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GEOLOGIC MAP OF THE ANCHORAGE C-5 QUADRANGLE, ALASKA

By

T.L. Pavlis[1]

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794 University Avenue, Basement
Fairbanks, Alaska 99709

[1]Lehigh University, Department of Geological Sciences, Williams Hall 31, Bethlehem, PA 18015.

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INTRODUCTION

LOCATION AND ACCESS

The Anchorage C-5 Quadrangle lies in the western Chugach Mountains about 12 km east of Palmer, Alaska. The quadrangle is traversed on the northwest and southwest corners by the Matanuska and Knik Rivers respectively, and most of the the quadrangle lies within a westward projecting, wedge-shaped prong of the Chugach Mountains. Total topographic relief in the quadrangle is approximately 2½ km with the lowest elevations along the Knik River and the highest elevations along the eastern edge of the quadrangle. Topography varies throughout the quadrangle but aside from the river valleys and northernmost foothills of the Chugach Mountains, most of the area is above tree line and is characterized by sharp ridges separating broad, U shaped, glacially carved valleys. The steepest terrain lies along the local drainage divide between the Knik and Matanuska Rivers where the relief locally approaches 1.5 km and active glaciers have steepened cirque headwalls. Most of the quadrangle is inaccessible except by foot or helicopter. Exceptions are the northwest corner of the quadrangle where the Glenn Highway follows the northern edge of the Matanuska River. A number of private, unimproved roads also allow limited access south of the Matanuska River. Access by fixed wing aircraft is limited to short landing strips in Friday Creek. An abandoned landing strip in Carpenter Creek is, at the time of this writing, overgrown and unusable.

PREVIOUS INVESTIGATIONS AND SCOPE OF THE PRESENT INVESTIGATION

Prior to 1970, the Chugach Mountains were largely unmapped aside from brief reconnaissance descriptions made during studies of the Matanuska Valley (for example, Barnes, 1962; Grantz, 1960, 1961a, 1962b). Barnes (1962) mapped the northwest part of the C-5 Quadrangle at that time and that mapping is only slightly modified in this report. S.H.B. Clark provided the first clear picture of the major lithologic groupings and structure of the area (Clark, 1972a, 1972b, and 1983 and mapping compiled by Magoon and others, 1976). The author conducted the first detailed investigations in the quadrangle during 1979 and 1980. That investigation, however, was limited to a 10 km wide strip across the eastern edge of the quadrangle (Pavlis, 1982a).

The map in this report (pl. 1) is a compilation of the previous mapping in the C-5 Quadrangle by Barnes (1962) and Pavlis (1982a) along with new detailed mapping in the remaining parts of the quadrangle. The new mapping along with limited field checking of Barnes'(1962) and Pavlis' (1982a) work was conducted as part of a 1982 DGGS mapping program. The 1982 mapping consisted of seven weeks of field work from late June to mid August. For the first five weeks mapping was conducted entirely on foot from eight base camps whereas the during the final two weeks full helicopter support was used. The 1982 field party consisted of T.L. Pavlis and M.E. Serfes (entire season) with additional support from D.H. Monteverde and L.F. Serpa during the final two weeks.

The geologic mapping was carried out on 1:25,000 scale topographic basemaps prepared by photo enlargement of U.S.G.S. 1:63,360 scale topographic maps of the quadrangle. Because of the difference in scale, the original field maps have been generalized to create the 1:63,360 scale map of this report.

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DESCRIPTION OF ROCK UNITS
MAJOR STRUCTURES AND TECTONOSTRATIGRAPHIC TERRANES

Use of the Terms Border Ranges Fault and Border Ranges Fault System

The central portion of the Anchorage C-5 Quadrangle is transected from southwest to northeast by a broad zone of faulting across which Jurassic and pre-Jurassic crystalline rocks have been juxtaposed against a late Mesozoic melange, the McHugh Complex (Clark, 1972b; Pavlis, 1982b). The Border Ranges fault is a major regional structure that was originally defined by MacKevett and Plafker (1974, p. 323) as a structural contact which "juxtaposes upper Paleozoic and lower Mesozoic rocks on the north against upper Mesozoic and Tertiary rocks." Thus, by this definition the Border Ranges Fault lies within the C-5 quadrangle.

At the same time as this nongenetic definition was presented, MacKevett and plafker (1974), interpreting the Border Ranges Fault as a late Meso§oic boundary beneath which the oldest units of the Alaskan-Aleutian subduction complex were accreted. Hence, this introduced a genetic implication to the Border Ranges Fault. Recent work (Winkler and others, 1981; Pessel and others, 1981; Pavlis, 1982a, 1982b; and Burns and others, 1983) has shown that the original Mesozoic elements of the boundary are strongly overprinted by Tertiary deformation that post-dates the initiation of convergence. Furthermore, it is now clear that disparate rock sequences characterize the crystalline terranes north of the section boundary (Winkler and others, 1981). As a result, considerable confusion has developed over the precise use of the term Border Ranges Fault; should the term refer to the genetic concept (and thus refer only to Mesozoic structure) or should the term be defined nongenetically by rock sequences separated along the contact? In this paper the following terminology will be used:

1. The terms Border Ranges fault and Border Ranges fault system refer to the entire system of faults (and possibly ductile shear zones) within crystalline rocks of the northern Chugach front (that is, within the northern Chugach crystalline belt of Pavlis, 1983). Thus, the term Border Ranges fault is used here in a nongenetic sense as comprising a macroscopic fault network

that may contain individual faults (or shear zones) of several ages. Because this zone of faulting is generally several kilometers wide (Winkler and others, 1981; Pessel and others, 1981; Burns and others, 1983) the term Border Ranges fault system is most appropriate for describing the structure at a scale of 1:63,360.

2. The term Border Ranges thrust will be used to designate the genetic concept of a Mesozoic megathrust as originally used by MacKevett and Plafker (1974).

3. In reference to younger reactivations of the Border Ranges fault, the terms Cenozoic Border Ranges fault or Cenozoic faults of the Border Ranges fault system will be used.

Tectonostratigraphic Terranes

The C-5 Quadrangle is underlain by rocks comprising two regionally extensive tectonostratigraphic terranes. Rocks throughout the northern half of the quadrangle are clearly part of the Peninsular terrane (Jones and Silberling, 1979) in that they contain the characteristic Peninsular terrane stratigraphy. Rocks in the southern third of the quadrangle include chaotic rocks of the McHugh Complex (Clark, 1973) and the structurally underlying Valdez Group; the two units that regionally are referred to respectively as the melange and flysch subterranes of the Chugach terrane (Plafker and others, 1977).

Between exposures of the Talkeetna Formation and exposures of rocks showing the characteristic chaotic structural style of the McHugh Complex (pl. 1) is a belt of complexly faulted crystalline rocks. Lithologically these crystalline rocks are composed of medium grade metamorphic rocks and at least two generations of plutonic rocks. The author previously described these rocks as the basement terrane for the structurally adjacent Peninsular Terrane (Pavlis, 1983), and although this relationship is probably true for most, if not all, of these crystalline rocks that correlation is not unequivocal. In particular, a tectonostratigraphic terrane, like the Peninsular Terrane, is a fault bounded entity that is defined by a characteristic cover sequence (Jones and Silberling, 1979 and Coney and others, 1980); yet, if that cover sequence is not present---as in exposures of "basement rocks"---the assignment of a crystalline rock sequence to a given terrane will always be equivocal. In most areas of the Cordillera this "flaw" in the terrane concept is insignificant because cover rocks are ubiquitous, but in the western Chugach Mountains "basement rocks" (crystalline rocks) are everywhere in fault contact with the Peninsular terrane cover; thus, the evidence for a correlation is debateable. The problem is further complicated because available absolute age data (see Pavlis, 1983) allow for both Jurassic and Cretaceous metamorphic events in the quadrangle, and as a result it is possible that some of the crystalline rocks are actually 'high grade equivalents' of Chugach terrane units.

Because of these uncertainties in correlation, a strict adherence to the terrane concept (as outlined by Jones and Silberling, 1979; Coney and others, 1980) requires that these crystalline rocks be separated as a distinct terrane (or terranes). In this report, the term Knik River terrane will be used for all rocks which cannot be clearly correlated to either the Peninsular terrane (as defined by exposures of Talkeetna Formation) or the Chugach terrane (indicated by both structural style and lithologic association). This term is simply a redefinition of terminology first presented by Carden and Decker (1977). Applying this definition the Knik River terrane includes an approximately 10 km wide belt of rocks along the Border Ranges Fault System. The northern edge is a broad (up to 1 km wide) fault zone that is herein referred to informally as the northern Chugach Fault zone, and the southern edge is a complex boundary formed by several generations of faults (pl. 1 and fig. 1).

PENINSULAR TERRANE

The Matanuska Valley and the northern foothills of the Chugach Mountains are underlain by rocks clearly belonging to the Peninsular terrane of Jones and Silberling (1979). The Peninsular terrane rocks form two structural-=lithologic sub-belts: 1. a 3-5 km wide belt of volcaniclastic rocks and probably co-eval granitoid plutons exposed in the northern foothills of the Chugach Mountains, and 2. a belt of late Mesozoic and early Tertiary sedimentary rocks exposed throughout the Matanuska Valley. The volcanic rocks of the northern Chugach Mountains belong to the Early Jurassic Talkeetna Formation (Barnes, 1962). The volcanics and associated plutons represent a basement sequence onto which the sedimentary rocks were deposited.

Rocks of the Peninsular terrane are not well exposed in the C-5 Quadrangle. This exposure problem is acute in the Matanuska Valley where thick glacial deposits mask most of the bedrock geology. Exposure is better in the Chugach foothills but most of the major drainages are filled with thick glacial and glacio-fluvial deposits.

Basement Sequence

Talkeetna Formation(Jtk): In the C-5 Quadrangle, the oldest rocks of the Peninsular terrane are a variety of volcanic rocks which apparently belong to the Talkeetna Formation. In the central Chugach Mountains Grantz (1960, 1961a, 1961b), Pessel and others (1981), and Burns and others (1983) have divided the Talkeetna Formation into a number of members. Poor exposure handicapped efforts at division and the Talkeetna Formation is not divided in plate 1.

The major exposures of the Talkeetna Formation occur along a 1-2 km wide, relatively continuous band which coincides closely with the Chugach Mountain front. This continuous outcrop band swings south of the mountain front near King Mountain. All other exposures of Talkeetna Formation occur as irregular outcrop masses, presumably roof pendants in the associated intrusives, and as fault bounded exposures.

In the C-5 Quadrangle, the Talkeetna Formation is mostly a massive volcanic unit with no obvious bedding. At both Crag and Pinnacle Mountain, however, thick bedded units dip steeply to the north suggesting that the band of Talkeetna Formation along the mountain front may represent a north dipping homoclinal sequence. Lithologically the major rock type of the Talkeetna Formation appears to be a massive pyroclastic rock. Some of these rocks are lithic tuffs with pebble to cobble sized clasts in a fine grained matrix. Most of the rocks, however, lack this obvious pyroclastic texture and probably represent originally fine-grained, thick-bedded, tuffaceous units. Flow units appear to be relatively uncommon. The volcanic rocks all appear to be predominantly intermediate to silicic in composition. An isolated exposure (sec. 17 and 18, T. 18 N., R. 4 E.) in lower Wolverine Creek, however, contains fine grained, highly altered, massive greenstones that presumably are a mafic part of the Talkeetna Formation.

Cumulate (?) gabbro (Jpg): One small body of coarse grained gabbro is exposed on opposite banks of lower Wolverine Creek (pl. 1). These gabbros are essentially pyroxene-plagioclase rocks and are characterized by sub-ophitic textures with 3-5 mm long plagioclase laths surrounded by pyroxene. These gabbroic rocks are probably cumulates and may be correlative with an extensive layered gabbro complex in the central Chugach Mountains (see Burns, 1983 and Burns and others, 1983 for details). The gabbros may also be correlative with layered gabbros of the Knik River terrane (unit lg, pl. 1) but because the latter are metamorphosed that correlation is less likely. The absolute age of the gabbros is unknown. In the C-5 Quadrangle they are clearly cut by mafic dikes and appear to be cut by granodiorites (Jgd) but their relative age with respect to the diorite-tonalite suite (Jpt and Jpd) is unclear.

Tonalite (Jpt) and diorite (Jpd) of the Peninsular terrane: A broad continuous belt of intermediate plutonic rocks lies beneath the Talkeetna Formation throughout the northern foothills of the Chugach Mountains. Small exposures of similar rocks in lower Wolverine Creek are probably also part of this intrusive series. The dominant lithology within this belt is hornblende tonalite characterized by fine to medium grained, hypidiomorphic granular textures. However, compositions vary throughout the belt with many rocks showing color indices of nearly 70 while quartz contents range from 0 to 30 percent. Most of these rocks are mapped as unit Jpt; a composite unit containing rocks ranging from hornblende gabbro to tonalite. Locally, however, the rocks are dominantly hornblende gabbro-diorite and are different separately (unit Jpd). Most of the compositional variability is recognizable on a mesoscopic scale and appears to be due to inhomogeneities in the original intrusives; not merely a result of several plutons of widely varying composition.

The contact between the intrusive complex and the Talkeetna Formation is well exposed only at Crag in the northwest corner of the quadrangle and in that locality, the rocks invade Talkeetna Formation. The intrusive relationship is evidenced by both an irregular contact zone and a clear textural zonation from hypidiomorphic granular to porphyritic as the contact is approached. Presumably this contact relationship also holds for other localities along the mountain front.

Granodiorite-adamellite plutons (Jgd): A number of small, leucocratic plutonic bodies; most with aerial exposures of less than 5 km^2; intrude tonalites and the Talkeetna Formation along the Chugach Mountain front. These plutonic masses vary in composition from granodiorite to adamellite but most appear to be granodiorite. The rocks generally carry both hornblende and biotite as mafic phases and quartz contents are generally 10-20 percent. The rocks show fine to medium grained, hypidiomorphic granular textures and plagioclase is commonly zoned suggesting cooling at relatively shallow crustal levels (Pavlis, 1982a, 1983).

Most of the granodiorite bodies are roughly circular or elliptical in outline with some irregular lobes projecting from the body. The plutons clearly intrude surrounding rocks but no chilled margin or contact aureole was recognized adjacent to the bodies. Pavlis (1982a) mapped some rocks adjacent to the small plug near the center of the quadrangle (SW¼ sec. 11, T. 18 N., R. 4 E.) as mafic hornfels. Reexamination of this area in 1982, however, showed the body to be fault bounded to the south and the 'mafic hornfels' appear to be mafic dike rock. The granodiorite bodies are generally massive igneous rocks but one body in the northeast corner of the quadrangle (NE¼ sec. 1, T. 18 N., R. 4 E.) is foliated along its southwest margin. This foliation presumably is an igneous flow foliation but the contact with adjacent rocks was not observed. Thus it is possible that the rock is an older gneissic rock unrelated to the other granodiorite bodies.

Cover Rocks

The northwest corner of the quadrangle is underlain entirely by late Mesozoic-early Tertiary sedimentary rocks of the Cook Inlet - Matanuska Valley - Copper River basin system (Barnes, 1962; Kirschner and Lyon, 1973). Regionally these rocks are middle Jurassic through Tertiary in age but in the C-5 Quadrangle only late Cretaceous and early Tertiary rocks are exposed (Barnes, 1962). These rocks include the Matanuska and Chickaloon Formations, both of which have been described regionally in some detail (Barnes and Payne, 1956; Grantz, 1960, 1961a, 1961b; Barnes, 1962; Kirshner and Lyon, 1973; Fisher and Magoon, 1978). Aside from changes south of King Mountain and along the Matanuska River the distribution of these units is largely a compilation of Barnes (1962) work.

Cretaceous Matanuska Formation (Km): In the C-5 Quadrangle the Matanuska Formation is a monotonous sequence of medium to dark gray, interbedded shale and graywacke. The graywackes vary from fine grained silty rocks to conglomeratic sandstone. In many exposures the Matanuska Formation shows conspicuous graded bedding suggesting that much of the unit represents a turbidite sequence (Grantz, 1964; Jones, 1967). The most complete sequence of the Matanuska Formation is along Granite Creek in the northwest corner of the quadrangle where a relatively intact, south dipping homoclinal sequence is exposed. In that exposure the rocks are rythmically bedded with individual graded units about 30 cm thick and the rocks show soft sediment folding suggestive of deposition on a slope. In most exposures of the Matanuska Formation, however, the rocks are thick bedded sandstones and conglomerate with minor shale, observations suggesting a more proximal position (Jones, 1967).

Paleocene Chickaloon Formation (Tc): The Chickaloon Formation is never well exposed in the C-5 Quadrangle except along stream drainages and in the northeast corner of the quadrangle where it is exposed within the mountains. The Chickaloon is characterized by interbedded, fluvial shales and sandstone. The sandstones are generally poorly sorted, cross-bedded gray rocks which weather to a buff color whereas the shales are gray to black, finely laminated rocks. Coal is locally abundant within the Chickaloon Formation (Barnes and Payne, 1956) and plant fossils are ubiquitous. South of King Mountain the Chickaloon Formation uncomformably overlies the Talkeetna Formation. The basal units consist of 20-30 m of massive conglomerate. The conglomerate contains pebbles of volcanic rock (presumably derived from the underlying Talkeetna Formation) but the dominant clasts are gray and red chert. The basal conglomerate does not appear to be present throughout the contact with the Talkeetna Formation, either due to structural complication or primary depositional patterns. The conglomerate, where present, grades upward into interbedded greenish sandstone, conglomerate, and reddish brown to deep brown shales. Barnes mapped these basal units as part of the Talkeetna Formation but the presence of abundant chert clasts in the conglomerate is more typical of the Chickaloon and Wishbone formation and thus the units are considered part of the Chickaloon Formation.

Younger Igneous Rocks

Tertiary felsic intrusives(Ti): The youngest rocks of known relative age are exposed in the NE corner of the quadrangle where they form King Mountain and an adjacent bedrock knob. The plutonic rocks are all fine to medium grained leucocratic igneous rocks that Barnes (1962) considered to be granodiorites. The rocks intrude the Paleocene Chickaloon Formation and appear to post-date a late Eocene-early Oligocene deformation in the Matanuska Valley (Barnes, 1962 and Kirschner and Lyon, 1973).

Mafic Dikes of Unknown Age (md): At scattered localities along the Chugach Mountain front mafic dikes, locally relatively closely spaced, constitute a significant percentage of the country rock although most are too small to be shown on the map. These dikes vary from fine grained diabase and (or) basalt to micro-diorite. The dikes vary in width from 20 cm to about 3 m and vary in abundance from scattered dikes to closely spaced, parallel dikes constituting as much as 50 percent of the rock. The dikes almost invariably have nearly east-west strikes and are near vertical. At two localities microdiorites are mappable. At both localities, however, it is unclear if this relationship is due to numerous closely spaced dikes (that is, 100 percent dike rock) or a single, fine grained intrusive mass. The age of the dikes is unknown but the consistency in orientation suggests they are relatively young, perhaps Tertiary in age. Burns and others (1983) work in the Anchorage C-3 and C-2 Quadrangles suggests that these dikes are abundant throughout the Chugach Mountain front but are probably of several generations.

Metamorphism

Tertiary and Cretaceous sedimentary rocks of the Peninsular terrane are unmetamorphosed except for minor hornfels adjacent to Tertiary intrusives. The Talkeetna Formation, however, shows variable effects of low grade regional metamorphism as well as contact metamorphism associated with the tonalitic plutonic rocks. The regional metamorphism of the Talkeetna Formation created the mineral assemblage chlorite + epidote + quartz, a non-diagnostic assemblage stable from the prehnite-pumpellyite to lower greenschist facies. The rocks clearly reach greenschist facies in contact aureoles, however as evidenced by metamorphic actinolite. Both the regional metamorphism and local contact metamorphism are not associated with penetrative deformation. Indeed, abundant veining and local sulfide mineralization suggests that the metamorphism of the Talkeetna Formation was largely a hydrothermal event coeval with volcanism and plutonism.

The plutonic rocks of the Peninsular terrane are unmetamorphosed and many are relatively unaltered. In many parts of the terrane, however, particularly in the more silicic rocks, some alteration of plagioclase and mafic minerals can be recognized. This alteration is presumably a late magmatic hydrothermal alteration. Elsewhere, however, both the plutonic rocks and the Talkeetna Formation are cut by complex vein networks containing prehnite and (or) zeolites(?). This veining demonstrates that some post-plutonic circulation of a low temperature hydrothermal fluid has occurred. The age and significance of this alteration is unknown.

KNIK RIVER TERRANE

The Knik River terrane is a faulted group of igneous and metamorphic rocks forming a 10 km wide band that extends from the southwest to northeast corner of the quadrangle. The terrane is internally disrupted by the Border Ranges fault system. Knik River terrane rocks from the east-central portion of the C-5 Quadrangle have been described in detail by Pavlis (1982a, 1983). This report reviews some of those observations along with field observations from the remainder of the terrane. For the purpose of description lithologically similar rock are described collectively. Nonetheless, the reader should keep in mind that because of the faulted bounded nature of the rocks, we could be lumping unrelated units. The ambiguity of this correlation is discussed in the last section of this report.

Metamorphic Rocks

Mafic (lg)-ultramafic (um) bodies: Tectonite ultramafic rocks, and cumulate ultramafic and mafic rocks are exposed in two large lensoidal masses near the topographic divide between Wolverine and Carpenter Creek. Together these fault bounded bodies constitute the Wolverine ultramafic complex of Clark (1972b). Similar rocks also occur in lower Jim Creek but in that locality ultramafic rocks occur only along a narrow band at the southern edge of a body composed predominantly of layered gabbro. Ultramafic rocks (talc-calcite schists) also occur as lenses within the unit JPrm and as xenoliths in the pluton west of the largest ultramafic body (pl. 1).

In all three mafic-ultramafic bodies a conspicuous layering dips to the south at shallow to steep angles (fig. 5d). The layering varies from macroscopic interlayering of gabbros and peridotite in the largest ultramafic body to mesoscopic interlayering of light and dark bands, pyroxene rich bands, or thin chromite layers. A small area on the east-southeast margin of the largest ultramafic body is underlain by tectonized ultramafic rocks showing isoclinally folded chromite bands and preferred orientation of minerals. Most of the rocks, however, do not show evidence of ductile deformation and many show cumulate textures, thus most of the rocks probably represent parts of a cumulate igneous complex. Dunite, generally with thin (1 mm to about 5 cm thick) bands of chromite, is the most abundant lithology in both ultramafic bodies of the Wolverine complex. Layered gabbro and clinopyroxene rich peridotites (originally wehrlites and [or] lherzolites) appear to be in about equal proportions in the largest ultramafic body but gabbros are absent in the smaller ultramafic body in upper Carpenter Creek (Pavlis, 1983).

All three ultramafic-mafic bodies have been metamorphosed at greenschist or lower-amphibolite facies. Mafic rocks are generally completely re-crystallized to amphibole + zoisite ± chlorite but a few rocks retain corroded clinopyroxene and plagioclase. Ultramafic rocks contain abundant remnant phases but show replacement patches of chlorite + tremolite, talc, tremolite alone, or talc + chlorite and (or) calcite. Serpentinization is ubiquitous at the margins of the ultramafic bodies but aside from shear zones, serpentine is generally absent within the ultramafic complexes.

The serpentine free paragenesis is the product of a hydrothermal metamorphism that was controlled by fracture permeability and involved marked mass transport in the fluid phase. The serpentine free paragenesis is not associated with penetrative deformation suggesting that either the metamorphic peak was post-kinematic or the ultramafic bodies were not penetratived deformed because they behaved as rigid pods deformed internally by shear zones (Pavlis, 1983).

The serpentinites are of two types: 1) a blocky, black or dark green, highly slickensided rock with serpentine growing largely as replacement patches; and 2) green to blue-green serpentine schist with 1-10 cm entrained blocks of less altered ultramafic rock. The former occur along the margins of the body and locally show evidence that the serpentinization and shearing post-date metamorphic tremolite and (or) chorite. The latter, however, occur largely in shear zones within the ultramafic masses and their age relationship to serpentine free metamorphic assemblages is unclear.

Mafic schists---foliated greenschist (g) and amphibolite (a): The most abundant metamorphic lithology of the Knik River terrane is a group of variably foliated mafic schists. The mafic rocks are compositionally indistinguishable in the field but metamorphic grade varies from the upper greenschist facies to amphibolite facies. In the field the rocks were divided into a greenschist unit (g) and an amphibolite unit (a). The rocks were designated as greenschist if they were distinctly greenish in color and contained obvious chlorite in hand specimen whereas amphibolites are all dark gray to black rocks without obvious chlorite in hand-specimen.

Although they were not divided during the mapping, the mafic schists are of two types: a) banded amphibolites and (or) greenschists in which mafic bands are interlayered with 1-10 cm thick bands of calc-silicate; and b) massive, foliated amphibolite and greenschist. In amphibolite facies rocks, the calc-silicate bands in the banded amphibolites contain diopside + garnet + plagioclase ± zoisite ± calcite (Pavlis, 1983). In lower grade rocks, however, much carbonate remains with only zoisite as a secondary mineral.

The mafic schists also contain intercalated bands and (or) lenses of pelitic schist which vary in size from thin 1 cm thick bands to layers several meters in thickness. In the higher grade rocks these bands may be infolds of pelitic schist but in the lower grade rocks similar argillaceous bands appear to be primary or a result of pre-metamorphic structural complications.

Metamorphic fabrics are of variable intensity within the mafic schists. This variation is pronounced in the lower grade units (JPg) where the rocks change from fine-grained unfoliated greenstones to strongly foliated chlorite-actinolite schist. In higher grade rocks a similar variation is recognized but the variation occurs as a subtle variation in the 'intensity' of the fabric, for example, a lineation that is sporatic. The changes in the intensity of fabric can locally be seen on a mesoscopic scale where foliated zones grade into massive rocks, and in these cases the foliated zones may represent ductile shear zones. However, the characteristic shear zone geometry is generally not observed, hence the zones could be local variations in the finite strain within a rock that was subjected to a relatively simple macroscopic strain pattern.

Permian (?) meta-chert and meta-argillite (ca): In the Jim Creek area the mafic rocks (unit g) are intimately associated with a sequence of deformed white or gray chert and dark argillaceous rock. These rocks occur as two mappable bands on the north bank of Jim Creek but argillaceous rocks also occurs as lenses and discontinuous layers within the mafic rock. The "mixing" mechanism for the greenstones and argillaceous rocks is uncertain but, as discussed below, at least some structural mixing is probable.

The meta-chert/argillite unit is characterized by complex internal folding with chert bands folded (commonly disharmonically) into tight nearly isoclinal folds. The cherts themselves show intense veining and recrystallization but lack a foliation. The argillaceous rocks, however, generally are moderately to strongly foliated phyllites and semischists.

The sedimentary origin of the metacherts and metaargillites is unequivocal and they are probably correlative with similar metasedimentary rock exposed south of the Knik River near Mount Eklutna (R. Bruhn, personal commun., 1982). That interpretation is significant because Clark (1972a) collected carbonates from the Eklutna area which yielded Permian fusilinids, hence the metasedimentary rocks in the Jim Creek area are probably Permian as well.

Quartz Rich Mica Schists (JPqs): Scattered throughout the Knik River terrane are a series of quartz rich, metasedimentary rocks mapped collectively as unit qs. The largest single exposure of this unit is along the upper divide between the south and north forks of Wolverine Creek (pl. 1). Included in this unit are a variety of metasedimentary rocks but the characteristic lithology is a mesoscopically laminated schist in which 1 m tò 2 cm thick quartzite bands are interleaved with mica schists. The mica schists are mostly garnetiferous biotite schist but many of the rocks also carry muscovite whereas others carry hornblende. The latter are generally quartzo-feldspathic and are similar to the 'brown schist' (JPbs) unit mapped in upper Wolverine Creek. The quartzites are generally micaceous but most are not flaggy. Some quartzites are calcareous and carry unusual calc-silicate assemblages (e.g. diopside, wollastonite, and garnet). The protolith for the quartz rich mica schists is almost certainly a sequence of bedded cherts and argillites (Pavlis, 1983). Indeed, aside from structural style and metamorphic grade the rocks are lithologically indistinguishable from the metachert/argillite unit (ca) of Jim Creek, and the two units may be correlative.

The quartz rich mica schists are locally rich in sulfide minerals (pyrite?) and as a result tend to weather to a reddish to dark reddish brown color. Where these rocks are engulfed by plutonic rocks (upper drainage of the south fork of Wolverine Creek - sec. 10, 11, 12, 16, 18, T. 17 N., R. 4 E.; and west of lower Carpenter Creek - N½ sec. 7, S½ sec. 6, T. 18 N., R. 5 E.) the primary (?) sulfides appear to have been remobilized and concentrated by hydrothermal circulation. As a result these zones stand out as bright red or dark reddish brown patches along the margins of, or engulfed by, plutonic rock. Where these rocks could be observed, the sulfide appeared to be entirely pyrite but it is possible that other minerals are present.

Hornblende-biotite, quartzo-feldspathic schist---'brown schist' (bs): In upper Wolverine Creek, the bulk of the rocks forming peak 6349 are a moderately foliated sequence of hornblende-biotite bearing quartzo-feldspathic schists. In the field they are distinguished from amphibolite by their brown color on a weathered surface and by the presence of biotite. They are distinguished from the quartz-rich schists by the absence of quartzite laminations. The rocks are a relatively massive unit forming steep craggy slopes. The massive character appears to be due to the interlocking quartzo-feldspathic matrix which prevents easy splitting along the foliation. The protolith for these rocks is unclear but the rocks are layered suggesting they are probably meta-sedimentary; perhaps meta-graywacke.

Marble (not differentiated): Marbles occur at scattered localities throughout the Knik River terrane but none are of sufficient areal extent to be shown at the scale of the mapping. The marbles are restricted to discontinuous thin bands (generally less than 10 m thick) or lenses within other units. The marble units are most abundant in the quartz rich schists (JPca and JPqs) but also occur sporadically within the mafic units (JPg and JPa). Most of the marbles are nondescript, gray laminated rocks with limited evidence of growth of secondary, metamorphic minerals; usually only tremolite as a secondary mineral. At one locality, however, in the Anchorage C-4 Quadrangle (S½ sec. 35, T. 19 N., R. 5 E.) the marbles lie along the margin of a large gabbro pluton and have been converted into skarn. The major minerals in these rocks are large (up to 5 cm in diameter) pink garnet and dark green pyroxene (hedenbergite ?) with lesser amounts of wollastonite, amphibole, and pyrite.

Red melange (rm): Along the northern margin of the Wolverine ultramafic complex and extending to the northeast into the Anchorage C-4 Quadrangle is a belt of mixed rocks characterized by a distinct melange-like structural style. This structural unit is characterized by blocks of relatively undeformed chert, gabbro, basalt, and ultramafic rocks floating in an argillaceous matrix. The matrix is generally foliated and consists of dark gray to black, quartz rich phyllite with minor pyrite. The weathering of the pyrite leads to the characteristic red staining in outcrop. Both the blocks and the melange matrix have been subjected to a post-kinematic metamorphism which produced ubiquitous biotite and phengite in the argillites and actinolite, chlorite, and epidote in mafic rocks. The red melange contains all of the metamorphic lithologies of the Knik River terrane, either as blocks or in the matrix, and therefore may have been produced from the same protolith.

Migmatites (m): At scattered localities along the northern edge of the Knik River terrane and along the Jim Creek-Wolverine Creek divide (N½ sec. 11, T. 17 N., R. 3 E.) amphibolites are invaded by large quantities of diorite and the rocks are best referred to as migmatites. These migmatites are apparently injection gneisses along the margins of diorite plutons as the rocks grade directly into massive igneous rocks. The rocks are relatively minor in abundance but are significant in that they demonstrate that the deformation of at least some of the metamorphic rocks predated the diorite plutons.

Quartzo-feldspathic gneiss (qg): At scattered localities throughout the Knik River terrane are a few small exposures of quartzo-feldspathic gneiss. Most of the gneisses are along the margins of large plutons and the foliation is presumably a primary igneous flow fabric. A few exposures, however, do not show this plutonic association and although their protolith is uncertain, they could represent small pre-kinematic or synkinematic plutons. The latter are all fine grained, leucocratic (color index less than 20) gneisses with biotite and hornblende as mafic phases, and in one locality mesoscopic, 10-50 cm thick bands of amphibolite are interlayered with the leucocratic gneiss.

Cataclastic rocks (cg and sm): Cataclastic rocks are widespread throughout the Knik River terrane. Cataclastic rocks occur along most of the major faults and locally the cataclastic zones are sufficiently wide to be mapped as distinct rock bodies. Typically, the cataclastic rocks occur in a distinct concentric pattern in which a cataclastic core is surrounded by successively less broken and altered rock. In the cataclastic core the primary rock type is generally obscured by both cataclasis and alteration, and the resulting 'cataclastic greenstone' (mapped as unit cg) is a massive, fine grained rocks, regardless of protolith. Locally, these rocks show a foliation defined by either alternating brown, green, or white layers; or 'scaly chlorite' bands separating phacoids of more massive rock. These intensely broken and altered rocks grade outward into wide zones of less intense shearing, generally shown by closely spaced fracture surfaces that do not necessarily show a pronounced preferred orientation. Similarly the intensity of alteration falls off and remnant minerals and textures become recognizable between sheared surfaces.

The cataclastic rocks were divided into two units: a) cataclastic greenstones (unit cg) in which the protolith has been obscured by alteration and cataclasis; and b) sheared metamorphic rocks (unit sm) in which the original protolith is clearly foliated metamorphic rocks but the primary foliation has served as a slip surface. The detailed delineation of the latter (unit sm) is somewhat arbitrary but the criteria used for mapping was that an older, metamorphic foliation surface must be polished or slickensided. The delineation of the 'cataclastic greenstones' (unit cg), however, was less subjective in that the unit represents areas where more than 50 percent of the rock had no recognizable protolith. The mapping of the cataclastic zones provides a relatively clear picture of the pattern of major faults. It is to be noted, however, that because only the intensely shattered and altered rocks were mapped, many of the fault zones are considerably wider than shown by the mapping.

New mineral growth within the cataclastic zones is suggestive of relatively low-temperatures during (or subsequent to) faulting. For example, epidote, quartz, chlorite, and prehnite are ubiquitous within the cataclastic zones; mineralogies suggestive of lower greenschist or sub-greenschist facies conditions (Pavlis, 1982b).

Plutonic Rocks

The Knik River terrane is invaded by at least two generations of plutonic rocks: a) an older series of post or syn-metamorphic intermediate and mafic plutons that pre-date a major faulting event and b) a younger suite of leucocratic, mostly trondhjemitic plutons that post-date most of the major faulting.

The older series includes both normal (clinopyroxene bearing) gabbro (Jcgb) and rocks which grade in composition from hornblende gabbro (hornblende-plagioclase rocks with greater than 50 percent mafics) to hornblende tonalite (Jd and Jt). The latter are the dominant plutonic rock type and although locally they are of mafic composition they are probably best considered as of the diorite-tonalite clan. Hornblende separates from three diorite samples collected in the northern half of the Knik River terrane (plutonic subterrane, fig. 1) yielded Early Jurassic (about 190Ma) K-Ar ages whereas hornblendes from a diorite in the southern half of the Knik River terrane yielded younger (135Ma) ages (Pavlis, 1983).

The younger plutonic series occurs as a series of individual plutons that are concentrated near the Knik River/Chugach Terrane boundary. An Early Cretaceous age for these plutons is indicated by: 1. a hornblende K-Ar age of 124Ma on the pluton in upper Carpenter Creek; a concordant U-Pb zircon age of 103Ma from the pluton in upper Wolverine Creek; and 3. a slightly discordant K-Ar age (116Ma-biotite and 126-hornblende) from the pluton in upper Jim Creek. (Pavlis, 1982a, in press; T. Hudson and J. Arth, personal commun., 1981; and R. Bruhn, personal commun., 1982).

Pyroxene gabbro of lower Carpenter Creek (unit Jcgb): Exposed along lower Carpenter Creek in the northeast corner of the quadrangle are a series of fault bounded slabs of coarse grained gabbro. Similar rocks were also seen as a fault bounded slab near the center of the quadrangle (N½ sec. 24, T. 18 N., R. 4 E.) and as roof pendants in a diorite pluton (S½ sec. 11, T. 18 N., R. 5 E.). The gabbros weather to a rust-brown color but are black on a fresh surface due to dark calcic plagioclase. The rocks are characterized by coarse hypidiomorphic granular textures. In order of abundance the primary mineralogy is calcic plagioclase + clinopyroxene + olivine + opaque, thus the rocks are 'normal' olivine gabbros. The rocks are slightly altered with olivine partially converted to serpentine + magnetite ± talc; and plagioclase is weakly sauseritized.

The Carpenter Creek gabbros are distinct from the layered gabbroic rocks of the Wolverine ultramafic complex in that the Carpenter Creek gabbros: a) are fresh and show no evidence of metamorphism; b) show no evidence of primary igneous layering; and c) are clearly plutonic rocks as they invade foliated metamorphic rocks west of Carpenter Creek and in the C-4 Quadrangle. Thus, the Carpenter Creek gabbros are probably unrelated to the layered ultramafic-mafic rocks of the Knik River terrane. The gabbros are locally invaded by diorite plutons and are therefore no younger than earliest Jurassic.

Jurassic intermediate plutonic rocks (Jg, Jd, Jt, Jdg): The northern half of the Knik River terrane is made up predominantly of intermediate plutonic rocks (plutonic subterrane, fig. 1). In this plutonic subterrane the rocks range in composition from hornblende gabbro (unit Jg) to tonalite (Jt). Most of the rocks are mineralogically indistinguishable and the distinction between various map units was made on a field judgment of modal abundances. Specifically the rocks are all basically quartz bearing hornblende-plagioclase rocks, although some of the tonalites also contain small amounts of biotite. Accessory minerals include abundant magnetite (up to 5 percent) and apatite (up to about 1 percent). The rocks were mapped as gabbro (Jg) if hornblende and opaques made up more than 50 percent of the rock and as tonalite (Jt) if quartz was in excess of 10 percent. Most of the rocks contain less than 10 percent quartz and less than 50 percent mafics, however, and were mapped as diorite (Jd). Local changes from gabbro to diorite are generally gradational and mapping a boundary is generally open to broad interpretation. The tonalites, however, appear to invade diorites and therefore may be the youngest plutons of the intrusive series (Pavlis, 1983).

Texturally, all of the intermediate plutonic rocks are characterized by medium to coarse grained hypidiomorphic granular textures with large, commonly poikilitic hornblendes growing with subhedral plagioclase and anhedral quartz. Locally the poikilitic character of the hornblendes can be seen in hand specimen where large equant hornblende grains have a 'snow flake' appearance due to numerous inclusions. A second textural variation is the local occurrence of pegmatite stringers in which 10-20 cm wide dikes of pegmatitic (individual crystals up to 5 cm in length) tonalite cross-cut the plutonic rocks.

The intermediate plutons are all clearly igneous rocks with little evidence od ductile deformation. This conclusion is evidenced not only by the textural observations noted above but also by abundant intrusive contact relationships including: 1) engulfing of metamorphic rocks by diorites in upper Wolverine Creek; 2) ubiquitous mafic xenoliths of unknown association along the northern edge of the main tonalite mass (just south of the northern Chugach fault zone); and 3) occurrences of injection migmatites (unit m) at several localities. Locally, however, the plutonic rocks are gneissic (Jdg); an observation suggesting ductile deformation. Nonetheless, the contact relationships between these gneisses and adjacent rocks is everywhere obscured by faulting. Thus, the gneissic foliations could also be a primary igneous flow foliation.

Diorite plutons of uncertain affinity (JKd): A series of small plutonic masses of diorite occur to the south of the red melange (unit rm) but it is not clear if these plutons are part of the larger plutonic mass in the northern half of the terrane or are a separate plutonic series. These plutons form mappable bodies on the east canyon wall of Carpenter Creek but smaller sills were also observed within metamorphic rocks in upper Carpenter Creek. The rocks are all diorites with the bulk of the rock comprised of equal proportions of pale green hornblende and plagioclase. Quartz makes up less than 5 percent of the rock and magnetite comprises less than 1 percent of the rock. Texturally, the rocks are characterized by hypidiomorphic granular textures with subhedral amphibole laths and anhedral plagioclase. Although no chemical data is available for these plutons the low magnetite contents and pale green color of the amphiboles suggests low iron contents. This observation implies the plutons may be related to the Cretaceous plutonic series since they also are characterized by low Fe contents. However, since the diorites appear to be invaded by the Cretaceous plutons and give older K-Ar ages (135Ma) the association is equivocal and the rocks could be Jurassic or older.

Altered tonalite or trondhjemite (JKt): At two localities in lower Wolverine Creek (SW¼ sec. 29, T. 18 N., R. 4 E. and S½ sec. 36, T. 18 N., R. 3 E.---not shown on map) strongly altered, leucocratic plutons of unknown affinity and age occur as small plugs in close association with a major fault zone. These rocks were probably leucro-tonalite or trondhjemite initially but plagioclase is intensely altered to clays and the original mafic mineral is converted to chlorite, hence few conclusions can be drawn about the primary rock. The plutons clearly post-date the main body of diorite and tonalite and their map pattern suggests they post-date motion on the fault zone. In detail, however, the contact relationships in the field are inconclusive and the relative age between the igneous rock and the fault zone is uncertain.

Cretaceous trondhjemitic plutons (Kt): Scattered throughout the Knik River terrane and locally intruding the McHugh Complex are a series of small plutons (areal exposures of about 13 to 20 km^2) composed of distinctive leucocratic igneous rocks. Lithologically, the Cretaceous plutons are characterized by compositions varying from tonalite to trondhjemite but a rock with a low color index (less than 20) is characteristic; that is, most are leuco-tonalites or trondhjemites. The rocks appear to be devoid of K-feldspar. Plagioclase, however, has low refractive indices suggesting sodic end members (albite or oligoclase). In darker phases, quartz contents are generally less than 20 percent and pale green hornblende is the dominant (or only) mafic phase. With decreasing color index, however, hornblende decreases relative to biotite and hornblende is generally absent in rocks with less than about 15 percent mafics. Some leucocratic rocks (color index less than about 10) also carry white mica but it is generally unclear if the mica is primary or secondary. At two localities (S½ sec. 7 and E¼ sec. 1, T. 17 N., R. 4 E.) the rocks also contained garnet. Both garnet bearing rocks are virtually devoid of other mafic phases.

The compositional variations of the Cretaceous plutons tend to be gradational and most do not appear to be related to multiple intrusive phases. Indeed, some of the compositional variations may be due to assimilation as the tonalites generally occur near the margins of the bodies whereas the trondhjemites occur near the center of large plutons. The plutons appear to have cooled rapidly because contact metamorphic effects tend to be limited. The Cretaceous plutons are, however, characterized by a pronounced hydrothermal alteration with ubiquitous alteration of feldspar to sericite, biotite to chlorite + prehnite ± zeolites, and hornblende to chlorite and epidote. The intensity of this alteration is highly variable and in some areas there is evidence of more than one generation of mineral growth. Texturally, the Cretaceous plutons are all characterized by primary hypidiomorphic granular textures produced by euhedral hornblende (in tonalites) and subhedral plagioclase grown with anhedral quartz. In many of the rocks quartz grains contain deformation bands and (or) sub-grain mosaics; an observation suggesting that the rocks have been ductilely deformed. The magnitude of this ductile deformation is apparently minor however, because the rocks are generally not foliated and the plutonic rocks cross-cut the deformational fabrics of their country rock; that is, they are not concordant plutons. A weak gneissic banding was recognized along the northern margin of a pluton in upper Wolverine Creek but the foliated rocks are restricted to a complex injection zone; thus, the gneissic bonding could be a product of igneous flow. Nonetheless, the deformed quartz grains imply that minor ductile deformation has occurred; either as a result of a distinctly younger event or deformation immediately following (or during) emplacement of the plutons.

Metamorphism

The Knik River terrane has a polymetamorphic history that is only partially understood. Three distinct metamorphic 'events' can be recognized through mineral assemblages and cross-cutting relationships: a) a regional greenschist to amphibolite facies metamorphic event (or events); b) a younger, retrograde event (or events) with effects localized along faults; and c) minor contact metamorphism adjacent to Cretaceous plutons. The effects of all three events in the eastern half of the quadrangle have been described in some detail (Pavlis, 1983), and a detailed study of the regional metamorphism is in progress (M. Serfes, Lehigh Univ. M.S. thesis, in prep.). Thus, the descriptions here are simply a summary of previous observations and generalities of the areal variations in metamorphic grade.

Regional metamorphism: The regional metamorphism is the oldest event in the Knik River terrane. In the northern half of the terrane the metamorphism is older than, or associated with, the emplacement of the Jurassic plutonic complex but in the southern half of the terrane K-Ar ages are Cretaceous and the only minimum age constraint is provided by Cretaceous plutons (Pavlis, 1983). This relationship, together with other arguments, leads to the possibility that both Cretaceous and Jurassic (or older) metamorphic events have affected the Knik River terrane. However, because the regional metamorphism appears to be relatively homogeneous throughout the quadrangle, the metamorphism is described below as if it were a single event. - Alternatives are discussed in the last section of this report.

Regional metamorphic assemblages imply a general increase in metamorphic grade from southwest to northeast. The lowest grade rocks are exposed in the Jim Creek area where mafic rocks (unit JPg) contain chlorite + actinolite + epidote + albite + opaques, and metamorphosed chert and argillite (unit JPca) contain chlorite + fine-grained biotite ± white mica. The presence of actinolite in mafic rocks suggests the greenschist facies and the presence of biotite in pelitic rocks implies at least middle greenschist facies conditions (Turner, 1981). However, the presence of chlorite and the absence of garnet in pelitic rocks, together with the occurrence of albite in mafic rocks, further suggests that temperatures were below the greenschist-amphibolite facies transition (as defined by Turner, 1981). Thus, in the Jim Creek area the metamorphic peak would appear to have been at middle to upper greenschist facies.

North and east of the Jim Creek area, the metamorphic rocks are characterized by mineral assemblages indicative of the lower amphibolite facies or the greenschist-amphibolite facies transition (classification of Turner, 1981). The exact boundary between greenschist and amphibolite facies rocks has not been accurately mapped but the approximate limit of greenschist assemblages is a north-south line between the centers of secs. 6 and 7, T. 17 N., R. 4 E. (pl. 1). East of that line the rocks contain a relatively uniform mineral assemblage including*: 1) hb = olig/ and + op ± ep ± chl ± qtz (mafic rocks); 2) hb + bi + olig + gn + qtz (brown schists -- metagraywackes(?)); 3) bi + qtz + mu + gn ± plag (pelitic rocks); and 4) a wide variety of calc-silicate assemblages including wollastonite bearing assemblages and ubiquitous diopside, garnet (presumably grossular), and amphibole (see Pavlis, 1983 for details). These assemblages are typical of the lower amphibolite facies, or greenschist-amphibolite facies transition as defined by Turner (1981). The author originally proposed (Pavlis, 1983) that much of the Knik River terrane was metamorphosed at the greenschist-amphibolite facies transition because albite occurred in some mafic rocks whereas plagioclase was oligoclase or andesine in most quartzo-feldspathic rocks. Subsequent work (M. Serfes, Lehigh Univ. M.S. thesis, in prep.) suggests that albite is rare in most of the Knik River terrane and that plagioclase is

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[1]abbreviations---hb = hornblende, olig = oligoclase, op = opaques, ep = epidote, chl = chlorite, qtz = quartz, bi = biotite, gn = garnet, mu = muscovite, and = andesine.

typically oligoclase or andesine, even in mafic rocks. Thus, although critical assemblages defining the amphibolite facies (for example, pelitic assemblages containing staurolite or cordierite) are not present (presumably because of bulk composition) the bulk of the Knik River terrane was probably metamorphosed at lower amphibolite facies conditions.

Retrograde metamorphism along faults: Superimposed upon the regional metamorphic rocks and the Jurassic plutonic complex are low-grade metamorphic assemblages that were apparently produced by hydrothermal circulation along faults. The major effects of this event (or events) are largely limited to the core of fault zones where alteration and cataclasis generally combine to obliterate evidence of original lithology (unit cg). These intense alteration zones, however, are generally surrounded by a broad halo of veining and associated growth of low-grade minerals. The hydrothermal circulation was clearly synchronous with movement on the fault zones as veins show mutual cross-cutting relationships with slickensided surfaces. Mineral assemblages characterizing the alteration are chlorite + epidote ± quartz, prehnite ± quartz, and serpentine (in ultramafic rocks). Because these assemblages are retrograde minerals produced in a chemically open system they are of marginal use in characterizing temperature conditions during faulting. Nonetheless, the presence of prehnite implies that temperatures were relatively low (less than 400°C) and the fluids were low in CO_2 (H. Winkler, 1979).

Contact metamorphism: Aside from alteration along the youngest faults (see descriptions below), the youngest metamorphic event is a highly localized contact metamorphism adjacent to Cretaceous plutons. In most of the Knik River terrane the magnitude of this event is obscure because the plutons invade rocks which were previously metamorphosed at moderate temperatures. Locally, however, the plutons cut low-grade rocks; for example, the pluton in upper Jim Creek cuts greenschists and a post-metamorphic fault, and in upper Carpenter Creek a pluton cuts rocks of the Chugach terrane. In these areas obvious contact metamorphic effects were limited to narrow halos from 5 to 50 m in width. This observation, together with the ubiquitous hydrothermal alteration of the Cretaceous plutons implies that the plutons were cooled largely by convective fluids.

ROCKS OF UNCERTAIN AFFINITY

Along Jim Creek, structural complexities of Tertiary faulting (discussed below) combined with the relatively low metamorphic grade of rocks in the adjacent Knik River terrane leads to local confusion on the position of the Knik River - Chugach terrane boundary. That is, distinguishing greenschist, meta-cherts, and meta-argillites of the Knik River terrane from greenstones, graywackes, chert, and argillite of the McHugh Complex is nearly impossible from field observations alone. Because of this problem two units of uncertain affinity (JKmx and JKca) were mapped along the terrane boundary.

Foliated chert and argillite (KJca)

Much of the area in the headwaters of Jim Creek is underlain by a slab of foliated meta-cherts and argillite. The slab is bounded on the north by a nearly vertical fault and on the south by a steeply north-dipping fault. The rocks have a well developed metamorphic foliation, show tight isoclinal folds, and weather to a reddish-brown color. The argillaceous rocks also contain biotite and phengite suggesting regional metamorphism at greenschist facies. These characteristics are similar to the meta-chert and argillite of the Knik River terrane (unit ca). The rocks in upper Jim Creek (unit KJca), however, do not appear to contain marble---a common lithology north of Jim Creek (unit ca). In addition, the metamorphic foliation in the KJca unit appears to vary in intensity, a feature more typical of foliated meta-sedimentary rocks of the McHugh Complex.

Mixed rocks of uncertain association (KJmx)

Along the northern slopes of Jim Creek is a sequence of rocks which show a structural style typical of much of the McHugh Complex but which is composed of diverse lithologies, some of which are more typical of the Knik River terrane. Lithologically this mixed unit is variable but is characterized by greenstone with some graywacke. Dark unfoliated to weakly foliated argillite, with or without gray chert, is generally present but is not sufficiently abundant to be considered a matrix for greenstone 'blocks.' These lithologies, together with local occurrences of both red mudstone and graywacke with argillite clasts, are typical of the McHugh Complex; yet, foliated greenschists, carbonates, and red-weathering cherts---common lithologies of the Knik River terrane---are present within the unit. Thus, the unit is best described as a unit of mixed structural/lithologic association.

CHUGACH TERRANE
DIVISION INTO SUB-TERRANES

Rocks belonging to the Chugach terrane are exposed throughout the southeast 1/3 of the quadrangle. In the C-5 Quadrangle the Chugach terrane is readily divided into two subterranes: a) an older (Early Cretaceous or older) chaotic unit adjacent to the Knik River terrane---the McHugh Complex of Clark (1973); and b) a younger (Campanion-Maastrichtian), deformed flysch sequence---the Valdez Group (Pavlis, 1982b; Tysdal and Plafker, 1978).

Regionally, the Valdez Group and McHugh Complex are not always easily distinguished (Plafker and others, 1977) but in the C-5 Quadrangle the two subterranes are easily distinguished on the basis of three major characteristics:

1) Metamorphosed graywackes and argillites of the Valdez Group are foliated whereas similar lithologies in the McHugh Complex are generally unfoliated and show mesoscopic structural disruption by faults.

2) In the C-5 Quadrangle the Valdez Group is devoid of greenstones and chert is extremely rare. The McHugh Complex, in contrast, contains abundant chert and greenstone.

3) The Valdez Group is foliated producing a rock that is easily shattered by frost action, thus talus slopes cover much of the exposure. The McHugh Complex, however, is extremely resistant and forms craggy slopes that are too steep to retain talus cover.

MELANGE SUB-TERRANE OF CHUGACH TERRANE

Overall Lithology and General Features of the McHugh Complex

In the C-5 Quadrangle rocks of the McHugh Complex are exposed along the high ridge north of Friday Creek and along the south bank of the north fork of Friday Creek. Graywacke and greenstone probably constitutes 75 percent or more of McHugh Complex exposures. The remainder of the McHugh Complex is composed of dark argillite with lesser amounts of chert, limestone, and exotic blocks of metamorphic rock.

Graywacke probably represents the most abundant lithology in the McHugh Complex. A typical graywacke in the complex is a fine to medium grained, poorly sorted sandstone which shows no obvious bedding in outcrop. In thin section quartz and plagioclase appear to be the main clasts but original lithic fragments have now been largely obscured by deformation and metamorphism. Coarse grained clastic rocks ranging from pebbly sandstone to cobble conglomerate have also been recognized locally. In these conglomerates argillite rip-ups are the dominant clast with lesser amounts of hornblende diorite, metachert, and metavolcanic rock. These conglomerates are significant because: 1) they clearly indicate that many, if not all, of the McHugh graywackes were deposited on, or below, a steep slope along which submarine debris flows picked up the argillite clasts; and 2) rocks now exposed north of the Border Ranges fault must have been exposed along, or close to, the slope since cobbles of hornblende diorite are now incorporated into the conglomerates.

Greenstones are nearly equal in abundance to the graywackes and occur as both massive units and green, fine-grained, clastic material interspersed with dark argillite. The latter are almost certainly pyroclastic sediments interspersed with the argillites. The latter are almost certainly pyroclastic sediments interspersed with the argillited. The former are massive, fine grained, green or blue-green rocks which generally show neither primary igneous textures nor a pronounced deformational fabric. In thin section, however, most show textures suggestive of a fine grained volcanic protolith and at a few localities pillow structures and pillow breccias were observed. Thus, the massive greenstones are presumably a sequence of basaltic(?) volcanic flows and (or) hyperabyssal intrusives, and were presumably erupted underwater.

Dark gray to black, quartz rich argillite also represents a major constituent of the McHugh Complex but it is less abundant than both graywacke and greenstone. Argillite occurs throughout the McHugh Complex but is generally not abundant, occurring as thin bands and lenses within sheared rocks. Argillite is the major lithology of one unit (Kam), however, where along with tuffaceous metasedimentary rocks it forms a "melange matrix" for a lithologically diverse unit. The argillite in the melange unit is unusual in that it generally lacks a foliation suggesting that much of the deformation observed in that unit (Kam) occurred under soft sediment conditions. The argillite is also unusual in that metamorphism ahs welded the rock into a massive, siliceous unit that forms some of the steepest slopes in the quadrangle.

The McHugh Complex also contains a few scattered occurrences of exotic lithologies. In the Jim Creek area, for example, red pelagic or hemipelagic mudstones occur within the unit JKmx in lower Jim Creek and on the north bank of Friday Creek. These occurrences along with both ubiquitous chert and argillite as well as occasional "exotic" blocks of pelagic(?) limestone are important because they support a pelagic or hemipelagic depositional environment for much of the McHugh Complex (Connelly, 1978). In addition to these pelagic or hemi-pelagic associations, exotic blocks of amphibolite, greenschist, and metasedimentary rocks orruc in the chert and argillite sequence of upper Carpenter Creek (unit Kam). Individual exotic blocks vary in size from a few 10's of meters in strike length to mappable masses surrounded by argillite (e.g. unit JKgs in upper Carpenter Creek). These exotic blocks presumably were derived from the Knik River terrane as the exotic blocks are broken internally with the intense post-metamorphic shearing and polishing concentrated along older metamorphic foliation surfaces.

The McHugh Complex is characterized by its structural complexity. In particular, original stratigraphic continuity is obscure because of structural disruption and (or) primary deposition as chaotic rocks (for example, olistostromes). The unit as a whole can therefore be considered a melange, and(or) broken formation (termination of Hsü, 1968). Thus, as in other melange complexes worldwide, the rocks are locally sufficiently complex that mapping at 1:1000 would not illustrate the complexity whereas elsewhere broad areas of relatively intact, lithologically monotonous rocks are readily shown at scales of 1:63,360 or smaller. Although the McHugh Complex is lithologically heterogeneous, most of the constituent lithologies are indistinguishable from a distance; for example, distinguishing meta-volcanic rocks (greenstones) from volcanogenic graywacke generally requires the use of a hand lens.

Map Units

Broken formations and melanges with chaotic fault networks (units Kw, Kwg, Kmj): Broken formations and melanges in which stratal continuity appears to have been disrupted largely by complex fault systems are the most abundant structural units of the McHugh Complex. These rocks are characterized by: a) ubiquitous faults which show no pronounced preferred orientation; b) scarcity of argillite and absence of an argillite 'matrix'; and c) structural disruption at a sub-macroscopic scale---that is, many individual outcrops appear to be intact rock but over distances of about 50-100 m the coherent rock bodies form a jumble with neither a consistent orientation nor predictable lithologic association. Following Hsü (1968) these three characteristics suggest that the term block on block melange or broken formation is appropriate for these units depending on if the unit is composed of several unlike lithologies or one lithology respectively.

Rocks with this block on block structural style were divided on the basis of lithology and structural position into three map units: a) undivided broken formations of Jim Creek (unit Kmj)---a unit which could be divided at a larger map scale; b) a graywacke/conglomerate broken formation (unit Kw); and c) graywacke - greenstone melange (unit Kwg).

Argillite matrix melange (unit Kam): In the eastern 1/3 of the C-5 Quadrangle a broad belt of structurally complex, argillaceous rocks lies adjacent to the Knik River terrane. Dark, massive argillite makes up the bulk of the unit and appears to form a 'melange matrix' for small phacoids and stringers of chert as well as large blocks (up to several hundred meters in strike length) of sheared foliated amphibolite and greenstone. One of these blocks is a mappable body of greenschist (unit KJgs) and is described separately. The argillites are generally dark gray to black rocks but locally contain abundant inclusions of green tuffaceous material. The argillites generally lack an obvious structural fabric despite the fact that the unit shows evidence of extreme structural complexity including: dismembered stringers and phacoids of chert, polishing and slickensiding of older ductile fabrics in amphibolite blocks, and intense shearing of greenstone blocks.

Phyllite and semi-schist (Ks): Penetratively deformed rocks occur only at sporatic localities within the McHugh Complex; usually as discrete, narrow shear zones within more massive units. Along the north fork of Friday Creek, however, penetratively deformed rocks occur as two mappable bands separating structural units of the McHugh Complex. These foliated units, unit Ks, are characterized by dark gray or green, fine grained, foliated phyllite and(or) semischist. The foliation is generally in part domainal with small (< 1 cm in length) lensoidal porphyroclasts surrounded by a foliated matrix. In most rocks it is unclear if this texture is inherited from the metamorphic protolith (that is, pebbly mudstone as a protolith) or if it is due to intense ductile deformation (that is, porphyroclasts in a blastomylonite). The rocks are clearly highly deformed, however, and mappable as distinct bands, characteristics not easily explained by a simple pebbly mudstone protolith. Hence, the rocks probably represent intensely deformed zones within the McHugh Complex.

Lensoidal rocks (unit Kl): Foliated rocks (unit Ks) just south of the north fork of Friday Creek transition downward to a structural unit with a distinct mesoscopic lensoidal fabric (unit Kl). Lithologically this unit is similar to the wacke-greenstone melange unit (Kwg). However, the unit (Kl) is structurally distinct in that closely spaced anastomosing fault networks divide the unit into 10 cm to 10 m long phacoids of diverse lithology and produce a mesoscopically foliated rock.

Greenschist of upper Carpenter Creek (unit KJgs): A large fault bounded slab of greenschist facies rock is exposed along the Carpenter Creek - Friday Creek divide. These rocks are similar to the adjacent argillite matrix melange in that disrupted cherts and non-foliated greenstones occur as blocks in a matrix. The matrix in the greenschist, however, is not dark unfoliated argillite but is moderately foliated chlorite-muscovite semischist. In addition, the greenschist is at higher metamorphic grade (greenschist facies) than the adjacent prehnite-pumpellyite facies rocks. These greenschists are probably higher grade equivalents of the adjacent argillite matrix melange, but the rocks could also be a low grade slice of the Knik River terrane.

Metamorphism

Although metamorphic grade is variable in the McHugh Complex, the bulk of the subterrane appears to have been metamorphosed at sub-greenschist facies conditions. Prehnite and pumpellyite are recognizable throughout the complex. Prehnite occurs commonly in meta-graywackes and argillites but is rare in metabasites. Pumpellyite is never abundant but occurs rarely in meta-graywackes and in some meta-basites. Some meta-basites, however, contain light green to blue-green actinolite suggesting metamorphism in the greenschist facies or high temperature sub-facies of the prehnite-pumpellyite facies (Turner, 1981).

FLYSCH SUBTERRANE: VALDEZ GROUP

Map Units

Black phyllites (Kbp): In the C-5 Quadrangle the structural top of the Valdez Group is occupied by a broad outcrop band (3-5 km wide) of highly deformed dark phyllites. Lithologically this unit is characterized by a muddy protolith in that meta-graywacke generally makes up less than 30 percent of the unit and those graywackes which are present are generally very fine grained and silty. In addition, the unit locally contains quartz rich layers that presumably are metachert layers. The argillaceous rocks in this unit are characterized by a dark gray to black color and a pronounced deformational fabric. The character of the deformational fabric varies along strikes from a slaty cleavage in lower Friday Creek to a phyllitic cleavage at the eastern edge of the quadrangle. The cleavage generally parallels bedding except at fold hinges. Bedding parallel cleavage is also present in graywackes but is often poorly developed. Most of the black phyllite unit is relatively coherent with bedding traceable throughout the outcrop. Locally, however, bands of mesoscopically disrupted rocks can be traced laterally in the unit. In these disrupted zones the rocks have a pronounced lensoidal appearance with small (5-20 cm in length) lenses of fine grained graywacke surrounded by dark phyllite. Clearly these rocks could originate by deformation of a diamictite protolith. Many of the lenses, however, are hook shaped and appear to be isolated fold hinges, thus a disruption by folding and transposition of layering is probably the origin of the lensoidal rocks.

Conglomerate graywacke (Kcg): Two bands of massive conglomeratic graywackes mark the transition from structurally higher muddy rocks (Kbp) and structurally lower, more sandy lithologies (Kfg). The conglomeratic graywackes are lithologically distinct as massive units of foliated coarse grained meta-graywacke in which large dark argillite chips are interspersed. The argillite chips presumably represent argillite rip-up clasts picked up by turbidity currents. The rocks are now strongly flattened, however, and the argillite chips occur as thin, wafers along the foliation plane.

Flaggy graywacke and argillite (Kfg): At the structurally lowest levels of the C-5 Quadrangle, the muddy black phyllite units give way to a unit of interbedded sandstones and shales in which the sandstone to shale ratio is at least 1:1. The scale of the vertical lithologic layering varies from thin (<-1 cm) laminations to large scale interbedding (> 100 m) of predominantly sandstone and predominantly shaly units. Because of this variability detailed study of this unit could undoubtedly separate a number of finer scale units.

Argillites within the unit are indistinguishable from the dark phyllites of the overlying structural units. The graywackes are clearly metamorphosed clastic rocks and locally are coarse grained and conglomeratic. The graywackes are distinctive, however, in that they contain an intense, layer parallel cleavage producing a flaggy rock which weathers to produce platy talus slopes. The cleavage in these flaggy graywackes is largely a domainal rough cleavage and presumably was produced by pressure solution.

STRUCTURAL GEOLOGY

The geologic structure of the C-5 Quadrangle is complex and many details of structural relationships may never be fully understood because of superposition of structures. Age constraints and limitations are considered in detail in the discussion of geologic history. In this section terrane boundary structure and the internal structure of individual terranes are described and apparent relative chronologies are considered. The descriptions progress from rocks at the structurally highest level (Peninsular terrane) to structurally lowest (Valdez Group subterrane of Chugach terrane).

PENINSULAR TERRANE

Aside from its faulted southern margin (northern Chugach fault zone), the Peninsular terrane is relatively intact. The character, and possibly the age, of major structural features change, however, from basement to cover rocks.

The extent of middle Mesozoic deformation in the cover rocks cannot be resolved in the C-5 Quadrangle because the only pre-Late Cretaceous rocks exposed are volcanic rocks of the Talkeetna Formation. Deformation of Late Cretaceous and Early Tertiary rocks, however, document significant Tertiary deformation. The major Tertiary structures of the Matanuska Valley are east-northeast striking, high-angle faults and a series of upright open to moderately tight, folds with east-northeast trending axes (Barnes, 1962). The fold axes parallel the trend of the Matanuska Valley and two major high angle fault systems: the Castle Mountain fault and an unnamed fault exposed along the lower Matanuska River (Barnes, 1962). The former lies a few km north of the C-5 Quadrangle but the latter is exposed within the quadrangle along the south side of the Matanuska River. The folding occurred in latest Eocene or early Oligocene time (Barnes and Payne, 1956). The age of the east-northeast trending high-angle faults is more poorly constrained. It would appear from regional evidence, however, that they have a long history of movement, including some Neogene displacement and local Quaternary slip (Barnes, 1962; Detterman and others, 1976; Bruhn, 1979; Bruhn and Pavlis, 1981). The Neogene history of the Matanuska Valley is complex but appears to have been dominated by north-northwest shortening along a conjugate set of northeast and northwest striking transcurrent faults as well as dip slip along the east-northeast trending high angle faults (Bruhn and Pavlis, 1981).

The Chickaloon Formation unconformably overlies the Talkeetna Formation in the northeast corner of the quadrangle, but west of Carpenter Creek the contact is almost certainly a high angle fault following the Chugach Mountain front. A fault is suggested because a simple north-dipping section of Chickaloon Formation along the mountain front cannot be accommodated in cross section and still be consistent with mapped bedding attitudes and rock distributions (see sections AA' and BB', pl. 1).

Immediately south of the Chugach Mountains the Jurassic igneous rocks appear to be relatively intact in that no major fault zones have been recognized and observable brittle deformation is limited to scattered slickensided surfaces with insignificant offsets. This belt of intact rocks extends for about 3 km south of the mountain front and appears to have been tilted northward as a large block. Evidence for this conclusion includes: a consistent moderate to steep, north dip of bedded rocks (Talkeetna and Chickaloon Formations) along the mountain front; and the north to south progressive increase in the grain size of plutonic rocks within the belt. The latter observation is particularly significant in that it suggests deeper structural levels to the south and is consistent with the regional tilting of a plutonic complex (unit Jpt) and its coeval volcanic cover (Talkeetna Formation).

KNIK RIVER TERRANE

Faulting

General characteristics, age relationships, and terminology: Along and south of the northern Chugach fault zone, the Knik River terrane and the southern edge of the Peninsular terrane are pervaded by high angle northeast striking faults of the Border Ranges fault system. The faults vary in scale from discrete faults with displacement of a few centimeters to major, mappable structures that separate disparate rock types and presumably have large displacements. Many of the mappable faults show narrow zones of cataclasis (<50m wide) and appear as discrete faults at a scale of 1:63,360. Elsewhere, however, broad fault zones up to 1 km wide are mappable as bands of altered cataclastic rock (units cg and sm).

Most of the broad zones of alteration and cataclasis are concentrated along the Knik River - Peninsular terrane boundary where a braided network of cataclastic zones form a 3-4 km wide band of faulting. Included in this group of faults are: a) the northern Chugach fault zone; b) a fault extending from the western edge of the quadrangle (SW¼ sec. 35, T. 18 N., R. 3 E.) to just east of Wolverine Creek where it probably joins the northern Chugach fault zone; and c) a broad fault zone within Peninsular terrane rocks (traceable from NE¼ sec. 2, T. 18 N., R. 4 E. to NW¼ sec. 31, T. 19 N., R. 5 E.) which branches from the northern Chugach fault zone. These faults all appear to be characterized by moderate (40-70°) northwest dips and presumably represent a transitional structural contact. The age of faulting and sense(s) of motion, however, is poorly constrained by the field relationships.

South of the northern Chugach fault system, the Knik River terrane is affected by at least two separate episodes of faulting. Many of the mappable faults within the Knik River terrane strike northeast (030-070) and dip to the northwest at a moderate angle (45-70°). At three localities (pl. 1) northwest dipping faults are cut by trondhjemitic plutons (Kt), and in upper Carpenter Creek a trondhjemitic pluton appears to cross-cut a northwest dipping fault between crystalline rocks and the McHugh Complex (shown by Pavlis, 1983 as the Border Range fault). Hence, at least some of the faulting along the Border Ranges fault system---presumably the northwest dipping faults---are older than the trondhjemitic plutons. In contrast, other faults within the Knik River terrane cut the trondhjemitic plutons. Where age relationships are recognized, however, these younger faults are characterized by east-north easterly strikes (060 to 090) and near vertical dips (70-90 north or south). In addition, all of the recognizable younger faults are marked by relatively narrow fault zones (a few meters wide) whereas northwest dipping faults (presumably belonging to the 'older' generation) are often broad (nearly 1 km wide) shear zones.

In contrast to rocks near the northern Chugach fault zone, most of the northwest dipping faults in the southern half of the Knik River terrane appear to be marked by relatively narrow (less than about 50 m wide) cataclastic zones. This southern belt of less intense cataclasis is bounded to the north, however, by a broad fault zone traceable across cross-cutting plutons from upper Jim Creek to just north of the Wolverine ultramafic complex. At this point (NW sec. 19, T. 18 N., R. 5 E.) the fault zone merges with a northwest dipping cataclastic zone that branches from the northern Chugach fault system and to the northeast the zones splay into a complex anastomosing fault system (for example, faulting in sec. 3, 4, and 9, T. 18 N., R. 5 E.). This complex fault system corresponds to the 'southern disrupted zone' described by Pavlis (1982b). This fault system probably includes faults of both the older and younger generation but is important in that is separates two distinct lithologic belts: a 'plutonic subterrane' on the north and a southern 'metamorphic subterrane' (fig. 1). The former is characterized by both abundant, intermediate to mafic plutonic rocks and earliest Jurassic (190-195 Ma) hornblende K-Ar ages. In the latter, however, hornblende K-Ar ages range from latest Jurassic to middle Cretaceous (135-107 Ma); the only plutonic rocks appear to be trondhjemitic (Kt and probable related rocks - JKd); and a wide range of metamorphic rocks, including alpine ultramafics, characterize the belt. These relationships suggest that the metamorphic subterrane could be distinct from the remainder of the Knik River terrane and the subterrane boundary could represent a major structural contact (i.e. the "real" Peninsular-Chugach Terrane boundary).

Younger Faulting: Younger (post-Jurassic) rocks are minor or absent in the plutonic subterrane (fig. 1); thus, the extent of younger faulting throughout the C-5 quadrangle is uncertain. In the southern half of the Knik River terrane, however, and extending into the Chugach terrane, a system of younger, high angle faults can be recognized (fig. 2 and pl. 1) including: a) a near vertical, northeast striking fault traceable across the quadrangle from the lower Jim creek through upper Carpenter Creek; b) two nearly parallel, approximately east-west striking faults in upper Jim Creek; and c) a northeast striking fault traceable from near the Knik River, along the north canyon wall of Friday Creek, and presumably extending across the quadrangle along the north fork of Friday Creek. The east-west striking faults of upper Jim Creek locally form the Knik River - Chugach terrane boundary. Similarly, the fault in upper Friday Creek offsets the McHugh - Valdez contact and therefore is technically the Eagle River fault despite the obvious polygenetic relationship. The absolute age of the younger faults is not well constrained but if one assumes they are all of the same age they are certainly younger than the trondhjemitic plutons and are presumably younger than the Eagle River fault (a latest Cretaceous or Paleocene structure according to Plafker and others, 1977). A minimum age indicator for the high angle faults is not present and it is possible that the faults have Neogene displacements.

Sense of motion: The sense of motion on all of the faults in the Knik River and Peninsular terranes is poorly constrained. Major amounts of thrust displacement apparently occurred along the Border Ranges fault system when the McHugh Complex was emplaced beneath the Peninsular terrane (MacKevett and Plafker, 1974) but the question of what structures were produced during that event cannot be answered unequivocally. Nonetheless, many of the faults in the plutonic subterrane, the northern Chugach fault zone, the Knik River - Chugach terrane boundary in upper Carpenter Creek, and many of the smaller faults in the Knik River terrane form an anastomosing set of northwest-dipping fault zones; some of which are clearly older than mid-Early Cretaceous. This relationship, together with regional observations, led the author (Pavlis, 1982b) to conclude that much of the northwest dipping faults were related to underthrusting along the Border Ranges fault and the work reported on here is consistent with that conclusion. Nonetheless, as discussed below, the Mesozoic system could be more complex.

The sense of motion on younger faults is also uncertain but their near vertical dip implies strike-slip faulting. This implication is supported by an apparent 6 km, right lateral offset of the Eagle River fault across the high angle fault in lower Friday Creek. This apparent offset could occur by dip-slip (south side downthrown), right lateral strike-slip, or a complex net slip. The vertical faults in the Jim Creek area, however, are characterized by east-northeast striking (070-075) throughgoing structures connected by east-west striking faults (fig. 2). The 15° angle of intersection is that predicted by Tchalenko (1970) for an east-northeast striking master fault and secondary east-west striking riedel shears along a right-lateral, strike slip fault system. In addition, the narrow outcrop width of the McHugh Complex is difficult to reconcile by dip-slip faulting with the south side downthrown because this sense of displacement should broaden the outcrop width of the McHugh Complex, not narrow it. Obviously, these relationships are not unequivocal but they suggest the younger faults originated as a right lateral strike-slip system; although subsequent dip-slip displacement (either south or north side downthrown) cannot be ruled out.

Pre-faulting structures

Reconstruction of the structural chronology prior to the disruption of the Knik River terrane is difficult because the original relationship between individual fault bounded slabs cannot be clearly resolved. The rocks could, for example, be of diverse origins from widely scattered localities and have been juxtaposed by faulting, or they could be rocks which have long been in close proximity and have been simply shuffled during the faulting. Pavlis (1982a, 1983) discussed this problem in detail and concluded that the latter is most in line with the available data. The new mapping provides some new insight into this problem but the precise age relationships and original association of the various slabs of the Knik River terrane still remain open to debate.

Metamorphic rocks of the Knik River terrane carry a variety of structural styles which appear to be dependent on lithology and structural position. Based on a qualitative judgement of the observed character of the structural fabric, the metamorphic rocks of the Knik River terrane can be divided into four major structural domains (fig. 3):

Domain I: Domain I includes the bulk of the foliated metamorphic rocks in the Knik River terrane and includes rocks metamorphosed from greenschist to amphibolite facies. Domain I is characterized by rocks with a moderate to strong metamorphic foliation (S_1) that is relatively planar on a mesoscopic scale (fig. 4). On a macroscopic scale, rocks of Domain I generally show a very open folding or heterogeneity of S_1 (fig. 4) but the foliation is relatively consistent in orientation over large areas (pl. 1). The mesoscopic foliation is defined by weak to moderate preferred orientation of micas and amphibole, lithologic layering, and in some meta-sedimentary rocks by trails of opaque minerals. Some rocks also show a nearly down-dip lineation (fig. 4) defined by elongate amphiboles, dimensional preferred orientation of grains, or both. Where lithologic layering is a prominent feature of the foliation it can generally be shown to be the product of isoclinal folding and resulting transposition of original bedding (?) into the foliation plane. Mesoscopic isoclinal folds (fig. 5) were observed in quartz rich mica schists (units JPq, JPqs, and JPca) and probably represent tight folding of original bedding in chert and argillite. Mesoscopic folds were not recognized, however, in either mafic schists (JPa and JPg) or quartzofeldspathic schist (JPbs), presumably due to poor layering in the protolith. The intensity of the foliation varies regionally but is most intense in the metasedimentary units and weakest in mafic rocks. In addition, the mafic rocks show considerable mesoscopic variability in the intensity of the structural fabric with strongly foliated bands a few meters thick interspersed with relatively massive greenstone-amphibolite. This mesoscopic variability in mafic rocks is not restricted to low grade rocks but occurs at all metamorphic grades.

Domain II: Rocks of Domain II occur only locally and in some cases grade into structural styles typical of Domain I. Domain II is characterized by rocks with a main phase tectonic fabric (S_1) that is indistinguishable from rocks in Domain I. Domain II rocks, however, show variable effects of an open to tight mesoscopic folding of S_1 structural fabrics. These second phase folds are generally approximately similar style folds (fig. 5) but the folds are not associated with an axial planar foliation.

Domain III: Domain III includes the map unit JPrm, a small area of quartz rich mica schists in upper Wolverine Creek, and part of unit g along the lower Jim Creek-Wolverine Creek divide. Rocks in Domain III are characterized by mesoscopic to macroscopic lensoidal structural fabrics. Most of the rocks are characterized by undeformed to mildly deformed blocks of meta-chert, meta-basalt, and meta-gabbro floating in a foliated matrix of dark phyllite (fig. 5). In the Jim Creek area, however, argillaceous rocks are subordinate and probably do not constitute a true matrix. The foliation in the phyllite matrix is generally domainal and is defined by bands of opaque minerals and flattened grains. This foliation is, in turn, overprinted by growth of post-kinematic micas and amphiboles (see Pavlis, 1983, fig. 8). These observations suggest that the foliation originated as a low grade slaty or phyllitic cleavage which was subsequently overprinted by post-kinematic growth of higher grade minerals.

Domain IV: Rocks of Domain IV include the two major ultramafic bodies of the Wolverine Complex and the body of layered gabbro exposed in lower Jim Creek. Aside from lithology, rocks of Domain IV are structurally distinct in that the bodies are not penetratively deformed. Indeed, penetrative deformation is limited to two forms: serpentine schists in narrow shear zones within the ultramafic bodies, and tectonite ultramafic rocks along the southeast margin of the largest ultramafic body. The latter are associated with isoclinal folding of chromite or pyroxene-rich bands and clearly were formed under high temperature conditions that pre-dated the upper greenschist facies metamorphism of the ultramafic complexes. The serpentine schists, in contrast, could be associated with syn-metamorphic shearing within the ultramafic masses. The exact relationship cannot be clearly established, however, because the metamorphic mineral growth within the shear zones is distinct from that in the undeformed portions of the ultramafic masses; that is, serpentine (antigorite?) in shear zones and chlorite + tremolite ± talc ± calcite in undeformed rocks. Serpentine is not incompatible with chlorite, tremolite, talc, and calcite particularly in a chemically open system (Winkler, 1979). Nonetheless, because serpentine is unstable in the amphibolite facies (Turner, 1981) the absence of serpentine in undeformed rocks could mean that the metamorphic peak was an amphibolite facies event that occurred prior to shearing at greenschist (or lower grade) conditions. Sheared serpentinites along the margins of the ultramafic masses further suggest this possibility. Nonetheless, field relationships neither confirm nor deny an age distinction between serpentine schists and metamorphic assemblages within the ultramafic complexes, and only very detailed studies of the shear zones will resolve the question.

CHUGACH TERRANE

McHugh Complex

The McHugh Complex as a whole is a structurally incoherent unit and is made up of diverse lithologies, hence the unit as a whole can be considered as a melange terrane (Plafker and others, 1977). Alternatively, since large areas are composed of a single lithology (for example, unit Kw), the McHugh Complex might better be termed a series of graywacke, greenstone, and argillaceous broken formations which are locally mixed to form melange sequences (after terminology of Hsü, 1968).

The disruption of the McHugh Complex varies in scale from the microscopic level to large scale mixing of lithologies, and probably originated from a complex history of superimposed processes. Nonetheless, the most obvious structures are complex fault networks and (or) veins suggesting that much of the strain was produced by brittle processes. With the exception of rocks in the 'lensoidal melange (unit Klm)' the faulting is seemingly chaotic with complex arrays of faults in apparently random arrangement. In addition to faulting, veining---locally intense---is an important manifestation of the brittle strain. The age of the veining relative to the faulting is not clear but some association seems likely. The veins themselves are mostly filled with quartz but some contain calcite. The veining occurs in two forms: a) as narrow, throughgoing veins that are clearly relatively young features; and b) variably spaced vein networks which commonly pervade the rock in a complex fashion. The veining occurs in all lithologies but appears to be most significant in meta-chert and argillite where closely spaced veins commonly cut small scale folds. Thus, the veining in cherts and argillites would appear to be relatively young in the deformational history. This relative chronology cannot be established in graywacke and greenstone, however, because mesoscopic folding is not obvious.

In addition to the pervasive brittle deformation, parts of the McHugh Complex also show evidence of ductile deformation. Ductile deformation is indicated by two distinct forms: a) occurrences of schistose rocks (unit Ks); and b) complex folding in cherts and argillites.

The schistose rocks (unit Ks) show extensive evidence of penetrative deformation including: fine grained quartz with seriate grain boundaries, marked preferred orientation of chlorite and (or) white mica, dimensional preferred orientation of some grains, and local occurrence of rocks with a blasto-mylonitic texture in which porphyroclasts float in a foliated, fine grained matrix. These foliated rocks are generally restricted to narrow bands, some of which are mappable (pl. 1). The continuity of the bands of foliated rocks within a complex which lacks a foliation implies that the schistose rocks probably represent ductile shear zones within the complex.

The syn-metamorphic deformation of foliated rocks (unit Ks and unmapped equivalents) is in marked contrast to the complex folding in argillaceous rocks (for example, much of unit Kam) where much of the deformation appears to be pre-metamorphic. In these rocks, bands of chert and (or) tuffaceous material are generally deformed into tight, disharmonic folds. Many of the folds are rootless and float in an argillite mass. The significant features of the folds, however, is that they typically are not associated with a distinct metamorphic fabric but rather float in a weakly foliated or unfoliated argillite matrix. This observation suggests that this disharmonic folding records a soft sediment deformation; either a deformation associated with sub-marine slumping, tectonic deformation of unlithified sediments, or both.

Valdez Group

The Valdez Group contrasts markedly with other rock sequences in the C-5 Quadrangle in that it shows little evidence of brittle deformation. Instead, the rocks are characterized by penetrative structural fabrics that record two major deformational events. The first phase (D_1) apparently led to an imbrication of the original stratigraphic succession and produced an intense, dominantly bedding-parallel cleavage. The second phase (D_2) led to open folding of D_1 structures and was associated with formation of one, and locally two, generations of crenulation cleavage.

Main phase (D_1) structures: The most obvious structural feature of the Valdez Group is a pronounced planar fabric (S_1) that generally parallels sedimentary bedding (S_0). This structural fabric (S_1) is generally penetrative to the microscopic scale and records the finite strain from the earliest recognized deformation of the Valdez Group. In argillaceous rocks S_1 varies from a slaty to phyllitic cleavage but secondary mineral growth is rarely visible in hand specimen. In some graywackes this cleavage is mesoscopically spaced (textural zone 2A of Bishop's [1972] classification) and often is formed at a moderate angle to bedding. In other areas (unit Kfg), however, the cleavage is penetrative to microscopic levels (T2B of Bishop, 1972) and parallels bedding. In the latter, examination of thin sections show that the cleavage is defined by dimensional preferred orientation of sand grains, secondary growth of very fine grained chlorite and (or) white mica, and anastomosing whisps of argillaceous material (presumably a product of pressure solution). On a macroscopic scale there is a crude geographic variation in cleavage development within the quadrangle. Specifically, in the western half of the quadrangle, argillaceous rocks are mostly slates and graywackes are T2A (Bishop, 1972, classification) whereas to the east phyllites and T2B metagraywackes are dominant. The significance of this observation is unclear but may indicate a slight increase in metamorphic grade to the east.

Although no attempt was made to quantify the finite strain, it seems clear that most of the rocks have experienced strains in the flattening field. This conclusion is evidenced by two observations: a) lineations (other than intersections) are only sporatically developed and where present, the lineation is usually weak; and b) in conglomeratic rocks deformed pebbles show no evidence of stretching---an observation exemplified by unit Kcg where argillite clasts are flattened into equant wafers along the foliation plane.

Mesoscopic folds associated with the main phase cleavage (S_1) were rarely observed. This observation could mean that the folds are extremely tight isoclines and simply were not recognized. That conclusion seems ad hoc, however, because exposure is generally excellent. Thus, it seems likely that mesoscopic folding is generally not a significant manifestation of D_1 in most of the rocks.

Despite the apparent scarcity of mesoscopic folds, the Valdez Group is locally characterized by mesoscopic stratal disruption (fig. 6) that appears to be the product of transposition by isoclinal folding. The stratally disrupted rocks, however, are limited to thin (10-30 m in structural thickness) bands which lie between rocks with intact bedding. Some of these bands could be interbeds of diamictite but most show evidence that stratal disruption occurred, at least in part, by tight folding and transposition of layering. This evidence includes: a) general lack of 'exotic' lithologies, and b) development of hook-shaped lenses (fig. 6)---a typical transposition structure.

The macroscopic D_1 structure of the Valdez Group is debatable, but in the C-5 Quadrangle it seems clear that the overall structure is characterized by a series of coherent packets bounded by shear zones in which strains are high and bedding is transposed into foliation (fig. 7). These shear zones are presumably thrusts. The principal evidence supporting this conclusion include the following. First, although the parallelism of cleavage (S_1) and bedding (S_0) implies isoclinal folding (Pavlis, 1982a), there is little evidence of regional overturning. Admittedly, in this area most younging indicators are ambiguous because of strain but where observed, they typically record upright bedding. Second, in two localities structures like those in figure 7 can be clearly outlined in the field. Third, this type of imbricate structure is developing today where thick sedimentary prisms enter a trench (for example, White, 1982 or Snavely and others, 1980) and thus the interpretation is actualistic.

This macroscopic structural interpretation is significant because a consideration of main phase cleavage (S_1) characteristics vs. structural position has an important implication to the structural history. Specifically, the character of S_1 does not change significantly through the zones of stratal disruption; that is, the fabric appears to be a flattening fabric because no obvious lineation is developed. This observation is surprising in light of the structural interpretation because the interpretation implies the disrupted zones should have a large component of simple shear---a plane strain system in which stretching is an important element of the finite strain. Although this observation could mean the macroscopic structural interpretation is in error, the simplest solution to the problem is to conclude that fabric development largely post-dated shearing. That is, stratal disruption occurred early during D_1 when soft-sediment conditions prevailed and subsequent shortening perpendicular to layering was largely responsible for the fabric development. The fabric development presumably occurred after the sediments were partially underthrust beneath trench a system.

<u>D_2 structures</u>: The main phase cleavage (S_1) of the Valdez Group is generally deformed into a series of open upright folds with northeast trending axes (fig. 8). These folds (F_2) record a second deformation of the Valdez Group, although the absolute age of this deformation is unconstrained in the C-5 Quadrangle. F_2 folds typically occur as open, symmetric folds with wavelengths of from about 1 to 10m. Larger scale folds are rare, except in the Jim Creek area (pl. 1) where several macroscopic F_2 folds can be inferred.

The F_2 folds are typically associated with an axial planar crenulation cleavage (S_2). This crenulation cleavage generally strikes northeast and dips steeply north or south. The cleavage is generally only developed in argillaceous rocks where it occurs as a series of closely spaced (.5-1 mm) wrinkles in the main phase cleavage. S_2 is best developed along the eastern edge of the quadrangle. S_2 apparently continues to increase eastward and transposes S_1 in the Anchorage C-3 Quadrangle (Burns and others, 1983).

Locally, a second crenulation cleavage (S_3?) cuts S_1 and is axial planar to isolated open folds. Like S_2, this cleavage is only well developed in argillaceous rocks. S_3(?) typically strikes north-south and is near vertical and locally occurs in rocks that are cut by S_2. Presumably this north-south striking cleavage post-dates S_2 because it is a weaker fabric. Nonetheless, clear cross-cutting relations have not been observed and they could be virtually synchronous or reversed in relative age.

GEOLOGIC HISTORY

AMBIGUITIES IN AVAILABLE AGE DATA

The northern Chugach Mountains have experienced a long and complex geologic history and many of the details are as yet obscure. The geologic history of the region is intimately tied to a series of major late Mesozoic tectonic events that profoundly affected the entire northern Cordillera. Thus, an understanding of the complex geology in the northern Chugach Mountains is important not only to the local geology but is also important from a regional perspective.

In the discussion below, a preliminary tectonic model is developed for the geologic history of the Anchorage C-5 Quadrangle. The model is constrained locally by cross-cutting relationships, stratigraphic ages, and absolute ages based on K-Ar geochronology reported elsewhere (Pavlis, 1983). Figure 9 is a summary of these local age constraints, together with regional fossil ages established by Clark (1972a, 1973); Tysdal and Plafker (1978); Karl and others (1979); Winkler and others (1981). These local relationships cannot totally constrain the geologic history, however, and any further constraints on the chronology must be gleaned from regional tectonic considerations. In the discussion below, three regional age relationships are used to develop a geologic history:

1. After the conclusions of numerous workers (for example, Jones and Silberling, 1979; Coney and others, 1980; Monger and others, 1982; Csejtey and others, 1982; and Pavlis, 1982b) it is assumed that much of the Early to middle Cretaceous history of southern Alaska and western British Columbia is related to the collision between an outer Cordilleran micro-continental block---Talkeetna super-terrane---and the North American Cordillera. This super-terrane is composed of the Peninsular, Wrangellia, and Alexander terranes as defined by Jones and Silberling (1979), and is now bounded on its inboard side by a complexly deformed suture zone and on it's outboard side by the Border Ranges fault.

2. Following a previous interpretation (Pavlis, 1982b) the Border Ranges thrust is presumed to be an Early Cretaceous structure which has been modified by Tertiary faulting, and the formation of the Border Ranges fault represents the formation (or re-establishment) of a northwest dipping (relative to present coordinates) subduction zone. The basis for this conclusion is not reviewed here but arises from a consideration of regional stratigraphy in the Peninsular terrane, regional fossil ages in the McHugh Complex, the Early Cretaceous age of cross-cutting plutons in the western Chugach Mountains, and the age of volcanism and plutonism in the Gravina-Nutzotin belt of southeast Alaska (Pavlis, 1982b).

3. The Talkeetna superterrane was welded to North America by Late Cretaceous (approx. 75Ma) time (Csejtey and others, 1982) and a latest Cretaceous Andean type arc was subsequently built on the collided block and the associated suture zone (Monger and Price, 1979). Thus, the Late Cretaceous and Tertiary history of the northern Cordillera is apparently related to the maturation of the Andean type arc and the subsequent conversion of the margin to the present complex combination of strike-slip and convergence.

PRE-MIDDLE JURASSIC HISTORY

The oldest geologic events in the C-5 Quadrangle are recorded by metamorphic rocks in the plutonic subterrane of the Knik River terrane (fig. 1). Similar rocks in the metamorphic subterrane could be correlatives but because cross-cutting diorite plutons are absent and K-Ar ages are Early Cretaceous (fig. 9), this correlation is equivocal. Indeed, as discussed below it is possible that the metamorphic subterrane was deformed and metamorphosed in the Cretaceous.

Just southwest of the Knik River, Clark (1972a) collected Permian fusilinids from carbonates associated with metacherts and greenstones. The rocks described by Clark (1972b) are indistinguishable from the metamorphic rocks (units g and ca) just north of Jim Creek. Furthermore, the two occurrences are directly along strike from one another, and both sequences form a similar structural sequence; that is, layered gabbro and ultramafic rock lying along the Border Ranges fault but structurally beneath the metavolcanic and metasedimentary sequence. These observations imply that many, if not all, of the metamorphic rocks are correlative with rocks described by Clark (1972a) and are therefore late Paleozoic in age.

The metamorphic rocks of the plutonic sub-terrane are characterized by the lithologic association of chert and argillite; pelagic(?) limestone; greenstone, locally pillowed; and layered mafic and ultramafic rock. The author noted previously (Pavlis, 1983) that this lithologic association is ophiolitic and that the protolith for these metamorphic rocks might therefore be oceanic crust and upper mantle along with a pelagic sedimentary cover (Pavlis, 1983). Recently, however, work by Burns (1983) suggests that the ultramafic masses are younger (Jurassic) than the adjacent metamorphic rocks and that the ophiolitic association is due to structural shuffling. Indeed, Burns (1983) presents compelling evidence that the ultramafic bodies represent the igneous roots of the Early Jurassic Peninsular Terrane arc.

Following their deposition but prior to the earliest Jurassic (about 190-195 Ma)---the hornblende K-Ar age of cross-cutting plutons (fig. 9)---metamorphic rocks of the plutonic subterrane (and possibly the metamorphic subterrane) were complexly deformed and regionally metamorphosed at greenschist to amphibolite facies. The details and tectonic setting for this deformational event are debateable. Based largely on the association of alpine ultramafic rocks, blueschists yielding earliest Jurassic (185-195 Ma) K-Ar ages (Carden and others, 1977), and the overall ophiolitic character of the metamorphic rocks; it was previously concluded (Pavlis, 1983) that the metamorphic rocks along the Border Ranges fault were originally deformed in a subduction zone and were subsequently metamorphosed during Early Jurassic plutonism. This conclusion was based largley on the following assumptions: 1) the 'red melange' (unit PPrm) has a structural style and lithologic association that was most easily reconciled by deformation at a subduction zone; and 2) the unit was presumed to be at least Early Jurassic in age because it's metamorphic history was indistinguishable from adjacent, clearly pre-190 Ma, metamorphic rocks. As noted above, however, the 'red melange' (unit JPrm) may be as young as Cretaceous; thus, its history may not be applicable to the pre-Jurassic history of the plutonic subterrane.

Despite ambiguities in the pre-Jurassic structural history, it is clear that by early Jurassic time voluminous gabbroic to tonalitic plutons (units JPgb, Jd, Jg, and Jt) invaded the plutonic sub-terrane of the Knik River terrane. The complexly deformed metamorphic rocks of the plutonic sub-terrane formed a basement terrane into which these plutons were emplaced. The country rock was thermally upgraded and injection migmatites, epidote free amphibolites, and wollastonite bearing skarns were locally developed along the plutonic margins. During this period gneissic banding developed along some plutonic margins and ductile deformational fabrics may have formed in some of the country rocks. This implies that either some deformation occurred during plutonism or that igneous flow along the plutonic margins created local deformation. Nonetheless, the plutons clearly post-date most, if not all, of the major deformation in their country rock. At the same time as plutons were invading the Knik River terrane a thick pile of volcanic rocks---the Talkeetna Formation---were laid down in the Peninsular terrane, and apparently co-eval plutons (units Jpt, Jpd, Jpg, and Jgd) were emplaced into this volcanic cover.

Lithologically and chronologically(?) the main plutonic series (hornblende gabbro to tonalite) of both the Peninsular and Knik River terranes are indistinguishable; hence, a correlation is implied. If this correlation were unequivocal, metamorphic rocks of the plutonic subterrane would represent a basement terrane onto which the Talkeetna Formation was deposited and into which intermediate plutons were emplaced. At present, however, there is no chemical or geochronological evidence to firmly establish this correlation nor has the critical contact between basement and cover (base of the Talkeetna Formation) been observed. Thus, because the boundary between the Knik River and Peninsular terranes is a major fault zone (northern Chugach fault zone), the correlation must be considered tentative. Nonetheless, the plutonic rocks are remarkably similar and in the absence of better age data it seems unnecessary to assume that the northern Chugach fault zone separates disparate rock systems. Thus, until more age data is available the plutonic subterrane is assumed to be a basement terrane onto which the cover sequence of the Peninsular terrane (Talkeetna Formation) was deposited and into which voluminous coeval plutons were emplaced.

MIDDLE JURASSIC TO EARLIEST CRETACEOUS

Following deposition of the Talkeetna Formation, possibly during deposition of the overlying Tuxedni Group (fig. 9), the volcanism characteristic of the Lower Jurassic ended throughout the Peninsular terrane (Kirshner and Lyon, 1973). Overlying sedimentary rocks show a relatively quiescent period from the Late Jurassic to the earliest Cretaceous (Connelly and Moore, 1980). By Late Jurassic time the Peninsular terrane had clearly amalgamated with Wrangellia and the Alexander terrane to form the Talkeetna superterrane but the superterrane was apparently not yet part of North America (Jones and Silberling, 1979).

During the Middle and early-Late Jurassic a magmatic arc (Tonsina-Chichagof belt) developed on Wrangellia and the Alexander terrane (Hudson, 1979). The significance and tectonic setting for this magmatic arc is poorly understood and it is possible that this event affected rocks in the C-5 Quadrangle. However, because the Peninsular terrane appears to have been quiescent throughout the Late Jurassic (Connelly and Moore, 1980), this period was probably one of quiescence in the C-5 Quadrangle.

EARLY CRETACEOUS

In the Early and middle Cretaceous a complex series of events occurred throughout the northern Cordillera as the Talkeetna superterrane collided with, and ultimately was accreted to, North America (Monger and others, 1982). The collision apparently led to the formation of a subduction zone along the trailing edge of the collided block, and the regional structure created by the underthrusting was the Border Ranges thrust (Pavlis, 1982b).

In the Anchorage C-5 Quadrangle the formation of the Border Ranges thrust was probably responsible for much of the structural complexity now observed. On the basis of the cross-cutting trondhjemitic plutons (unit Kt) it appears that two major structural features relate to this event. First, the intense deformation of unit Kam of the McHugh Complex is older than the trondhjemitic plutons and therefore at least part of the McHugh Complex was emplaced prior to 124 ± 8Ma (K-Ar age of the pluton reported in Pavlis, 1983). It should be noted that because of this relationship the initial period of underthrusting along the Border Ranges thrust is similarly constrained as pre-mid-Early Cretaceous (Pavlis, 1982b). Second, the northwest dipping faults of the Knik River terrane, as well as the broad zones of alteration and cataclasis which parallel them, were presumably formed during underthrusting. This genetic relationship is implied because the northwest dipping fault zones are roughly parallel to structural fabrics in the McHugh Complex and are sub-parallel to the structural contact between the Knik River and Chugach Terranes, a contact which appears to be cut by the trondhjemitic plutons. Because of the northwest dip of the northern Chugach fault zone it presumably was also formed during this event; yet this conclusion should be considered preliminary because critical cross-cutting relationships are not available (fig. 9).

These cross-cutting relationships have been described previously (Pavlis, 1982b) and lead to a relatively simple tectonic scenario. The Cretaceous deformational history apparently begins about 130Ma ago as Pacific Ocean floor began underthrusting beneath the juvenile convergent margin and as a result two successive events occurred in the C-5 quadrangle. The oldest of these events was the extensive faulting of the Peninsular and Knik River terranes. This event was apparently produced by the underthrusting along the Border Ranges thrust and as a result of this deformation the older plutonic rocks and their associated metamorphic country rocks were shattered along the extensive system of northwest dipping faults. Sometime during this event, oceanic pelagic-hemipelagic sediments, basalt, and graywackes were disrupted by underthrusting and ultimately were accreted beneath the Border Ranges thrust; an event now recorded by unit Kam of the McHugh Complex. Following this extensive faulting event, trondhjemitic plutons (unit Kt) were generated at depth and emplaced into both the Knik River terrane and unit Kam of the McHugh Complex. The plutons may have been emplaced at a late phase in the deformation, however, because they are slightly deformed and are locally emplaced into rocks that appear to be of nearly the same age; that is, the radiometric ages are indistinguishable from many regional fossil ages for the McHugh Complex. Therefore, deformation and emplacement of part of the McHugh Complex as well as the intrusion of plutons appear to have spanned a geologically short time interval (possibly less than 10Ma).

The emplacement of the McHugh Complex and associated faulting in the Knik River terrane may have been immediately preceded by, or possibly coeval with, a third structural event: the ductile deformation in the metamorphic subterrane of the Knik River terrane. This suggestion can be neither confirmed nor denied on the basis of the present data base, yet at least four observations suggest that it is a possibility:

1. The amphibole K-Ar ages of metamorphic rocks in the subterrane are Early Cretaceous (two ages reported in (Pavlis, 1983) are 107 ± 5Ma---impure separate---and 121 ± 8Ma). These ages are indistinguishable from the K-Ar ages of the trondhjemitic plutons (unit Kt) and thus, the ages could have been thermally reset (Pavlis, 1982b and 1983). Nonetheless, the ages are all from amphibole separates; a mineral not easily reset by thermal events (Jåger, 1978); hence, the ages could approximate the age of metamorphism.

2. In comparison to adjacent terranes, the metamorphic subterrane does not appear to be pervaded by intense faulting. Indeed, much of the faulting within the subterrane is younger than the trondhjemitic plutons and those older faults present are narrow, discrete fault zones; a relationship contrasting markedly with the ubiquitous broad cataclastic zones in the plutonic subterrane. One explanation for this observation is that the entire metamorphic subterrane is a large fault bounded body that remained relatively intact during intense faulting along its margins This hypothetical fault bounded body would be about 3 km thick and at least 20 km in strike length. Although these dimensions are not unreasonable, they are much larger than those of adjacent fault bounded bodies. This observation is particularly unusual because the rocks lie closest to the tectonic boundary with the McHugh Complex, the area where the most intense deformation might be anticipated. The alternative explanation that metamorphism and deformation are synchronous with early motion on the Border Ranges thrust does not suffer from this problem.

3. Overall, the metamorphic subterrane is characterized by a variation in structural style that appears to be related to structural level. Rocks lying immediately above the McHugh Complex are characterized by a single phase of intense deformation which led to isoclinal folding and commonly transposition of primary (?) layering. The rocks are generally LS tectonites with a nearly down-dip lineation developed on a foliation that parallels the lower structural contact. One to two kilometers above the structural base this zone of intense fabrics passes upward into more heterogeneous structure; that is, relatively undeformed ultramafic bodies, poly-deformed tectonites; and the chaotic rocks of unit JPrm. Although complex faulting could explain this observation (Pavlis, 1982b, 1983), the development of a relatively homogeneous zone of ductile deformation paralleling the Border Ranges fault is easily explained as a 1-2 km wide zone of simple shear.

4. Although the trondhjemitic plutons clearly post-date the major deformation of adjacent rocks their are some indications that they are slightly deformed. These indicators include: serate textures of some quartz grains; a faint foliation at some localities; and the wavy appearance, in

thin section, of some biotite grains. Clearly these textures could have been produced by flow during emplacement of the magma; yet intense diking along plutonic margins implies the magma was highly fluid and would be unlikely to produce significant primary flow textures. Furthermore, the serate textures in quartz are indicative of a solid-state flow (Hobbs and others, 1976).

5. Recent work by Burns (1983) suggests that the alpine ultramafic bodies represent basal cumulates of the Early-Middle Jurassic Peninsular terrane arc and are therefore Early or Middle Jurassic in age. The ultramafics, however, are metamorphosed along with the adjacent rocks of the Knik River terrane. Thus, if Burns (1983) conclusions are correct, the maximum age for metamorphism in the metamorphic subterrane is younger than the minimum age for metamorphism in the adjacent plutonic subterrane. The logical solution to that paradox is that the metamorphism in the metamorphic subterrane is actually Early Cretaceous.

Together these observations imply that Early Cretaceous ductile deformation may have occurred within the metamorphic subterrane. Without geochronologic evidence, however, this hypothesis is largely speculative. Thus, until Rb-Sr or U-Pb ages become available, the details of the early Cretaceous history---particularly with regard to ductile deformation in the metamorphic subterrane---will remain problematic. Nonetheless, future work should consider the possibility that some, if not all, of the ductile deformation and metamorphism in the metamorphic subterrane is the product of Early Cretaceous underthrusting along the Border Ranges fault system. Indeed, it is even possible that the generation of the trondhjemitic plutons is somehow tied to this hypothetical event.

LATE CRETACEOUS TO PALEOCENE

Following emplacement of the Early Cretaceous plutons the geologic record in the C-5 quadrangle is incomplete until latest Cretaceous or earliest Tertiary time. Regionally, the McHugh Complex has yielded a few fossils as young as Albian (Connelly, 1978; Plafker and others, 1977; Tysdal and Plafker, 1978; Winkler and others, 1981; Karl and others, 1979), thus it would seem that subduction and the accretion of structural units of the McHugh complex continued into the early Late Cretaceous. The Eagle River fault, however, represents a regional 'tectonic unconformity' in that it separates the Albian and pre-Albian rocks of the McHugh complex from rocks of the Valdez Group; a sequence which has yielded no fossils older than Campanian (Tysdal and Plafker, 1978). The origin of this 'tectonic unconformity' along the Eagle River fault is enigmatic and could record a middle Cretaceous trike slip period, a 'subduction erosion' event (terminology of Scholl and others, 1980), or a cessation of subduction. The early Late Cretaceous lower Matanuska Formation and its correlatives (Jones, 1967) are stratigraphically complex but would appear to be a forearc basin deposit (Connelly and Moore, 1980); a conclusion suggesting that subduction was continuous during the period. Nonetheless, the data are inconclusive and the problem needs further clarification.

By latest Cretaceous time, however, the convergence record resumes in the C-5 Quadrangle with the deposition, deformation, and emplacement of the Valdez Group. Simultaneously, rocks which are lithologically similar to the Valdez Group---the upper Matanuska Formation---were deposited in a forearc basin along the southern edge of the Talkeetna superterrane (Connelly and

Moore, 1980). These forearc basin deposits may be a proximal facies of the Valdez Group (Fisher and Magoon, 1978). The Valdez Group has generally been considered as a structurally stacked series of latest Cretaceous (Campanian - Maestrictian) trench fill turbidites (Moore, 1973; Plafker and others, 1977; Tysdal and Plafker, 1978; Nilsen and Moore, 1979; and Nilsen, 1982). Because the Valdez Group has yielded only latest Cretaceous fossils (Tysdal and Plafker, 1978) this interpretation further implies that the deposition, deformation, and emplacement of the Valdez Group spanned a short time interval; that is, the fossil ages are essentially the emplacement ages. This relationship is not unequivocal, however, because it is possible that the Chugach terrane represents a deep sea fan emplaced as a single tectonic unit (J. Decker, oral presentation, 1982). If the latter were true the emplacement age for the entire unit could be early Tertiary.

Despite this age question the Valdez Group was ultimately thrust beneath the McHugh complex and a series of complex structures were formed. In the C-5 Quadrangle it appears that this deformation was characterized by imbricate thrusting. The deformation apparently progressed from soft sediment thrusting during which narrow zones of high strain and stratal disruption developed along decollement, to later relatively homogeneous flattening strain imposed upon the entire structural stack. Following this main phase of deformation, the Valdez Group was subjected to a second deformation. This deformation created broad open folds with east-northeast trending axes, steep axial planes, and an associated axial planar crenulation cleavage. A third (?) deformation recorded by a sporatic north-south striking, nearly vertical, crenulation cleavage is also present but probably does not represent a significant event. Both the age and origin of the second and third deformation of the Valdez Group are unknown.

During the accretion of the Valdez Group it would appear that the older rocks (McHugh Complex, Knik River terrane, and Peninsular terrane) were not subjected to significant deformation because in the Matanuska Valley there was a nearly uninterrupted deposition of sediments from the Latest Cretaceous to the mid-Eocene (Kirshner and Lyon, 1973). These sedimentary rocks are generally thought to record the filling of a forearc basin that extended from at least the Alaska Peninsula to the Wrangell Mountains (Fisher and Magoon, 1978). However, mapping in the C-5 Quadrangle, together with the work by Pessel and others (1981) and Burns and others (1983) in the central Chugach Mountains raises some doubt about this simple interpretation. Specifically, south of King Mountain (pl. 1) and elsewhere along the Chugach Front (Burns and others, 1983) the Chickaloon(?) Formation uncomformably overlies the Talkeetna Formation. Indeed, all along the northern Chugach front no cover rocks younger than Talkeetna Formation have been found other than Tertiary fluvial deposits of the Chickaloon(?) Formation. However, in the Matanuska Valley a thick (up to 7 km thick) Jurassic and Cretaceous section separates the Talkeetna Formation from the Tertiary (Kirshner and Lyon, 1973). Thus, along the Chugach front a huge thickness of sediments was either never deposited or was removed by erosion. The exact age of this erosional event (or events) is highly uncertain from the available data and the need for detailed stratigraphic studies is clear. Nonetheless, it would appear that an important, but poorly understood, complication may have affected the region at the beginning of the Tertiary. Possible complications could include: a) a complication from strike-slip faulting along the Border Ranges fault during deposition of the Paleocene rocks; b) emergence of the region as a trench-slope break similar to the modern Sunda Arc (see Karig, 1974); and c) middle Tertiary shuffling---presumably by strike-slip faulting---of rocks with a different Mesozoic depositional history.

MIDDLE TERTIARY TO PRESENT

During the middle Tertiary a series of events occurred in the C-5 Quadrangle and adjacent regions, but because of the paucity of middle Tertiary rocks and the probable superposition of events, the exact connection between local events cannot be made with certainty. In the Matanuska Valley the Tertiary history is relatively well documented through cross-cutting relationships observed in Tertiary sedimentary rocks. The non-marine sedimentation that characterized the Paleocene continued into the early Eocene with the deposition of the Wishbone Formation (Barnes, 1962). In the late Eocene or early Oligocene these sedimentary rocks were faulted and deformed into upright folds with east-northeast trending axes (Barnes, 1962 and Kirshner and Lyon, 1973). The sense of displacement on faults during this period is unclear but significant strike slip displacement may have occurred on east-northeast striking high angle faults; for example, the Castle Mountain fault (Boss and others, 1976). This deformation was clearly complete by the end of Oligocene time because Late Oligocene rocks unconformably overlie the folded rocks (Barnes and Payne, 1956) and Tertiary plutons (unit[1] Ti) are apparently undeformed (Barnes, 1962). Following this folding event, Neogene deformation in the Matanuska Valley continued (or was reestablished) with north-south shortening accommodated by a conjugate set of strike-slip faults and high angle reverse motion along the Castle Mountain fault and other east-northeast striking high angle faults (Bruhn and Pavlis, 1981).

In the Chugach Mountains, Tertiary deformation has also occurred but aside from the Matanuska Valley, Tertiary rocks do not appear to be present in the C-5 Quadrangle. Thus, a detailed deformational history tied to the tectonic events in the Matanuska Valley cannot yet be made. Nonetheless, a number of observations provide some insight into Tertiary events.

In the C-5 Quadrangle, faults with documented young motion (post-unit Kt or post Eagle River fault) are east-northeast striking near vertical faults. In the Matanuska Valley faults of this orientation have documented middle Tertiary and Neogene offsets; hence, the faults within the Chugach Mountains may well be middle Tertiary in age and may have Neogene offsets. This conclusion is supported by Pessel and others (1981) and Burns and others (1983) observation that both the Chickaloon Formation and Tertiary felsic plutons are caught up along high angle fault systems in the central Chugach Mountains.

The sense of motion on the high angle fault systems cannot be unequivocally resolved. However, the riedel shear geometry of high angle faults in lower Friday Creek together with the apparent right lateral offset of the Eagle River fault in that area, suggest that the net-slip has been dominantly right-lateral strike slip. It is of note that the Tertiary high angle faults in the Chugach Mountains are nearly parallel to the Castle Mountain fault, a regional structure which has long been considered as a potential early Tertiary strike-slip fault (Boss and others, 1976). Thus, it is possible that the high angle fault of the Chugach Mountains together with the Castle Mountain fault form a system of right-lateral strike slip faults.

From the observations in the C-5 Quadrangle it appears likely that a significant middle Tertiary event, probably coeval with the folding in the Matanuska Valley, affected rocks throughout the northern Chugach Mountains. In the Chugach Mountains the principal effect of that deformation was the formation of a system of high angle faults which apparently represent a system right-lateral strike slip faults. The aggregate offset is unclear but the faults with known displacement do not appear to be major structures. Nonetheless, it is possible that some, or all, of the cataclasis along the northern Chugach fault could be of this age; that is, the faults are not constrained by cross-cutting plutons (fig. 9). Thus, if the cataclasis along these faults were Tertiary it is conceivable that large offsets, presumably strike-slip, have occurred.

During the Neogene, the high angle faults were probably reactivated as dip-slip faults, and much of the observed northward tilting along the Chugach front may have originated during the Neogene. From the Miocene to present, the Chugach Mountains have experienced relatively rapid uplift (Boss and others, 1976) and one of the regional consequences of that event was the development of a regional system of dip-slip faults paralleling the Kenai-Chugach Mountain front (Pavlis and Bruhn, 1983). In the C-5 Quadrangle, it is unclear exactly which faults, if any, moved during this period. Slickenside studies along the faulted southern margin of the largest ultramafic mass (pl. 1) suggest that the latest motion on that structure was dip-slip (Pavlis, 1982a). Thus, several of the younger structures could have Neogene motions.

REFERENCES CITED

Barnes, F.F., 1962, Geologic map of lower Matanuska Valley, Alaska: U.S. Geological Survey Miscellaneous Geological Inventory Map I-359, scale 1:63,360.

Barnes, F.F., and Payne, T.G., 1956, Wishbone Hill district, Matanuska Valley coal field: U.S. Geological Survey Bulletin 1016, 88 p.

Bishop, D.G., 1972, Progressive metamorphism from prehnite-pumpellyite to greenschist facies in the Dansey Pass area, Otago, New Zealand: Geological Society of America Bulletin, v. 83, p. 3177-3198.

Boss, R.F., Lennon, R.B., and Wilson, B.W., 1976, Middle ground shoal oil field, Alaska: in North American oil and gas fields: American Association of Petroleum Geologists Memoir 24, p. 1-22.

Bruhn, R.L., 1979, Holocene displacements measured by trenching the Castle Mountain fault near Houston, Alaska: in Short Notes on Alaskan Geology 1978, Alaska Division of Geological and Geophysical Surveys Special Report 61, p. 1-4.

Bruhn, R.L., and Pavlis, T.L., 1981, Late Cenozoic deformation in the Matanuska Valley, Alaska: Three dimensional strain in a forearc region: Geological Society of America Bulletin, pt. 1, v. 92, p. 282-293.

Burns, L.E., 1983, Border Ranges mafic and ultramafic complex: plutonic core of an intraoceanic arc: Ph.D. Dissertation, Stanford Univ., Palo Alto, California.

Burns, L.E., Little, T.A., Newberg, R.J., Decker, J.E., and Pessel, G.H., 1983, Preliminary geologic map of parts of the Anchorage C-2, C-3, D-2, and D-3 Quadrangles, Alaska: Alaska Division of Geological and Geophysical Surveys Report of Investigation 83-10, 3 sheets, 1:25,000.

Carden, J.R., Connelly, W., Forbes, R.B., and Turner, R.L., 1977, Blueschists of the Kodiak Islands, Alaska: An extension of the Seldovia schist terrane: Geology, v. 5, p. 529-535.
Carden, J.R. and Decker, J.E., 1977, Tectonic significance of the Knik River schist terrane, south-central Alaska: Alaska Division of Geological and Geophysical Surveys Geologic Report No. 55, p. 7-9.
Clark, S.H.B., 1972a, Reconnaissance bedrock geologic map of the Chugach Mountains near Anchorage, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-350, scale 1:250,000.
Clark, S.H.B., 1972b, The Wolverine Complex, a newly discovered layered ultramafic body in the western Chugach Mountains, Alaska: U.S. Geological Survey Open-File Report 522, 10 p.
Clark, S.H.B., 1973, The McHugh Complex of southern Alaska: U.S. Geological Survey Bulletin 1372-D, 11 p.
Clark, S.H.B., 1983, Reconnaissance geologic map of the Chugach Mountains in the Anchorage C-5 and C-6 Quadrangles, Alaska: U.S. Geological Survey Open-File Report OF83-0336, scale 1:63,360.
Coney, P., Jones, D.L., and Monger, J.W.H., 1980, Cordilleran suspect terranes: Nature, v. 288, p. 329-333.
Connelly, W., 1978, Uyak Complex, Kodiak Island, Alaska: A Cretaceous subduction complex: Geological Society of America Bulletin, v. 89, p. 755-769.
Connelly, W. and Moore, J.C., 1980, Tectonic history of the continental margin of southwestern Alaska, late Triassic to earliest Tertiary, in S. Alexander, ed., The relationship of plate tectonics to Alaskan geology and resources: Alaska Geological Society Symposium, p. H1-H29.
Csejtey, B., Jr., Cox, D.P., Evarts, R.C., Stricker, G.D. and Foster, H.L., The Cenozoic Denali fault system and the Cretaceous accretionary development of southern Alaska: Journal of Geophysical Res. 87, 3741-3754, 1982.
Dettermann, R.L., Plafker, G., Tysdal, R.G., and Hudson, T., 1976, Geology and surface features along the Talkeetna segment of the Castle Mountain - Caribou fault system, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-738.
Fisher, M.A. and Magoon, L.B., 1978, Geologic framework of lower Cook Inlet, Alaska: American Association of Petroleum Geologists Bulletin, v. 62, p. 373-402.
Grantz, A., 1960, Generalized geologic map of the Nelchina area, Alaska, showing igneous rocks and larger faults: U.S. Geological Survey Miscellaneous Inventory Map 312, scale 1:48,000.
Grantz, A., 1961a, Geologic map and cross sections of the Anchorage (D-2) Quadrangle and northeasternmost part of the Anchorage (D-3) Quadrangle, Alaska: U.S. Geological Survey Geological Inventory Map I-342, scale 1:48,000.
Grantz, A., 1961b, Geologic map of the north two-thirds of Anchorage (D-1) Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geological Inventory Map I-343, scale 1:48,000.
Grantz, A., 1964, Stratigraphic reconnaissance of the Matanuska Formation in the Matanuska Valley, Alaska: U.S. Geological Survey Bulletin 118, p. 111-113.
Hill, M., Morris, J., and Whelan, J., 1981, Hybrid granodiorites intruding the accretionary prism, Kodiak, Shumagin, and Sanak Islands, southwest Alaska: Journal of Geophysical Res. 86, 10591-10606.

Hobbs, B.E., Means, W.D., and Williams, P.F., 1976, An outline of structural geology: John Wiley & Sons, New York, 571 p.
Hudson, Travis, 1979, Mesozoic plutonic belts of southern Alaska: Geology, v. 7, p. 230-234.
Hsü, K.J., 1968, Principles of melange and their bearing on the Franciscan-Knoxville paradox: Geological Society of America Bulletin, v. 79, p. 1063-1074.
Jäger, E., 1979, Introduction to geochronology, in Lectures in Isotope Geology, Jäger, E., and Hunziker, J.C., eds.: Springer-Verlag, New York, p. 1-12.
Jones, D.L., 1967, Cretaceous ammonites from the lower part of the Matanuska Formation, southern Alaska, U.S. Geological Survey Professional Paper 547, 49 p.
Jones, D.L., and Silberling, N.J., 1979, Mesozoic stratigraphy - the key to tectonic analyses of southern and central Alaska: U.S. Geological Survey Open-File Report 79-1200, 41 p.
Karig, D.E., 1974, Evolution of arc systems in the western Pacific, Annual Review Earth Planetary Science, v. 2, p. 51-76.
Karl, S., Decker, J., and Jones, D.L., 1979, Early Cretaceous radiolarions from the McHugh Complex, south-central Alaska: U.S. Geological Circular 804-B, p. B88-B90.
Kirchner, C.E., and Lyon, C. A., 1973, Stratigraphy and tectonic development of the Cook Inlet petroleum province: in Arctic Geology, American Association of Petroleum Geologists, Memoir 19, p. 396-407.
MacKevett, E.M., Jr., and Plafker, George, 1974, The Border Ranges fault in south-central Alaska: U.S. Geological Survey Journal of Research, v. 2, p. 323-329.
Magoon, L.B., Adkinson, W.L., and Egbert, R.M., 1976, Map showing geology, wildcat wells, Tertiary plant fossil localities, K-Ar dates, and petroleum operations, Cook Inlet area, Alaska: U.S. Geological Survey Miscellaneous Investigation Series Map I-1019, scale 1:250,000.
Monger, J.W.H., and Price, R.A., 1979, Geodynamic evolution of the Canadian Cordillera - progress and problems: Canadian Journal of Earth Science, v. 16, p. 777-791.
Monger, J.W.H., Price, R.A., and Tempelman-Kluit, D.J., 1982, Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera: Geology, v. 10, p. 70-75.
Moore, J.C., 1973, Complex deformation of Cretaceous trench deposits, south-western Alaska: Geological Society of America Bulletin 84, p. 2005-2020.
Nilsen, T.H., and Moore, G.W., 1979, Reconnaissance study of Upper Cretaceous to Miocene stratigraphic units and sedimentation facies, Kodiak and adjacent islands, Alaska: U.S. Geol. Survey Professional Paper 1093, 34 p.
Nilsen, T.H., 1982, Accretion model for the Cretaceous Chugach terrane, southern Alaska: U.S. Geological Survey Circular 844, p. 93-97.
Pavlis, T.L., 1982a, Deformation along a late Mesozoic convergent margin: the Border Ranges fault system, southern Alaska: (Ph.D. thesis): Salt Lake City, University of Utah, 177 p.
Pavlis, T.L., 1982b, Origin and age of the Border Ranges fault, southern Alaska, and its bearing on the late Mesozoic tectonics of Alaska: Tectonics, v. 1, p. 343-368.

Pavlis, T.L., 1983, Pre-Cretaceous crystalline rocks of the western Chugach Mountains, Alaska: Nature of the basement of the Jurassic Peninsular Terrane: Geological Society of America Bulletin, v. 93, p. 1329-1344.

Pavlis, T.L. and Bruhn, R.L., 1983, Deep seated flow as a mechanism for the uplift of broad forearc ridges and its role in the exposure of high P/T metamorphic terranes: Tectonics, v. 2, p. 473-497.

Pessel, G.H., Henning, M.W., and Burns, L.E., 1981, Preliminary geologic map of parts of the Anchorage C-1, C-2, D-1, D-2 Quadrangles, Alaska: State of Alaska Division of Geological and Geophysical Surveys Open-file Report AOF-121.

Plafker, George, Jones, D.L., and Pessagno, E.A., Jr., 1977, A Cretaceous accretionary flysch and melange terrane along the Gulf of Alaska margin: U.S. Geological Survey Circular 751-B, p. B41-B43.

Scholl, D.W., VonHuene, R., Vallier, T.L., and Howell, D.G., 1980, Sedimentary masses and concepts about tectonic processes at underthrust ocean margins: Geology, v. 8, p. 546-568.

Snavely, P.D., Jr., Wagner, H.C., and London, D.L., 1980, Geologic cross section of the central Oregon continental margin: Map and Chart Series MC-28J, Geological Society of America, Boulder, Colorado.

Tchalenko, J.S., 1970, Similarities between shear zones of different magnitudes: Geological Society of America Bulletin, v. 81, p. 1625-1640.

Turner, F.J., 1981, Metamorphic petrology: Mineralogic field and tectonic aspects: 2nd edition, McGraw-Hill, 524 p.

Tysdal, R.G. and Plafker, G., 1978, Age and continuity of the Valdez Group, southern Alaska: in Changes in stratigraphic nomenclature of the U.S. Geological Survey, Sohl, N.F., and Wright, W.B., compilers: U.S. Geological Survey Bulletin 1457-A, p. A120-A124.

White, R.S., 1982, Deformation of the Makran accretionary sediment prism in the Gulf of Oman (northwest Indian Ocean): in Trench - forearc geology: Sedimentation and tectonics on modern and ancient active plate margins, Leggett, J.K., ed.: Blackwell Scientific Publications, London, p. 357-372.

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

Winkler, H.G.F., 1979, Petrogenesis of metamorphic rocks (5th edition): Springer-Verlag, 348 p.

FIGURE CAPTIONS

Figure 1. Terrane map of the Anchorage C-5 Quadrangle showing distribution of major tectonostratigraphic terranes and subterranes described in report.

Figure 2. Map of Anchorage C-5 Quadrangle showing faults known to offset Cretaceous plutons and (or) younger rocks (solid lines). Other high angle faults with suspected Tertiary motion are shown with dashed lines.

Figure 3. Map of Knik River Terrane in the Anchorage C-5 Quadrangle showing structural domains described in text.

Figure 4. Equal-area stereographic projections summarizing major fabric elements in metamorphic rocks of the Knik River terrane. 4a and 4c are poles to foliation (S_1) for metamorphic rocks of Domain Ia and Ib respectively. 4b shows trend and plunge of mineral lineations (L_1) in domain Ia. 4d and 4e show major fabric elements in two small areas of Domain II. Note that small circle distribution of L_1 and F_1 fold axes about F_2 fold axes clearly shows the refolding of these D_1 elements by F_2 folds. 4f shows poles to igneous layering and (or) foliation in the largest ultramafic mass (Domain IV).

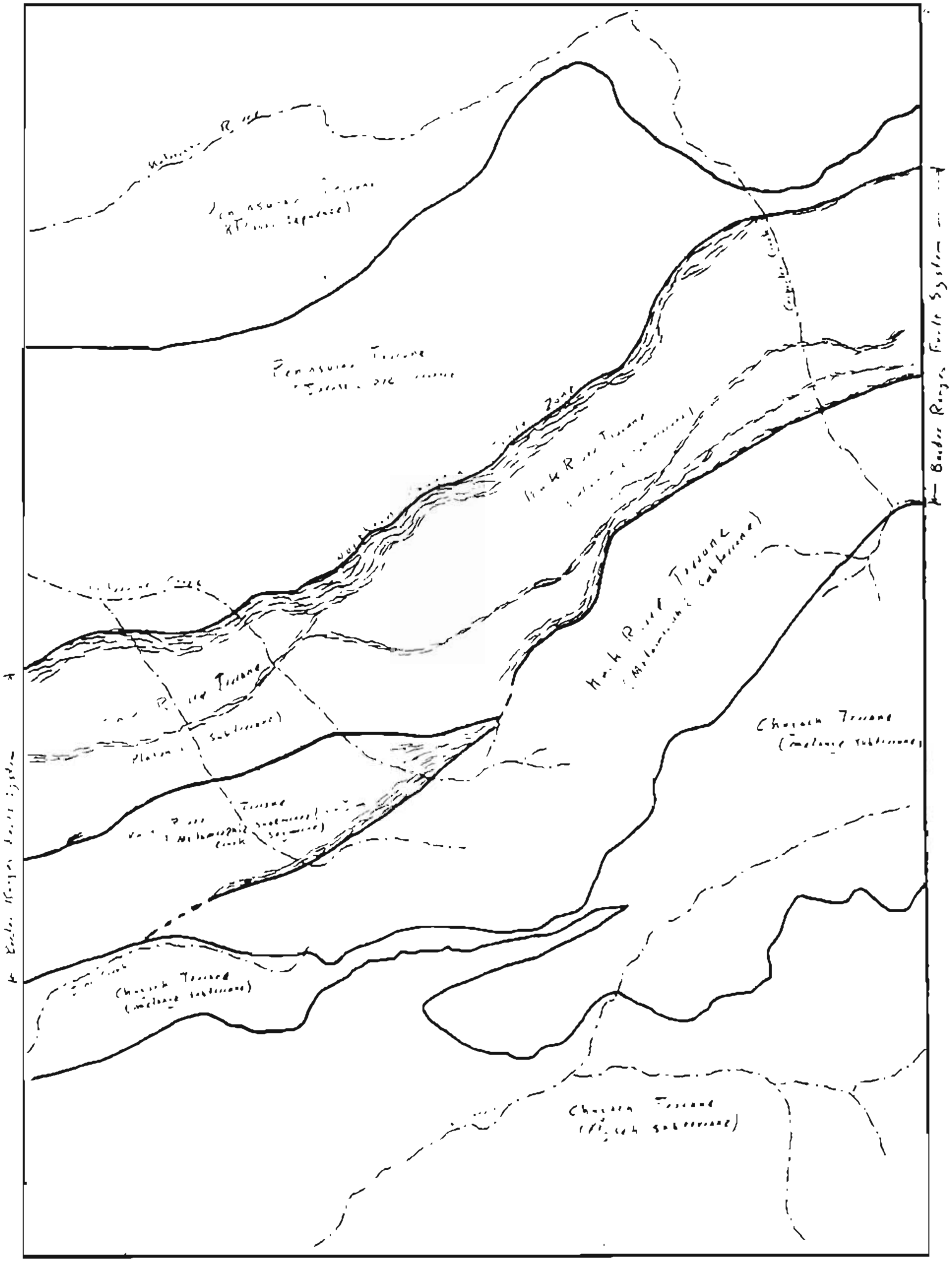
Figure 5. Illustration of structural style variations in the Knik River terrane. 5a shows main phase (F_1) isoclinal folds with axial planar schistosity (S_1). Photo is from upper Carpenter Creek, Domain Ia. 5b illustrates refolding of D_1 fabrics by F_2 folds in Domain II. Note dome and basin style interference patterns. Photo is from upper Carpenter Creek in the large roche moutonnee. 5c shows structural styles in the 'red melange' of Domain III. Note the simple chevron folding of chert beds contrasting markedly with the strongly foliated (sheared?) character of adjacent argillaceous rocks.

Figure 6. Illustration of various stages of bedding transposition in shear zones of the Valdez Group. 6a shows classic incipient transposition of bedding (S_o) into phyllitic cleavage (S_1); whereas 6b shows complete transposition with lenses of graywacke floating in a foliated, argillaceous 'matrix.'

Figure 7. Diagrammatic sketch of imbricate structures in Valdez Group. 7a shows documented systems where fold 'roll-overs' are clearly developed; whereas 7b shows a typical system where the high strain zones are paralleled by both S_o and S_1.

Figure 8. Equal-area stereographic projections summarizing orientations of major fabric elements in Valdez Group. 8a shows poles to main phase slaty-phyllitic cleavage (S_1) and axes of recognized main phase folds (F_1). 8b shows orientations of major D_2 structures cutting S_1 fabrics.

Figure 9. Summary of chronologies recognized within and between structural elements of the C-5 Quadrangle. Age constraints are summaries of this work and previous work reported by Pavlis (1982b).



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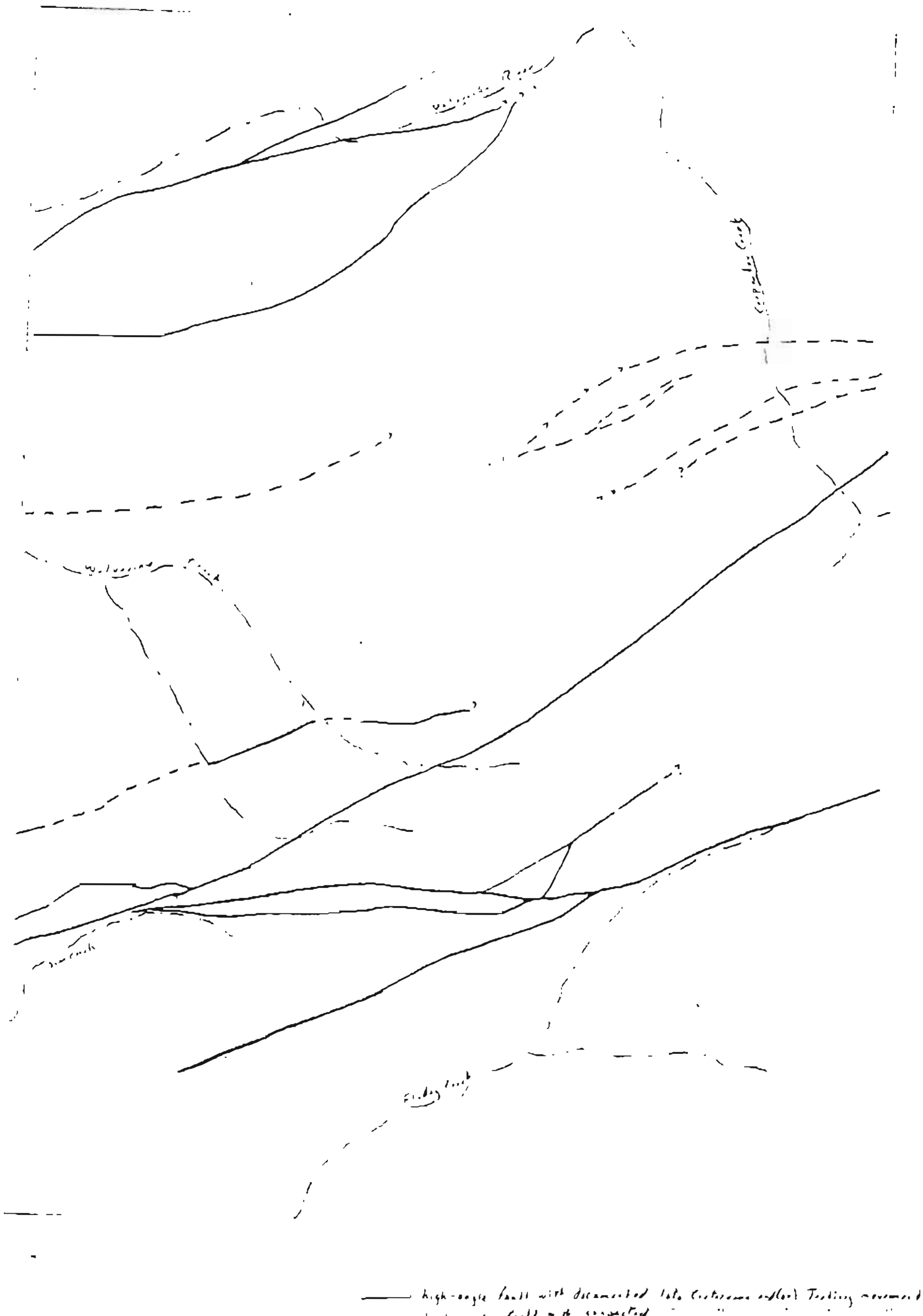

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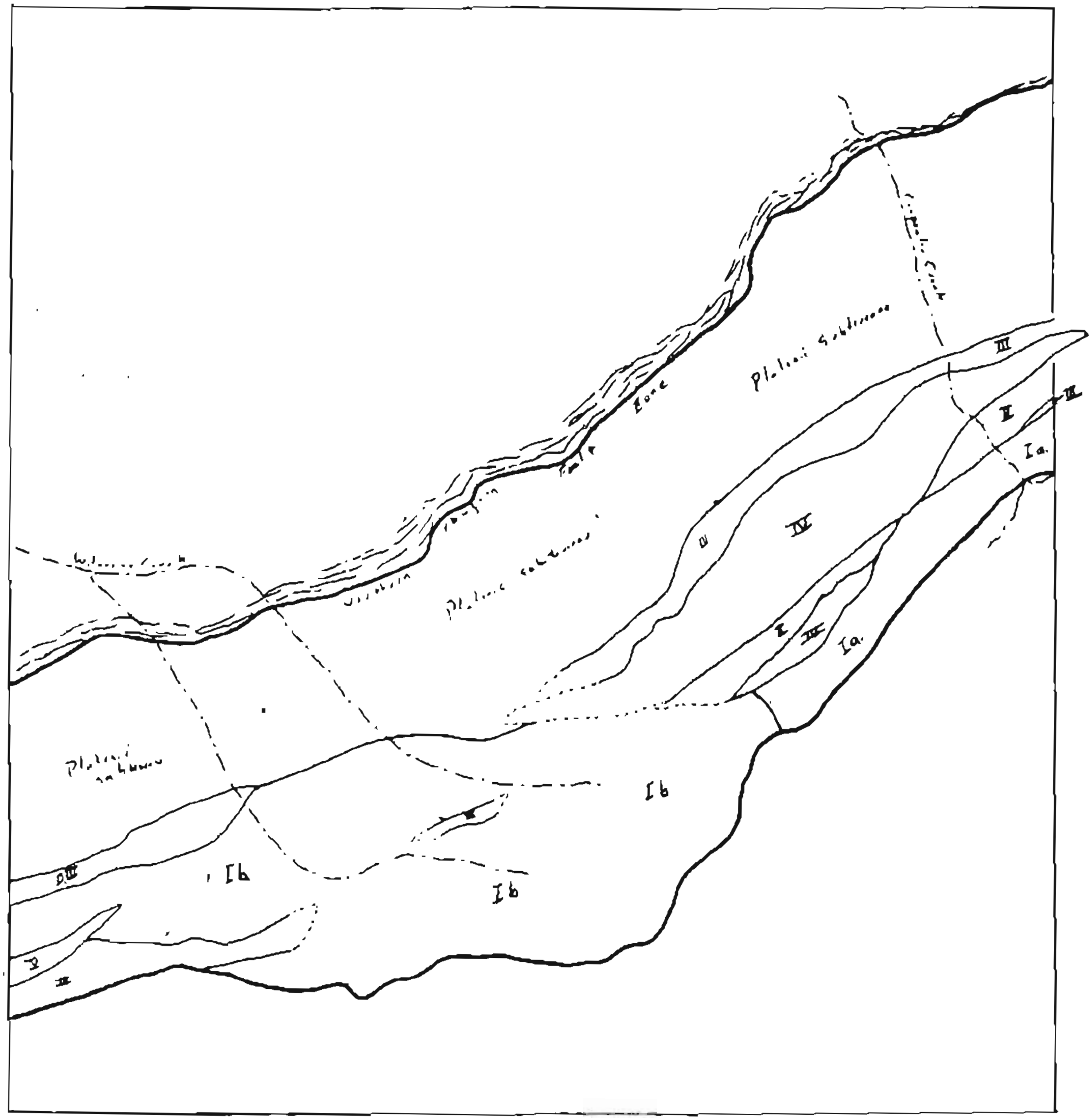

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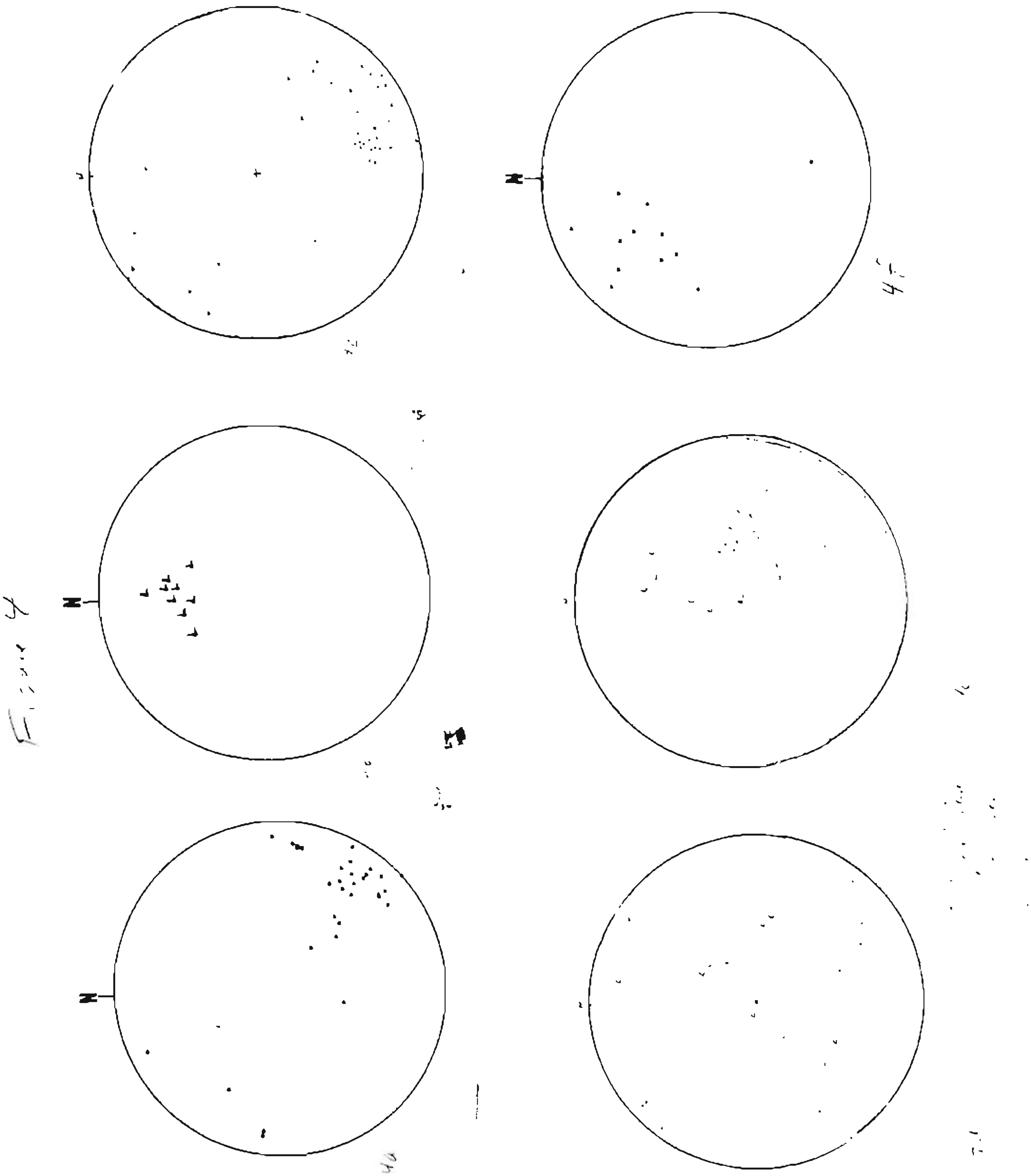

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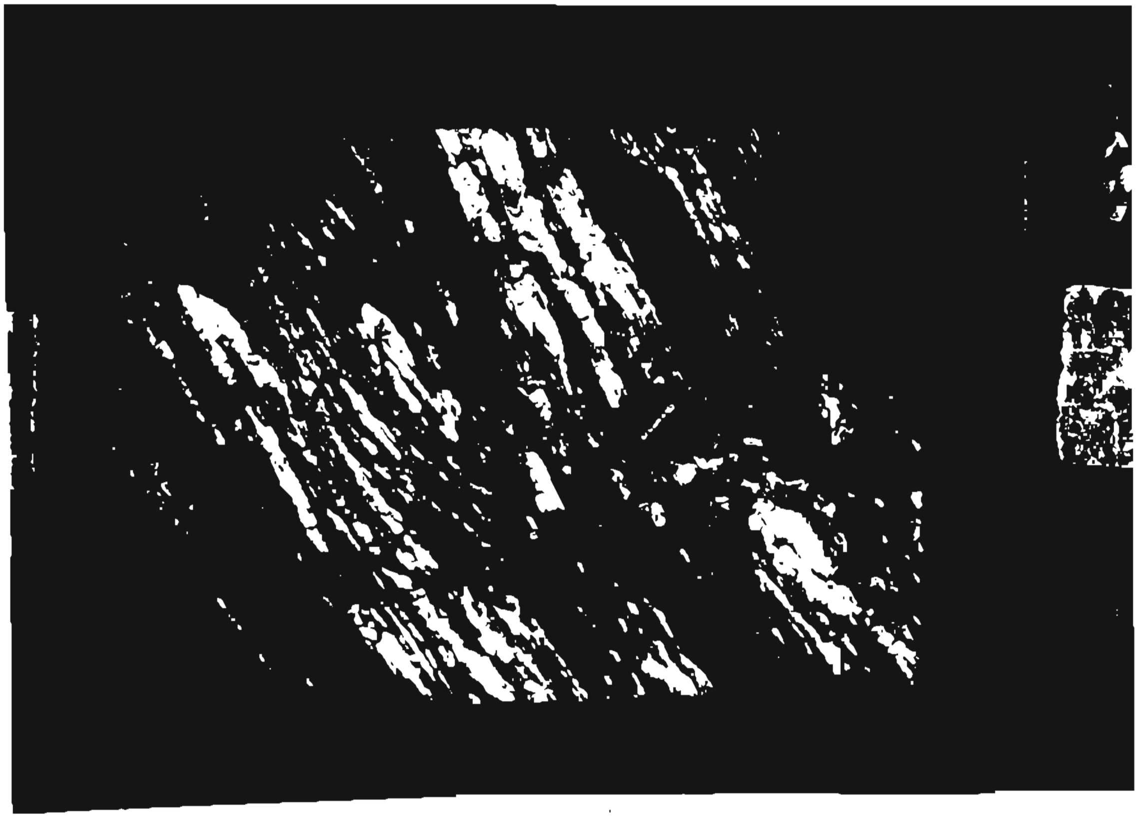

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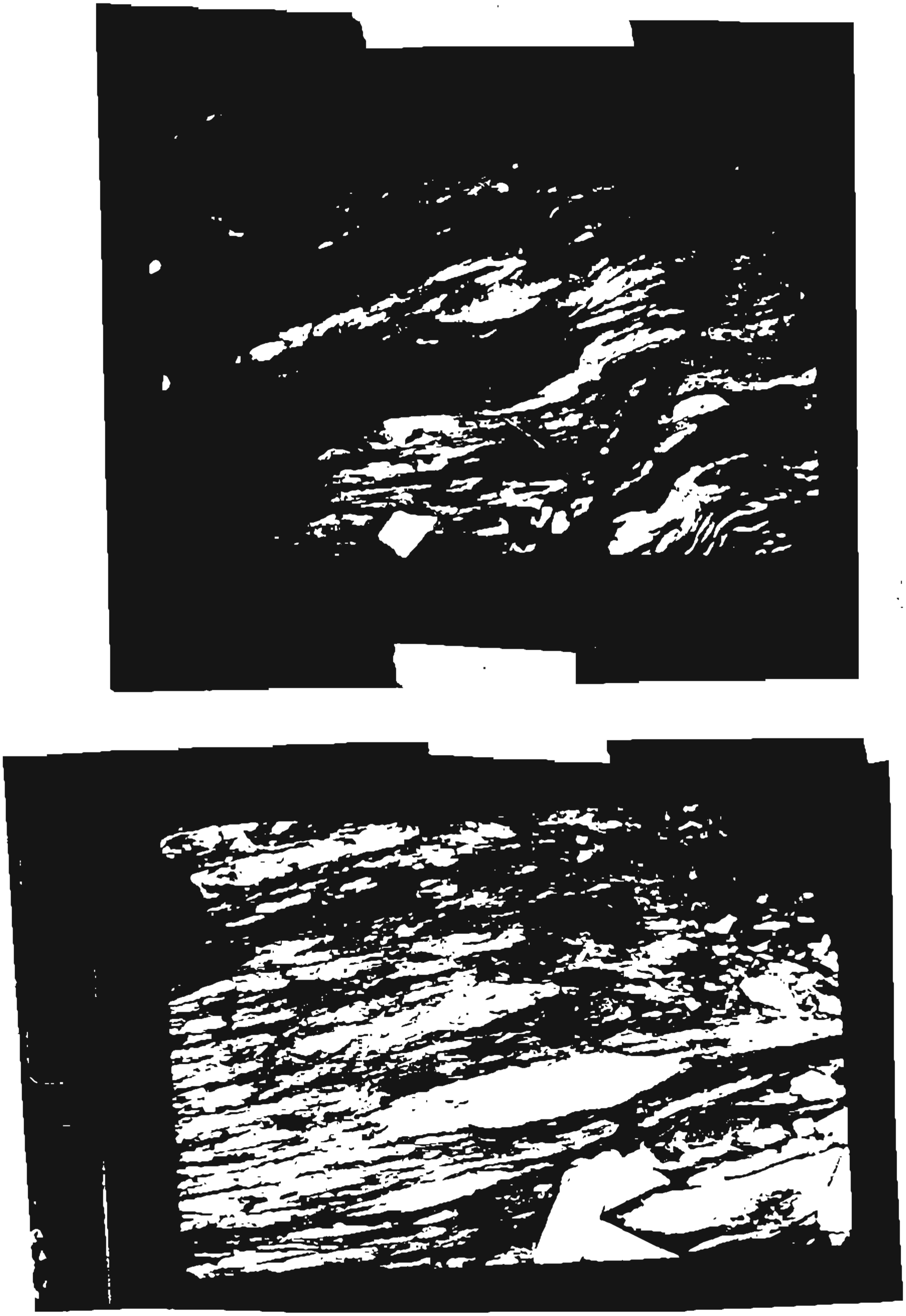

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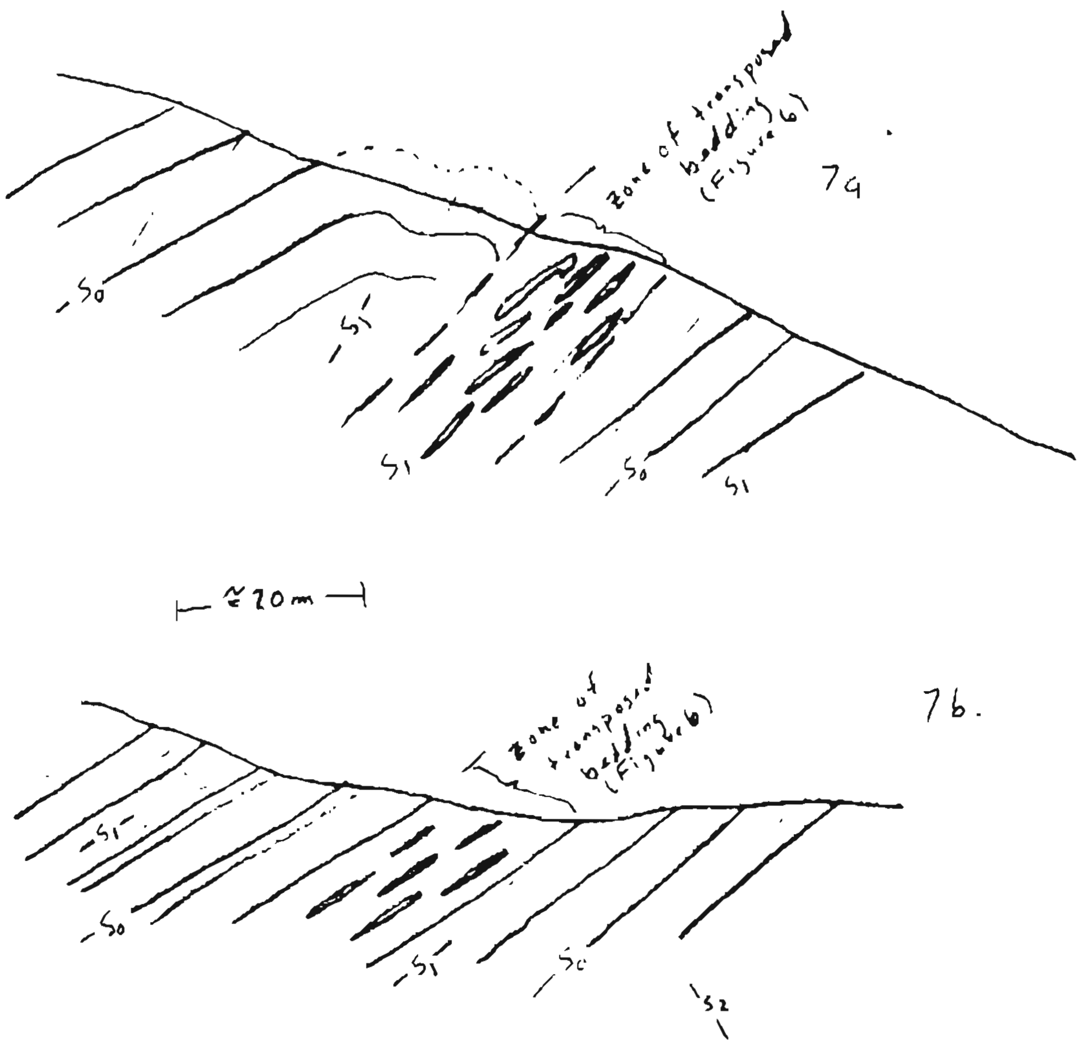

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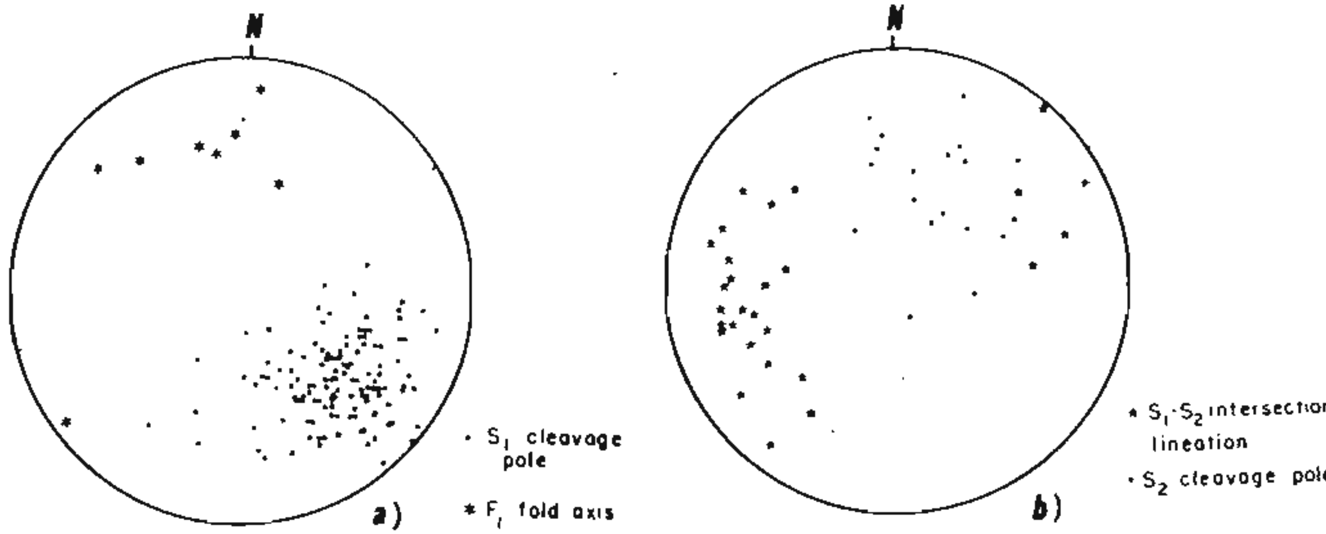

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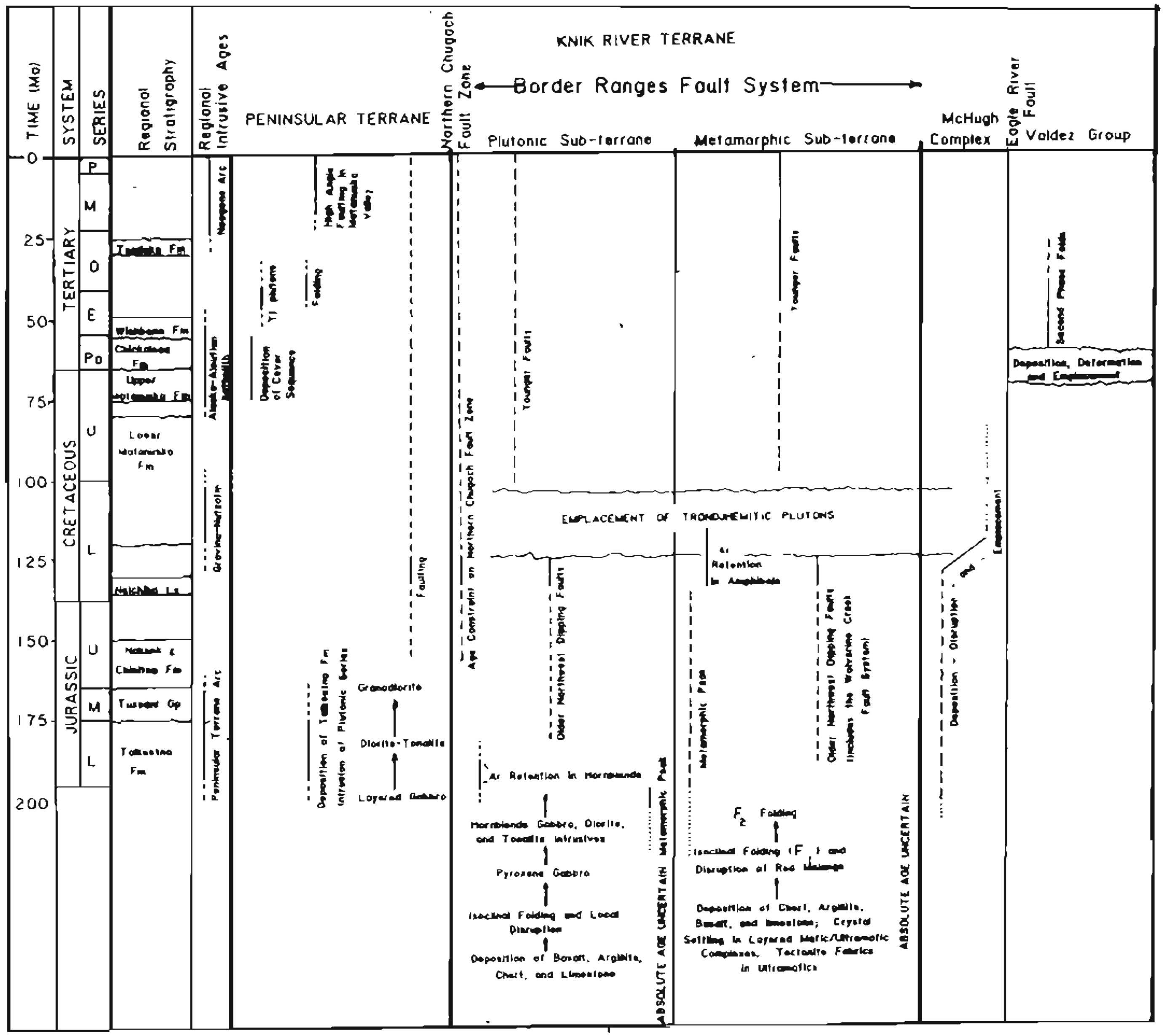

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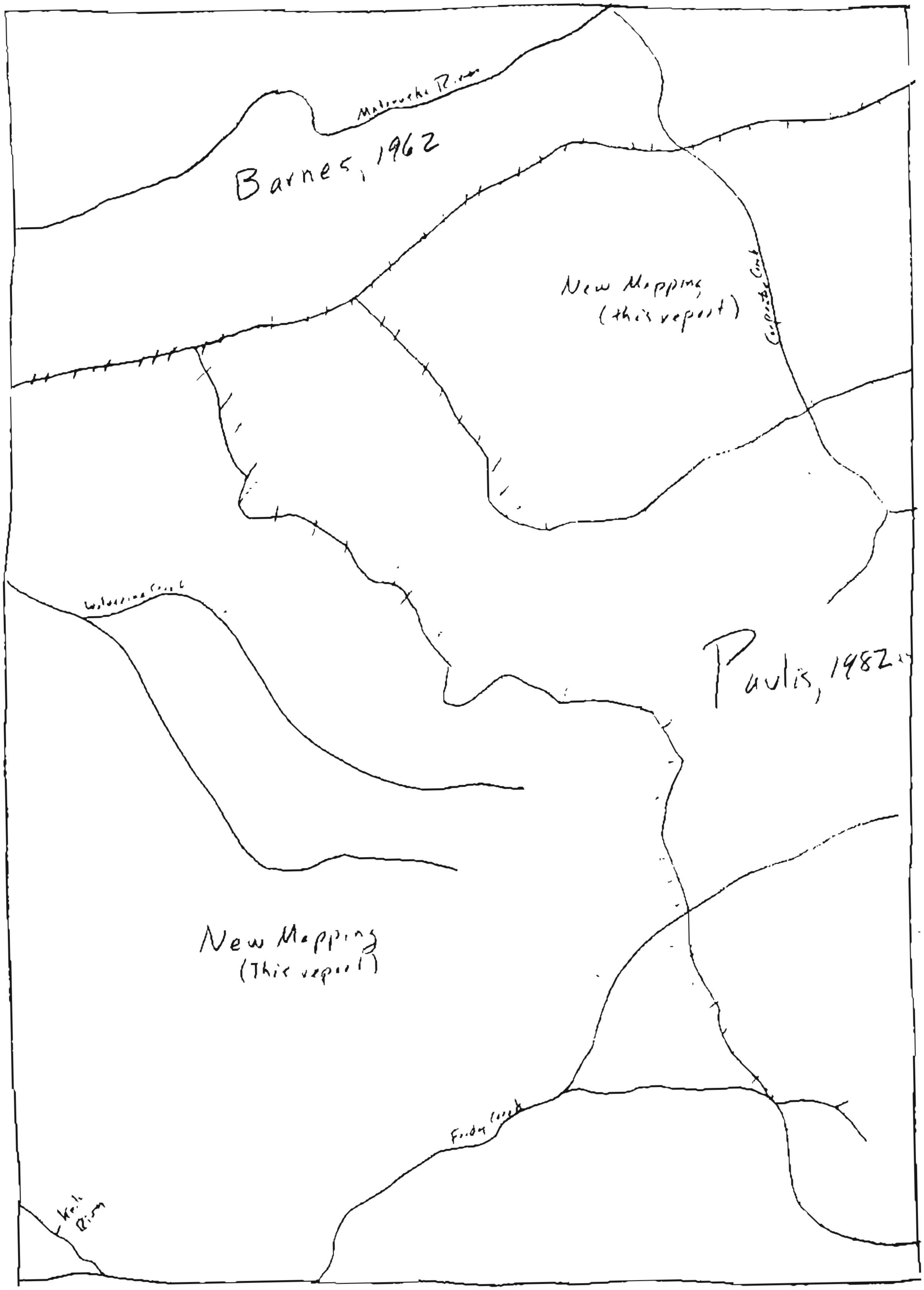
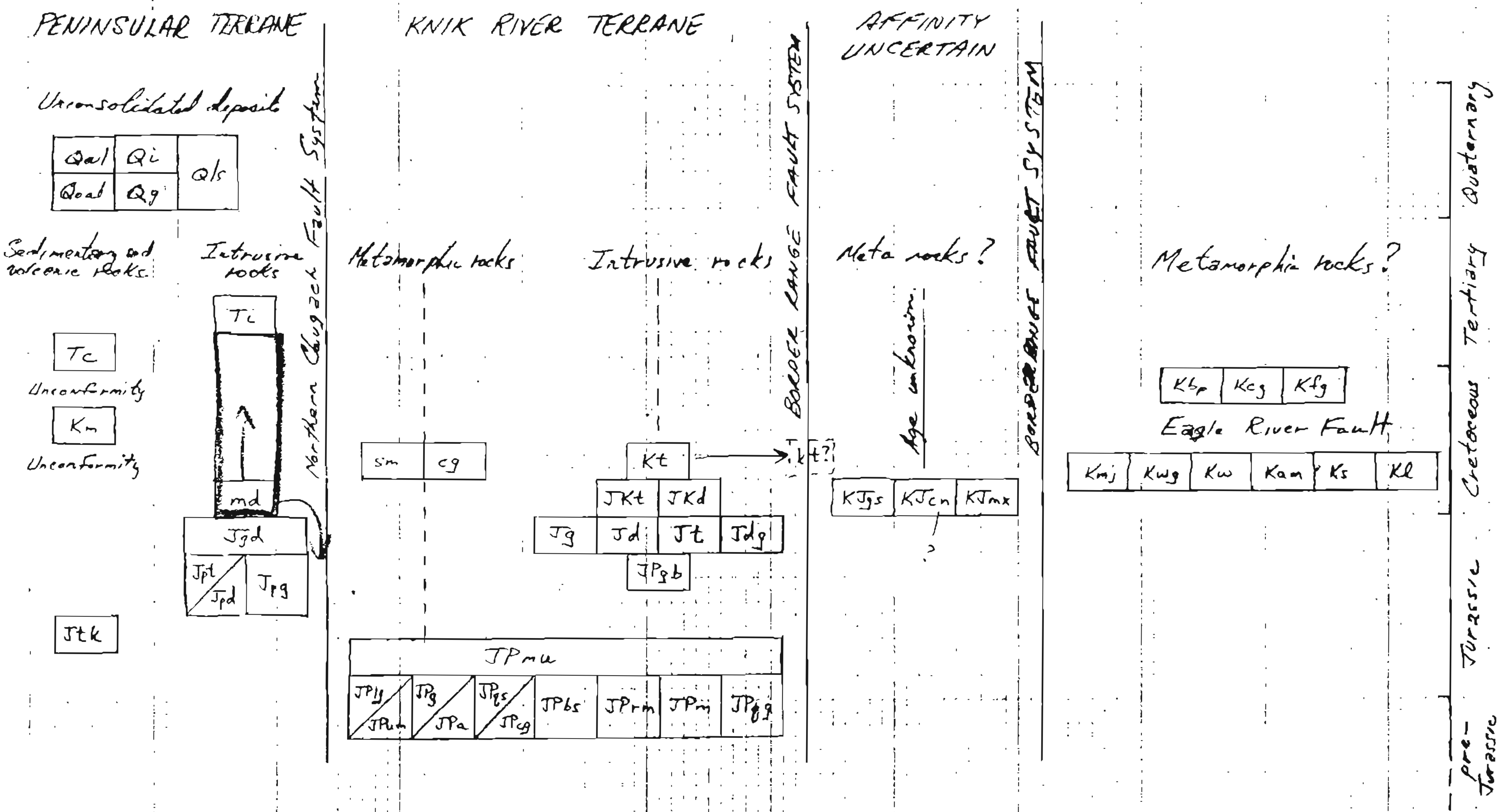
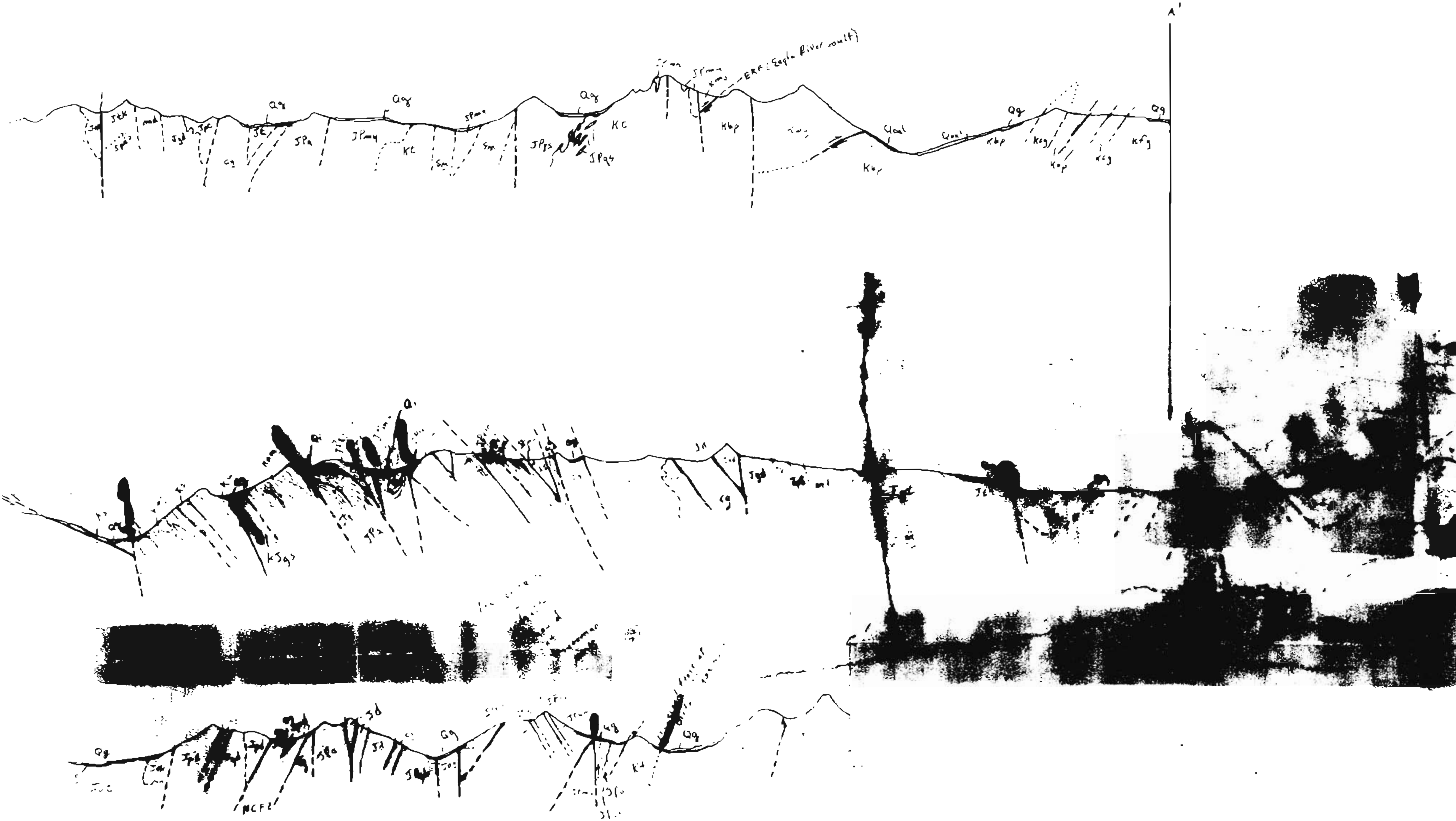
Source of Mapping

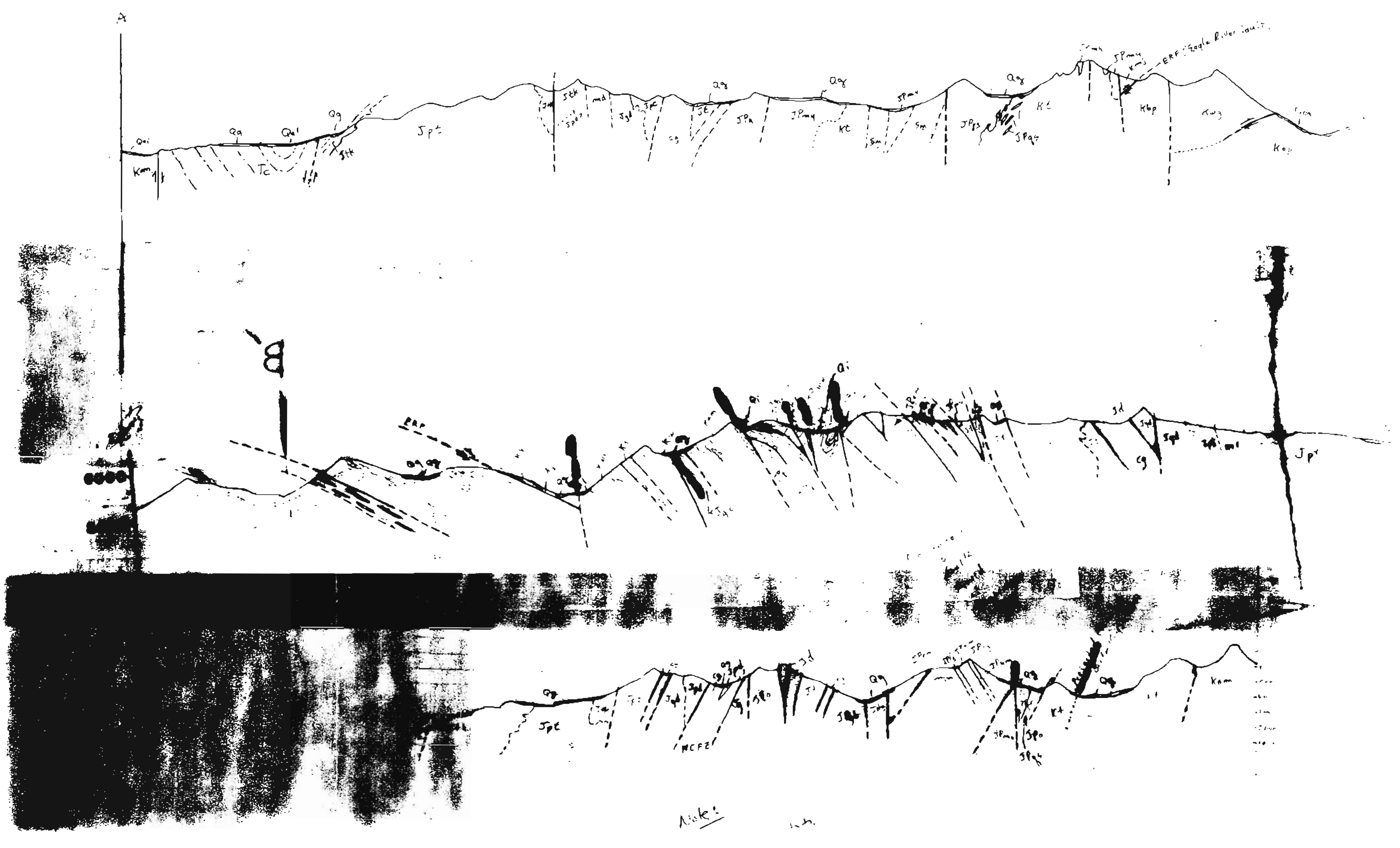
Reduced version of this map should be a small inset in Plate 1



CORRELATION OF MAPS UNITS




A'
EKF: Eagle River fault


A
ERF: Eagle River fault
Jpt
Tc
Kbp
Kop
B
ERF
Qi
Jgd
Jpt
NCFZ
Note: