, 1972a.

Clark, S. H. B., The Wolverine Complex, a newly discovered layered ultramafic body in the western Chugach Mountains, Alaska, U.S. Geol. Surv., Open File Rep., 522, 10pp., 1972b.

Clark, S. H. B., The McHugh Complex of southern Alaska, U.S. Geol. Surv., Bull., 1372-D, 11, 1973.

Coney, P. J., Mesozoic-Cenozoic Cordilleran plate tectonics, Mem. Geol. Soc. Am., 152, 33-50, 1978.

Coney, P. J., D. L. Jones, and J. W. H. Monger, Cordilleran suspect terranes, Nature, 288, 329-333, 1980.

Connelly, W., Uyak Complex, Kodiak Island, Alaska: A Cretaceous subduction complex, Geol. Soc. Am. Bull., 89, 755-769, 1978.

Cowan, D. S. and R. F. Boss, Tectonic framework of the southwestern Kenai Pennsula, Alaska, Geol. Soc. Am. Bull., 89, 155-158, 1978.

Crawford, M. L. and L. S. Hollister, Contrast of metamorphic and structural histories across the Work Channel lineament, Coast Plutonic Complex, British Columbia, J. Geophys. Res., 87, 3849-3860, 1982.

Csejtey, B., Jr., W. H. Nelson, D. L. Jones, N. J. Silberling, R. M. Dean,M. S. Morris, M. A. Lanphere, J. G. Smith, and M. L. Silberman, Reconnaissance geologic map and geochronology, Talkeetna Mountains quadrangle, northern part of Anchorage quandrangle, and southwest corner of Healy quadrangle, Alaska, U. S. Geol. Surv. Open File Rep. 78-558-A, 60 pp., 1978.

Csejtey, B., Jr., D. P. Cox, R. C. Evarts, G. D. Stricker, and H. L. Foster, The Cenozoic Denali fault system and the Cretaceous accretionary development of southern Alaska, J. Geophys. Res., 87, 3741-3754, 1982.

Davis, G. A., J. W. H. Morgan, and B. C. Burchfiel, Mesozoic construction of the Cordilleran 'collage', central British Columbia to central California, in Mesozoic paleogeography of the western United States, Pacific Coast Paleogeography Symposium 2, edited by D. G. Howell and K. A. McDougall, pp. 1-32, Society of

Economic Paleontologists and Mineralogists, Tulsa, Okla., 1978.
Decker, J. E., Mid-Cretaceous subduction event in southeastern Alaska, Geol. Soc. Am., Abstracts with Programs, 12, 103, 1980.
Dettermann, R. L., G. Plafker, R. G. Tysdal, and T. Hudson, Geology and surface features along the Talkeetna segment of the Castle Mountain-Caribou fault system, Alaska, U.S. Geol. Surv. Misc. Field Studies Map, MF-738, 1976.
Dewey, J., Suture zone complexities: A review, Tectonophysics, 40, 53-67, 1977.
Dickinson, W. R., Sedimentary basins developed during evolution of Mesozoic-Cenozoic arc-trench system in western North America, Can. Jour. Earth Sci., 13, 1268-1287, 1976.
Dickinson, W. R. and R. M. Seely, Structure and stratigraphy of forearc regions, Am. Assoc. Pet. Geol. Bull., 63, 2-31, 1979.
Fisher, M. A. and L. B. Magoon, Geologic framework of lower Cook Inlet, Alaska, Am. Assoc. Pet. Geol. Bull., 62, 373-402, 1978.
Forbes, R. B. and M. A. Lanphere, Tectonic significance of mineral ages of blueschists near Seldovia, Alaska, J. Geophys. Res., 78, 1383-1386, 1973.
Fuchs, W. A., Tertiary tectonic history of the Castle Mountain - Caribou fault system in the Talkeetna Mountains, Alaska, Ph.D. thesis, Univ. of Utah, Salt Lake City, 1980.
Grantz, A., Generalized geologic map of the Nelchina area, Alaska, showing igneous rocks and larger faults, U.S. Geol. Surv. Misc. Invest. Ser. Map I-312, 1960.
Grantz, A., Geologic map and cross sections of the Anchorage (D-2) Quadrangle and northeasternmost part of the Anchorage (D-3) Quadrangle, Alaska, scale 1:48,000, U.S. Geol. Surv. Misc. Geol. Invest. Ser., Map I-342, 1961.
Grantz, A., Stratigraphic reconnaissance of the Matanuska Formation in the Matanuska Valley, Alaska, U.S. Geol. Surv. Bull., 1181-1, 11-133, 1964.
Grantz, A., Strike-slip faults in Alaska, U.S. Geol. Surv. Open File Rep., 82 pp., 1966.
Hill, M., J. Morris, and J. Whelan, Hybrid granodiorites intruding the accretionary prism, Kodiak, Shumagin, and Sanak Islands, southwest Alaska, J. Geophys. Res., 86, 10,591-10,606, 1981.
Hillhouse, J. W., C. S. Grommé, and T. L. Vallier, Paleomagnetism and Mesozoic tectonics of the seven devils volcanic arc, J. Geophys. Res., 87, 3777-3794, 1982.
Hudson, T. G., Mesozoic plutonic belts of southern Alaska, Geology, 7, 230-234, 1979.
Irving, E., J. W. H. Monger, and R. W. Yale, New paleomagnetic evidence for displaced terranes in British Columbia, edited by D. W. Strangwag, The Continental Crust and its Mineral Deposits, Spec. Pap., Geol. Assoc. of Can., 20, 441-456, 1980.
Jones, D. L., Structural elements and biostratigraphical framework of Lower Cretaceous rocks in southern Alaska: edited by R. Casey and P. F. Rawson, The Boreal Lower Cretaceous, Geol. J. Spec. Issue, 5, 1-18, 1976.
Jones, D. L. and S. H. B. Clark, Upper Cretaceous (Maestrichtian) fossils from the Kenai-Chugach Mountains, Kodiak and Shumagin Island, southern Alaska: U.S. Geol. Surv. Jour. Res., 1, 125-136, 1973.
Jones, D. L. and A. Grantz, Cretaceous ammonites from the lower part of the Matanuska Formations, southern Alaska, U.S. Geol. Surv. Prof. Pap., 547, 49, 1967.
Jones, D. L., and N. J. Silberling, Mesozoic stratigraphy-The key to tectonic analyses of southern and central Alaska, U.S. Geol. Surv. Open File Rep., 79-1200, 41, 1979.
Jones, D. L., N. J. Silberling, and J. W. Hillhouse, Wrangellia--

A displaced terrane in northwestern North America, Can. J. Earth Sci., 14, 2565-2577, 1977.
Jones, D. L., N. J. Silberling, W. Gilbert, and P. Coney, Character distribution and tectonic significance of accretionary terranes in central Alaska Range, J. Geophys. Res., 87, 3709-3717, 1982.
Karig, D. E., Evolution of arc systems in the western Pacific, Annu. Rev. Earth Planet. Sci., 2, 51-76, 1974.
Karl, S., J. Decker, and D. L. Jones, Early Cretaceous radiolarians from the McHugh Complex, south-central Alaska, U.S. Geological Survey in Alaska, Accomplishments During 1978, U.S. Geol. Surv. Circ., 804-B, B88-B90, 1979.
Kirschner, C. E., and C. A. Lyon, Stratigraphy and tectonic development of the Cook Inlet petroleum province, in Arctic Geology, Mem. 19, Am. Assoc. Pet. Geol., 396-407, 1973.
Kuniyoshi, S., and J. G. Liou, Contact metamorphism of the Karmutsen Volcanics, Vancouver Island, British Columbia, J. Petrol., 17, 73-79, 1976.
Lanphere, M. A., and D. L. Jones, Cretaceous time scale from North America, Contributions to the Geologic Time Scale, edited by G. V. Cohee, M. F. Glaesner, and H. D. Hedberg, Stud. Geol. Tulsa Okla., 6, 259-268, 1978.
MacKevett, E. M., Jr., and G. Plafker, The Border Ranges fault in south-central Alaska, U.S. Geol. Surv. J. Res., 2(3), 323-329, 1974.
Magoon, L. B., W. L. Adkinson, and R. M. Egbert, Map showing geology, wildcat wells, Tertiary plant fossil localities, K-Ar dates, and petroleum operations, Cook Inlet area, Alaska, scale 1:250,000, U.S. Geol. Surv. Misc. Invest. Ser., Map I-1019, 1976.
Marshak, R. S., and D. E. Karig, Triple junctions as a cause for anomalous near-trench igneous activity between the trench and volcanic arc, Geology, 5, 233-236, 1977.
Metz, P. A., Occurrences of sodic amphibole-bearing rocks in the Valdez C-2 quadrangle, Geol. Rep. Alaska Div. Geol. Geophys. Surv., 51, 27-29, 1976.
Monger, J. W. H., and R. A. Price, Geodynamic evolution of the Canadian Cordillera-progress and problems, Can. J. Earth Sci., 16, 770-791, 1979.
Monger, J. W. H., R. A. Price, and D. J. Tempelman-Klait, Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera, Geology, 10, 70-75, 1982.
Moore, J. C., Cretaceous continental margin sedimentation, southwestern Alaska, Geol. Soc. Am. Bull., 84, 595-614, 1973a.
Moore, J. C., Complex deformation of Cretaceous trench deposits, southwestern Alaska, Geol. Soc. Am. Bull., 84, 2005-2020, 1973b.
Moore, J. C. and W. Connelly, Mesozoic tectonics of the southern Alaska margin, in Island Arcs, Deep Sea Trenches, and Back Arc Basins, Maurice Ewing Ser., Vol. 1, edited by M. Talwani and W. C. Pitman, 1, pp. 71-82, AGU, Washington, D.C., 1977.
Moore, J. C. and R. L. Wheeler, Structural fabric of a melange, Kodiak Islands, Alaska, Am. J. Sci., 278, 739-765, 1978.
Moore, J. C. and W. Connelly, Tectonic history of the continental margin of southwestern Alaska, late Triassic to earliest Tertiary, in The Relationship of Plate Tectonics to Alaskan Geology and Resources, edited by S. Alexander, pp. H1-H29, Alaska Geological Society Symposium 6, Anchorage, Alaska, 1980.
Nilsen, T. H., Accretion model for the Cretaceous Chugach terrane, southern Alaska, U.S. Geol. Surv. Circ., 844, 93-97, 1982.
Nilsen, T. H., and G. W. Moore, Reconnaissance study of Upper Cretaceous to Miocene stratigraphic units and sedimentation

facies, Kodiak and adjacent islands, Alaska, U.S. Geol. Surv. Prof. Pap., 1093, 34, 1979.

Pavlis, T. L., Deformation along a late Mesozoic convergent margin: The Border Ranges fault system, southern Alaska, Ph.D. thesis, Univ. of Utah, Salt Lake City, 1982.

Pessel, G. H., M. W. Henning, and L. E. Burns, Preliminary geologic map of parts of the Anchorage C-1, C-2, D-1, D-2 quadrangles, Alaska, Open File Rep., AOF121, Alaska Div. of Geol. and Geophys. Surv., College, Alaska, 1981.

Plafker, G., D. L. Jones, T. G. Hudson, and H. C. Berg, The Border Ranges fault system in the Saint Elias Mountains and Alexander Archipelago, The U.S. Geological Survey in Alaska: Accomplishments During 1975, U.S. Geol. Surv. Circ., 733, 1976.

Plafker, G., D. L. Jones, and E. A. Pessagno, Jr., A Cretaceous accretionary flysch and melange terrane along the Gulf of Alaska margin: The U.S. Geological Survey in Alaska, Accomplishments during 1976, U.S. Geol. Surv. Circ,. 751-B, B41-B43, 1977.

Rose, A. W., Geology of chromite-bearing ultramafic rocks near Eklutna, Anchorage Quadrangle, Alaska, Rep. Alaska Div. of Mines and Miner. 18, 20, 1966.

Seely, D. R., P. R. Vail, and G. G. Walton, Trench slope model in The Geology of Continental Margins, pp. 249-260, Springer-Verlag, New York, 1974.

Stone, D. B., and D. R. Packer, Tectonic implications of Alaska Peninsula paleomagnetic data, Tectonophysics, 37, 183-201, 1977.

Stone, D. B., and D. R. Packer, Paleomagnetic data from the Alaska Peninsula: Geol. Soc. Am. Bull., 90, 545-560, 1979.

Stone, D. B., B. C. Panuska, and D. R. Packer, Paleolatitudes versus time for southern Alaska, J. Geophys. Res., 87, 3697-3708, 1982.

Tysdal, R.G., and G. Plafker, Age and continuity of the Valdez Group, southern Alaska, in Changes in Stratigraphic Nomenclature of the U.S. Geological Survey, edited by N. F. Sohl and W. B. Wright, U.S. Geol. Surv. Bull., 1457-A, A120-A124, 1978.

Van Hinte, J. E., A Cretaceous time scale, Am. Assoc. Pet. Geol. Bull., 60, 498-516, 1976.

Winkler, H. G. F., Petrogenesis of Metamorphic Rocks, 5th ed., Springer-Verlag, New York, 1979.

Winkler, G.R., M. L. Silberman, A. Grantz, R. J. Miller, and E. M. MacKevett,Jr., Geologic map and summary geochronology of the Valdez Quadrangle, southern Alaska, U.S. Geol. Surv., Open File Report, 80-892-A, 1981.

(Received November 30, 1981;
revised July 23, 1982;
accepted August 10, 1982.)