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Report of Investigations 92-4
THE WOLVERINE CREEK SEQUENCE: EVIDENCE FOR
AN ALLOCHTHON BELOW THE BROOKS RANGE
ALLOCHTHON, WESTERN BROOKS RANGE, ALASKA

By Lome E. Young



STATE OF ALASKA Department of Natural Resources DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

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THE WOLVERINE CREEK SEQUENCE: EVIDENCE FOR AN ALLOCHTHON BELOW THE BROOKS RANGE ALLOCHTHON, WESTERN BROOKS RANGE, ALASKA

By Lorne E. Young¹

ABSTRACT

The Wolverine Creek sequence in the De Long Mountains of the Brooks Range thrust and fold belt is structurally lower than and stratigraphically distinct from the both Kelly River allochthon and the Brooks Range allochthon, which is also known as the Endicott Mountains allochthon. The Wolverine Creek sequence is exposed in the Mount Raven and Rok fensters. Within Mount Raven fenster are two(?) twice-folded thrust sheets of Mississippian to Cretaceous chert, carbonate, and clastic rocks. The southwest margins of Mount Raven and Rok fensters have been modified by wrench faulting and possible extension. In at least one locality in the Wolverine Creek sequence, a zone of relatively proximal bioturbated siltstone lithologies interfingers with very fine grained distal clastic and authigenic sediments of the Siksikpuk Formation. The Wolverine Creek sequence, proposed to be allochthonous, has stratigraphic similarities to the parautochthonous sequence of the Lisburne Hills.

INTRODUCTION

Data presented in this report support the recognition of a new structurally lowest sequence in the De Long Mountains of the northwestern Brooks Range, Alaska (fig. 1). This is designated the "Wolverine Creek" sequence after Moore and others (1986). The term "sequence" is used throughout for the Wolverine Creek assemblage, solely because its allochthonous character is not proven at this time. Use of the term "sequence" does not imply the Wolverine Creek assemblage is merely a local variant of the Brooks Range allochthon. If allochthonous, the structurally lower Wolverine Creek sequence increases published calculations of shortening in the western Brooks Range and may necessitate a revision of structural and stratigraphic interpretations, with resultant economic and scientific implications.

Two fensters of the Wolverine Creek sequence aggregating 350 km² are located in the western DeLong Mountains of the Brooks Range, 155 km east of Point Hope, Alaska (figs. 1-4). The northeastern fenster is informally referred to as Mount Raven fenster and the southwestern one as Rok fenster. This region is perhaps best known for its numerous zinc-lead-barite deposits, including the Red Dog Mine (Tailleur, 1970; Moore and others, 1986; and Young, 1989). For this reason, the focus of recent publications has been the Kuna Formation of the Brooks Range allochthon (known as the Endicott Mountains allochthon in the central Brooks Range), which is the host for base-metal deposits. Most of the detailed information presented in this report is drawn from previously unpublished data gathered by Cominco American Inc. during the detailed mapping of 6000 km² over a period of nine years. The accompanying geological maps contain minor additions from Curtis and others (1990), Eliersieck and others (1990), and Mayfield and others (1990). Some interpretations are based on 1:24,000-scale true-color low-altitude aerial photographs. The "study area" referred to in this paper concerns the Mount Raven and Rok fensters and immediately adjacent outcrop areas, and the "map area" refers to that area covered by figure 4.

GEOLOGY

INTRODUCTION

The Brooks Range thrust and fold belt contains regionally correlatable thrust fault-bounded mid-Paleozoic to Upper Mesozoic lithostratigraphic assemblages juxtaposed during the compressional north-vergent Upper Jurassic to Cretaceous Brookian orogeny. An autochthonous sequence lies in the subsurface north of the Brooks Range, consisting dominantly of Paleozoic metasedimentary rocks truncated by a sub-Mississippian unconformity and overlain by unmetamorphosed Upper Paleozoic to Mesozoic sediments. The autochthonous sequence dips southward and floors the thrust belt and is exposed in correlative parautochthonous uplifts in the central axis and southern flanks of the Brooks Range (Mull, 1982; Mull, Roeder, and others, 1987).

Not including the Wolverine Creek sequence, five structurally and stratigraphically discrete sediment-dominant allochthons and two igneous-dominant allochthons are recognized in the western Brooks Range (fig. 3). Each

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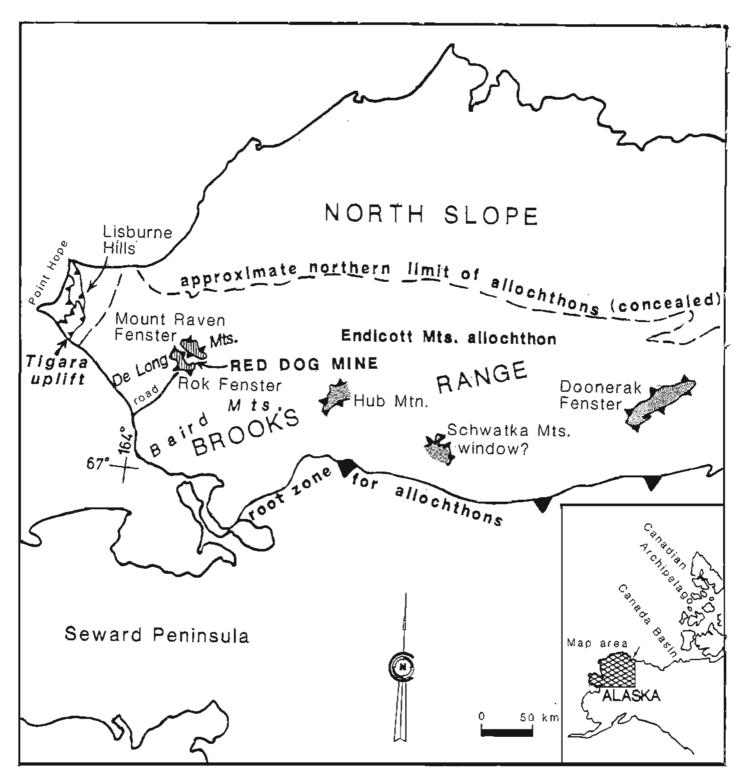


Figure 1. Location map of Mount Raven and Rok fensters and selected northern Alaska features discussed in the text.

sedimentary allochthon contains one or more definable thrust fault-bounded stratigraphic assemblages of Devonian or Mississippian to Early Cretaceous age (Mayfield and others, 1988). With some exceptions, sedimentary facies of the allochthons are more distal or finer-grained (or both) than coeval facies in the underlying autochthonous/parautochthonous sequence; likewise, coeval formations in successively higher allochthons are commonly more distal. These facies relationships are most strongly expressed in Upper Devonian to Triassic rocks. Late Devonian time is represented by uplift, erosion, and folding in the autochthonous/parautochthonous sequence (Newberry and others, 1986; Hubbard and

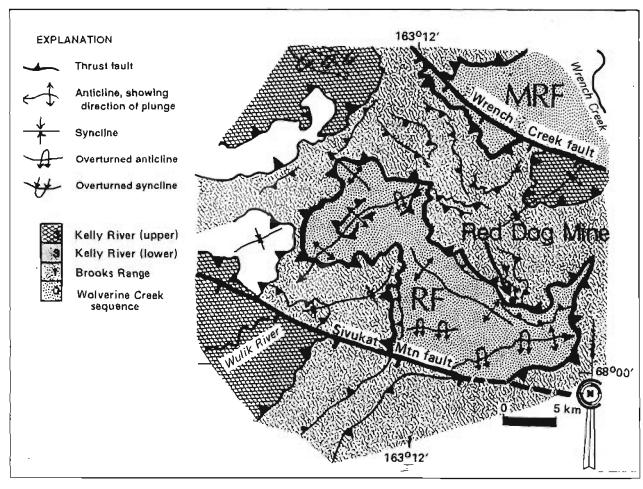


Figure 2. Simplified geology of Rok fensier (RF), the southern part of Mount Raven fensier (MRF), and principal geologic structures between the Wrench Creek and Sivukat Mountain faults. The unpatterned areas on the west side represent poorly differentiated Picnic Creek(?) allochthon and olistostromal units of the Brooks Range allochthon.

others, 1987), by fluvial-deltaic deposits in structurally lower allochthons, and by carbonate in structurally higher allochthons (Tailleur and others, 1967). In Early Mississippian time the sub-Mississippian unconformity surface of the autochthonous/parautochthonous sequence received fluvial-deltaic deposits of the Kekiktuk Conglomerate and Kapaloak Sequence (Moore and others, 1984; Woidneck and others, 1987), in contrast with Early Mississippian distal deltaic shale and siltstone and platform carbonate in the allochthons (Mayfield, and others 1988). Similarly, during Permian and Early Triassic time the autochthonous/parautochthonous sequence (excepting the Lisburne Hills) received siltstone, sandstone, and conglomerate of the Sadlerochit Group, in contrast to deposition of shale and chert on the allochthons. In the present coordinate reference frame, the observed facies relationships between the allochthons suggest an original south-facing mid-Paleozoic to Mesozoic passive continental margin. At specific intervals (for example, Upper Mississippian) the continental margin paleogeography is complex and defined by alternations of shallower and deeper water facies outboard. In part, this relationship is attributed to marginal extension and block faulting (Moore and others, 1986).

Lower Jurassic(?) to Lower Cretaceous extension and subsequent Lower Cretaceous rifting in the Canada Basin (Tailleur, 1969; Crane, 1987a,b; Hubbard and others, 1987) is associated with Middle to Upper Jurassic reversal of the prevalent southerly clastic transport regime, when graywacke of the Okpikruak Formation was shed from the northward-advancing thrust front of the ancestral Brooks Range (Bird, 1987; Mayfield and others, 1988). Upper Jurassic to Lower Cretaceous olistostrome deposition and south-over-north thrust juxtaposition of the sedimentary allochthons during the Brookian orogeny was driven by collapse and obduction of an upper Paleozoic to Mesozoic ocean basin now represented by the structurally highest igneous-dominant allochthons (Crane, 1987a,b; Mayfield and others, 1988). The progressive

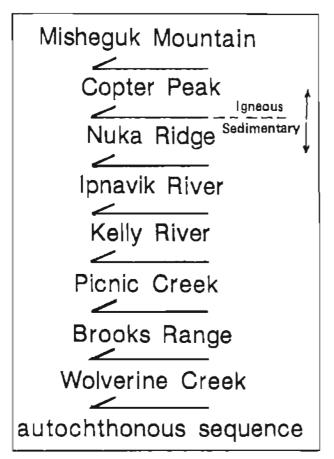


Figure 3. Summary of reported and proposed relationships between northwestern Brooks Range allochthons, Wolverine Creek sequence, and the autochthonous sequence. Modified from Moore and others, 1986; Mayfield and others, 1988.

south-over-north thrust collapse of a wide part (+560 km) of the pre-Brookian passive continental margin encompassed multiple-facies regimes and resulted in pronounced stratigraphic variations between the sedimentary allochthons (Moore and others, 1986; Mayfield and others, 1988). The Middle Jurassic to Lower Cretaceous (Neocomian) graywackes of the Okpikruak Formation are the youngest allochthonous units and are depositionally overlapped by little-deformed Albian foredeep strata of the Colville Basin. Post mid-Cretaceous east- to northeast-vergent contractional deformation of the Tigara uplift (Campbell, 1967; Mayfield and others, 1988) has resulted in folds with northerly and northwesterly trending axes and east-directed thrusting in the Lisburne Hills (fig. 1). (The Tigara uplift is not included here with the Brookian orogeny, this compressional event partially overprints earlier north- to northwest-vergent Brookian structures in the western De Long Mountains.)

REGIONAL SYNTHESIS

The northwestern part of Alaska (fig. 1) is divisible into four major physiographic and geologic elements, from north to south:

- The North Slope, which represents the foreland to the Brooks Range thrust belt. In this region Albian (Lower Cretaceous) and younger foredeep strata of the Colville Basin conceal older strata of the autochthonous sequence as determined from exploratory oil wells (Bird, 1981; Witmer and others, 1981; Sable and Stricker, 1987)
- 2. The northern Brooks Range, which represents the essentially unmetamorphosed forward part of the thrust belt and includes the Wolverine Creek sequence and overlying allochthons discussed herein
- 3. The central and southern Brooks Range, which represents the largely older and metamorphosed hinterland of the thrust and fold belt. In this area are one or more windows-duplexes in the area of Mount Doonerak, the Schwatka Mountains, and possibly Mount Angayukaqsraq (Hub Mountain), in which parautochthonous rocks correlatable with the autochthonous sequence are exposed (Mull and Tailleur, 1977; Mull, 1982; Mull and others, 1987; Mull, Roedar, and others, 1987: Karl and others, 1989)
- 4. The root zone to the Brooks Range thrust belt, now modified or destroyed by extension (Miller, 1987; and Oldow and others, 1987), which coincides with the south margin of the Brooks Range.

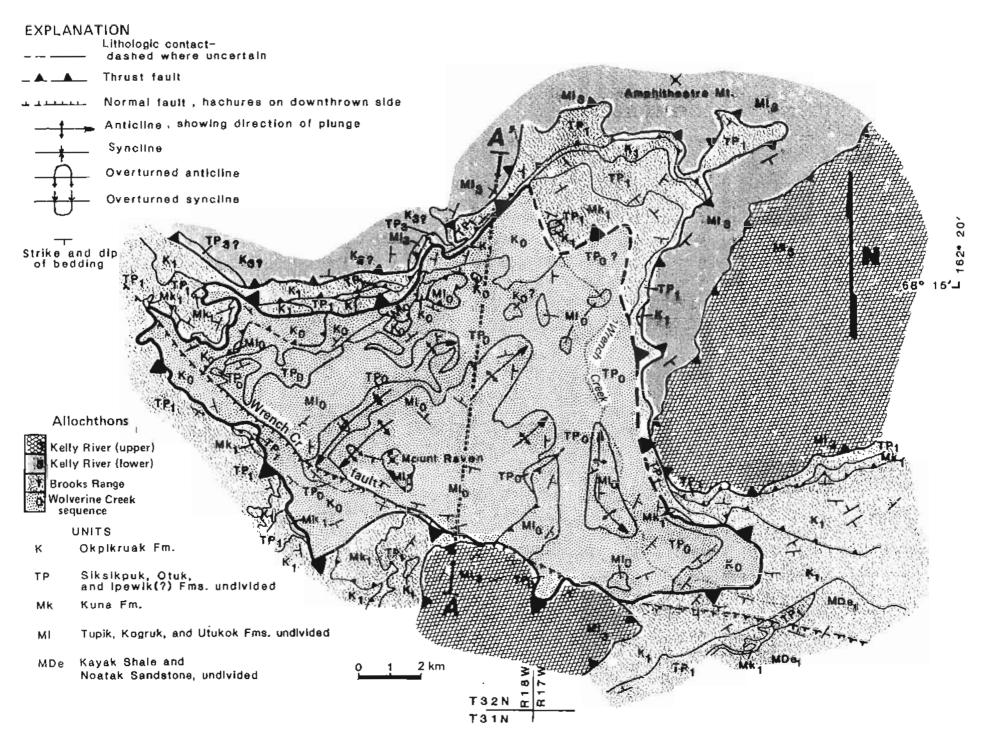


Figure 4. Geology of Mount Raven fenster map area.

A fifth geologic element is represented by the parautochthonous Lisburne Hills sequence, which lies west of the Brooks Range (fig. 1). This sequence exhibits the sub-Mississippian unconformity and Lower Mississippian fluvial-deltaic facies of the autochthonous sequence, but has chert and shale in the Permian to Triassic interval as per the allochthonous sequences (Campbell, 1967; Moore and others, 1984).

GEOLOGY OF THE STUDY AREA

Two(?) thrust sheets and several thrust wedges of Mississippian through Jurassic(?) carbonate, chert, shale, and siltstone and Lower Cretaceous flysch are exposed in Mount Raven fenster (fig. 4). Because of its highly resistant nature, the silicifed Kogruk Formation of the Wolverine Creek sequence constitutes the highest peaks within Mount Raven fenster, typically 260-320 m higher than the surrounding hills. The dark weathering and prominent cherty aspect of the silicified Mississippian carbonate rocks led Ellersieck and others (1990) to assign the structurally lowest assemblage in Mount Raven fenster to the Picnic Creek allochthon (and thus was interpreted to lie structurally above the Brooks Range allochthon).

In the map area (fig. 4), the Wolverine Creek sequence and two allochthons of Upper Devonian or Lower Mississippian to Lower Cretaceous sedimentary rocks are present. These are, in ascending structural order, the Wolverine Creek sequence, the Brooks Range allochthon, and the Kelly River allochthon. To more clearly demonstrate the structural position of these assemblages, units on figure 4 are subscripted 0, 1, or 3, referring to the Wolverine Creek sequence, Brooks Range allochthon, and Kelly River allochthon, respectively. The Picnic Creek allochthon (Ellersieck and others, 1979), which regionally lies between the Brooks Range and Kelly River allochthons (fig. 3), may be represented locally in the map area as a thin panel of Etivluk Group, but is inconsequential at map scale.

A detailed geological map of Mount Raven fenster (fig. 4) and accompanying cross section (fig. 5) show that formations of the Wolverine Creek sequence consistently dip beneath the Brooks Range allochthon on all sides and that the Brooks Range allochthon, in turn, dips beneath the Kelly River allochthon. Stratigraphic relations on the margins of Mount Raven fenster generally support upright bedding, although tectonic thinning and disruption has caused obvious local complications. Similar structural relations are documented on the margins of Rok fenster (fig. 2).

LOCAL STRATIGRAPHY

The two demonstrable allochthons recognized in the map area (figs. 4-6) are unambiguously correlative to the Brooks Range and Kelly River allochthons (Mayfield and others, 1988; Ellersieck and others, 1990). The structurally lowest Wolverine Creek sequence differs in specific ways from the Brooks Range and Kelly River allochthons as described by Mayfield and others, (1988). In the following sections the stratigraphy of the two allochthons and the Wolverine Creek sequence is described and contrasted. The stratigraphic columns for the Wolverine Creek sequence in figure 7 are extrapolated from numerous incomplete measured and estimated sections and should be considered interpretive.

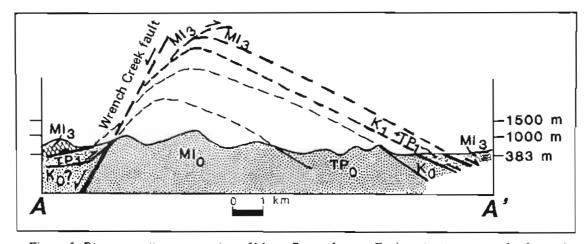


Figure 5. Diagrammatic cross section of Mount Raven fenster. Explanation is same as for figure 4.

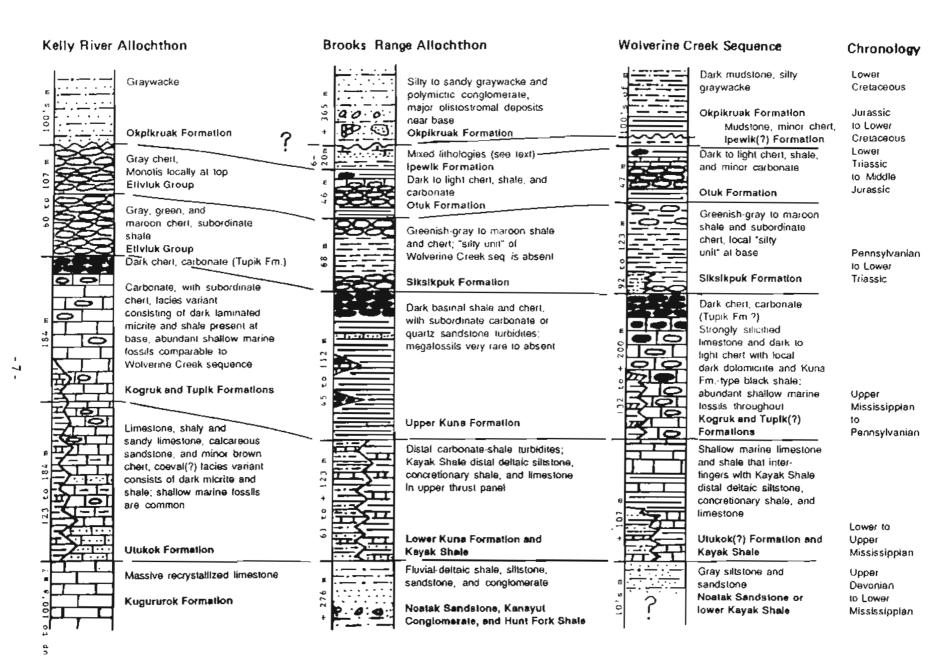


Figure 6. Stratigraphic comparison of the allochthons and sequences in the study area. The Picnic Creek allochthon is not included because of its structural removal in much of the study area. Sources of data referenced in text. The correlations are not exact as formation contacts are moderately diachronous across the allochthons. Explanation of patterns is same as for figure 7.

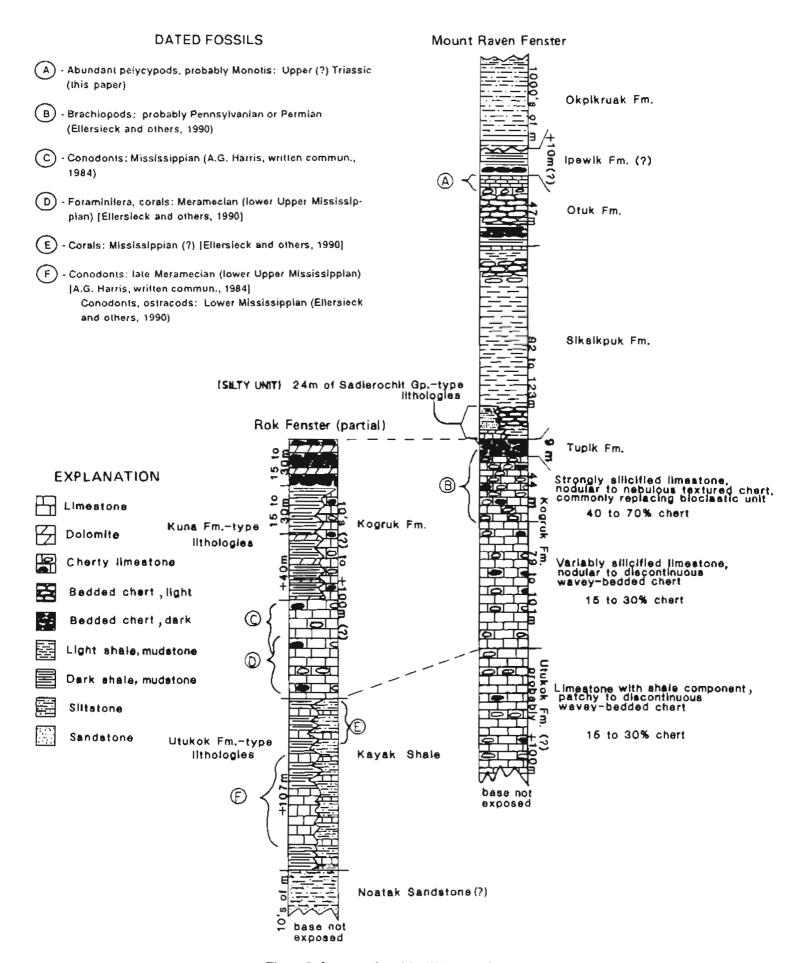


Figure 7. Stratigraphy of the Wolverine Creek sequence.

WOLVERINE CREEK SEQUENCE

The stratigraphically lowest exposures of the Wolverine Creek sequence are found in southeastern Rok fenster, and consist of tens of meters of laminated to thin-bedded locally pyritic gray siltstone or fine-grained quartzitic sandstone, or both, and dark-gray to black concretionary micaceous shale (figs. 6, 7). This basal unit is lithologically and stratigraphically comparable to Upper Devonian or Lower Mississippian formations described by Smith (1913); Bowsher and Dutro (1957); and Moore and others (1984). On the basis of lithology and stratigraphic position beneath the Kayak Shale, Ellersieck and others (1990) and I have mapped this facies as Noatak Sandstone. Pyritic horizons in basal siltstone and sandstone of southeastern Rok fenster compare to pyritic horizons seen widely in the Noatak Sandstone of the Brooks Range allochthon northeast of the study area.

In Rok fenster, thinly laminated to thin-bedded concretionary dark-gray to black shale, laminated to thin-bedded siltstone, and impure carbonate of the Lower Mississippian Kayak Shale (Ellersieck and others, 1990) overlie the basal unit. The Kayak Shale underlies or interfingers northward and westward with thin- to thick-bedded fossiliferous limestone and thin-to medium-bedded dark shale or orangish-weathering cherty carbonate and silty carbonate. Included within this carbonate-dominant assemblage are thin-bedded to massive sparite and rhythmically alternating thin to thick zones of micritic limestone and dark shale which, in northern Rok fenster, yield conodonts of Early and early Late Mississippian age (A.G. Harris, written commun., 1984; Ellersieck and others, 1990) and are thus assigned in part to the Utukok Formation (Sable and Dutro, 1961). In this locale of Rok fenster, facies similar to concretionary Kayak Shale and Utukok Formation (carbonate) are interbedded.

Overlying the Kayak Shale (or alternately, the Utukok Formation) is up to 145 m of medium-bedded to massive, commonly intensely silicified limestone and nodular or irregular-bedded black and brown chert. In general, the chert is of replacement origin, as shown by its highly irregular distribution and the common presence of megafossils that have been replaced by chert. The carbonate contains abundant silicified shallow-water fossils, including corals, bryozoans, brachiopods, and thinly laminated wavey algal(?) structures. Fine-grained dolosparite and dolomicrite form the dominant carbonate lithotype at one locale. These assemblages are correlated with the Upper Mississippian and Lower Pennsylvanian Kogruk Formation (Sable and Dutro, 1961; Ellersieck and others, 1990). A distinctive bioclastic unit which has been largely replaced by dark nebulous-textured chert occurs near the top of the Kogruk Formation in the Wolverine Creek sequence. In southernmost Rok fenster the Kogruk Formation intertongues eastward with laminated black shale and laminated to medium-bedded black chert of the Kuna Formation. Overlying the Kogruk Formation in both Mount Raven and Rok fensters is a 9- to 30-m-thick zone of thin- to medium-bedded black chert and subordinate silicified carbonate. This zone is provisionally assigned to the Tupik Formation (Sable and Dutro, 1961). The bedded black cherts of the Wolverine Creek sequence are considered to represent a combination of primary biogenic silica deposition and selective silica replacement of pre-existing planar carbonate beds.

The black chert and silicified carbonate unit is conformably overlain by 92 to 120 m of laminated to thin-bedded gray, greenish-gray, and maroon shale and radiolarian chert of the Siksikpuk Formation (Patton, 1957; Mull and others, 1982; Ellersieck and others, 1990). The age of the Siksikpuk Formation in the Wolverine Creek sequence is uncertain but certainly includes Permian. On average, the basal Siksikpuk Formation in the Wolverine Creek sequence is shale dominant, with increasing chert content upsection as per the Brooks Range allochthon. However, the Siksikpuk Formation in the Wolverine Creek sequence displays unique sedimentary features not recognized in this formation in any of the structurally higher sedimentary allochthons in the western De Long Mountains: 1) Very rare intraformational shale-pebble conglomerate occurs in the upper half of the formation. 2) Barite rosettes (normally broadly disseminated in higher allochthons) are concentrated enough to form discrete beds up to 15 cm thick in shale in the middle of the Siksikpuk Formation. 3) Thinly laminated silver-, lead-, and zinc-rich copper sulfide layers are locally distributed in upper Siksikpuk Formation baritic shale. 4) Locally, at the base of the Siksikpuk Formation in the Wolverine Creek sequence, is a distinctive 4.6- to 9.1-m-thick unit of yellowish-weathering, light-colored laminated shale that is sometimes manganiferous and lenticular cleaving. This unit, informally called the yellow shale unit, is not to be confused with the reddish-orange weathering, chert-bearing unit that occurs regionally at the base of the Siksikpuk Formation in the Brooks Range allochthon (Moore and others, 1986).

In at least one locality in Mount Raven fenster the yellow shale unit is underlain by a silty unit consisting of 24 m of thinly laminated to thin-bedded flaggy-gray to dark-gray silty dolomicrite, noncalcareous to weakly calcareous,

moderately to strongly indurated fine-grained gray siltstone, silty shale, and silty(?) chert; current ripples, mudchips, and bioturbation(?) characterize the unit. The silty unit grades upsection to Siksikpuk-type shale and chert and abruptly downsection to dark chert and silicified carbonate mapped as Kogruk Formation by Ellersieck and others (1990). The silty unit is superficially analagous to the pyritic green siltstone reported at the base of the Siksikpuk Formation on the Endicott Mountains allochthon by Siok (1985) 330 km east of Mount Raven fenster. This correlation should be viewed with caution, as probable equivalents to the Endicott Mountain allochthon in the study area (Brooks Range allochthon) are hundreds to thousands of meters structurally upsection of the Wolverine Creek sequence. Also, the observations of Siok (1985) reflect the expected eastward Permo-Triassic facies transition in the allochthons, from distal Siksikpuktype to proximal Sadlerochit-type facies; this relationship does not apply 330 km farther west.

Overlying the Siksikpuk Formation is a 47-m-thick unit that consists (in ascending order) of rusty-weathering laminated to thin-bedded black, green, or creamy shale, variegated chert, dark micrite, and dolomicrite; thin-bedded gray radiolarian chert; and thin-to medium-bedded gray dolomitic chert and Monotis-bearing dolomitic limestone. This unit is correlated with the Lower Triassic to Middle Jurassic Otuk Formation (Mull and others, 1982; Ellersieck and others, 1990), which contains the same subdivisions.

The Otuk Formation contains a distinctive marker horizon located at or just downsection from the contact between the gray radiolarian chert unit and the overlying carbonate unit (fig. 7). This marker horizon consists of 1.2 to 2.4 m of (supergene) jarosite-stained laminated to thin-bedded black chert with thinly laminated black shale partings, commonly topped by a single thin bed of white (bentonitic?) clay. Locally, in northern Rok fenster, a +10-m-thick(?) unit of medium-bedded to laminated black chert and laminated black shale overlies the Monotis-bearing unit. This dark facies compares lithologically and stratigraphically to the Blankenship Member (Mull and others, 1982) of the Otuk Formation. Greenish lenticular mudstone and silty chert with fetid barite nodules locally overlie the Otuk Formation. No precise stratigraphic counterpart to this baritic unit is known locally or regionally; it might be an unusual facies variant of the Ipewick Formation.

The stratigraphically highest unit in the Wolverine Creek sequence consists of a basal assemblage of hundreds of meters of dark mudstone overlain by hundreds—possibly thousands—of meters of alternating fine-grained graywacke and dark mudstone. This is correlated with the Neocomian Okpikruak Formation (Ellersieck and others, 1990), which unconformably or disconformably overlies all other formations. The Okpikruak Formation of the Wolverine Creek sequence is commonly tectonically disrupted, forming a distinctive unit consisting of small siltstone boudins "floating" in black mudstone.

BROOKS RANGE ALLOCHTHON

The Brooks Range allochthon structurally overlies Okpikruak Formation of the Wolverine Creek sequence along a thrust fault (Moore and others, 1986). In the central Brooks Range this allochthon is known as the Endicott Mountains allochthon (Mull, 1982; Siok, 1985). East of the study area is the Ivotuk Sequence (Martin, 1970), a possible facies variant of the Brooks Range allochthon.

Two stratigraphically distinguishable thrust panels are present in the Brooks Range allochthon in the study area, and are contrasted in Moore and others (1986). The base of the Brooks Range allochthon in the study area (fig. 6) is defined by 276+ m of fluvial-deltaic gray, greenish gray, and maroon chert-quartz pebble conglomerate, quartzitic sandstone, siltstone, and argillite. These units are variously assigned to the Upper Devonian Hunt Fork Shale and Noatak Sandstone or Upper Devonian to Lower Mississippian (?) Kanayut Conglomerate (Smith, 1913; Nilsen and others, 1985; Moore and others, 1986; Ellersieck and others, 1990).

Conformably above the fluvial-deltaic assemblage is 61 to 123+ m of thinly laminated to thin-bedded gray to black concretionary shale, siltstone, and limestone of the Lower Mississippian Kayak Shale in the upper thrust panel or laminated dark calcareous shale-calcarenite turbidite of the lower Kuna Formation in the lower thrust panel (Mull and others, 1982; Moore and others, 1986; Ellersieck and others, 1990). These facies grade upwards to 45 to 112 m of thinly laminated to laminated black shale and subordinate sandy carbonate turbidites, which are overlain by laminated to medium-bedded black radiolarian chert (and micrite in the upper thrust panel), all within the Upper Mississippian to Pennsylvanian upper part of the Kuna Formation (Mull and others, 1982; Moore and others, 1986; Ellersieck and others, 1990).

The Siksikpuk Formation conformably overlies the Kuna Formation along a light chert - dark chert redox boundary. Three chert samples collected from the Kuna-Siksikpuk Formation contact and the basal orange-weathering zone of the Siksikpuk Formation south of Mount Raven fenster contain Upper Mississippian to Lower Pennsylvanian radiolarians (I. Tailleur, pers. commun., 1989). If the work of Mull and others (1982) and Ellersieck and others (1990) is considered, the possible age of the Siksikpuk Formation in the Brooks Range allochthon of the study area ranges from Pennsylvanian to Permian or Lower Triassic. However, this conclusion is not supported by faunal data on the Endicott Mountains allochthon, which shows the Siksikpuk Formation to be entirely Permian (C.G. Mull, written commun., 1992). The Siksikpuk Formation in the Brooks Range allochthon totals 68 m, consisting of: basal variably pyritic or marcasitic, orange-weathering thin- to medium-bedded gray radiolarian chert with subordinate gray to white laminated shale, overlain by laminated gray, greenish-gray, and maroon shale, all capped by thin- to medium-bedded gray and maroon radiolarian chert (Moore and others, 1986). The Otuk Formation of the Brooks Range allochthon is the same as described for the Wolverine Creek sequence, with the exception that the Brooks Range allochthon contains less carbonate in the Monotis-bearing unit.

The Jurassic to Lower Cretaceous Ipewik Formation locally overlies the Otuk Formation in the study area, although it is often absent against the Lower Cretaceous unconformity. The Ipewik Formation consists of a diverse assemblage of maroon, green, and gray shale or mudstone, siltstone with local dendritic feeding traces, distinctive redbrown weathering coquinoid limestone with Valanginian pelycypods, silty chert, and diagnostic light-colored fine-grained arenite (Crane and Wiggins 1976; Moore and others, 1986; Ellersieck and others, 1990).

The Neocomian Okpikruak Formation is everywhere present at the top of the Brooks Range allochthon in the study area. It consists of hundreds of meters of fine- to coarse-grained graywacke, dark lenticular-cleaving mudstone, and polymictic pebble to boulder conglomerate, which grades laterally to major polylithic olistostromal deposits (Moore and others, 1986). The olistostromal deposits are highly variable, but include meter- to kilometer-scale slabs of mafic igneous rocks, limestone, chert, and arkosic limestone of the Nuka Formation. Olistoliths of Nuka Formation arkosic limestone from Okpikruak Formation in the Brooks Range allochthon contain conodonts with color-alteration indices (CAI) of 2.5 to 3 (Mayfield and others, 1990); conodonts from in-situ Nuka Formation of the Nuka Ridge allochthon (fig. 3) southwest from the study area have a CAI of 1.0 (A.G. Harris, written commun., 1984). Another variant of the olistostromal unit consists of debris flows of angular clast-supported Monotis-bearing chert of the Otuk Formation, Permian(?) chert, and Mississippian(?) black chert.

KELLY RIVER ALLOCHTHON

The Kelly River allochthon is exposed south, east, and north of Mount Raven fenster. A moderately to severely tectonized unit of massive limestone of the Upper Devonian Kugururok Formation forms the structural base of the Kelly River allochthon just east of the map area (Sable and Dutro, 1961; Curtis and others, 1990). The Kugururok Formation lies structurally above Okpikruak Formation of the Brooks Range allochthon along a thrust fault, although structural remnants of chert and carbonate of the Picnic Creek(?) allochthon are locally recognized along this contact.

Overlying the Kugururok Formation are 123 to 184 m of orangish-weathering thin- to thick-bedded reworked fossiliferous carbonate and sandy carbonate of the Lower Mississippian Utukok Formation (Curtis and others, 1990; Ellersieck and others, 1990). The Utukok Formation is conformably overlain by about 184 m of medium-bedded to massive fossiliferous limestone and subordinate brown patchy replacement chert of the Upper Mississippian Kogruk Formation. The generally nonsiliceous limestone and light-brownish impure chert of Kogruk Formation in the Kelly River allochthon contrasts strongly with the intensely silicified limestone and dark-brown to black chert in the Kogruk Formation of the Wolverine Creek sequence. The structurally lower thrust panel of the Kelly River allochthon (fig. 4) contains a facies variant consisting of laminated micrite and black shale at the base of the Kogruk Formation (Curtis and others, 1990). A unit of dark chert and subordinate shale of the Upper Mississippian and younger(?) Tupik Formation overlies the Kogruk Formation east of the map area (Sable and Dutro, 1961).

Overlying the Kogruk or Tupik Formations are 60 to 107 m of light-colored variegated thin-bedded radiolarian chert and subordinate shale of the Pennsylvanian to Lower Jurassic Etivluk Group (Mull and others, 1982). This relatively condensed chert-rich section contrasts with the thicker and more shale-rich section that overlies Kogruk Formation of the Wolverine Creek sequence or Brooks Range allochthon. The Ipewik Formation is not recognized in

the Kelly River allochthon (Mayfield and others, 1988). Graywacke of the Okpikruak Formation represents the youngest formation of the Kelly River allochthon; it is little studied in the map area and detailed descriptions are not available.

FACIES VARIATIONS BETWEEN THE ALLOCHTHONS

Generally, the Wolverine Creek sequence, and Brooks Range and Kelly River allochthons represent progressively more distal sedimentary environments (fig. 6). An important exception is during Late Mississippian time, when extension and block faulting were prevalent (Moore and others, 1986). Upper Devonian to Lower Mississippian facies of the Wolverine Creek sequence and Brooks Range allochthon commonly contain more clastic material and less carbonate than coeval facies in the Kelly River allochthon. The Pennsylvanian to Lower Jurassic assemblage in the Wolverine Creek sequence and Brooks Range allochthon contains thicker shale intervals and less authigenic (chert) deposits than coeval facies in the Kelly River allochthon, with the Wolverine Creek sequence containing the thickest and most proximal clastic assemblage of the three. In Early Cretaceous time, when the clastic transport regime was reversed, the Wolverine Creek sequence received a finer grained clastic (graywacke) assemblage and little or none of the polymict conglomerate and olistostromal material of the Brooks Range allochthon.

The progressively distal character of the Wolverine Creek sequence, Brooks Range allochthon, and Kelly River allochthon suggests that each represents a progressively more outboard strip of a south-facing pre-Brookian passive continental margin, which generally agrees with the conclusions of Mayfield and others (1988).

STRUCTURE

INTRODUCTION

The Okpikruak Formation is a definitive guide to the footwall of thrust-fault planes between allochthons (or intraallochthon thrust sheets). In the western De Long Mountains, thrust-fault planes most commonly display Devonian or Mississippian formations in the hanging-wall and Okpikruak Formation in the footwall. The dip or fabric of hangingwall and footwall formations is typically concordant or semiconcordant to the plane of the thrust fault. In drill cores, the fault planes vary from razor thinness to tens of meters thick and are associated with varying thicknesses of gouge and mylonite-textured rock. In addition to stratigraphic and faunal observations, the evidence for thrust faults includes mylonitic fabrics, boudinaged competent beds or broken formation in the footwall and (more rarely) in the hanging wall of the fault plane.

The north-vergent aspect of Brookian deformation in the western Brooks Range is indicated by south-to southeast-dipping thrust fault planes which cut upsection to the north, southward-tapering thrust fault wedges, east-west or northeast-southwest trending fold axes, and overturned isoclinal folds with south-dipping axial planes.

LOCAL STRUCTURE

One tectonically disrupted thrust sheet and one relatively more coherent thrust sheet(?) of the Wolverine Creek sequence is documented in Mount Raven fenster (fig. 4). The two(?) thrust sheets are also present within Rok fenster. The structurally highest thrust sheet is disrupted and typically consists of stratigraphically correct attenuated stratigraphy or tectonic melange composed of Kogruk, Siksikpuk, and Otuk Formation lithologies within a matrix of flysch of the Okpikruak Formation. Siksikpuk and Otuk Formations of the structurally highest thrust sheet are not demonstrable at map scale (fig. 4). The absence of exotic lithologies such as arkose or igneous rocks and presence of structural fabric (boudinage and "mylonite") suggests a tectonic (vs. olistostromal) origin for this melange. An example of the discontinuous nature of the structurally highest thrust sheet is demonstrated by three widely separated wedges of Kogruk Formation along the northwestern margin of Mount Raven fenster (fig. 4). The disrupted structurally highest thrust sheet has a minimum thrust translation of 15 km; its demonstrable partial involvment in north-northwest/south-southeast compression suggests it is a Brookian feature. This thin but widespread disrupted thrust sheet is evidence that at least a part of the Wolverine Creek sequence is not autochthonous sensu stricto.

The structurally lower thrust sheet(?) volumetrically and areally dominates Mount Raven fenster and is the floor of the Wolverine Creek sequence in Mount Raven and Rok fensters. Within this thrust sheet(?), rock units are less

disrupted and laterally more continuous than in the upper thrust sheet. Although this lower sequence is not unequivocally allochthonous, it is internally thrusted and folded. Many folds are interpreted to be overturned to the north with southward-dipping axial-plane thrusts.

STRUCTURAL CHRONOLOGY

Structure within the study area is dominated by possibly five local to regionally extensive episodes, which are listed in speculative chronological order based on apparent order of superimposition:

- North-vergent Brookian thrust faulting, evidenced by complete regional juxtaposition of northward-younging allochthons
- 2. North- to northwest-vergent Brookian compression, which folds the previously gently dipping(?) thrust fault planes of episode one (as expressed by major northeast-trending synforms-antiforms that affect all structural levels) and includes the major northeast-trending antiform which elongates Mount Raven fenster and a series of smaller northeast-trending upright and overturned folds. Northwest-southeast Brookian compression is supported by 210 joint-plane measurements in and near the study area.
- Right-lateral wrench faulting, illustrated by the Wrench Creek and Sivukat Mountain faults. Large-scale rightlateral drag of earlier formed (originally northeast-trending) folds adjacent to the Wrench Creek fault northwest of the map area is permissive evidence that right-lateral movement postdates Brookian compression
- 4. Northeast-directed compression (of the Tigara uplift; fig. 1), which is manifested by (a) northwest-trending thrust scarps and upright and overturned northwest-trending folds, including the broad ill-defined northwest-trending folds that elongate the southern half of Mount Raven fenster and all of Rok fenster, and (b) northeast-vergent thrust-fault panels with northeast-striking sedimentary beds. Thrust-fault vergence is based on the interpretation that thrust-fault planes cut upsection to the northeast and that some thrust wedges exhibit a southwest-tapering geometry. Evidence that the Tigara uplift postdates Brookian deformation (sensu lato) is provided by southwest-dipping cleavage superimposed on the main northwest-dipping (Brookian) fold limb of Mount Raven fenster and by northwest-trending thrust scarps that may cut across northeast-trending thrust scarps.
- 5. Northeast-southwest extension and down-to-the-southwest movement along the older Wrench Creek fault trace, as manifested by linear segments where the upper part of the Wolverine Creek sequence or structurally higher allochthous are downthrown against Kogruk Formation along the south margin of Mount Raven and Rok fensters (figs. 2, 4, 8, 9). Episodes 3 and 5 might be reconciled by a single episode of divergent wrench faulting.

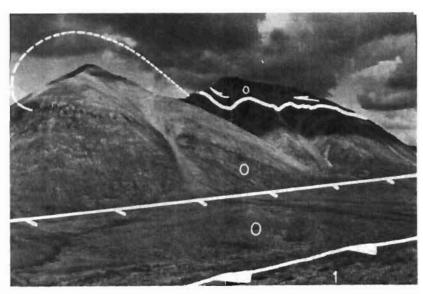


Figure 8. View to northeast at Mount Raven (right peak) showing selected geologic features. The Brooks Range allochthon (1) in right foreground is thrust over the Wolverine Creek sequence (0). The Wrench Creek fault (hachures on downthrown side) defines the southern limit of Kogruk Formation in Mount Raven fenster.

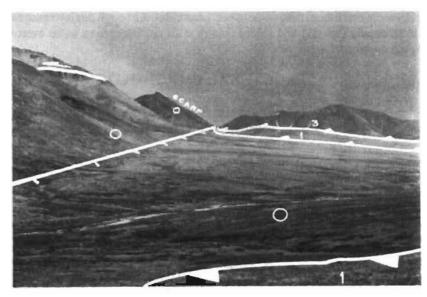


Figure 9. View to southeast showing prominent footwall scarp faces related to the Wrench Creek fault. Note the hanging-wall drag effects, evidenced by near pinchout of Brooks Range allochthon (1) between Kelly River allochthon (3) and Wolverine Creek sequence (0) in notch at background center.

WRENCH CREEK AND SIVUKAT MOUNTAIN FAULTS

The Wrench Creek fault plane dips steeply southwest, cuts parallel to adjacent bedding planes in the underlying Wolverine Creek sequence, and steeper than average bedding planes in the overlying Brooks Range and Kelly River allochthons (figs. 4, 5, 9). The fault is postulated to have right-lateral slip of unknown magnitude and is downthrown at least hundreds of meters on the southwest side. Individual formations within the downthrown block display related drag effects adjacent to the Wrench Creek fault, including thinning and dip convergence with the fault plane. Because of this process, the Brooks Range allochthon is absent and the Kelly River allochthon lies directly on the Wolverine Creek sequence along the eastern part of the fault trace (figs. 4, 5, 9). This fault is part of the "Wrench Creek transcurrent fault zone" of Martin (1970). A similar parallel fault that defines the southern margin of Rok fenster 23 km southwest of Mount Raven (fig. 2) is part of the "Sivukat Mountain transcurrent fault zone" of Martin (1970). Both faults cut more than one thrust sheet or allochthon and thus are not simple tear faults.

The Wrench Creek and Sivukat Mountain faults are part of a larger set of regionally extensive northwest-trending linears that are visible on aerial photographs and which transect the western Brooks Range. In contrast with the Wrench Creek fault, which displays right-lateral drag features on aerial photographs, the Sivukat Mountain fault shows no obvious drag features, but some of the more easterly trending en-echelon folds in southern Rok fenster may be attributed to right-lateral slip on this fault. Latest (extensional?) movement on these structures is possibly Albian or younger, as suggested by an extension of the Wrench Creek fault, which can be seen on aerial photographs to extend from Mount Raven fenster through the Brooks Range foothills and across outcrops of Albian-age Fortress Mountain Formation (Mayfield and others, 1990), 48 km to the northwest.

CONTACT ZONE OF THE WOLVERINE CREEK SEQUENCE AND BROOKS RANGE ALLOCHTHON

Except in the vicinity of the Wrench Creek fault, bedding measurements in Mount Raven fenster suggest that outcrops nearest to the contact between the Wolverine Creek sequence and the structurally overlying Brooks Range allochthon dip between 5° and 55°, averaging 30°. However, since the fault plane is not everywhere concordant to bedding in the hanging-wall and footwall formations, these measurements are only an approximate guide to dip of the fault plane. The fundamental nature of the thrust contact between the Wolverine Creek sequence and Brooks Range allochthon is

shown by intense regional deformation of the upper part of the Wolverine Creek sequence below the Brooks Range allochthon. Near the thrust plane, Okpikruak Formation of the Wolverine Creek sequence contains rootless elongated slivers of Kogruk, Siksikpuk, and Otuk Formation lithologies up to 0.8 km long. Deformation on a local scale is demonstrated by boudinaging of silty layers in the Okpikruak Formation of the Wolverine Creek sequence over a vertical distance of hundreds of meters, and by complex interleaving of rock types from different formations over tens to hundreds of meters. In extreme cases, the latter boudinage is associated with a very finely imbricated polylithic aggregate with "mylonitic" texture. The thrust contacts of the Wolverine Creek sequence, Brooks Range allochthon, and Kelly River allochthon on the north side of Mount Raven fenster are illustrated in figure 10. The relationship between the Mount Raven and Rok fensters is shown in figure 11.

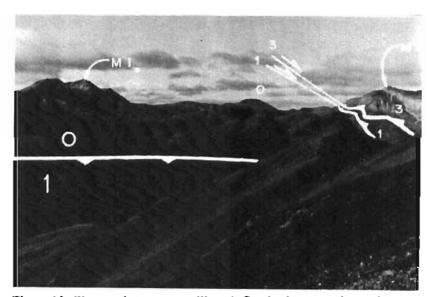


Figure 10. Westward view across Wrench Creek, showing relationships on north side of the Mount Raven fenster. Note the dark-light contrast between coeval Kogruk Formation (MI) of the Wolverine Creek sequence (0) and Kelly River allochthon (3). More abundant chert and silicification causes the darker coloration in Kogruk Formation of the Wolverine Creek sequence.

Further evidence of the fundamental nature of the fault contact between the Wolverine Creek sequence and Brooks Range allochthon is indicated by numerous widely separated clusters of hydrogen-sulfide-charged springs that are located near the bounding fault throughout the map and study areas. These springs are suggestive of considerable vertical or lateral fluid movement (or both) along the fault contact between the Wolverine Creek sequence and the Brooks Range allochthon.

GEOPHYSICS

Magnetic profiles and contoured magnetic maps suggest that the Mount Raven and Rok fensters are located along a regional positive magnetic feature. A magnetic profile by Tailleur (1970) and contoured magnetic map by Geoterrex, Ltd. (1981) demonstrate a uniform positive magnetic gradient northward across the study area. On a regional contoured magnetic map (Decker and Karl, 1977) the Mount Raven and Rok fensters approximate the southeastern edge of a northwest(?)-trending magnetically positive feature which is centered near Mount Kelly, 36 km northwest of Mount Raven. Also, a CS-AMT (Controlled-source audio-magnetotelluric) survey conducted across the Wrench Creek fault on the south side of Mount Raven fenster indicates a relatively abrupt (positive) resistivity gradient northward from the fault trace (unpublished Cominco American Incorporated files).

The areal extent and relative strength of the positive magnetic anomaly is permissive evidence for uplifted basement in the subsurface, perhaps reflecting the presence of a regional northwest-trending antiformal basement feature. The relationship of the Wrench Creek fault and Mount Raven and Rok fensters to the positive magnetic anomaly

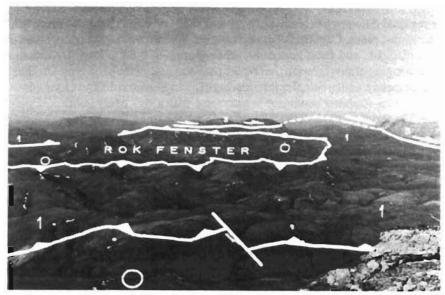


Figure 11. View south from the top of Mount Raven, showing the relationship between Mount Raven fenster (foreground) and northwestern Rok fenster.

warrants further investigation. The abruptly higher resistivities indicated by the AMT survey northeast from the Wrench Creek fault support the geologic conclusion that Okpikruak Formation (relatively less resistive) on the southwest side of the fault is downthrown against the more resistive, silicified Kogruk Formation to the northeast.

DISCUSSION

The Wolverine Creek sequence in the Mount Raven and Rok fensters is stratigraphically comparable to the Upper Paleozoic part of the parautochthonous Lisburne Hills sequence, 125 km to the northwest. Features in common include: 1) lithologically similar Carboniferous stratigraphy, especially with regard to the Nasorak Formation (including the Cape Thompson member) and Kogruk Formation of the southern Lisburne Hills as viewed by the author and described by Campbell (1967); 2) a zone of chert-rich breccia or silicified (nebulous-textured) bioclastic material near the top of the Kogruk Formation; 3) a relatively shale-rich Pennsylvanian to Triassic section above the Kogruk Formation; 4) a local calcareous siltstone and yellow shale unit near the base of the Siksikpuk Formation; 5) the four divisions of the Otuk Formation; and 6) abasal mudstone-dominant Lower Cretaceous section (see Ogotoruk Formation of Campbell 1967).

The sub-Mississippian unconformity of the Lisburne Hills sequence is not recognized in the Wolverine Creek sequence. If the laminated quartzitic siltstone and sandstone at the exposed base of the Wolverine Creek sequence is Noatak Sandstone (as favored by the author and by Ellersieck and others, 1990), rather than the basal sandstone member of the Kayak Shale (Bowsher and Dutro, 1957) or Kapaloak Sequence (Moore and others, 1984), then the unconformity is probably absent and the Wolverine Creek sequence is stratigraphically linked with the allochthonous sequences.

However, there are important differences between the Wolverine Creek and Lisburne Hills sequences. The Mississippian section of the Lisburne Hills sequence (Campbell, 1967; Moore and others, 1984) is thicker than coeval(?) stratigraphy in the Wolverine Creek sequence. Color-alteration indices for conodonts from the Wolverine Creek sequence are typical of those of structurally lower allochthons of the forward part of the thrust belt, being in the range of 3-4 (Harris and others, 1983; A.G. Harris, written commun., 1984; Ellersieck and others, 1990); they are higher than the average range of 1-2.5 for both the post-Silurian conodonts of the Lisburne Hills (Harris and others, 1983) and the autochthonous sequence of the Colville Basin (North Slope) subsurface (Harris and others, 1987). This indicates a different thermal history for the Wolverine Creek sequence than the Lisburne Hills and the autochthonous sequences of the forelands. In addition, the Wolverine Creek sequence has been strongly affected by a northerly vergent Brookian compressional event, which is lacking—or not as well developed or preserved—in the Lisburne Hills sequence.

CONCLUSIONS

The Siksikpuk Formation in the Wolverine Creek sequence is thicker and contains a local coarser grained facies (silty unit) that distinguishes it from coeval rocks in the structurally overlying Brooks Range allochthon. This difference, coupled with the pronounced facies differences between the Wolverine Creek sequence and Brooks Range allochthon in Late Mississippian and perhaps Neocomian time, suggests that the Wolverine Creek sequence and Brooks Range allochthon are stratigraphically distinct assemblages. The evidence for the allochthonous character of the Wolverine Creek sequence consists primarily of its apparent involvement in Brookian deformation, as indicated by northerly vergent(?) folds, and thrust faults with over 15 km displacement. Because the rocks of the Wolverine Creek sequence are the structurally lowest assemblage exposed in the area, confirmation of the basal relationships await seismic studies and deep drilling. Also, the lack of a laterally extensive coarse-clastic Permian to Triassic facies (as per the Sadlerochit Group) in the Wolverine Creek sequence is evidence that the Wolverine Creek sequence is not stratigraphically comparable to either the autochthonous sequence of the North Slope or the parautochthonous sequence exposed in the Doonerak and Schwatka Mountains windows in the central to southern Brooks Range (illustrated by Mull, 1982). By contrast, the Upper Mississippian and younger stratigraphy of the Wolverine Creek and parautochthonous Lisburne Hills sequences have important stratigraphic similarities.

By using present coordinates, the Upper Paleozoic part of the Lisburne Hills sequence is proposed to be an eastward-(thrust) transported facies equivalent of the Wolverine Creek sequence. In late Paleozoic time the Wolverine Creek sequence represented a part of a continuous strip of the passive continental margin situated south of the area affected by the sub-Mississippian orogeny. In contrast, the more northwesterly Lisburne Hills sequence was situated within the area affected by the sub-Mississippian orogeny, but farther west of the autochthonous sequence than at present.

From Late Mississippian to Early Cretaceous time the Wolverine Creek and Lisburne Hills sequences shared similar depositional regimes. During the Pennsylvanian or Permian to Triassic interval, both sequences received dominantly fine-grained clastic rocks and chert because they were situated south and west, respectively, of the coarseclastic apron of the Sadlerochit Group, which characterizes the autochthonous sequence. During subsequent Upper Jurassic to Cretaceous Brookian deformation, the frontal thrust was aligned along the southern margin of the area affected by the sub-Mississippian orogeny. The Wolverine Creek sequence, Brooks Range allochthon, and other structurally higher allochthons that lack the sub-Mississippian unconformity were thrust northward over the autochthonous sequence, moving the Wolverine Creek sequence closer to the Lisburne Hills sequence. The higher conodont color-alteration indices of the Wolverine Creek sequence reflect the structurally low position of this sequence in the Brookian orogen as opposed to the Lisburne Hills sequence. Younger post-mid-Cretaceous east-vergent thrusting of the Tigara uplift, contemporaneous with northeast compression of Mount Raven fenster, further closed the distance between the parautochthonous Lisburne Hills sequence and the Wolverine Creek sequence. This hypothesis supports the interpretations that the Lisburne Hills sequence is parautochthonous (Moore and others, 1984) and within the sub-Mississippian orogenic regime, yet lithologically similar to the upper Paleozoic and lower Mesozoic parts of the allochthonous sequences (Mayfield and others, 1988). The evidence in this report further refines this hypothesis by demonstrating that the upper Paleozoic to lower Mesozoic part of the Lisburne Hills sequence resembles the Wolverine Creek sequence more strongly than the stratigraphy of the Brooks Range or Kelly River allochthons of the western Brooks Range.

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