STATE OF ALASKA

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

Tony Knowles, *Governor*

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CONTENTS

FIGURES

SHEET

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GEOLOGIC MAP OF THE SAGAVANIRKTOK B-1 QUADRANGLE, EASTERN NORTH SLOPE ALASKA

by
R.R. Reifenstuhl,[1] C.G. Mull,[1] E.E. Harris,[1] D.L. LePain,[1] DeAnne S. Pinney,[1] and W.K. Wallace[2]

DESCRIPTION OF MAP UNITS

QUATERNARY UNCONSOLIDATED DEPOSITS

Alluvial Deposits

Qa **Stream Alluvium**—Elongate deposits of moderately to well sorted, well stratified, pebble–cobble gravel, sand, and silt, with few[3] to numerous boulders, deposited in active stream channels, floodplains, and associated low terraces. Deposit is medium to thick bedded, locally crossbedded, and shows fining-upward cycles. Cobbles generally rounded. Extensive willow–alder thickets grow on many Qa deposits in mature valley fills. Seasonal icings (aufeis) are prevalent along some streams, notably Echooka River, in much-widened areas of alluvial deposition. Surface smooth except for local low scarps.

Qac **Abandoned-Channel Deposits**—Elongate deposits of variable grain size, sorting, and bedding style deposited in channels of former meltwater streams not related to modern stream regimens and subsequent underfit streams. Composition ranges from slightly washed drift with thin, local surface lags of cobbles and boulders to well-sorted, clean pebble–cobble gravel, and gravelly medium to coarse sand with rare to numerous cobbles to 0.5m diameter; thin to thick bedded, locally crossbedded. Surface smooth with local low scarps and bogs.

Qaf **Alluvial Fan Deposits**—Fan-shaped, heterogeneous mixtures of poorly to moderately sorted, partially stratified gravel with some sand and silt and scattered to numerous, subangular to rounded boulders, especially in proximal areas. Deposits are locally channelized across fan surface. Clasts generally locally derived from the immediate vicinity along the short, steep streams feeding the fans. May include torrential fluvial deposits and debris-flow deposits. Thick to thin bedded. Generally form at intersection between tributary and trunk streams. Surface smooth except for numerous shallow, interconnected channels.

Qas **Silty Alluvium**—Irregular, elongated deposits of moderately well stratified silt and minor fine sand deposited by streams traversing areas of thick silt cover. May include fine-grained debris-flow deposits, especially in the upper reaches adjacent to actively melting frozen silt deposits. Lower reaches may be deeply incised. Deposit is generally composed of reworked eolian silt. Moderately to well sorted and medium to thin bedded; locally crossbedded. Surface smooth except for numerous shallow, interconnected channels, local low scarps, and local small ponds forming beaded drainage.

Qat **Terrace Alluvium**—Elongate deposits of well sorted, well rounded to subrounded pebble-cobble gravel and sand with trace to some silt and rare to numerous boulders forming stream terraces bordering floodplains. Deposits reflect former channels and flow regimes related to multiple Wisconsin-age glaciations in the stream headwaters. Generally thickly mantled by ice-rich, reworked silt deposits. Surface smooth to hummocky with local low scarps and bogs.

Qfp **Floodplain Alluvium**—Elongate deposits of moderately to well sorted, well-stratified, fluvial gravel, sand, and silt with few to numerous boulders in floodplains and associated low terraces. Deposits may reflect former channels and flow regimes. Typically mantled by thin layer of silty overbank deposits. Generally finer grained than similar deposits in Qa unit because of deposition during flood-stage events. May locally include Wisconsin to Holocene terrace alluvium. Lower surfaces may be flooded during

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[3]Terms used to describe the estimated percentages of cobbles and boulders are 'numerous', 'scattered', and 'rare.' 'Numerous' implies that drilling through the layer would encounter two cobbles or boulders in an interval of 0.6 m; 'scattered' implies that drilling would encounter two cobbles or boulders in an interval of 3 to 4.5 m; and 'rare' implies that drilling would encounter two cobbles or boulders in an interval of more than 4.5 m.

periods of maximum stream discharge. Ground ice content highly variable. Surface smooth to hummocky with local low scarps and bogs.

Colluvial Deposits

Qc **Undifferentiated Colluvium**—Irregular, heterogeneous blankets, aprons, and fans of angular to subrounded rock fragments, gravel, sand, and silt that are left on slopes, slope bases, or high-level surfaces by residual weathering and complex mass-movement processes, including rolling, sliding, flowing, gelifluction, and frost creep. May include greatly modified drift of older glaciations. Locally washed by meltwater and slope runoff. Medium to thick bedded; thickness highly variable. Surface smooth, lobed or terraced and, if deposit is thin, generally reflects configuration of underlying bedrock surface.

Qca **Colluvial–Alluvial Valley Fill, Fan and Apron Deposits**—Fan- and tongue-shaped and elongate heterogeneous mixture of subangular rock fragments and pebble–cobble gravel with some sand and silt deposited at the bases of steep walls and upper stream courses primarily by debris flows and brief, intense (torrential) summer streamflows May include or be capped by a considerable amount of redeposited eolian silt. Locally washed by meltwater and slope runoff. Alluvial–colluvial fan deposits are formed or modified when seasonal snowpack is melting. Surface steep to gently sloping and smooth, except for local low scarps.

Qcr **Talus and Rubble Deposits**—Irregular cones, drapes, and sheets of coarse (1 m diameter and larger blocks are common), heterogeneous, angular rock fragments and rubble with minor silt, sand, and gravel deposited more or less in place at the base of steep slopes by block weathering, frost riving, snow avalanches, free fall, tumbling, rolling, and sliding. Deposits are widely subjected to secondary reworking by cryoturbation, including frost heave and frost jacking of rock fragments. Surface steep, irregular, generally unvegetated, covered with numerous angular rock fragments, and characterized by openwork rubble mounds.

Qdf **Debris–Fan Deposits**—Fan-shaped heterogeneous mixture of sand, silt, and gravel with rare to numerous angular rock fragments deposited at the mouths of steep bedrock couloirs by debris flows and seasonal meltwater. Surface smooth to locally irregular.

Glacial Deposits

Echooka Drift

[after Detterman (1953), Detterman and others (1958), and Waythomas (1991)]
(Itkillik II drift of Hamilton, 1986)

Qde **Undifferentiated Drif of Echooka Age**—Heterogeneous blanket of pebble–cobble gravel, sand, and silt, with rare to numerous boulders. Deposited directly from glacial ice and by glacial meltwaters. Sorting, bedding, and clast roundness highly variable, depending on degree of water reworking. Deposit locally includes or is gradational with outwash. Surface smooth to slightly irregular.

Qdme **Moraine Deposits of Echooka Age**—Heterogeneous mounds and ridges of pebble–cobble gravel, sand, silt, and clay in varying proportions deposited directly from glacial ice; contains rare to numerous boulders. Clast roundness varies from rounded to subangular. Nominal soil development up to 20 cm thick with well-established tussock vegetation. Surface is hummocky and generally retains primary morainal morphology. Moraine crest is approximately 15–20 m higher than elevation of Echooka River channel.

Qoe **Outwash Deposits of Echooka Age**—Elongate heterogeneous mixture of washed, rounded to subrounded pebble–cobble gravel with some sand and silt and scattered to numerous subangular to rounded boulders deposited by meltwater streams draining margins of former glaciers. Thin to thick bedded, locally crossbedded. Surface generally smooth and gently sloping, except for local low scarps.

Qofe **Outwash Fan Deposits of Echooka Age**—Fan-shaped heterogeneous mixture of washed, rounded to subrounded pebble–cobble gravel with some sand and silt and scattered to numerous subangular to rounded boulders deposited by meltwater streams draining margins of former glaciers. Thin to thick bedded, locally crossbedded. Surface generally smooth and gently sloping, except for local low scarps of anastomosing former stream channels.

Itkillik Drift

[after Detterman (1953), Detterman and others (1958), and Waythomas (1991)]
(Itkillik I drift of Hamilton, 1986)

Qdir **Reworked Drift of Itkillik Age**—Heterogeneous blanket of pebble–cobble gravel, sand, silt, and clay in varying proportions deposited by glaciers; contains rare to numerous boulders deposited directly from glacial ice. Sorting, bedding, and clast roundness highly variable, depending on degree of water reworking. Deposit locally includes or is gradational with outwash. May be blanketed by up to a meter of ice-rich organic silt and peat. Observed thickness ranges from a thin and patchy veneer or lag of pebbles and cobbles over ice-scoured bedrock at the mountain front to more than 3 m of bedded sand and gravel northwest of Cache One Lake. Maximum thickness is likely much greater. Surface smooth to highly irregular with local bogs and ponds.

Qdmi **Moraine Deposits of Itkillik Age**—Heterogeneous mounds and ridges of pebble–cobble gravel, sand, silt, and clay in varying proportions deposited directly from glacial ice; contains rare to numerous large (1 m diameter and greater) angular to subangular boulders. Till typically consists of rounded to subangular pebbles and cobbles up to 20 cm diameter in a dark bluish-gray, plastic, silty clay matrix. Steep banks of kettle ponds in frozen till are subject to slumping and flowing as they thaw. Includes local deposits of abundant, mostly rounded, pebbles and cobbles in sandy matrix that are interpreted as kame and kame terrace deposits. May be blanketed by up to a meter of ice-rich organic silt and peat. Surface is irregular and hummocky and generally retains primary morainal morphology.

Qfdi **Fan-Delta Deposits of Itkillik Age**—Fan-shaped deposit of sand and pebble gravel laid down near margin of former meltwater lake by stream entering lake. Well sorted and medium to massive bedded, locally crossbedded. Surface smooth and mantled in tussock-tundra, has some standing water. Abundant frost boils bring well-rounded pebbles, cobbles, and sand to the surface.

Sagavanirktok River Drift

[after Detterman (1953), Detterman and others (1958), Hamilton (1986), and Waythomas (1991)]

Qdms **Moraine Deposits of Sagavanirktok River Age**—Heterogeneous mounds and ridges of pebble–cobble gravel, sand, silt, and clay in varying proportions deposited directly from glacial ice. Forms prominent broad, arcuate ridge that encircles younger Itkillik-age moraines where Echooka River exits the mountain front.

Qds **Undifferentiated Drift of Sagavanirktok River(?) Age**—Very thin and patchy veneer of pebbles, cobbles, and boulders deposited directly from glacial ice of Sagavanirktok age and older. Commonly preserved as only a scattered lag of exotic cobbles and boulders on ice-scoured bedrock and bedrock rubble. May be blanketed by a meter or more of ice-rich organic silt and peat in low-lying areas.

Complex Deposits

Qs **Swamp Deposits**—Elongate to blanket deposits of complexly interbedded peat, organic silt, and organic sand accumulated as surface deposits in local basins and in former stream channels, and downslope from springs and seeps. Saturated and locally frozen and ice rich. Thickness highly variable, but may locally exceed 5 m. Surface smooth, hummocky, or pitted. May have standing water.

Qsr **Retransported Silt**—Heterogeneous blankets, fans, and aprons of silt and organic silt originally laid down by eolian processes and subsequently extensively reworked by fluvial and colluvial processes; includes silt-rich debris-flow deposits. May contain angular clasts of local origin. Massive to thinly bedded, with some wavy bedding and crossbedding. Thickness highly variable. Commonly perennially frozen and ice rich. Surface steep to gently sloping with numerous shallow, interconnected channels and local low scarps.

Qsu **Perennially Frozen Silt, Undifferentiated**—Irregular blankets of massive, generally homogeneous, unconsolidated silt of eolian origin, largely retransported from original hillside sites of eolian deposition to lower slopes and valley bottoms by mudflows, slopewash, and gullying. May include areas of primary upland silt. Locally organic-rich and fetid with interbedded peat and woody layers. Permafrost in valley bottoms creates poor drainage, manifesting as beaded drainage and local bogs. Ground ice is abundant.

Slope failures and small-scale earthflows are common along streamcuts and on slopes. Maximum observed thickness was approximately 3 m, but total thickness is potentially much greater. Surface generally smooth to gently sloping with local low-center ice-wedge polygons; locally pitted and gullied by melting of ice-rich permafrost (thermokarst). Wood collected from a depth of approximately 160 cm in a frozen silt cutbank along a small tributary stream of Shaviovik River (147°14'23"W, 69°20'49"N) was radiocarbon dated at 2,580±40 yr B.P. (GX-26137) and peat collected from a depth of 133 cm in melting ice-rich fetid silt on the low ridge north of Fin Creek (147°8'28"W, 69°30'8"N) was radiocarbon dated at 4,110±140 yr B.P. (GX-26139), providing minimum limiting dates for these deposits.

Qts **Thawed Silt Deposits**—Heterogeneous blankets of poorly to moderately stratified silt and organic silt generally equivalent to Qsu unit and subsequently extensively modified by extreme melting of ice-rich permafrost and overland stream flow. Includes semicircular to irregularly shaped deposits of moderately stratified, heterogeneous, silt, sand, and organic silt filling small, often interconnected basins resulting from the melting of ice-rich permafrost in silt. Saturated and locally refrozen, locally ice rich. Surface may be pitted and hummocky or characterized by numerous shallow, interconnected channels; small ponds and boggy areas are abundant.

Manmade Deposits

Qh **Artificial Fill Deposits**—Pebble–cobble gravel with trace to some sand and silt forming base for drill pad. Well to poorly sorted. Surface smooth.

BROOKIAN SEQUENCE

The Brookian sequence was named for a Jurassic(?) to recent sedimentary succession in arctic Canada (Lerand, 1973). In Alaska these mineralogically immature, marine and nonmarine sediments were southerly-sourced from the uplift of the Brooks Range orogen, and are part of the fill of the North Slope foreland basin, known as the Colville basin. West and north of the map area, the Brookian sequence is up to 4,000 m thick (Bird and Molenaar, 1987). In the Sagavanirktok B-1 Quadrangle the Brookian sequence is composed of three map units: (1) Prince Creek Formation of Late Cretaceous to early Tertiary age; (2) Canning Formation of Late Cretaceous to Tertiary age, and (3) pebble shale and Hue Shale unit (undifferentiated) of Early to Late Cretaceous age.

TKp **Prince Creek Formation** (Upper Cretaceous to lower Tertiary)—Light gray, 'salt and pepper', brown-weathering, medium to coarse grained, moderately sorted, subangular to subrounded, massive to laminated, locally cross-bedded, sandstone, pebbly sandstone, and granule conglomerate. In map area, exposures are mostly limited to stream cuts along Fin Creek and Shaviovik River. Exposures are estimated to be 80 percent sandstone, 5–10 percent conglomerate and 10 percent shale, siltstone, and coal. Conglomerate is light gray, weathers reddish brown, is locally iron stained and well cemented (silica and iron oxide), forms blocky-weathering ledges, is mostly poorly consolidated, and contains subrounded to rounded clasts up to 25 cm, with local interbeds of sandstone, shale, and lignite. Sedimentary structures in conglomerate include large-scale cross-bedding, but conglomerate is generally massive and sand-matrix supported. Siltstone interbeds are dark gray to brown, commonly interbedded with mudstone and local coal, contain laminated and cross-bedded laminations, and weather to small blocks. Petrographic point counting on sandstone (four thin sections, 100 points; figs. 1, 2) indicates that the framework grain averages are 25–35 percent monocrystalline quartz, 30 percent light gray chert, 30 percent very dark gray chert, and minor lithic grains. Outcrop point-counted conglomerate clasts are: 36 percent light gray chert, 22 percent dark gray chert, 23 percent black chert, 11 percent quartz, 5 percent claystone, and minor argillite and coal.

Kc **Canning Formation** (Upper Cretaceous) (Molenaar and others, 1987)—Dark gray to medium gray, locally calcareous and bentonitic, interbedded, fine- and very-fine-grained, moderately well sorted sandstone, siltstone, and shale. Sandstone is typically rhythmically layered, laterally continuous, with planar- and cross-bedding, thin-bedded, with local medium and thick beds. Rare amalgamated sandstone beds are greater than 1 m thick. Bedding surfaces may include black organic material, white mica, and trace fossils. Bouma sequences commonly include T_{a-d}, T_{b-d}, T_{c-d}, and T_c. Sedimentary structures include complete and partial Bouma sequences, and suggest turbidite deposition in a mid fan environment. Petrographic point counting (figs. 1, 2) indicates that framework grains are 55 percent monocrystalline quartz,

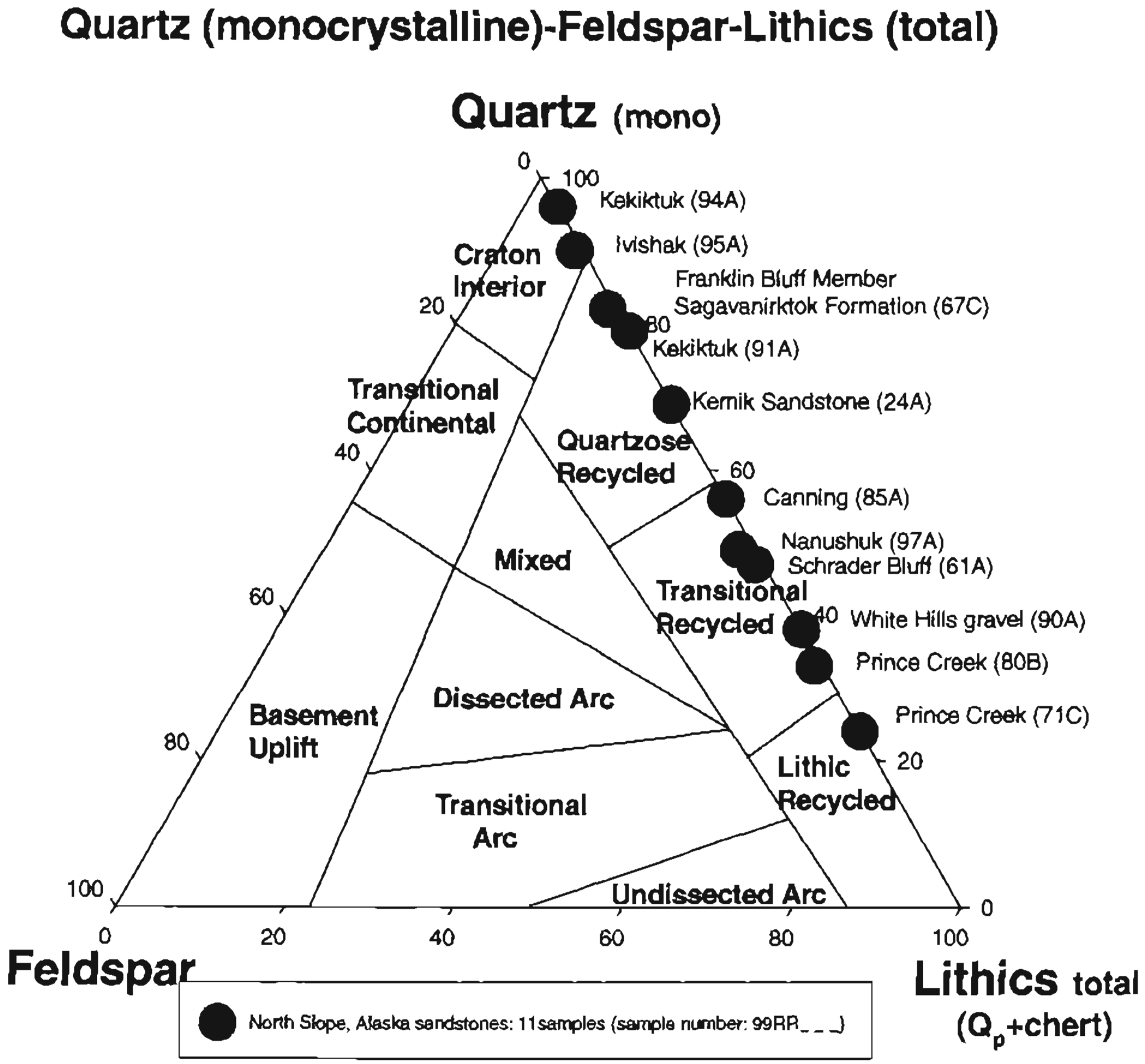

Figure 1. *Quartz (monocrystalline) versus feldspar versus total lithics (including polycrystalline quartz and chert) for 11 sandstones from the Sagavanirktok Quadrangle, eastern North Slope Alaska (fig. 2). One hundred points counted per thin section. Fields are from Dickinson and Suczek, 1978.*

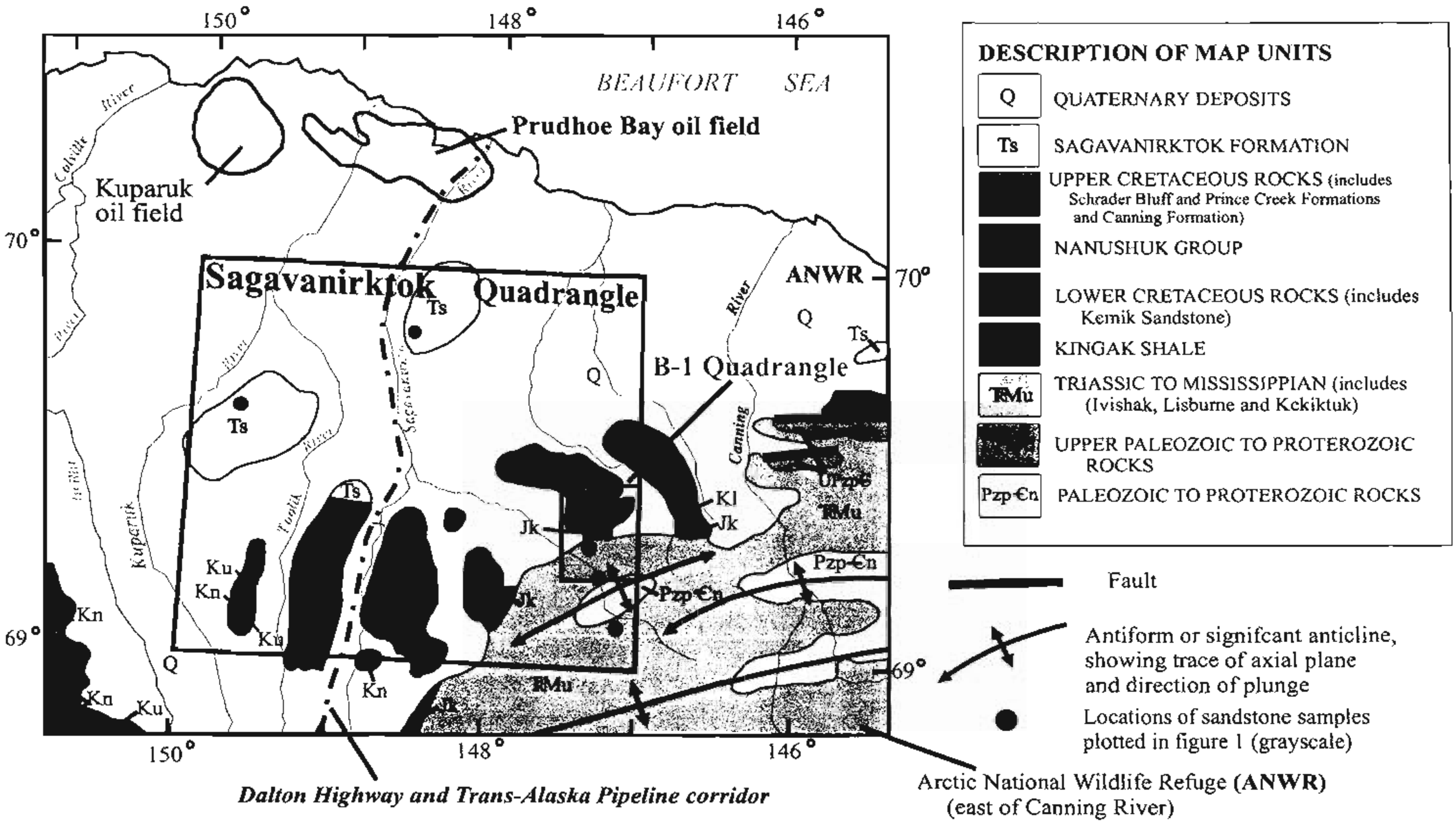

Figure 2. *Generalized geology of the 1:250,000-scale Sagavanirktok Quadrangle, Alaska, and surrounding area, and locations of point-count sandstone thin-section samples (fig. 1).*

20–30 percent sedimentary, metasedimentary, and volcanic rock fragments, 5–10 percent chert, 4 percent plagioclase feldspar, and 2–3 percent white mica. Ductile grain deformation is minor. In map area unit is probably Campanian but regionally becomes younger and is as young as Tertiary to the northeast, the direction of inferred progradation (Molenaar and others, 1987). Thickness is approximately 300 m in the map area.

Kphu **Pebble shale and Hue Shale unit, undifferentiated** (Lower to Upper Cretaceous) (Molenaar and others, 1987)—Poorly exposed black, fissile, laminated clay shale containing scattered rounded chert pebbles and frosted quartz grains (pebble shale unit), overlain by bentonitic clay shale, thin-bedded (2–10 cm thick) silicified tuff beds with fissile black organic-rich shale interbeds, and thin bentonite seams (Hue Shale) which, where exposed, weather from yellow-gray to bright orange-red. Clay shale and fissile organic-rich shale have high total organic carbon (TOC) content up to 4 percent and regionally constitute an important hydrocarbon source-rock horizon. Regionally, the upper part of the pebble shale unit contains radioactive black shale that is correlative with the 'gamma ray zone' (GRZ) or 'hot radioactive zone' (HRZ), an important stratigraphic marker in the subsurface of the North Slope. In map area, unit is best exposed in a stream cut on Kemik Creek in SW¼ Sec. 8, T 1 S, R 21 E, and in rubble exposures in SW¼ Sec. 13, T 1 S, R 20 E. Age of the pebble shale unit is Hauterivian–Barremian (Micropaleo Consultants, Inc., *in* Mull, 1987), and the Hue Shale is Aptian(?) to Campanian (Molenaar and others, 1987). Thickness of undifferentiated unit probably <300 m.

ELLESMERIAN SEQUENCE

The Ellesmerian sequence was named for a Mississippian to Jurassic age sedimentary succession in arctic Canada (Lerand, 1973). In Alaska, the Ellesmerian sequence consists of mineralogically mature, stable platform sediments deposited adjacent to a northern source area. In the Sagavanirktok B-1 Quadrangle, the Ellesmerian sequence includes: (1) Kekiktuk Conglomerate [Lower Mississippian], (2) Kayak Shale [Lower to Upper Mississippian] of the Endicott Group, (3) Alapah Limestone and Wahoo Limestone of the Lisburne Group [Mississippian and Pennsylvanian, respectively], (4) Echooka Formation and Ivishak Formation of the Sadlerochit Group [Permian and Triassic], (5) Shublik Formation [Triassic], (6) Kingak Shale [Jurassic to Lower Cretaceous], and (7) Kemik Sandstone [Lower Cretaceous; Hauterivian].

Kemik Sandstone (Lower Cretaceous, Hauterivian) (Keller and others, 1961; Detterman and others, 1975; Mull, 1987)—The distinctive, resistant, quartzose sandstone unit now known as the Kemik Sandstone was originally mapped by Leffingwell (1919) as a part of the Ignek Formation (abandoned), in the Sadlerochit Mountains 50 km east of the map area. Keller and others (1961) named it the Kemik member of the Okpikruak Formation, based on its exposures in the Sagavanirktok B-1 Quadrangle, and Detterman and others (1975) redefined it as a member of the Kongakut Formation. In order to clarify stratigraphic relationships and simplify the nomenclature of the North Slope and northeastern Brooks Range, Mull (1987) raised the Kemik Sandstone to formation status, including two members: the Ignek Valley Member, consisting of fine-grained to conglomeratic sandstone; and the Marsh Creek Member, consisting of burrowed pebbly siltstone. Knock (1987) documented a detailed study of Kemik facies and depositional environments in Ignek Valley and on the north side of the Sadlerochit Mountains 50–80 km east of the map area. The regional distribution of Kemik (and equivalent sands) and the pebble shale unit, and their relationship to the mid-Neocomian unconformity, suggest that these rocks were derived from a northern source, and deposited above or adjacent to the rifted margin of the Arctic Alaska plate.

Regionally, the Kemik is well exposed from the eastern end of Ignek Valley to the Canning River, between the Sadlerochit and Shublik Mountains (Mull, 1987; Knock, 1987; Robinson and others, 1989), and in scattered rubble ridges and stream cuts from the Canning River 56 km southwest to the Echooka River in the area of the Sagavanirktok B-1 and B-2 quadrangles. The Kemik is present in a number of wells on the east-central North Slope as far as 110 km west of the Canning River. It commonly overlies the regional mid-Neocomian unconformity commonly referred to as the Lower Cretaceous unconformity (LCU), which cuts downsection to the north, and thus unconformably overlies a variety of rock units. At the Echooka River, in the Sagavanirktok B-2 Quadrangle 15 km west of the map area, the Kemik conformably overlies Kingak Shale where the unconformity becomes an intrabasinal correlative conformity (Reifenstuhl, 1995; 1994).

In the Sagavanirktok B-1 Quadrangle, we recognize two distinct mappable facies trends within the Ignek Valley Member of the Kemik Sandstone. These facies, which are juxtaposed by a north-vergent thrust fault, consist of a northern belt of dominantly bioturbated sandstone that appears to conformably and gradationally overlie the

Kingak Shale, and a thinner, dominantly massive, homogeneous sandstone facies trend to the south that overlies Kingak Shale at a sharp unconformity. Measured sections of the Kemik on the Canning and Echooka rivers (Reifenstuhl, 1995) and outcrop studies in the map area indicate coarsening- and thickening-upward sandstone successions. Depositional environments in the northern and southern facies belts include upper shoreface, barrier island with tidal channel-fill, subaerial (with local paleosol), and offshore shelf. The Kemik in both facies trends is conformably overlain by the pebble shale unit at a sharp contact that suggests rapid marine transgression.

Petrographic point count analyses of the Kemik from both the northern and southern facies belts (figs. 1, 2) show that the sandstone is well sorted, subrounded, and silica cemented, with minor porosity. Framework grains consist of 75–80 percent monocrystalline quartz, 15–20 percent rock fragments, and less than 5 percent feldspar. The quartz is dominantly monocrystalline, with minor amounts of stretched metamorphic quartz and vein quartz. Black chert is the dominant rock fragment, with lesser amounts of weathered, leached-white tripolitic chert. Other rock fragments are minor constituents and include shale, siltstone, limestone, dolomite, and siliceous sandstone. Glauconite, muscovite, sericite, collophane, zircon, and tourmaline are also present in trace amounts. Silica cementation is extensive as quartz overgrowths. Point-count data indicate a recycled orogenic or quartzose recycled provenance. Regionally, local sources are indicated by the significant increase in chert and carbonate clasts, from west to east in the subsurface.

Regionally, porosity values for all Kemik samples range from 0.8 to 14.1 percent and average 5.3 percent. Subsurface samples range from 3.9 to 8.4 percent and average 6.2 percent. Comparison of the average porosity of the 43 surface samples (5.3 percent) to the average porosity of the five subsurface samples (6.2 percent) shows a 17 percent higher subsurface porosity (Reifenstuhl, 1995). Petrophysical analyses indicate very low permeability ranging from 1.6 to 0.0004 millidarcies. However, the Kemik contained gas shows in the 'Kemik anticline' wells in the map area, and Gautier (1987) reported a hydrocarbon-productive sandstone and conglomerate interval in correlative beds in a well of the Point Thomson area, 50 km northeast of the map area.

The Kemik Sandstone is correlated with other sandstone bodies that overlie the LCU in the subsurface: Put River Sandstone (Prudhoe Bay oil field); upper Kuparuk River Formation (Kuparuk oil field); Cape Halkett sandstone (NPRA); Point Thomson sand (west of ANWR); and 'Tapkaurak sand' (Aurora #1 well, east of Kaktovik). Where sandstone is absent above the LCU, the overlying pebble shale unit lies directly on the LCU.

In the Sagavanirktok B-1 Quadrangle the Kemik is deformed into open, tight, and overturned folds, and thrust-fault imbrications. Imbricate thrust-fault repetitions of the Kemik are also present in the Kemik #1 well in the map area, and in the Exxon Canning River Unit A-1 well 40 km northeast (Bird and others, 1987).

The Kemik in the Sagavanirktok B-1 Quadrangle is dated as Hauterivian, based on the occurrence of the ammonite *Simberskites* sp. in the Kemik at the Echooka River, in the Sagavanirktok B-2 Quadrangle, 15 km west of the map area (Mull, 1987).

Kkb **Kemik Sandstone, bioturbated facies** (northern facies belt)—Medium gray to dark brownish-gray, very-fine-grained quartz arenite; consists principally of intensely bioturbated sandstone and silty sandstone that appears to gradationally overlie Kingak Shale. Unit forms predominantly rubble-covered ridges that weather dark gray to black on aerial photos, in contrast with massive facies of the Kemik (Kkm) to the south, which on aerial photos forms black rubble traces. Top of unit consists of 0.3 to 10 m of clean, massive and laminated, very-fine-grained quartzose sandstone. Lower part is dominantly intensely bioturbated sandstone that appears to grade downward into underlying Kingak Shale, similar to the stratigraphic relationships at a well-exposed locality at the Echooka River (Sagavanirktok B-2 Quadrangle), where the basal Kemik forms an apparent intrabasinal correlative conformity with the underlying Kingak Shale. This gradational relationship contrasts markedly with the contact at the base of the massive facies (Kkm) in the southern facies belt. Contact with overlying pebble shale unit is not exposed in the Sagavanirktok B-1 Quadrangle, but is probably a sharp contact. Thickness estimated at ~40 m.

Kkm **Kemik Sandstone, massive facies** (southern facies belt)—Medium gray, very-fine-grained, dominantly well bedded, laminated, homogenous quartz arenite; unconformably overlies Kingak Shale at a sharp basal contact; forms rubble-covered ridges that support abundant black lichens that yield a distinctive very dark gray to black character on aerial photographs. Thickness estimated 20 m. Lower part of unit and the Lower Cretaceous unconformity (LCU) are well exposed in a stream cut on the Shaviovik River in NW¼ Sec. 24, T 1 S, R 20 E, where the base of the Kemik consists of 2 m of bimodal, ferruginous, orange-weathering siltstone that contains prominent, very coarse, well rounded, clear quartz grains. This bed is overlain by 1 m of conspicuously bioturbated sandstone with local well preserved root casts, which in turn is overlain by 1 m of silty shale. Upper part of the Kemik at this locality consists of 13 m of evenly bedded, parallel-laminated, clean, very-fine-grained sandstone. The upper contact with the overlying pebble shale unit is covered, but is probably a sharp contact. In the map area, the stratigraphic succession of Kingak, LCU, and massive facies of the Kemik contrasts sharply with the stratigraphic sequence of markedly thicker bioturbated facies of the Kemik of the northern belt. The succession is allochthonous above a detachment in the Kingak Shale and is emplaced onto the northern, bioturbated facies by a north-vergent thrust of unknown displacement.

In the adjacent Mt. Michelson B-5 Quadrangle east of Fin Creek, a belt of thin Kemik Sandstone <3 m thick overlies Kingak Shale and is overlain by thin pebble shale, which in turn is overlain by Albian to Cenomanian(?) turbidites (Mull, 1987) that may be correlative with the Gilead sandstone (Reifenstuhl, 1990; 1991; 1989; Pessel and others, 1990). This belt of very thin Kemik and Albian turbidites also appears to be on a north-vergent thrust sheet that structurally overlies the massive Kemik facies but has been eroded and does not extend into the Sagavanirktok B-1 Quadrangle. By analogy with better exposures of similar thin Kemik facies near Bathtub Ridge in Demarcation Point Quadrangle 200 km to the east (Camber and Mull, 1986), this very thin Kemik (<3 m) was probably deposited as an event deposit in a basinal setting (Mull, 1987).

KJk **Kingak Shale** (Jurassic to Lower Cretaceous) (Leffingwell, 1919)—Black fissile clay shale and soft silty claystone; contains pyrite and scattered chert and quartz pebbles, common clay ironstone, and pyrite-bearing concretions and ironstone layers. Locally contains minor very-fine-grained sandstone interbeds with ironstone concretions. The unit is soft and incompetent, typically folded and contorted, recessive weathering and poorly exposed except in cutbanks; forms vegetation-covered and shale-rubble slopes. Best exposed along Kemik Creek in center of map area (Sec. 6, T 1 S, R 21 E). Conformably to disconformably underlies the Kemik Sandstone and conformably overlies the Shublik Formation. The Kingak Shale is regionally a major structural detachment horizon between thrust duplexes (Meigs and Imm, 1995; Wallace and Hanks, 1990; Pessel and others, 1990). Thickness at least 350 m in the Kemik Creek area (Molenaar, 1983) but is probably structurally thickened in many areas by thrust repetition and folding.

Tru **Triassic rocks, undifferentiated**—Includes Shublik Formation, Ivishak Formation, and Kavik Shale as described below. Undifferentiated unit is mapped along the mountain front in western part of map area where extensive rubble cover prevents delineation of individual units.

Trs **Shublik Formation** (Middle to Upper Triassic) (Leffingwell, 1919)—Organic-rich, dark gray to black, phosphatic, medium- to thin-bedded bioclastic limestone with interbedded calcareous siltstone and shale, and minor calcareous sandstone. Limestone beds and interbedded shale are generally sooty, locally contain fetid odor, and contain abundant compressed pectinoid pelecypods, *Halobia* sp. and *Monotis* sp. Upper part of the formation consists of soft black, clay shale that weathers recessively to chips. In outcrops both south and east of the map area, the top of the formation contains a very-fine-grained calcareous sandstone bed that may be correlative with the Karen Creek Sandstone. Exposures are limited to a few stream cuts along the mountain front in eastern part of map area. Unit marks the transition from dominantly siliciclastic Permian to Lower Triassic deposition to dominantly shale deposition in the overlying Jurassic. Regionally, the thickness is approximately 70–100 m (Keller and others, 1961).

Sadlerochit Group (Lower Permian to Middle Triassic) (Detterman and others, 1975)—Leffingwell (1919) named the Sadlerochit Formation for a heterogeneous clastic rock succession in the northeastern Brooks Range that included orthoquartzite, chert, limestone, sandstone, siltstone, and shale thought to be Pennsylvanian age. Later work by Girty (1906) considered the rocks to be Permian. Subsequent work by Keller and others (1961) subdivided the unit into the Ivishak and Echooka members, of Early Triassic and Late Permian age, respectively. Still later studies by Detterman and others (1975) raised the Sadlerochit Formation to group status and elevated the Ivishak and Echooka members to formation rank.

Tri **Ivishak Formation** (Lower Triassic) (Detterman and others, 1975)—Dark gray, fine-grained quartz sandstone grading to siltstone, light tan-brown- to red-brown-weathering, overall in coarsening- and thickening-upward packages 2–5 m thick, with thin- to medium-bedded (up to 8 cm) sandstone with interbedded siltstone partings. The unit contains a thick package of medium to thick sandstone beds (average 20 cm thick) with thin siltstone partings; the top of the unit is a fining-upward package. Internal sedimentary structures include thin, parallel laminations; small-scale, low-angle cross-bedding; wave- and current-ripple bedforms; wavy bedding surfaces where cross-bedded; and ball-and-pillow load structures locally in thick beds. Sandstone shows low to moderate bioturbation with mottled appearance locally; some bedding surfaces covered with crawling traces show undisturbed laminations. Bioturbation increases upsection. In map area, the upper part of the unit is probably correlative with the Fire Creek Siltstone Member of the Ivishak of Detterman and others (1975), and the underlying, thicker sandstone package is tentatively correlated with the Ledge Sandstone Member. Grades downward into the Kavik Shale Member. Petrographic point counting (figs. 1, 2) indicates that framework grains are 90 percent monocrystalline quartz, 10 percent polycrystalline quartz and chert, and minor plagioclase and lithic grains. Thickness is estimated to be several hundred meters.

Trik **Ivishak Formation, Kavik Shale Member** (Lower Triassic)—Dark gray to black silty shale and very-thin-bedded to thinly laminated siltstone. Unit is characterized by recessive weathering, has limited outcrop in the map area, and is typically exposed only as rock-chip rubble. Unit grades upward into sandstone of the Ivishak.

Pe **Echooka Formation** (Permian) (Keller and others, 1961)—The Echooka Formation crops out along the Philip Smith Mountains front as prominent dark cuestas that contrast with the underlying light-colored Lisburne Group and the overlying recessive Kavik member of the Ivishak Formation. The basal 60–70 m consists of slabby- to blocky-weathering (up to 1.2 m blocks), dark brown to brownish-black, dark brown to rust-red-brown weathering, highly bioturbated, mottled siliceous siltstone, very-fine-grained siliceous sandstone, and lesser silicified limestone with sponge spicules. No internal bedding features were observed in the map area, but color banding is locally visible. The endostratal trace fossil *Zoophycos* is prominent on bedding planes in the lower 60–70 m of the section. Rust-red oxidation stains up to several centimeters in diameter are scattered throughout the lower part of the unit, a result of oxidation of pyrite cubes that are scattered throughout. The upper 20–30 m of the units is less siliceous than the lower 60–70 m; it is also highly bioturbated and weathers light tan to gray to very dark gray where the rock is more siliceous. Top of unit is not exposed in map area. Base is marked by generally poorly exposed clast-supported limestone and chert pebble conglomerate with angular to subangular, poorly sorted, sandy and limy clay matrix. Conglomerate may be a channel fill, unconformably overlying platform carbonates of the Lisburne Group.

The lithologic character and stratigraphic position of the Echooka above a subaerial unconformity (Crowder, 1990) indicate that it is a transgressive succession. The highly bioturbated character of the Echooka indicates slow sedimentation rates so that burrowing organisms had time to destroy all primary stratification and to homogenize the sediment. The ubiquitous presence of the trace fossil *Zoophycos* and apparent absence of other identifiable trace makers suggest that sediment pore waters immediately below the sediment-water interface were oxygen deficient. Siliceous sponge spicules suggest deeper, quiet water conditions and may account for the siliceous nature of the rock, which is not regionally common to the Echooka Formation but is prominent in the map area, especially east of the Echooka River. The spicules indicate indigenous sponge population or spicule transport. Glauconite, common in the Echooka Formation elsewhere, was not observed in the map area, but abundant limonitic spots may indicate weathered glauconite in addition to the ubiquitous rusty red-brown weathered and oxidized pyrite cubes and nodules.

In the map area, the unit is relatively well exposed in two partial sections. One section measured and described is in a small topographic saddle immediately west of an unnamed, north-northwest-flowing stream in the SW¼, Sec. 1, T 2 S, R 20 E. A second 90-m-thick section, located in the drainage immediately east of the saddle, begins within a meter or two of the sub-Echooka unconformity. Northeast-trending folds that parallel the mountain front thicken the Echooka, and the unit is cut by abundant fractures and cleavage. Both are oblique or perpendicular to bedding. Total thickness is about 90 m.

Lisburne Group (Mississippian to Lower Pennsylvanian)—Schrader (1902) described and named the Lisburne Formation for a thick succession of light gray limestone in the Cape Lisburne area of the western Brooks Range. Leffingwell (1919) later referred to similar rocks in northeastern Alaska as the Lisburne Limestone. Detailed studies by Bowsher and Dutro (1957) in the Shainin Lake area of the central Brooks Range subsequently raised the Lisburne Formation (limestone) to group status and subdivided it into two formations: Wachsmuth Limestone (Lower and Upper Mississippian), which pinches out to the northeast, and Alapah Limestone (Upper Mississippian). In the northeastern Brooks Range, the Alapah Limestone is overlain by the Wahoo Limestone (Brosgé and others, 1962) of Late Mississippian to Early Pennsylvanian age (Armstrong and others, 1970; Imm, 1986), which is not recognized with any certainty west of the central Philip Smith Mountains Quadrangle southwest of the Sagavanirktok B-1 map area. In the Sagavanirktok B-1 Quadrangle we recognize three mappable units: 'upper Lisburne,' 'middle Lisburne,' and 'lower Lisburne,' which are approximately equivalent to the Wahoo Limestone and upper and lower Alapah, and lower Alapah.

IPMlu **Lisburne Group, upper part**—Medium to light gray, very light gray to buff weathering, thin- to very-thick-bedded, interbedded lime mud and bioclastic grainstone and wackestone that is commonly crinoidal, and subordinate buff-weathering dolostone. Locally massive beds have no visible internal structures, but some beds contain coral fossil hash. White to light gray nodular chert layers and lenses are locally common. The upper Lisburne unit is a resistant, cliff-forming interval with cyclical stratigraphy that defines 10–20-m-thick massive successions that form topographic steps. Color variations define thinner beds within the massive beds, and include light gray and yellow to tan-stained rocks. The uppermost Lisburne near the contact with the overlying Echooka consists of limestone and dolomite with some nodular chert concretions parallel to bedding. The contact with the overlying Echooka Formation is not exposed in the map area. This unit is approximately equivalent to the Wahoo Limestone, and is between 150 and 375 m thick. It typically forms kilometer-scale folds with curved hinge zones and common box-fold geometry with associated cleavage, especially in hinge zones and tighter folds.

PMlm **Lisburne Group, middle part**—Medium gray and dark gray banded, medium-gray-weathering interval that is transitional between upper and lower Lisburne map units; difficult to differentiate from upper Lisburne in some exposures. Cycles thinner and with more dark, finer-grained interbeds than in upper Lisburne. The middle part of the Lisburne in the map area forms more uniform slopes than the 'step-forming' upper Lisburne but locally forms cliffs and consists of alternating resistant and rubbly intervals. Alternating competent and incompetent layers typically form chevron folds parasitic to kilometer-scale folds. Solution cleavage is common, especially in hinge zones and tighter folds.

Mll **Lisburne Group, lower part**—Sooty black, dark-gray-weathering, recessive mudstone and wackestone interval that mostly forms slopes consisting of small rubble blocks. Distinct thin (~10–40 cm) beds where well exposed, with subordinate thicker and more resistant interbeds. The lower part of the Lisburne commonly contains colonial and solitary corals, dark gray to black nodular chert layers and lenses. Typically forms angular folds parasitic to kilometer-scale folds. Solution cleavage common, especially in hinge zones and tighter folds. In the map area, the lower part of the Lisburne is approximately equivalent to the lower Alapah Limestone, and probably equivalent to the informal lower shale sequence in the Echooka River region (Pessel and others, 1990) to the southwest. The lower part of the Lisburne probably interfingers with the underlying Kayak Shale, but is rarely exposed beneath talus from the overlying cliff-forming limestones.

Endicott Group (Upper Devonian to Lower Mississippian)—The Endicott Group was named by Tailleur and others (1967) for a thick succession of shale, sandstone, and conglomerate exposed in the Endicott Mountains of the central Brooks Range, where it is nearly 3,000 m thick and includes the Upper Devonian Hunt Fork Shale, Upper Devonian Noatak Sandstone, Upper Devonian to Lower Mississippian Kanayut Conglomerate, and the Lower Mississippian Kayak Shale. Collectively, these formations comprise an aerially extensive regressive–transgressive clastic wedge derived from a northern landmass, with no regionally significant unconformities. As defined by Tailleur and others (1967), in the northeastern Brooks Range (including the Sagavanirktok B-1 Quadrangle) the Endicott Group is much thinner and consists of the Kayak Shale (Lower to Upper Mississippian) (Bowsher and Dutro, 1957) and the Kekiktuk Conglomerate (Mississippian) (Brosgé and others, 1962), which overlies a major regional angular unconformity that truncates lower Paleozoic to Proterozoic(?) rocks. This succession contrasts markedly with the much thicker Endicott Group in the central Brooks Range, and comprises a transgressive succession that probably represents the northeastern continuation of the transgressive portion of the Endicott Group in the central Brooks Range. In the Sagavanirktok Quadrangle, the Endicott Group is exposed only around the flanks of the core of the Echooka anticlinorium, and is present only in the southeastern part of the Sagavanirktok B1 Quadrangle.

Mky **Kayak Shale** (Lower to Upper Mississippian) (Bowsher and Dutro, 1957)—Dominantly black, sooty, fissile shale and silty shale, with subordinate siltstone, quartz sandstone, and dark-gray- to maroon-weathering silty limestone, lime mudstone, and wackestone. The upper part of the Kayak consists of dark gray to black silty calcareous shale and thin-bedded limestone that weathers yellowish or reddish-brown; in the Sagavanirktok B-1 Quadrangle, it may be mapped as lower Lisburne, but this upper part, as well as the middle part, strongly resembles the upper and middle Kayak as mapped in parts of the Arctic National Wildlife Refuge (ANWR) to the east. The upper part of the Kayak commonly contains yellowish-brown-weathering fossiliferous beds with fossil assemblages including thin-walled articulated bivalves, ostracode fragments, crinoid ossicles 1–2 cm long, at least three varieties of corals including *Lithostrotionella* sp., *Syringipora* sp., a solitary horn coral, and a large thick-walled valved (productid) brachiopod(?). The middle part of the Kayak consists dominantly of black fissile shale that is rarely exposed other than as shale flakes in float; the lower part of the fissile black shale includes subordinate thin beds of tan-brown-weathering quartz sandstone. Near the Kayak-Kekiktuk contact, the base of the Kayak appears to interfinger with the underlying Kekiktuk Conglomerate and contains thin, plane-parallel and lenticular beds of very-fine-grained sandstone. The basal unit includes tan-brown to gold-brown quartz semischist with small-scale, parasitic folds with fold axes that average east-northeast strike and 5° plunge; folds are generally upright.

Mkt **Kekiktuk Conglomerate** (Lower Mississippian) (Brosgé and others, 1962)—Medium gray, light gray to tan-brown and orange-brown-weathering, very–fine-grained sandstone, siltstone, and silty shale, with subordinate amounts of medium-grained quartzose sandstone, chert- and quartz-granule conglomerate, and minor anthracitic coal. Sandstone beds are 2–20 cm thick; siderite concretions are locally present. Bedding structures include wavy non-parallel laminae, small-scale trough cross-laminae, ripple cross-laminae, starved ripples, and plane-parallel laminae. Siltstone, silty shale, and clay shale comprise thick successions (up to 10 m thick) between sandstone units. Granule- and pebble-conglomerate include rounded clasts of vein quartz and quartz semischist and are concentrated near the basal contact with the pre-Mississippian. Weathering character is flaggy to slabby. Many beds are ripple cross laminated in sets up to 10 cm thick. Petrographic studies (figs. 1, 2) show that monocrystalline quartz is the dominant framework grain (80–96 percent), with the remaining grains consisting of chert and polycrystalline quartz, with minor lithic grains and weathered-out opaque minerals. Shale locally includes bioturbated or possibly pedoturbated (mixing of soil components) dark–gray- to red-weathering siltstone with abundant carbonaceous material, small, poorly preserved plant fragments, and small pieces of anthracitic coal. Around the flanks of the Echooka anticlinorium, the basal Kekiktuk is marked by a coal-bearing mudstone succession and minor pebble conglomerate, with poorly preserved plant fragments in siltstone and silty shale in the lower 25 m. Anthracitic coal is limited to the lower 20–30 m. In the southeastern Sagavanirktok B-1 Quadrangle on the north side of the anticlinorium, the Kekiktuk is slightly coarser grained than on the south flank. One granule conglomerate bed includes plants in growth position that are rooted to the underlying interbedded organic siltstone and very-fine-grained ripple-laminated sandstone.

The organization of the Kekiktuk is very different from that in outcrop to the northeast and in the subsurface to the north and northwest. A generalized interpretation of the Kekiktuk involves deposition in a suite of related settings including nonmarine and marginal-marine environments. Nonmarine environments include low- to moderate-sinuosity, mixed-load(?) fluvial channel complexes and coal-bearing alluvial flood basins with thin crevasse-splay deposits. Marginal-marine environments span the spectrum of tide-influenced estuarine sub-environments including bayhead deltas, subaqueous tidal sand flats, and tidal channel and bar complexes. Small-scale, wave-generated structures are common, but less abundant than larger, current-generated structures in marginal-marine facies.

The Kekiktuk is not well dated but regionally is considered to range from latest Tournaisian to early Visean (Early to Late Mississippian) in the range-front region of the northeastern Brooks Range. It rests with angular discordance on pre-Mississippian rocks, but the basal unconformity is not exposed in the map area.

FRANKLINIAN SEQUENCE

The Franklinian sequence was named for a sequence of Upper Cambrian through Devonian rocks in northern Canada with a northerly source (Lerand, 1973). In northeastern Alaska, this succession is commonly considered to be composed mostly of pre-Mississippian rocks. In the Sadlerochit and Shublik Mountains, the Franklinian sequence includes (from youngest to oldest) the Nanook Limestone (Cambrian to Devonian; Dutro, 1970), the

Katakturuk Dolomite (Precambrian; Dutro, 1970), and the Neruokpuk Formation (Precambrian; Reiser and others, 1978), which probably unconformably underlies the Katakturuk Dolomite (Robinson and others, 1989). In the Sagavanirktok B-1 Quadrangle, the pre-Mississippian rocks consist of the Neruokpuk Formation (Dutro, 1970), and crop out only in the southeast portion of the map area.

pM **Pre-Mississippian rocks, undifferentiated**—Dominantly calcareous quartz semischist with subordinate calcareous pelitic siltstone, and black and pale green phyllite. Quartz semischist weathers orange-brown, tan-brown, tan-gold, and gray, and comprises very-fine- to fine-grained rounded detrital quartz grains, and light tan-brown to gold mica. Semischist is thin to medium, parallel bedded; schistose fabric is variously oriented at low and high angles to bedding. Alternating light and dark laminae are common. Pelitic siltstone is very thin, parallel to wavy discontinuous bedded; cleavage is prominent and parallel, or at low angles, to bedding. Phyllite is dominantly black with a subordinate pale green variety and is characterized by axial planar cleavage. Other than plane-parallel lamination, sedimentary structures in the semischist are rare and include current-ripple cross-lamination, small-scale trough cross-lamination, hummocky cross-stratification; flute marks, and load casts. Black phyllite occurs locally within quartz semischist as rip-up clasts and as contorted lenses in convolute laminated quartz semischist. Phyllite becomes progressively more abundant on the northern flank of the Echooka anticlinorium. The quartz semischist to phyllite ratio is >5 on the south side and increases progressively toward the north side, where it is <1. Bedding and cleavage consistently strike easterly and dip moderately to steeply toward the south. Bedding to cleavage relations indicate large-scale isoclinal folds and stratigraphic facing indicators show both upright and overturned folds. The age and total thickness of the calcareous sandstone and phyllite unit are unknown and may be correlative to calcareous siltstone and sandstone unit of the Precambrian Neruokpuk Formation (Dutro, 1970).

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