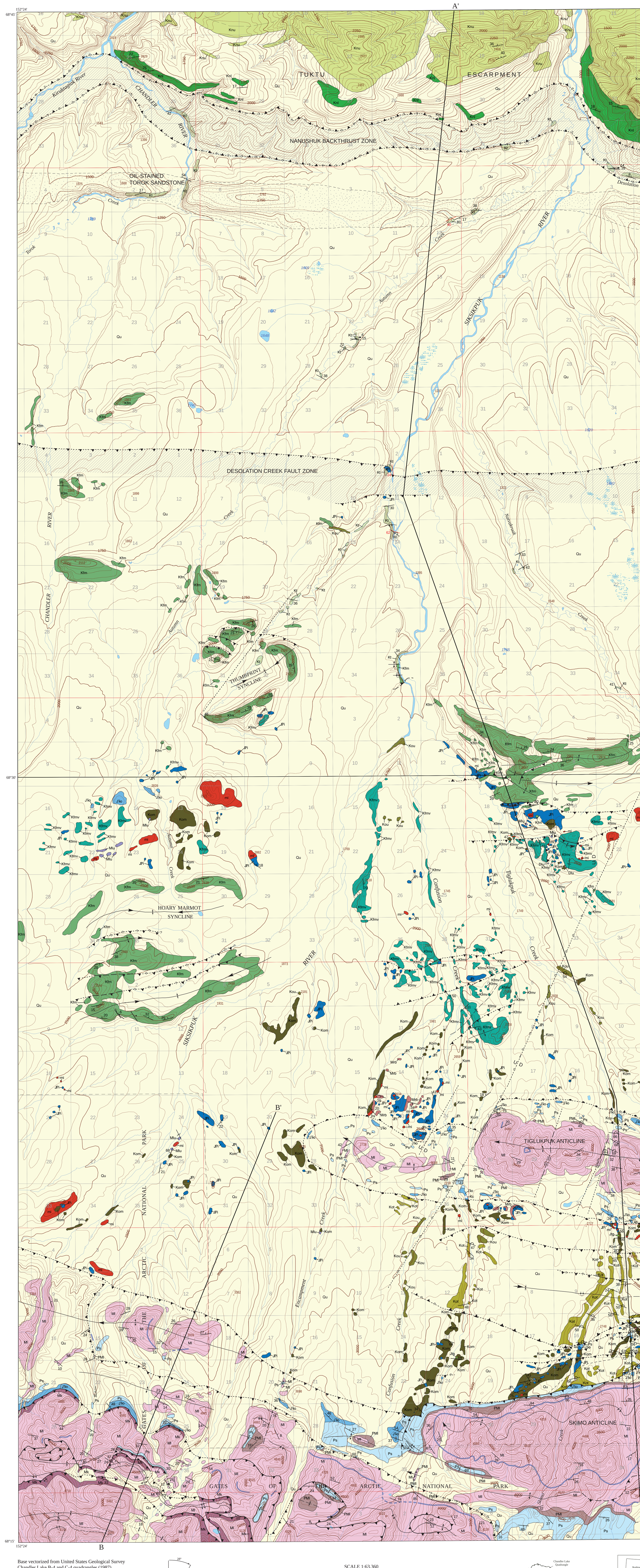
ALASKA DIVISION OF GEOLOGICAL &
GEOPHYSICAL SURVEYS

PRELIMINARY INTERPRETIVE REPORT 2007-1
PEAPPLES *et al.*



Base vectorized from United States Geological Survey
Chandler Lake B-4 and C-4 quadrangles (1987).
Universal Transverse Mercator projection, zone 5.
1927 North American Datum

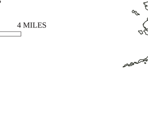
TRUE NORTH
MAGNETIC NORTH
28°
APPROXIMATE MEAN
DECLINATION, 1971

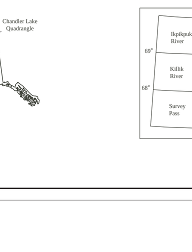
SCALE 1:63,360

1 0 1 2 3 4 5 KILOMETERS

1 .5 0 1 2 3 4 MILES

CONTOUR INTERVAL 50 FEET NORTH OF 68°30'; 100 FEET SOUTH OF 68°30'





DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Qu — **Surficial Deposits, undifferentiated** (Quaternary)—Includes alluvium, terrace gravel, outwash, fan deposits, and glacial drift of Itkillik, Sagavanirktok, and Anaktuvuk age. See Hamilton (1979) for description and distribution.

BEDROCK DEPOSITS

SYNTECTONIC DEPOSITS AND DEPOSITS OF THE COLVILLE BASIN FOLDBELT

Nanushuk Formation—(revised nomenclature, Mull *et al.*, 2003) Upper unit dominantly nonmarine sandstone, conglomerate, siltstone, shale, and coal. Lower unit dominantly marine sandstone, siltstone, and shale.

Knu — **Nanushuk Formation, upper part** (Cenomanian to Albian)—Sandstone, medium gray to yellowish brown, fine- to coarse-grained, thin- to thick-bedded lithic and chert arenite, and local conglomerate and conglomeratic sandstone; forms resistant beds and rubble traces. Interbedded recessive rocks, which make up the greater thickness of the upper unit, consist of dark gray clay shale, carbonaceous shale, silty shale, siltstone, and local coal beds. Framework grains in sandstones consist dominantly of quartz and chert, with lesser amounts of lithic fragments and detrital feldspar; cemented with silica and, less commonly, calcite. Conglomerate clasts are predominantly subrounded pebbles and cobbles of white quartz and black, gray, greenish-gray, and maroon chert, with local ironstone (siderite), coal, gray sandstone and quartzite, argillite, and mafic igneous rocks. Sandstones generally upward-fining and -thinning successions of sandstone with plane-parallel beds and laminae, tabular and trough cross-stratification, asymmetrical ripple cross-lamination and bedforms, and basal channel scours; upward-coarsening and -thickening sandstone successions present locally within recessive-weathering silty shale and siltstone succession. Sandstone bodies up to 30 m thick pinch out laterally over 1–2 km in silty shale and siltstone. The upper Nanushuk represents deposition in lower delta plain, fluvial, and alluvial flood-basin settings. The top of Nanushuk is not exposed in map area. Thickness: 600 m immediately north of map area (Ahlbrandt *et al.*, 1979); up to a few hundred meters thick in northernmost part of map area.

Knl — **Nanushuk Formation, lower part** (Albian)—Sandstone, siltstone, silty shale, and minor clay shale. Sandstone is light- to medium green-gray to light yellowish-brown, fine- to medium-grained, thin- to medium-bedded, locally thick-bedded, lithic arenite. Mudstone and orange-brown siderite rip-up clasts are present at the base of many sandstone beds. Interbedded dark-gray, fissile to chippy weathering silty shale and medium- to dark-gray siltstone; medium-gray clay shale and dark-gray carbonaceous shale present locally. Lithologies are arranged in upward-coarsening and -thickening successions capped by sandstone with a variety of sedimentary structures, including plane-parallel lamination, current- and wave-ripple cross-lamination, and current and wave ripple bedforms, hummocky and swaley cross-stratification, large- and small-scale trough cross-stratification and, locally, planar-tabular and tangential cross-stratification. Macrofossils are common and include marine pelecypods and ammonites. Biogenic structures are common, and include *Teichichnus*, *Diplocraterion*, *Rhizocorallium*, *Planolites*, *Paleophycos*, *Schaubcylindrichnus*, and *Rosselia*, among others. Coalified plant fragments and impressions are locally common. The lower Nanushuk represents deposition in shoreface, delta-front, and prodelta settings. Upward intertonguing of marine and marginal-marine strata marks transition to upper Nanushuk. Sandstones generally tight, porosity <10 percent, permeability <1 md (Ahlbrandt *et al.*, 1979). Thickness: 250–300 m.

Kt — **Torok Formation** (Albian to Aptian; Gryc *et al.*, 1951; Patton, 1956)—Silty shale, siltstone, and minor shale and sandstone. Silty shale and shale are dark gray, fissile to chippy weathering, and commonly include millimeter-scale laminae and bed-parallel calcareous concretions. Interbedded siltstone and sandstone are green-gray to gray-brown weathering, thin- to medium-bedded; commonly include graded bedding, current-ripple cross-lamination and bedforms, convolute bedding, load casts, groove and minor flute casts, rip-up clasts of silty shale, and scattered coalified plant fragments <2 cm in length. Cone-in-cone structure locally common in siltstone. Biogenic structures limited to *Planolites* and less common *Paleophycos* burrows. Thick succession of amalgamated sandstone and granule conglomerate turbidites and associated gravity flow deposits exposed on the east bank of the Chandler River in the lower half(?) of the Torok at the type section. Succession extends west and east of the Chandler River; extends east of the map area at least to Desolation Creek. Strong to faint hydrocarbon odor present in many beds from this succession and solid hydrocarbon is locally common. Sandstone and conglomerate in the amalgamated succession appear very similar to sandstone and granule conglomerate near the top of the Fortress Mountain Formation at Castle Mountain, 15 miles to the west, a characteristic originally noted by Molenaar (1988). Oil-stained sandstone and solid hydrocarbon within an amalgamated sandstone interval is present at two localities on the west side of Autumn Creek. Similar staining in sandstone along Desolation Creek east of the map area and on the Chandler River to the west define a trend of >15 miles lateral extent (Houseknecht and Schenk, 2006). This interval may be up to 800 feet thick (unpublished measured section by D. LePain; Mull *et al.*, 2003), although structural detachment just to the north makes thickness estimation uncertain. The presence of hydrocarbons suggests the Torok was once a hydrocarbon reservoir but has been breached, probably during Tertiary backthrusting. This interval has further regional implications for source rock distribution and hydrocarbon migration pathways and timing. The Torok is a thick outer shelf (prodelta), slope, and basinal succession. Outer shelf deposits near the top of the unit intertongue with the lower Nanushuk in the northernmost part of the map area, at Tuktu Escarpment. Thickness: greater than 6,000 m, based on seismic data; the base of the unit is not exposed in the map area.

Kfm — **Fortress Mountain Formation** (Albian to Hauterivian [?]; Patton and Tailleur, 1964)—Gray to light green-gray conglomerate and sandstone interbedded with medium gray siltstone and dark gray silty mudstone. The coarser-grained facies typically form linear ridges framing broad folds with conspicuous, inwardly-plunging synclines ("thumbprint" map pattern). Maximum grain size decreases markedly to the north, grading basinward into the Torok Formation (*e.g.* Detterman *et al.*, 1963). The top is nearly everywhere a Holocene erosional surface and the formation unconformably overlies tectonized Okpikruak mélange consisting of chaotic blocks of chert, mafic igneous rocks, and limestone. Regional relationships suggest it may also locally overlie coherent Okpikruak Formation (Mull, 1985). The basal contact is nowhere well exposed, but may represent an erosional unconformity along which a later fault is co-located. Total thickness is difficult to constrain, but <1,000 m of section are probably exposed within the map area. Biostratigraphic control is limited, but regional paleontologic data have historically favored an early to middle Albian age for this formation (Molenaar *et al.*, 1988). However, micropaleontologic data (C.G. Mull, unpublished data; M. Mickey, 2004, written commun.) suggest rocks assigned to this formation in the map area may be as old as Hauterivian.

Conglomerate facies are typically framework supported, but are usually poorly sorted leading to mixed clast size populations (granule to pebble) and abundant very fine- to fine-grained lithic sandstone matrix. Moderately to excellently sorted, open-framework granule conglomerate occurs locally, but is limited in lateral and vertical extent. Clasts are typically moderate to well-rounded leading to rare imbrication, except in matrix-lean facies. Clasts are dominated by varicolored chert and siliceous mudstone (up to 90 percent) with lesser amounts of altered mafic volcanic rocks and greenish-gray sandstone. Other more rare clasts include organic-rich mudstone (tasmanite) and dark gray silicified limestone with probable Mississippian fauna (A. Harris, 2005, written commun.) which usually exist as "outsized" cobbles up to 20 cm. Distinctive pink granitoid clasts are seen in more southern exposures and appear to be confined to the uppermost portions of the formation (Wartes and Carroll, 2003). Conglomerate beds are typically massive and range from 1–2 m thick. Bed boundaries are commonly diffuse, except where highlighted by interbedded sandstone; conglomerate units locally amalgamate into bedsets up to 20 m thick, which can collectively record both fining- and coarsening-upward trends. Some conglomerate bodies are lenticular at the outcrop scale and curvilinear surfaces are commonly visible from a distance. Crude to well-developed trough cross-stratification is locally prominent. Large linear and sinuous crested dunes (up to 30 cm amplitude) are preserved at the tops of some granule conglomerate beds.

Sandstone facies are lithic rich and dominantly very fine- to fine-grained. Beds are typically 5–10 cm thick, commonly weathering in a distinctive slab or "flagstone" rubble. Beds are usually massive, although faint plane-parallel lamination is common, particularly in association with low-angle cross-stratified facies. Sandstone is locally rippled, including rare, but distinctive oscillatory and interference bedform geometries. Floating coarse to very coarse sand grains are common and locally form planar discontinuous stringers. Carbonaceous and woody debris is common. Trace fossils are rare and typically include non-diagnostic, simple bedding parallel feeding traces. Solitary occurrences and thin coquinas of marine pelecypods are observed, but rare.

Recessive weathering siltstone and silty mudstone are only exposed in stream cuts and gullies, although they probably represent the dominant facies within this formation. These fine-grained rocks are commonly massive and weather in small hackly chips. Bedding is defined by abundant bedding-parallel, hard calcareous concretions that form a distinctive "dot-dash-dot" pattern. Some of these concretions are preferentially located along very fine-grained sandstone beds that locally preserve excellent sedimentary structures typical of the Bouma sequence (scour, grading, ripples, *etc.*; Bouma, 1962). Numerous yellow to yellow-green bentonites occur in the lowermost exposures of this facies. Load casts, flutes, or flame structures are not common within this unit, probably due to the dearth of actual shale or claystone. Almost no body fossils have been recovered from this facies and evidence for biogenic reworking is rare.

Kfmv — **Eo-Fortress Mountain, Informal Member of the Fortress Mountain Formation** (Aptian [?] to Valanginian [?])—Informal name applied to a clastic interval of light green-gray sandstone and conglomerate rich in tan to beige to light green tuffaceous grains. Medium to dark gray siltstone may be interbedded with sandstone. The unit appears to underlie the Fortress Mountain Formation, although similar facies and petrology may indicate a shared genetic history. Locally appears structurally interleaved with more intensely deformed allochthonous chert, igneous, limestone, and sandstone blocks. Total thickness is unknown due to structural disruption, but is probably less than 300 m thick. Age is uncertain, but map relationships suggest it is older than typical Fortress Mountain Formation. The lighter gray-green hue imparted by the tuffaceous grains is reminiscent of the Cobblestone Member of the Fortress Mountain Formation, a unique sandstone that was informally recognized by Kelley (1990) and adopted and defined by Mull *et al.* (2003) for rocks exposed in the eastern Chandler Lake Quadrangle (May and Cobblestone creeks), 40 miles east of this map.

Conglomerate beds are poorly to very poorly sorted, and locally supported in a sandstone matrix. Varicolored chert and altered mafic igneous clasts are common, usually moderately rounded. The unit is distinguished by a matrix-supported breccia facies association of subangular to angular light tan to light green (chloritized?) aphanitic tuffaceous clasts and abundant pale to turquoise green chert or siliceous mudstone. Lapilli grains and reworked plagioclase phenocrysts are locally observed in the tuffaceous component. Dark gray mudstone rip-up clasts are locally abundant. Sandstone beds locally include the distinctive tan to green angular granules, and appear to be slightly lighter colored than typical Fortress Mountain Formation, but otherwise occur in a similar motif of thin-bedded (5–10 cm) tabular units.

SYNTECTONIC TURBIDITES, MÉLANGE AND OLISTOSTROMAL DEPOSITS

Kou — **Okpikruak Formation, undifferentiated** (Patton and Tailleur, 1964)—Medium to dark gray and green-gray, interbedded lithic sandstone, siltstone, and shale. The best and most continuous exposures occur within a broad synclinorium along Tiglukpuk Creek between the mountain front and Tiglukpuk Anticline. Due to structural complexity, discontinuous exposures, and the absence of fossils, it is often not possible to distinguish which belt of Okpikruak to assign to a particular exposure (*i.e.*, melange, turbidites, or olistostromes).

Kom — **Okpikruak Formation, mélange** (Valanginian)—Sandstone, siltstone, and shale, commonly intensely deformed into "broken formation" and mixed in tectonic mélange that includes sheared blocks of Imnaitchiak chert, mafic igneous rocks, and local limestone with probable Carboniferous fauna (J. Dumoulin, 2005, written commun.). This structurally disrupted association was formerly assigned to the Tiglukpuk Formation (Patton, 1956), but is here included in the Okpikruak Formation. Most biostratigraphic data, especially the locally abundant bivalve *Buchia sublaevis*, indicate a Valanginian age. Deformation commonly obliterates primary sedimentary features and sandstone bodies become dislocated into strongly fractured and offset structural lenses separated by dark gray to black, vitreous, sheared mudstone. Distinctive spherical, slightly calcareous concretions are concentrated in a few exposures and range from 1–20 cm in diameter. Several thin, poorly sorted matrix-supported conglomerate beds are present and include clasts of chert, diorite, basalt, and fossiliferous Mississippian limestone (J. Dumoulin, 2005, written commun.). Clasts range from subangular to rounded and are locally as large as cobbles. Nearby large chert and mafic igneous blocks may be olistoliths that represent a continuum of disorganized sedimentary deposits. Olistoliths (described below) occur as isolated exposures ranging from meters to tens of meters in their maximum dimension.

Kot — **Okpikruak Formation, turbidites** (Berriasian)—Petrologically similar to Okpikruak mélange (Kom), but differentiated here based on stratigraphic coherency and apparent age difference suggested by the presence of the bivalves *Buchia okensis*, *B. subokensis*, *B. uncitoides*, and *B. volgensis* (W. Elder, 2006, written commun.). Best known from a structurally coherent section of approximately 400 m of interbedded lithic sandstone, siltstone, and shale that is well exposed along the east bank of Tiglukpuk Creek. This section is dominated by monotonous, rhythmically interbedded siltstone and very fine-grained sandstone. Individual sandstone beds are tabular, laterally continuous, typically about 5 cm thick, and vary from internally massive with sharp grain size breaks to more normally graded beds. Beds exceeding a meter in thickness are rare and commonly exhibit flute and groove casts and preserve large ball and pillow, flame, and other soft sediment loading features. Some buff-orange to tan weathering sandstone beds concentrate discontinuous calcareous concretions that preserve fine sedimentary details such as scouring, lamination, ripples, and bioturbation—all of which cannot be discerned in unaltered facies. *Planolites* trace fossils are observed locally. Some bedding planes preserve distinctive concentrations of finely disseminated mica. Siltstone and lesser shale typically weather in a nodular, hackly fabric and are commonly inter-laminated at 2–5 mm scale with very fine-grained sandstone.

OLISTOLITHS FROM HIGHER ALLOCHTHONS

JPi — **Imnaitchiak Chert** (Jurassic to Pennsylvanian; Mull *et al.*, 1987)—Dominated by varicolored, thin-bedded chert, siliceous mudstone, siltstone, and thin, organic-rich shale. Most exposures within the map area are small, isolated rubble-crops, limiting knowledge of the relationship with adjacent units. These small exposures occur within map-scale "broken formation" in which many different units are juxtaposed, presumably by protracted thrusting during emplacement of far-traveled thrust sheets. The common association with mafic igneous blocks may suggest an affinity with the Ipnavik River Allochthon, recognized to the west in Killik River and Howard Pass quadrangles (*e.g.* Mull *et al.*, 1994). All exposures are intensely deformed, often by disharmonic folding and tightly spaced imbricate faulting. The most complete exposure, near the confluence of Tiglukpuk Creek and the Siksikpuk River, suggests the unit is less than 100 m thick. At this locality, the Imnaitchiak is immediately overlain by the Fortress Mountain Formation, although the nature of the contact (unconformity or fault) is unclear.

The Imnaitchiak Chert typically weathers a buff-yellow to yellow-orange color; the most common colors in fresh surfaces are light to medium greenish-gray, bluish-gray, reddish-brown, and dark gray. Bright turquoise-green chert is somewhat rare and appears to be in close association with altered mafic igneous bodies, and, in one locality just east of the map area along Natvakruak Creek, underlies a volcanic tuff. In select exposures, a unique sooty, organic-rich, desiccated, fissile black shale is observed. This shale weathers a distinctive sulfur-yellow to yellow-green color. Cross-cutting zones of reddish-brown weathered horizons appear to mark fault gauge. Rare fragmented pectinoid pelecypods have been observed in the map area and wispy bioturbation fabrics in many cherts and siliceous mudstones suggest some biogenic activity.

mi — **Mafic igneous rocks**—Isolated outcrops of vesicular basalt and diorite. Commonly forms sills in the Imnaitchiak Chert and the Rim Butte Unit of the Lisburne Group. One outcrop shows unambiguous pillows. Believed to have intruded the lower Etivluk Group, which includes Imnaitchiak Chert (JPi), and into the Rim Butte unit, both of the Ipnavik River allochthon. Pillow basalts are likely from the Copter Peak allochthon.

Jtg — **Tuffaceous graywacke**—Named by Patton and Tailleur (1964) for isolated exposures of tuffaceous graywacke and associated units within the now abandoned Tiglukpuk Formation. Sandstone is light green-gray and visibly lighter colored than nearby Okpikruak Formation sandstone. Grain size ranges from fine- to very coarse-grained sandstone. Most framework grains are volcanic lithics surrounded by up to 50 percent nondescript clay matrix. In contrast to other Brookian units, there is very little quartz, and detrital chert grains are also very rare. The unit is locally poorly sorted and bears outsized mud rip-ups and possible tuff fragments. Bedding is typically not graded, suggesting mass flow deposition. Some flow tops exhibit weak planar lamination and ripple cross lamination, suggesting some late stage tractional processes may have reworked the tops of some beds. Interbedded mudstone is also unique and typically siliceous, brittle and hard, dark gray to black, and exhibits a distinctive iridescent hue on some bedding planes (manganiferous?). Deformation is locally concentrated in this lithology and displays "pencil cleavage," a fabric not observed in other Brookian mudstone.

Although this unit was originally thought to be Upper Jurassic (Patton and Tailleur, 1964), subsequent paleontologic work revised the age to Middle Jurassic (Jones and Grantz, 1964; Imlay and Detterman, 1973). New pelecypod specimens (*Retroceramus lucifer* and *Retroceramus ambiguus*) collected during our mapping confirmed the older age interpretation (W. Elder, 2006, written commun.). This unit was recognized in two localities within the map area, south of Tiglukpuk Anticline, along Tiglukpuk and Confusion creeks. Both exposures occur within a tectonized belt of Okpikruak Formation mélange (Kom) and probably represent olistoliths. Although presently known from a small number of localities in the western half of the Chandler Lake Quadrangle (Patton and Tailleur, 1964), it remains likely that more exposures exist but are presently grouped under the Okpikruak Formation or the now abandoned Tiglukpuk Formation.

Mrb — **Lisburne Group, Rim Butte unit** (Mississippian; Dumoulin *et al.*, 1993)—Thick-bedded to laminated, commonly color-banded succession of variably siliceous, mainly very fine-grained clastic limestone and chert; light to dark gray to grayish black but weathers medium gray, yellowish brown, grayish orange, and grayish red. Rhythmic and well-defined 2–75 cm beds, locally separated by mudstone selvages. Bioclasts include pelmatozoan debris and sponge spicules. Contains early Late Mississippian (Meramecian to early Chesterian) conodonts from a range of shallow to relatively deep marine environments, as well as redeposited older conodonts of Early Mississippian (Kinderhookian and Osagean) age (A. Harris, 2005, written commun.). Conodont taphonomy indicates post mortem hydraulic transport and supports interpretation of limestone beds as fine-grained turbidites. Commonly intruded by mafic dikes and sills. Present only as isolated blocks up to 25 m maximum dimension.

Mlu — **Undifferentiated limestones** (Mississippian)—Partially silicified limestone of unknown affinity. Several occurrences consist of skeletal-peloidal grainstone and packstone that contain pelmatozoan and bryozoan debris, foraminifers, conodonts of Early Mississippian age (A. Harris, 2004, written commun.), and local volcanic lithic clasts. Lithofacies and age are consistent with derivation from various allochthons.

Dlu — **Undifferentiated limestones** (Upper Devonian [Famennian])—Partially silicified limestone of unknown affinity; isolated outcrops are observed in the Fortress Mountain fold belt in the east-central portion of the map area. Several occurrences consist of skeletal packstones that contain abundant calcispheres and (or) algal clasts as well as conodonts of late Late Devonian (Famennian) age (A. Harris, 2006, written commun.). Lithofacies and age are consistent with derivation from various allochthons.

ENDICOTT MOUNTAINS ALLOCHTHON

Kc — **Buchia limestone coquina** (Valanginian)—Distinctive reddish-brown weathering, thin-bedded limestone, with thin interbeds and partings of dark gray to black, fissile shale, composed entirely of the pelecypod *Buchia sublaevis*. Commonly structurally infolded with upper part of the underlying Otuk Formation. Undeformed stratigraphic thickness unknown, but probably <100 cm. Exposure is limited to the south flank of Tiglukpuk Anticline.

J̄io — **Otuk Formation** (Middle Jurassic to Lower Triassic; Mull *et al.*, 1982)—Interbedded fossiliferous black chert, limestone, and organic-rich black sooty shale in four lithogenetic units, in ascending order: (1) a basal poorly exposed shale member—black organic shale (Middle and Lower Triassic); (2) the "chert" member—black silicified mudstone, chert and shale (Middle and Upper Triassic); and (3) the limestone member—thinly interbedded shale and thin-bedded black- and light-gray banded limestone and silicified limestone commonly with abundant pelecypods *Monotis* sp. and *Halobia* sp., weathers yellowish-tan (Upper Triassic); (4) Blankenship Member (Middle and Lower Jurassic)—organic-rich black shale is poorly exposed in this map area. Unit is commonly intensely deformed in the map area but a coherent section is present on the east and west banks of Tiglukpuk Creek along the south flank of Tiglukpuk Anticline (Bodnar, 1984; Kelley, 1990).

Informal shale, chert, and limestone members all exposed in mapping area. Shale member consists of rhythmically interbedded light green silty shale with few gray-weathering limestone beds or nodules, black shale and (or) light green silty dolomitic shale; very little evidence of bioturbation. Chert member composed of intervals of resistant black chert and silicified limestone interbedded with black sooty shale; *Monotis* sp. and *Halobia* sp. pelecypods present on bedding planes; wispy laminations and banded weathering patterns. Limestone member consists of cycles of limestone and shale; beds are very even and continuous; abundant *Monotis* sp. pelecypods. Disconformable contact with underlying Siksikpuk Formation is well exposed on the west bank of Tiglukpuk Creek.

Ps — **Siksikpuk Formation** (Permian; Patton, 1957)—Informal units A, B, C, and D (Siok, 1985) are recognized on Skimo, Tiglukpuk, Firestone, and other creeks, in descending order: (A) yellowish-brown weathering calcareous siltstone; (B) maroon to greenish-gray silty shale with barite and siderite; (C) greenish-gray siliceous siltstone or chert; and (D) gray clay shale. Age is Wolfcampian to Leonardian (Adams *et al.*, 1997) based on megafossils and conodonts. Contact with the overlying Otuk Formation is exposed on the west side of Tiglukpuk Creek. Disconformable contact with the underlying Lisburne Group is well exposed on the east bank of Skimo Creek at the mountain front.

Lisburne Group (Lower Pennsylvanian [Morrowan] to Lower Mississippian [Osagean]; Bowsher and Dutro, 1957)—Dominantly massive, light to dark gray weathering, cliff-forming crinoidal limestone and dolostone. Contains light gray to black chert nodules, lenses, and beds that vary from sparse to abundant throughout the section. Local leached pinpoint to vuggy porosity filled with solid hydrocarbon, especially in dolostone. Distinctive interval of sooty black shale, phosphorite, and limestone (Mlp) in upper part; locally exposed dark limestone, siltstone, and shale (PMl) at top. Crops out in series of folded thrust sheets forming northern flank of Endicott Mountains. Stratigraphy varies in detail both from east to west and north to south; overall thickness apparently increases southward in higher thrust sheets. Section at Skimo Creek is most thoroughly studied in the map area and is more than 900 m thick. Locally divided into:

PMl — **Lisburne Group, pennsylvanian to mississippian section** (Lower Pennsylvanian and Upper Mississippian)—Limestone, siltstone, and shale. Distinctive dark-weathering, recessive interval that locally forms uppermost part of Lisburne Group. Brownish gray-weathering, dark gray to black lime mudstone and calcareous shale overlain by reddish brown-weathering, dark-gray, non-calcareous shale, silty shale, and spiculitic siltstone. Unit best exposed along Skimo Creek, where it is 40 m thick and about 7 m above the base of the unit, contains a distinctive 45-cm-thick bed of burrowed skeletal grainstone that is glauconitic, pyritic, and phosphatic. Conodonts of late Late Mississippian (Chesterian) age found in glauconitic grainstone bed near base of unit, but spiculitic siltstone at top of unit yields conodonts of early Morrowan (early Early Pennsylvanian) age (A. Harris, 2004, 2005, written commun.). Upper contact with Siksikpuk Formation is sharp and apparently disconformable. Unit apparently thins and disappears west of Encampment Creek and south of the headwaters of Skimo Creek in higher thrust sheets outside the map area.

Ml, Mlp — **Lisburne Group, mississippian section,** Ml (Upper and Lower Mississippian)—Light to dark gray to brownish gray limestone, lesser dolostone, and nodular, lenticular, and layered replacement chert. Variations in color, bed thickness, and resistance to erosion throughout section define markers that can be mapped in local areas. Light to medium gray weathering intervals typically are thicker bedded (up to ~2 m) and contain less abundant chert than typically dark gray to black weathering intervals; both include highly resistant, cliff-forming intervals and less resistant, rubble-prone intervals. Conodonts and foraminifers indicate that most of the section is Late Mississippian (Meramecian and Chesterian) but the lowermost 150 m are late Early Mississippian (Osagean; Armstrong and Mamet, 1977; Whalen *et al.*, 2006). Dolostone intervals (10–20 m thick) at several levels in unit contain 5–10 percent intercrystalline, moldic, and vuggy porosity. Conformable basal contact with Kayak Shale is gradational over ~10 m.

Shale, limestone, and phosphorite, Mlp (Upper Mississippian)—Thinly interbedded black, sooty, calcareous shale, lime mudstone, phosphatic limestone, and phosphorite forms distinctive recessive unit ~30 m thick in upper part of Lisburne. Calcareous concretions common up to 0.5 m in diameter. At Skimo Creek, top of unit is 170 m below base of Siksikpuk Formation. Black shale has total organic carbon contents as high as 6–8 percent as well as elevated values of Zn, V, Ni and other metals. Limestone contains locally abundant sponge spicules and radiolarians. Phosphatic rocks (Patton and Matzko, 1959) found mainly in five or more intervals, ~5 to 40 cm thick, distributed through 4–12 m of section near top of unit. Phosphate occurs as bright blue to lilac sand to pebble sized grains, many with oolitic layering, in matrix of carbonate or silica cement; some beds contain as much as 30 percent P_2O_5 (Kurtak *et al.*, 1995). Conodonts and goniatite cephalopods (Gordon, 1957; Dumoulin *et al.*, 1997) indicate an age of Late Mississippian (late Meramecian–early Chesterian) for this unit. Observed at least locally to western edge of map area; may disappear to south.

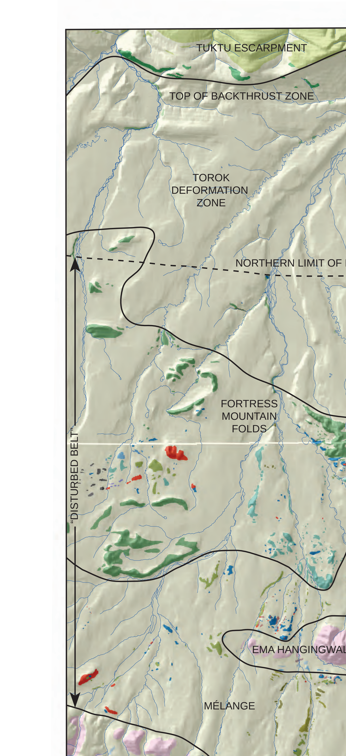
Mk — **Kayak Shale** of the Endicott Group (Lower Mississippian; Bowsher and Dutro, 1957)—Dominantly recessive, slope-forming, uniform black fissile shale. Mostly clay shale to silty shale that forms shiny, planar plates 1–2 mm thick. Bare shale outcrop or scree on steep slopes, tundra on gentle slopes. Local 1 cm interbeds of laminated to ripple cross-laminated siltstone to very fine-grained sandstone. Common 20–40-cm-thick lenticular beds of rusty orange-weathering bioclastic limestone. Broken and abraded fossil debris includes crinoids, brachiopods, bryozoans, and rugose corals. Local isolated 1.5–3-m-thick beds of limestone, especially near top of unit. Similar in composition to lenticular interbeds, but gray to orange-gray weathering, massive to platy, locally cross bedded. These limestone beds commonly are folded and faulted. Unit is at least 165 m thick, but base is not exposed in map area. Basal detachment for thrust sheets commonly within Kayak Shale.

MDk — **Kanayut Conglomerate** of the Endicott Group (Lower Mississippian to Upper Devonian; Bowsher and Dutro, 1957)—Present only in subsurface on cross section interpretations, but present in outcrop just south of the map area. Thick (up to 3,000 m) clastic sequence of shale, sandstone, and conglomerate. In descending order: Stuver Member, interbedded sandstone and chert-pebble conglomerate, minor siltstone and shale deposited in meandering fluvial channels. Shainin Lake Member, massive chert-pebble conglomerate and chert-grain sandstone deposited in braided streams. Ear Peak Member, interbedded sandstone, siltstone, and shale deposited in meandering fluvial channels and alluvial plains.

OLISTOSTROME MODEL

Olistostromal deposition is our preferred model for the occurrence of large (up to tens of meters scale) exotic blocks of limestone, chert, mafic igneous, and other lithologies within mud and sand mélange. Large exotic blocks of this type are widespread in the western Chandler Lake Quadrangle (Mull and Sonneman, 1974), and to the west in the Killik River Quadrangle (Mull *et al.*, 1994), and Howard Pass and Misheguk Mountain quadrangles (Mull and Sonneman, 1974). During early Brookian uplift, structurally high allochthons were exhumed and sediments derived from them were deposited (*i.e.*, Okpikruak) in the early Colville Basin to the north (present coordinates). Submarine chaotic mixing of blocks from several allochthons occurred simultaneously with Okpikruak turbidite deposition. Cannibalism of turbidites and olistoliths at the thrust front resulted in further complicated age and structural relationships within the olistostrome belt. Crane (1987) differentiates and describes several olistostromal sequences in the Siksikpuk River area.

Most olistostromal blocks in the Siksikpuk River area are recognizable as known lithologies from higher structural allochthons, such as the Ipnavik River Allochthon. These allochthons are better represented in the western Brooks Range foothills, where a western regional plunge has allowed preservation of higher structural levels. The origin of some blocks, such as the tuffaceous graywacke and the undifferentiated limestones, is ambiguous, and they may have eroded from one of several possible allochthons, or are only known to exist in far-distant allochthons.



Structural domains discussed in the text. EMA—Endicott Mountains allochthon. After Wallace *et al.*, 2006.

SEQUENCE OF DEPOSITIONAL AND TECTONIC EVENTS

Carboniferous: Deposition of thick platform carbonate rocks of Lisburne Group in area of future Endicott Mountains allochthon (EMA). Deposition of calcareous turbidites of the Rim Butte unit of the Lisburne Group on the proto-Ipnavik River Allochthon (IRA) south of EMA.

Permian: Deposition of distal Siksikpuk Formation silt on pre-EMA. Intrusion of mafic igneous bodies within future Ipnavik River allochthon to the south.

Middle Triassic to Middle Jurassic: Deposition of Otuk Formation limestone and shale in pre-EMA. Deposition of tuffaceous graywacke on unknown distal southern allochthon.

Late Jurassic to Early Cretaceous (Early Neocomian–Berriasian to Valanginian): Stacking of allochthons in Brookian orogen and foredeep deposition of Okpikruak turbidite sediments derived from early uplift. North-vergent thrusting and allochthon emplacement. "Cannibalism" at the thrust front of syntectonic deposits and thrust sheets providing a source of olistoliths from the Ipnavik River, Nuka Ridge, and Copter Peak allochthons, and possibly Picnic Creek and/or Kelly River allochthons. Formation of syntectonic olistostromes and mélange.

Early Cretaceous (Late Neocomian–Hauterivian to Barremian?): Local deposition of syntectonic Brookian Eo-Fortress Mountain formation. Continued olistostromal deposition.

Early Cretaceous (Late Neocomian to Aptian): Northward progradation and interfingering of basal Fortress Mountain Formation clastic rocks and Torok Formation shale into southern Colville Basin.

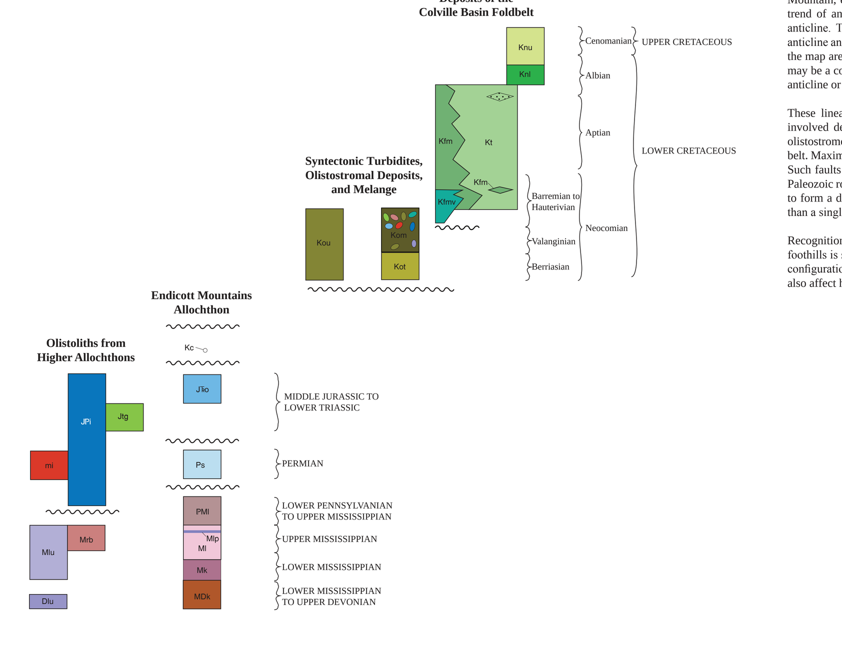
Early Cretaceous (Aptian): Continued syntectonic deposition of Fortress Mountain and Torok Formations.

Early Cretaceous (Aptian?): Earliest possible gentle "rumpled rug" style folding and thrusting of Fortress Mountain sediments.

Early to Late Cretaceous (Albian, Cenomanian): Clastic nonmarine and marine deltaic deposition of the Nanushuk Formation in the Colville Basin, and unroofing of higher allochthons to expose EMA to become a major sediment source in the Colville Basin. Local syndepositional folding.

Early, Middle Tertiary (~60 Ma & ~45Ma): Renewed and out-of-sequence thrusting from south and final emplacement of EMA at present-day mountain front. Further structural complication within the disturbed belt. Folding within Cretaceous "passive roof" units above a detachment in the Torok Formation. Backthrusting of Nanushuk Formation forming the Tuktu Escarpment. North-directed thrusting along the Desolation Creek Fault. Transverse faulting, cross-cutting EMA and juxtaposing Eo-Fortress Mountain sediments and later syntectonic deposits.

CORRELATION OF BEDROCK MAP UNITS



STRUCTURAL SUMMARY

The map area exposes progressively higher structural and stratigraphic levels toward the north. Stratigraphically distinct "allochthons" of more distal facies have been transported from the south (Moore *et al.*, 1992).

The far-traveled Endicott Mountains allochthon is exposed in the southern part of the map area and extends in the subsurface as far north as the Desolation Creek fault. In the map area, this allochthon displays different structural styles in different parts of the stratigraphic section separated by incompetent detachment units. The lowest and most competent interval consists of the Mississippian carbonates of the Lisburne Group (Ml), which are bounded by detachments in the underlying Kayak Shale (Mk), and in the overlying shale and silt of the Pennsylvanian Lisburne Group (PMl) and Siksikpuk Formation (Ps). This unit forms thick thrust sheets and large folds. The Siksikpuk and Otuk (J̄io) Formations generally follow folds in the underlying Lisburne, but also display smaller folds and more closely spaced thrust faults detached above the Lisburne. Mélange (Kom) and turbidites (Kot) of the Okpikruak Formation are detached structurally above the Otuk Formation.

South of the range front, the Endicott Mountains allochthon consists of a stack of large-displacement imbricate thrust sheets. To the south, these are planar and dip gently to the south, and their hangingwall anticlines typically are eroded. To the north, the hangingwall anticlines (1.5–4 km wide) are preserved above folded thrust faults.

The range front is defined by an abrupt northward decrease in structural relief of folded thrusts in the erosionally resistant Lisburne carbonates. The local structural high of the Tiglukpuk anticline exposes the only Lisburne north of the range front (other than much smaller blocks in Okpikruak mélange). This structure is interpreted as an erosional window into a hangingwall anticline.

The Okpikruak Formation overlies the EMA both structurally and stratigraphically. Although it is part of both the Endicott Mountains and Ipnavik River allochthons, it is not commonly preserved as part of the EMA stratigraphic package. North of the range front, the Okpikruak Formation forms the bulk of the "disturbed belt." It is folded above underlying folded thrusts except where it has been eroded over the top of the Tiglukpuk anticline. The Okpikruak Formation includes two structurally distinct elements: mélange and turbidites. The mélange consists of a deformed matrix of mudstone that includes structurally disrupted sandstone beds. The mélange incorporates variably sized olistoliths and/or tectonic lenses derived from higher allochthons, the Endicott Mountains allochthon, and locally the Eo-Fortress Mountain (Kfmv). The mélange has a strong structural fabric and displays complex minor folding and faulting. The turbidites are more coherently deformed into asymmetrical chevron folds. Fossil ages indicate that turbidites were thrust over mélange before being folded in the Tiglukpuk syncline.

Late to post-tectonic deposits of the Colville basin depositionally overlie the Endicott Mountains allochthon and are exposed in the northern part of the map area. To the south, rocks of the Eo-Fortress Mountain and Fortress Mountain (Kfm) Formations unconformably overlie Okpikruak mélange and form a belt of conspicuous folds. Wide (2–3 km), relatively flat-bottomed synclines separate narrower (1–2 km) and sharper anticlines. Abrupt inward plunges form distinctive "thumbprint synclines." The abrupt changes in plunge and complex variations in trend reflect multiple directions of shortening (~N-S and ~E-W), possibly at different times, and may have been influenced by regional or local transverse faulting (see inset map). The Fortress Mountain Formation displays rounded folds that vary in size according to the local thickness and competency of the unit. The more massive Eo-Fortress Mountain displays steeper plunges and less well-defined folds. The folds are locally cut by both forethrusts (south-dipping) and backthrusts (north-dipping).

The Torok Formation (Kt) shale displays chevron folds, mostly of sub-map-scale, and minor thrusts in a broad, complexly deformed belt. Structures are mainly north-vergent in the southern part of the belt and south-vergent in the northern part of the belt. A major backthrust zone to the north is localized near the top of the Torok Formation. It is overlain by homoclinally north-dipping beds of the Nanushuk Formation (Knu and Knl), which form the Tuktu escarpment as a result of their resistance to erosion. To the north of the map area, the Nanushuk and younger deposits form a broad belt of wide, flat-bottomed synclines and narrower cuspate anticlines. These are similar in geometry to the folds in the Fortress Mountain Formation, but are larger because the unit is thicker. The Nanushuk Backthrust beneath the base of the Nanushuk Formation is interpreted to represent a triangle-zone roof thrust that separates north-vergent imbrication below from detachment folding above.

The Desolation Creek fault is a significant but poorly exposed fault in the southern part of the Torok deformation zone. It marks the northern exposed limit of Okpikruak mélange and the blocks within the mélange both east and west of the map area. Within the map area, the fault places a block of Imnaitchiak Chert over Torok on a south-dipping thrust fault. Similar isolated exposures of Imnaitchiak chert and mafic igneous rocks at several localities just east and west of the map area document a linear belt in which older allochthonous rocks have been brought to the surface by north-vergent thrusting. Modeling of detailed gravity data (Peapples *et al.*, 2005; Brown *et al.*, 2006) supports this interpretation. The fault does not mark the northern limit of the Fortress Mountain Formation.

The Desolation Creek fault is interpreted to be an out-of-sequence thrust because it cuts rocks of the Endicott Mountains allochthon and places them over rocks that were deposited after emplacement of the allochthon. Other thrust faults interpreted to be out-of-sequence thrusts include the range-front thrust along the northern margin of the Skimo anticline, a blind thrust interpreted to underlie the Tiglukpuk anticline, and several thrusts that place Okpikruak mélange over the Fortress or Eo-Fortress Mountain formations.

The emplacement and large-displacement imbrication of the Endicott Mountains allochthon was the first major structural event in the map area. The deposition of the Okpikruak Formation occurred during this event, resulting in formation of olistostromes and syndepositional deformation. Major displacement of EMA was probably complete by the time of Fortress Mountain deposition, although contraction may have continued locally into Nanushuk time (Cole *et al.*, 1997; Mull *et al.*, 2003; Finzel, 2004). Renewed shortening after deposition of Fortress Mountain, Torok, and Nanushuk resulted in formation of map-scale folds in EMA, Fortress Mountain, and Nanushuk, out-of-sequence thrusting, and deformation within the Torok, including formation of the roof-thrust near its top. Regional fission-track geochronology indicates that most of this deformation occurred during an event at ~60 Ma, although some deformation may have occurred during later events at ~45 and 25 Ma (*e.g.*, O'Sullivan, 1993, 1996; O'Sullivan *et al.*, 1997).

REGIONAL TRANSVERSE FAULTS

Several northeast-southwest trending strike-slip faults with dominantly left-lateral sense of slip are mapped cutting outcrops of the Lisburne Group on Tiglukpuk anticline. Where relatively well constrained by outcrop data, these faults trend approximately N 30° E and crosscut the dominant east-west trending structural grain in the map area. The most prominent of these faults cuts the west end of Tiglukpuk anticline and is inferred to continue to the northeast at least 10 miles north of Tiglukpuk anticline to the east of the conspicuous anticlinal trend of Fortress Mountain Formation. A marked northeastward deflection of the eastern end of this anticlinal axis is inferred to be related to left-lateral slip along the fault. Between Tiglukpuk anticline and the folded Fortress Mountain Formation this fault appears to bound outcrops of the Eo-Fortress Mountain Formation and some of the olistostrome.

A short segment of a relatively well-constrained N 30° E-trending cross-cutting fault is also mapped cutting Fortress Mountain Formation in the small "thumbprint" syncline west of Siksikpuk River. This fault may extend northeastward through an area of few outcrops and along the course of a linear reach of the Siksikpuk River south of the Tuktu Escarpment.

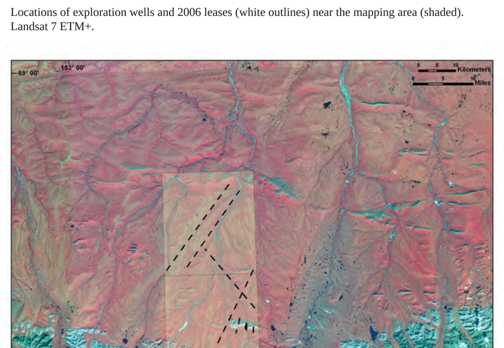
In addition to the relatively well-constrained cross-cutting faults, at least one poorly constrained regional northeast-trending fault is inferred to cross the northwestern part of the map area (inset). Because of its highly inferred nature and the absence of definitive map control, it is not included on the geological map. This regional fault is on trend with a similar inferred left-lateral strike-slip fault mapped in the Umiat Quadrangle to the north (Mull *et al.*, 2002). In the map area, it is inferred to trend along the course of Autumn Creek and appears to bound contrasting structural styles of deformation in the Lisburne Group at the mountain front at Chandler Lake, west of the map area. Elsewhere along the central and western Brooks Range foothills, similar northeast-trending regional faults appear to bound outcrops of the Fortress Mountain Formation that are preserved as local closed basins informally termed "thumbprint synclines." The late stage of polyphase deformation along these faults may explain the formation of the small local closed basins in the Fortress Mountain Formation such as Thumbprint syncline and Hoary Marmot syncline in the map area.

A poorly constrained, northwest-trending right lateral fault is also inferred in the map area. This fault is inferred to trend northwest-southeast from north of Thumbprint syncline, southeast up Tiglukpuk Creek and its eastern tributary past the eastern end of Tiglukpuk anticline to bound the western end of Nasaurak Mountain, east of the map area. It is inferred to bound the western end of the trend of anticlinally folded Fortress Mountain Formation north of Tiglukpuk anticline. The apparent eastward steepening of the north flank of Tiglukpuk anticline and southeastward deflection of its anticlinal axis at the eastern edge of the map area are compatible with inferred right slip along this fault. This fault may be a conjugate of the documented fault that cuts the west end of Tiglukpuk anticline or the long regional fault inferred along Autumn Creek.

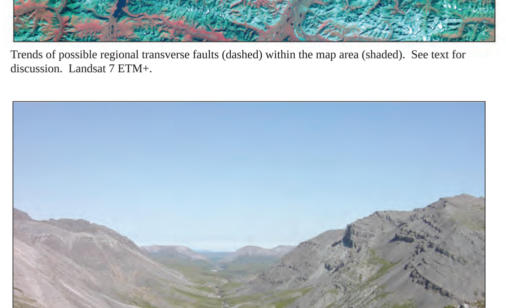
These linear faults appear to represent a relatively late stage of basement-involved deformation that postdates emplacement of the allochthons and the olistostrome, and cross-cuts the general east-west trends of folds in the foothills belt. Maximum slip on any one fault at depth is inferred to be a few miles or less. Such faults at depth may propogate upward from the competent basement and Paleozoic rocks through the less competent Mesozoic rocks of the Colville Basin to form a diffuse zone of rupturing along multiple strands at the surface rather than a single, well-defined fault.

Recognition and mapping of late stage cross-cutting faults in the Brooks Range foothills is significant because such faults may play a role in the formation and configuration of subsurface structures and hydrocarbon traps. The faults may also affect hydrocarbon migration pathways and trap seals.

Locations of exploration wells and 2006 leases (white outlines) near the mapping area (shaded). Landsat 7 ETM+.



Trends of possible regional transverse faults (dashed) within the map area (shaded). See text for discussion. Landsat 7 ETM+.



View North of Lisburne outcrops along Tiglukpuk Creek at Skimo Anticline. Tiglukpuk Anticline in the distance.

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MAP SYMBOLS

- National Park boundary
- Traceable beds
- Contact - dotted where concealed or inferred.
- Fault - dashed where inferred or approximately located; dotted where concealed; queried where doubtful.
- U / D — High angle fault, displacement indicated where known.
- Thrust fault - sawteeth on upper plate.
- Major detachment surface - may not imply older over younger; teeth on upper plate.
- Overturned thrust - sawteeth on hangingwall.
- Fault Zone
- 14 — Fold axis-showing trace of axial plane and direction of plunge; dashed where approximately located; dotted where concealed; queried where uncertain. Measured plunge and asymmetry shown where known.
- Syncline
- Anticline
- Monocline
- Overturned anticline
- Overturned syncline
- Strike and dip of beds
  - 30 — Inclined
  - Vertical
  - Horizontal
  - 30 — Overturned
- Dip of beds (cross section only)
- 30 — Strike and dip of fault
- Extent of oil-stained sand in Torok Formation

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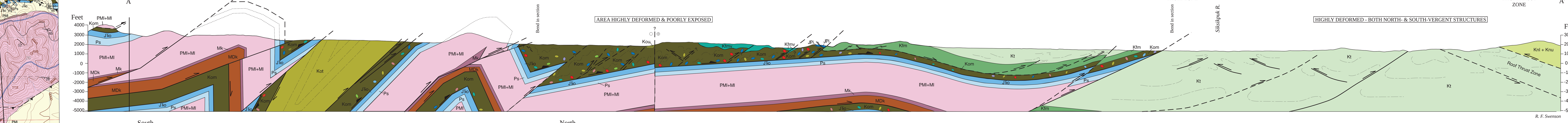

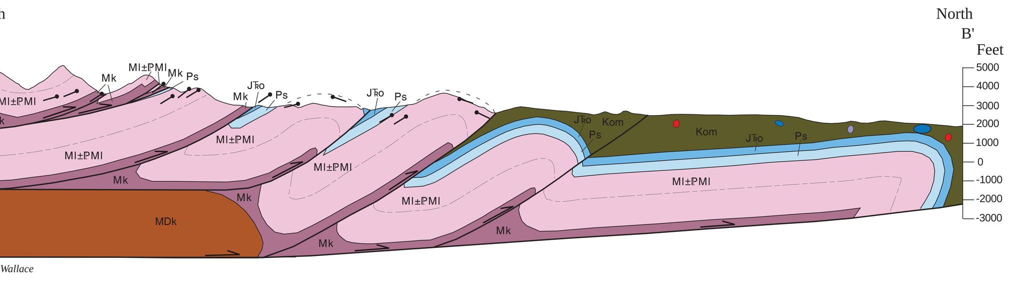

GEOLOGIC MAP OF THE SIKSIKPUK RIVER AREA, CHANDLER LAKE QUADRANGLE, ALASKA

by

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