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KEMIK SANDSTONE, ARCTIC NATIONAL WILDLIFE REFUGE, NORTHEASTERN ALASKA

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C.G. Mull[1]

ABSTRACT

The Kemik Sandstone (revised name) of Early Cretaceous (Hauterivian) age crops out extensively in the Sadlerochit and Shublik Mountains area of the Arctic National Wildlife Refuge (ANWR) in northeastern Alaska. At its maximum development, the Kemik consists of about 100 ft of clean quartzose very fine to fine-grained sandstone. In ANWR the Kemik overlies a regional mid-Neocomian unconformity that truncates progressively older beds to the north. In Ignek Valley, which separates the Sadlerochit and Shublik Mountains, the Kemik truncates the Jurassic part of the Kingak Shale, but on the north side of the eastern Sadlerochit Mountains, it truncates the Lower Triassic Ivishak Formation of the Sadlerochit Group. To the south the unconformity dies out, and the Kemik is apparently gradational with the Lower Cretaceous part of the Kingak Shale.

Three contrasting Kemik facies are recognized. The most significant facies is a laminated, cross-bedded sandstone facies that is widespread on the south side of the Sadlerochit Mountains and is interpreted as a barrier island complex. It is here named the Ignek Valley Member and is a potential hydrocarbon reservoir in the subsurface.

Development of the Ignek Valley Member barrier-island complex appears to have been primarily by a process of vertical accretion with no major lateral migration of the facies trends either landward or seaward. Decreasing size and abundance of distinctive white tripolitic-chert clasts in the sandstone suggest longshore drift from northeast to southwest along the barrier island. The chert clasts were probably derived from truncated Mississippian to Pennsylvanian Lisburne Group northeast of the Sadlerochit Mountains.

A burrowed pebbly siltstone facies on the north side of the eastern Sadlerochit Mountains is interpreted as a back barrier lagoonal deposit. This facies is here named the Marsh Creek Member. South of the barrier island deposits of the Ignek Valley Member Mountains area, a silty and muddy facies represents offshore marine deposition.

Mapping suggests that the barrier island sediments were deposited in a relatively narrow belt that trends about S 80° W through the Sadlerochit and Shublik Mountains area. However, in the Marsh Creek area on the north side of the eastern Sadlerochit Mountains, the burrowed pebbly siltstone facies of the Marsh Creek Member of the Kemik is structurally overlain by imbricated sections of the Kingak Shale and the cross-bedded sandstone facies of the Ignek Valley Member of the Kemik. These beds were displaced northwestward on a thrust sheet that has subsequently been folded by uplift of the Sadlerochit Mountains.

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The Kemik Sandstone is conformably overlain by the pebble shale unit, a laminated black marine shale that contains scattered concentrations of pebble to boulder size clasts of chert and quartzite. The contact of the pebble shale with the three Kemik facies is sharp and does not interfinger; it appears to indicate a rapid marine transgression over the Kemik. The regional distribution of the Kemik Formation and the pebble shale unit and their relationship to the mid-Neocomian unconformity suggest that these rocks were derived from and deposited over the rifted margin of the Arctic Alaska plate.

INTRODUCTION

The Kemik Formation (revised name) of Early Cretaceous (Hauterivian) age is a relatively thin but continuous unit up to about 100 ft thick in the Sadlerochit and Shublik Mountains area of the Arctic National Wildlife Refuge (ANWR) and adjacent areas of northeastern Alaska. It is overlain by a distinctive section that consists of an unnamed pebble shale unit of Hauterivian-Barremian age, and the Upper Cretaceous Colville Group (fig. 1). In most of the area the Kemik is underlain by the Lower Cretaceous to Jurassic Kingak Shale. West of ANWR, the Kemik is present in scattered rubble ridges and stream cuts from the Canning River 35 mi southwest to the Echooka River. It has also been encountered in a number of wells drilled on the east-central Arctic Slope. This report focuses on the Kemik of the Canning River-Sadlerochit Mountains area of ANWR (figs. 2 and 3), where the relationships between the major facies are best exhibited. Previously considered a member of the Kongakut Formation, the Kemik is here revised and raised to formation status with two members in the northeastern Brooks Range foothills.

A major facies of the Kemik is a very fine to fine-grained clean quartzose very fine-grained sandstone that may have reservoir potential in the subsurface. It is both overlain and underlain by black shale with a high content of organic material. Because of its possible reservoir potential and close association with hydrocarbon source beds, it is considered a major objective for hydrocarbon exploration in the subsurface of ANWR. In the northern part of its outcrop area, the Kemik overlies a regional mid-Neocomian unconformity that truncates the Kingak Shale and older rocks; this major unconformity is present throughout Arctic Alaska.

The Kemik is correlated with several discontinuous sandstone bodies, including the Put River Sandstone in the Prudhoe Bay oil field, the upper part of the Kuparuk River Formation in the Kuparuk oil field, the Cape Halkett sandstone (informal name) in the National Petroleum Reserve in Alaska, and a reported hydrocarbon productive sandstone and conglomerate interval in the subsurface of the Point Thompson area west of ANWR. Where sandstone is absent above the unconformity, the overlying pebble shale unit rests on the unconformity.

LOCATION AND DISTRIBUTION

In ANWR, the Kemik is most extensively exposed in Ignek Valley, a long east-west trending valley separating the Sadlerochit and Shublik Mountains. In this area, the Kemik can be traced for nearly 20 mi as an almost unbroken outcrop, although many portions of the outcrop consist entirely of frost-

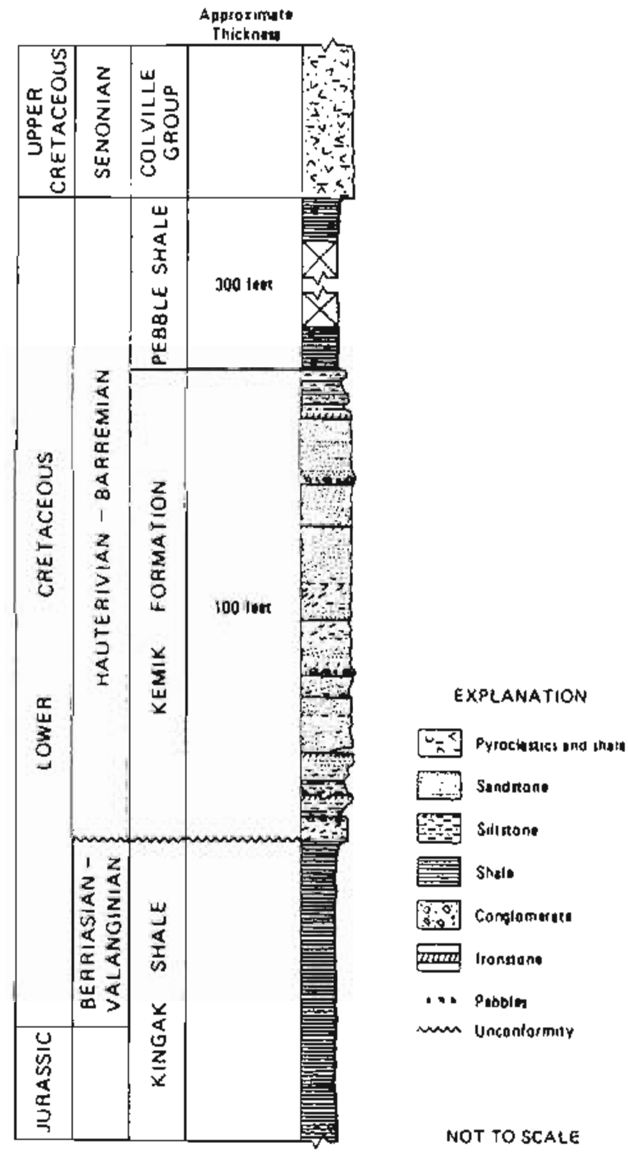

Figure 1. Generalized stratigraphic column of Ignek Valley Member Kemik Sandstone and adjacent formations in Ignek Valley, between Sadlerochit and Shublik Mountains.

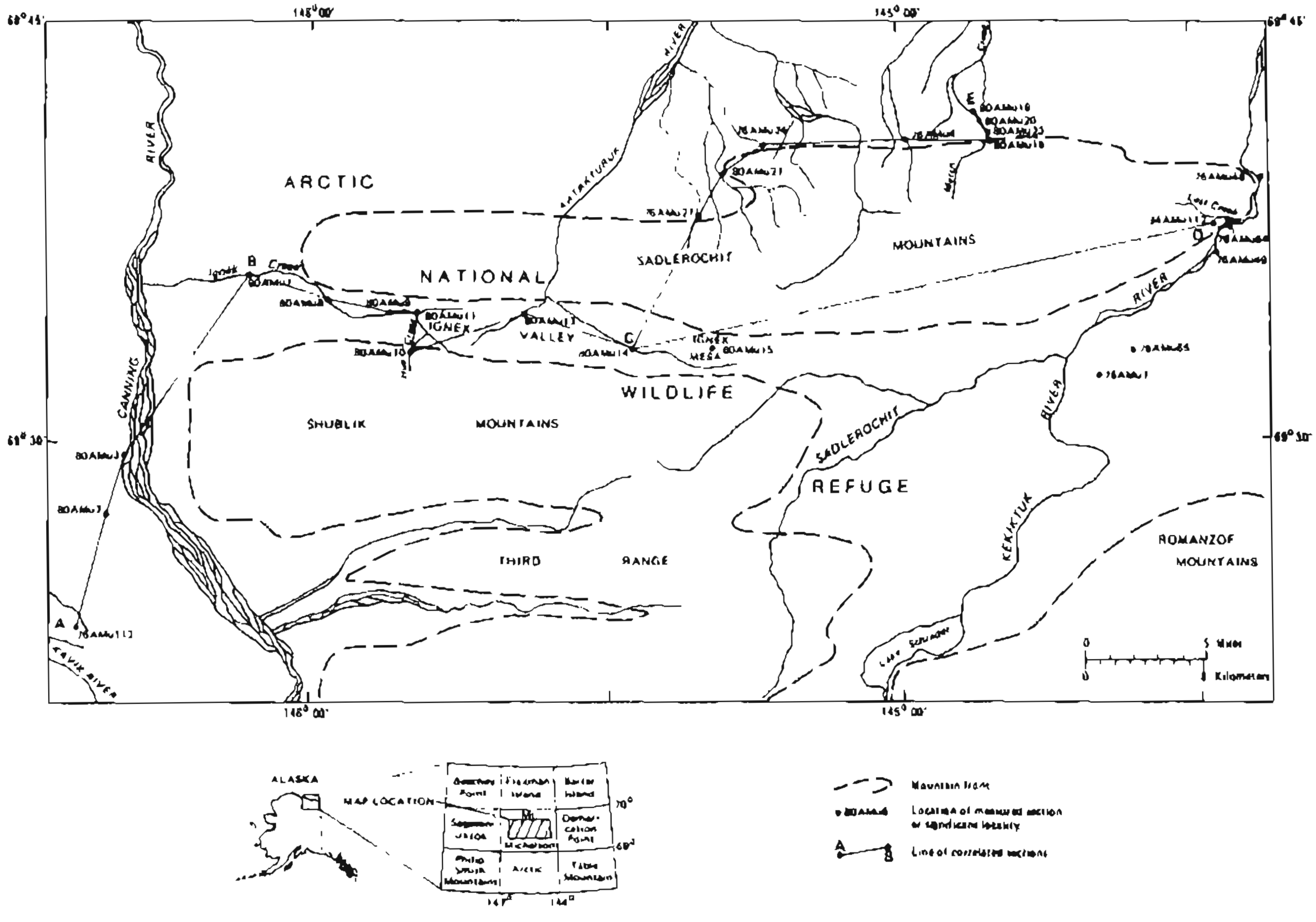

Figure 2. Index map of Sadlerochit and Shublik Mountains area, Arctic National Wildlife Refuge, showing location of significant outcrops and measured sections, and lines of correlated sections (figs. 11, 12, and 13).

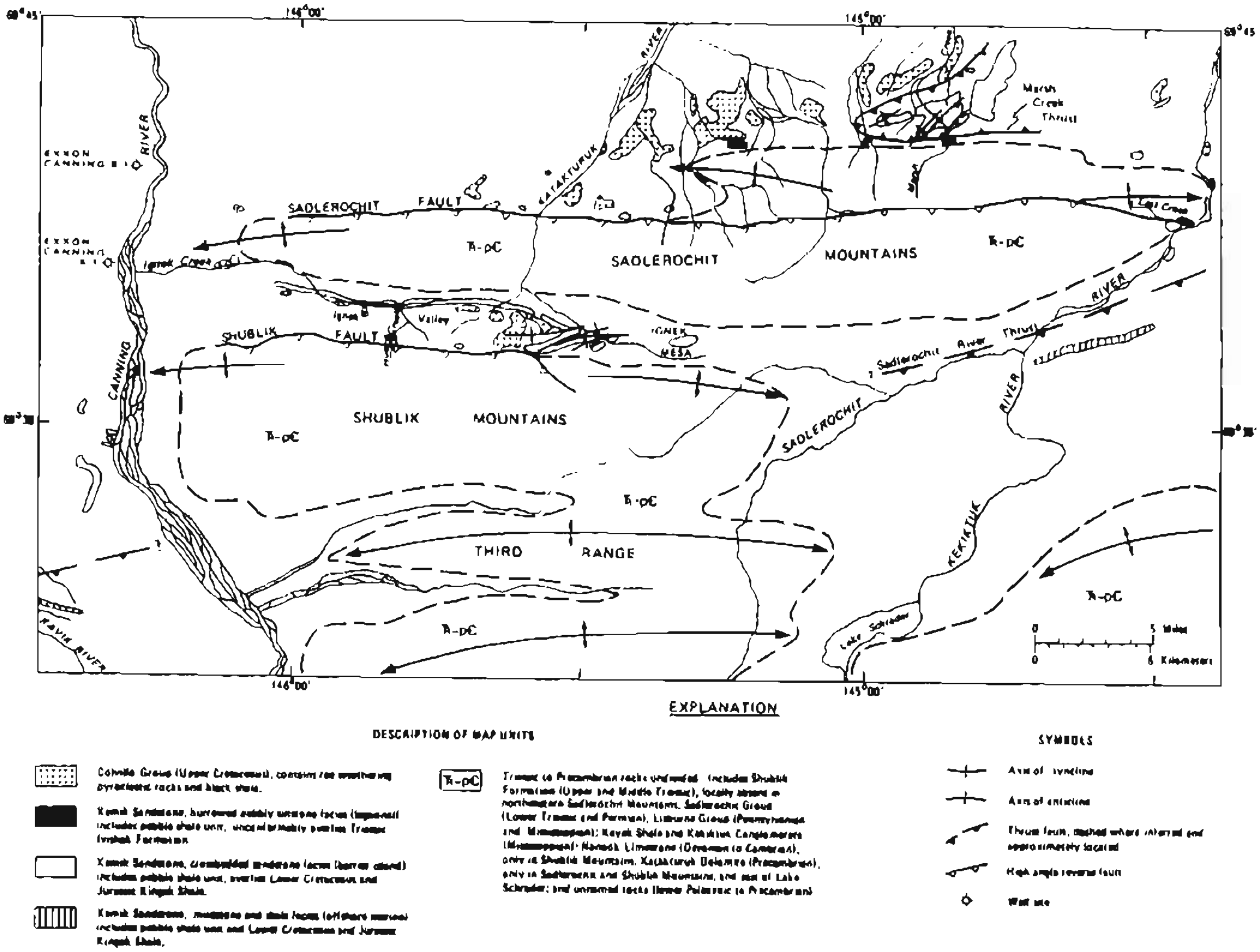

Figure 3. Simplified geologic map of Sadlerochit and Shublik Mountains area showing generalized distribution of pyroclastic rocks of Upper Cretaceous Colville Group, cross bedded sandstone of the Ignek Valley Member and burrowed pebbly siltstone of the Marsh Creek Member of the Kemik, and Triassic and older rocks. Rocks of Lower Cretaceous to Jurassic Kingak Shale and Lower Cretaceous pebble shale unit are included with the Kemik.

shattered rubble (fig. 4). The best exposures are found where streams cut across the outcrop belt. At several localities in Ignek Valley, two or three intervals of Kemik Sandstone are present. In at least one of these localities two separate sandstone bodies were deposited, but at other localities, one sandstone interval is repeated by small thrust faults (fig. 4). On the north side of the eastern Sadlerochit Mountains, two discrete facies of the Kemik are present. However, the exposures are not continuous except near Marsh Creek, where relatively continuous exposures are separated by a number of small thrust faults (fig. 5). West of Marsh Creek, the few exposures are generally in active stream cuts.

PREVIOUS INVESTIGATIONS AND HISTORY OF KEMIK NOMENCLATURE

The rock unit here defined as the Kemik Sandstone was originally mapped in the Sadlerochit Mountains area by Leffingwell (1919) as a lower member of the "Ignek Formation", thought to be of Jurassic age. The Ignek Formation, as defined by Leffingwell, included rocks now known as the Kemik Sandstone, the overlying pebble shale unit, and the shale and pyroclastic rocks of the Upper Cretaceous Colville Group (fig. 1). Leffingwell described in detail the stratigraphic and structural relationships in several areas, including a puzzling and significant location at Marsh Creek which is discussed in a later section of this report.

In the Shaviovik-Sagavanirktok Rivers area west of the Canning River, Keller and others (1961) recognized a conspicuous sandstone horizon of Early Cretaceous age that they named the "Kemik sandstone member of the Okpikruak Formation"; they considered the Kemik as the basal sandstone of the formation. (The Okpikruak Formation, which consists dominantly of turbidites, is typically recognized along the mountain front in the Anaktuvuk Pass area 160 mi southwest of the Canning River.) However, Keller and others did not recognize the Kemik as the same unit as Leffingwell's lower "Ignek Formation" along the Canning River and in Ignek Valley, apparently because of structural complications and absence of fossils.

Detterman and others (1975) abandoned the terms Okpikruak and Ignek Formations in northeastern Alaska and redefined the Kemik Sandstone as a member of a new formation, the Kongakut Formation. The term Kongakut Formation was applied to strata in part coeval with, but lithologically distinct from, the Okpikruak Formation. In the southern Demarcation Point Quadrangle (fig. 2, mapped by Reiser and others, 1981), 30 mi south of the Brooks Range mountain front, the Kongakut consists of a lower clay shale member, the Kemik Sandstone Member, the pebble shale member, and an upper siltstone member. At the type locality at Bathtub Ridge, the siltstone member constitutes about half of the formation and is nearly 1000 ft thick. It contains abundant features typical of turbidite deposition. In the Philip Smith Mountains Quadrangle (fig. 2) 90 mi southwest of the Canning River, the Kongakut Formation consists entirely of turbidites similar to those of the siltstone member; Brosgé and others (1979) report that it is over 900 ft thick. The Kemik Member and the pebble shale member are not recognized, and the clay shale member is not differentiated from the Kingak Shale in the Philip Smith Mountains Quadrangle.

Figure 4. View to east in Ignek Valley, showing outcrops of Kemik Sandstone and pyroclastic rocks of Colville Group. Dark weathering dip slopes on south flank of Sadlerochit Mountains are formed by sandstone and conglomerate of the Triassic to Permian Sadlerochit Group (Ivishak and Echooka Formations). Light colored carbonate rocks of Lisburne Group (Mississippian and Pennsylvanian) underlie the Sadlerochit. Kc---Colville Group, Kk---Ignek Valley Member of Kemik Sandstone, Jk---Kingak Shale, T Ps---Sadlerochit Group, PMl---Lisburne Group.

Figure 5. View to east, of cross-bedded sandstone of Ignek Valley Member of Kemik Formation along Marsh Creek, north side of eastern Sadlerochit Mountains. Note thrust imbrication of Kemik; a number of thrust faults with apparently relatively small displacement imbricate the Kingak, Kemik, and pebble shale in this area. Kps---pebble shale unit; Kk---Kemik Formation, cross-bedded sandstone facies of Ignek Valley Member; Jk---Kingak shale.

In the Sadlerochit and Shublik Mountains area of northern ANWR, Detterman and others (1975) recognized only the Kemik and pebble shale members of the Kongakut; the siltstone member of the Kongakut is not present and the clay shale member is not differentiated from the Kingak Shale. In fact, the pebble shale and Kemik members of the Kongakut are found together with the siltstone member only at the type locality of the Kongakut in the southern Demarcation Point Quadrangle. The relationship between the type Kongakut Formation at Bathtub Ridge and the Kemik and pebble shale members in the Sadlerochit and Shublik Mountains area is diagrammatically illustrated in figure 6.

In order to clarify stratigraphic relationships and simplify the nomenclature of the Arctic Slope and northeastern Brooks Range, the Kemik is here raised to formation status with two members on the north side of the Brooks Range. At the type locality of the Kongakut Formation, the Kemik remains as a member of the Kongakut pending further study. This usage is in accordance with the North American Stratigraphic Code, (North American Commission on Stratigraphic Nomenclature, 1983, Articles 19, 24 and 25). The type section of the Kemik, as originally defined by Keller and others (1961), is on Kemik Creek, a tributary at the Shaviovik River (NE ¼, Sec. 18, T1S, R21E). The type section of the Ignek Valley Member of the Kemik Sandstone is here established on the upper Katakturuk River in Ignek Valley (fig. 7) (NE¼ of SE¼, Sec. 3, T2N, R27E). The type section of the Marsh Creek Member is on the west fork of Marsh Creek (fig. 8) (SW¼ of SE¼, Sec. 22, T4N, R29E). Molenaar and others (this volume) also raise the Kemik to formation status.

The rationale for revising the nomenclature is as follows:

1. The Kemik is a conspicuous unit lithologically distinct from the overlying and underlying beds, and is easily mapped at scales of 1:250,000 and 1:63,360.

2. In the northeastern Brooks Range foothills, the Kemik Sandstone and overlying unnamed pebble shale unit crop out in areas separate and discrete from outcrops of the siltstone member of the Kongakut Formation.

3. The Kemik Sandstone and the siltstone member of the Kongakut Formation are lithologically distinctive rock units that were deposited in distinctly different depositional settings. As will be shown below, the Kemik consists of light-gray sandstone and siltstone deposited in a barrier island and lagoonal setting adjacent to a source area to the north. The siltstone member of the Kongakut Formation consists of thinly interbedded dark-gray siltstone and mudstone deposited as distal turbidites derived from an orogenic belt to the south.

STRATIGRAPHY OF THE KEMIK AND ADJACENT FORMATIONS

In the Sadlerochit Mountains area the Kemik unconformably overlies the Kingak Shale and, locally, older rocks. The Kingak Shale (Leffingwell, 1919) consists of black shale that is over 1000 ft thick in many areas; it was

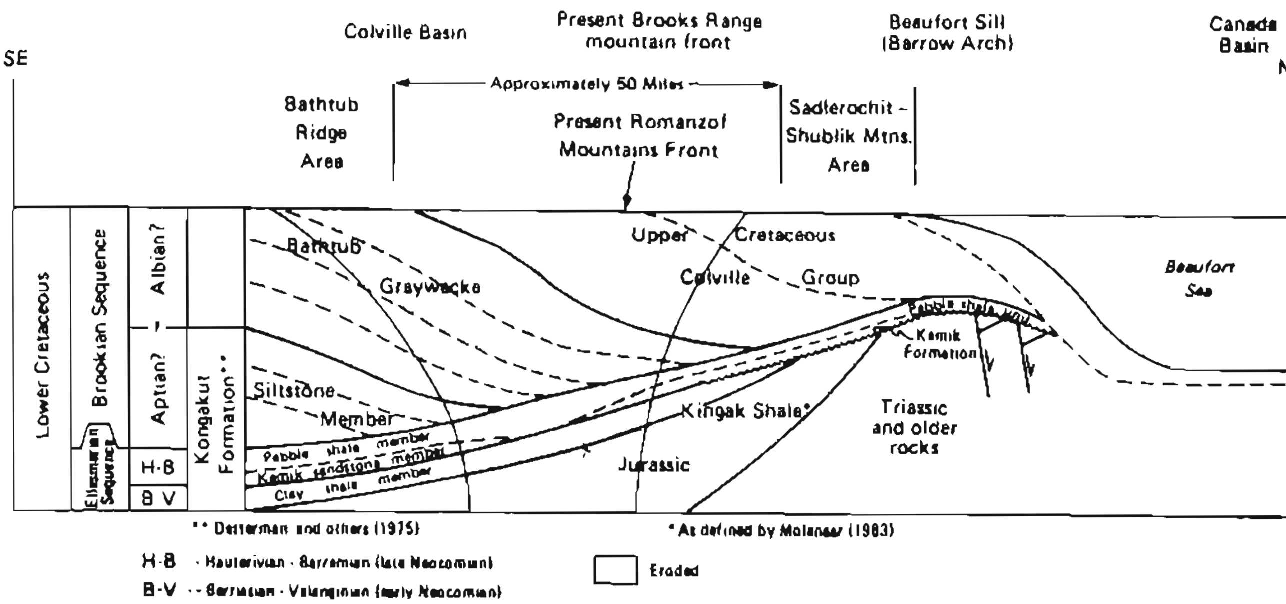

Figure 6. Diagram showing inferred stratigraphic and structural relationships of Cretaceous strata in present northeast Brooks Range at end of Cretaceous time. Solid lines are time lines as well as formation boundaries. Dashed lines in siltstone member of Kongakut Formation, Bathtub Graywacke, and Colville Group represent foreset and bottomset beds downlapping from the south. Lightly shaded area indicates rocks now eroded.

Figure 7. Type section of Ignek Valley Member of Kemik Formation on upper Katakturuk River (locality 80AMu14), showing cross-bedded sandstone facies. Section is 100 ft thick and unconformably overlies Jurassic Kingak Shale. View to northeast.

Figure 8. Type section of Marsh Creek Member of the Kemik Formation on west fork of Marsh Creek, north side of eastern Sadlerochit Mountains (locality 76AMu4). Section unconformably overlies Triassic Ivishak Formation, and is overlain by thrust fault and Jurassic strata. View to north. Kps---pebble shale unit; Kkbs---Kemik Formation, burrowed pebbly siltstone facies of Marsh Creek Member; Jk---Kingak Shale; T i---Ivishak Formation.

originally considered to be entirely Jurassic age, but the top is now thought to be of Early Cretaceous age (Molenaar, 1983).

The pebble shale unit that overlies the Kemik consists of laminated black shale with a high organic content, and contains zones with scattered matrix-supported pebbles and cobbles that are composed dominantly of chert and quartzite. Many samples of the pebble shale unit also yield abundant well-rounded, frosted quartz grains. As used here, the top of the pebble shale unit also contains thin bentonite beds and a zone of high radioactivity informally known as the gamma ray zone; these beds are as young as Albian. Originally described by Collins and Robinson (1967) in the subsurface of the Barrow area, 250 mi northwest of ANWR, the pebble shale unit is widely recognized both in the subsurface and in surface exposures of the northern Arctic Slope. It is not well exposed on the surface, but in most places in the subsurface its thickness is remarkably uniform, ranging from 200 to 300 ft (Molenaar, 1983; Mull, 1985).

The Kemik Sandstone, the overlying pebble shale unit, and underlying Kingak Shale are the uppermost rocks of the Ellesmerian sequence (Lerand, 1973), a sequence of rocks derived from a northerly provenance. In the northeastern Brooks Range and subsurface of the Arctic Slope, the Ellesmerian sequence consists of platform type sedimentary rocks ranging from Mississippian to Early Cretaceous age.

The Kemik Sandstone and pebble shale unit were deposited at a significant point in the stratigraphic evolution of northern Alaska, when a previously relatively stable platform area to the north ceased to influence deposition and was abruptly truncated and transgressed by marine deposits. This abrupt change in sedimentation patterns was related to rifting of the Arctic Alaska plate; the stratigraphic relationships of the Kemik and related rocks provide information on the nature of this tectonic event, which is discussed in a later section of this report.

The Ellesmerian sequence is overlain by the Brookian sequence of clastic rocks derived generally from a southerly source, the Brooks Range. Along the mountain front southwest of the Canning River and southeast of the Sadlerochit River, the base of the Brookian sequence consists of a tongue of Albian turbidites (Reiser and others, 1971). Farther to the southeast, in the southern Demarcation Point Quadrangle, the base of the Brookian sequence consists of turbidites of the siltstone member (Aptian?) of the Kongakut Formation and the Bathtub Graywacke of Albian(?) age (Detterman and others, 1975) (fig. 6). These sediments apparently pinch out northward. In the Sadlerochit Mountains area, the base of the Brookian sequence is here considered to be the Upper Cretaceous Colville Group that disconformably overlies the pebble shale (Molenaar, 1983; Mull, 1985).

The lower part of the Colville Group in the Sadlerochit Mountains area consists of organic paper shale, bentonite, and silicified pyroclastic rocks that weather to form red rubble-covered hillsides. Detterman and others (1975, fig. 11) have correlated these rocks with the Shale Wall Member of the Seabee Formation. The upper part of the Colville Group consists of thin bedded turbidites. Molenaar (1983) recommended informal usage of the term "shale of Colville Group" for all these Upper Cretaceous rocks; and in this volume, Molenaar and others suggest a revised nomenclature for the Upper Cretaceous and part of the Albian rocks of the northeastern Arctic Slope.

LITHOLOGY AND PETROGRAPHY

The Kemik Sandstone consists of two major lithologies that are the dominant constituents of two contrasting facies trends: a cross-bedded sandstone facies and a burrowed pebbly siltstone facies of the Marsh Creek Member. These contrasting facies are described in more detail in a later section of this report.

The most conspicuous exposures of the Ignek Valley Member consist of fine-grained, light- to medium-gray sandstone that forms a resistant ridge (figs. 4, 5, and 7) and weathers to a distinctive light-brown color with thin dark-red bands. These rocks commonly fracture to form a smooth flat or conchoidal surface on which bedding features are etched in relief by differential weathering (fig. 9). The sandstone grains are dominantly quartz, with a significant percentage of white tripolitic-chert grains that give hand samples a conspicuous speckled appearance. Thin zones of chert- and quartz-pebble conglomerate are common, as well as isolated pebbles floating in a matrix of sandstone. Scattered pelecypods are present, commonly in the red-weathering silty zones.

The dominant lithology of the Marsh Creek Member is siltstone which contains numerous isolated quartz and gray and black chert pebbles, but lacks megafossils and white tripolitic-chert pebbles. The burrowed pebbly siltstone of the Marsh Creek Member forms rounded outcrops and rubble ridges that are generally not as well exposed as the Ignek Valley Member, but the few well-exposed sections exhibit the same characteristic banded appearance with reddish brown weathering concretionary zones (fig. 8).

Petrographic examination shows that the Ignek Valley Member of the Kemik is a very fine to fine-grained, moderate to well sorted, subangular to subrounded sandstone. It can be described as a mature sublitharenite (Folk classification), or a lithic quartz sandstone. It is composed of 75 to 80 percent quartz, 15 to 20 percent rock fragments, and less than 5 percent feldspar. The quartz is dominantly monocrystalline, with minor amounts of stretched metaquartz and vein quartz. Chert is the dominant rock fragment; other rock fragments consist of shale, siltstone, limestone, dolomite, and siliceous sandstone. Glauconite, muscovite, sericite, collophane, zircon, and tourmaline are minor constituents. Silica cementation is extensive and occurs predominantly as quartz overgrowths. The conspicuous thin dark red-weathering siltstone and sandstone beds contain hematite, siderite, calcite, and dolomite cement. Sandstone in the cross-bedded sands of the Ignek Valley Member contains almost no matrix; the burrowed siltstone of the Marsh Creek Member contains a higher matrix content consisting of silt-sized quartz, sericite, and clay.

Conglomerate clasts in both members of the Kemik consist dominantly of quartz and gray to black chert. In the Ignek Valley Member conspicuous earthy white tripolitic chert makes up a high percentage of the clasts in

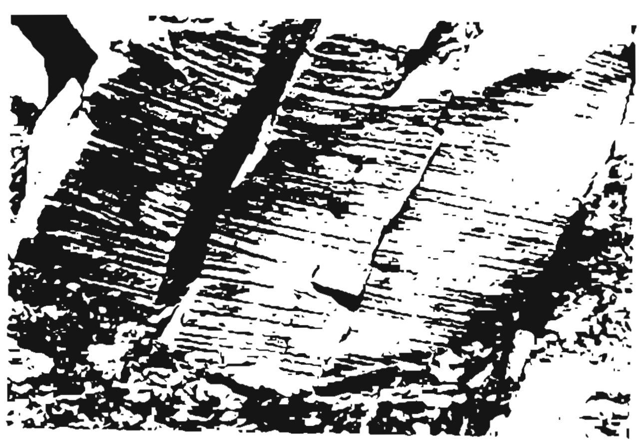

Figure 9. Typical weathering of conchoidal fractured surface of sandstone in Ignek Valley Member, on which bedding features are etched in relief. Knife is 4 in. long.

some conglomerate zones (fig. 10) and is absent in others. Tripolitic-chert is not present in the Marsh Creek Member. Petrographic study of the tripolitic-chert revealed sponge spicules and occasional radiolarians. Other types of chert contain forams, echinoderm fragments, and other fossil material in addition to sponge spicules and radiolarians.

Provenance

The composition of the Kemik suggests that it was derived from a mature sedimentary source with only a minor contribution from a metamorphic terrain. Sandstone of the Permian to Triassic Sadlerochit Group, the Lower Mississippian Kekiktuk Conglomerate, and other lower Paleozoic rocks were the probable source of recycled quartz. Similarity of the chert pebbles in the Kemik to chert in the carbonates of the Mississippian to Pennsylvanian Lisburne Group suggests that the Lisburne was a major source of chert detritus.

Reservoir Potential

The mineralogy of the Ignek Valley Member of the Kemik, which consists dominantly of stable grains of quartz and chert with little matrix, suggests potential as a reservoir for hydrocarbons, although silica cementation is pervasive in outcrop samples. Three samples, selected because they appeared to be less tightly cemented than most outcrop samples, were analyzed for porosity and permeability by Core Laboratories, Inc. The porosity in the samples analyzed ranged from 5.7 to 11.8 percent, but permeability was negligible.

Although the permeability analyses of the outcrop samples do not suggest reservoir potential, the Kemik in outcrop may not be representative of conditions in the subsurface. Jamison and others (1980) report that the Put River Sandstone in the Prudhoe Bay field, which is correlative with the Kemik, has porosity values averaging 12 percent and measured permeability that ranges from 10 md to 404 md. In addition, the Kuparuk River Formation, the upper part of which is probably correlative with the Kemik, is oil productive in the Kuparuk River oil field (Paris and Masterson, 1985).

CONTACTS

In the Sadlerochit and Shublik Mountains area, the Kemik overlies a regional angular unconformity that to the north truncates progressively older beds. In the Ignek and Canning River valleys, the Ignek Valley Member of the Kemik overlies Jurassic-Lower Cretaceous Kingak Shale. However, the Marsh Creek Member, exposed along the north flank of the eastern Sadlerochit Mountains, unconformably overlies the Triassic Ivishak Formation of the Sadlerochit Group. At Last Creek, at the east end of the Sadlerochit Mountains, the Marsh Creek Member overlies the Middle and Upper Triassic Shublik Formation. Faunal data indicate that this unconformity occurred in the middle of the Neocomian. In most places where it is exposed, the base of the Kemik in both members has an interval of chert- and quartz-pebble conglomerate up to 3-ft thick that grades up into very fine to fine-grained sandstone or siltstone. A 2-in.-thick greenish-gray clay zone at the top of the Kingak has been observed at several localities. Southwest of Kemik

Figure 10. Chert pebble conglomerate from Ignek Valley Member. White pebbles are earthy tripolitic chert. Large round pebble in lower left is 1 in. diameter.

Creek, the Kemik conformably and gradationally overlies the Neocomian part of the Kingak Shale (Molenaar, 1983).

The contact of both members of the Kemik Sandstone with the overlying pebble shale unit is sharp but conformable. At several localities where it is well exposed, the top 3 in. to 1 ft of the uppermost bed of the Ignek Valley Member contains scattered matrix-supported chert pebbles. In some cases the bedding in this top interval is defined by a pebble layer gradationally overlain by very fine-grained sandstone. The interval probably represents reworking of unlithified Kemik sand by the overlying transgressive pebble shale. The similarities in the microfauna of the pebble shale unit and the Kemik suggest that little time is represented by the Kemik-pebble shale contact. However, Detterman and others (1975) suggest that this contact is an unconformity at which the Kemik has locally been truncated.

PALEONTOLOGY

The Kemik Sandstone is dated as Hauterivian (Early Cretaceous) based upon the ammonite Simbirskites sp. collected from the Kemik on the Echooka River (J.W. Miller, written commun., 1985) (table 1). J.H. Callomon (written commun., 1986) further states that this fossil is from the group of Simbirskites (Speetoniceras) spetonensis or subinversis Pavlow, of Early Hauterivian age. Molenaar (1983) also reported a probable Simbirskites sp. from the Echooka River locality, and Detterman and others (1975) reported Simbirskites sp. from the Kemik Sandstone Member at the type locality of the Kongakut Formation at Bathtub Ridge.

A scattered fauna consisting mostly of pelecypods has been collected from the Kemik Sandstone at a number of localities. The fossils collected in this study, in addition to Simbirskites sp., include the following (J.W. Miller, (written commun., 1981 and 1985):

> Astarte ignekesis Imlay, Thracia stelcki McLearn, Entolium utukokense Imlay, Panope (?) kissoumi McLearn, Pleuromya sikanni McLearn, Camptonectes dettermani Imlay, Cucullaea (Dicranodonta) dowlingi McLearn, Veniella sp., Arctica sp., Cylindroteuthis sp. and Ditrupa cornu Imlay.

A similar fauna was reported by Keller and others (1961) from the lower part of the "Ignek Formation" along the west bank of the Canning River. Imlay (1961) considered this fauna to be Albian in age based on its association with the Albian ammonites Gastroplites sp. and Paragastroplites sp. found in strata west of ANWR. On the basis of its association also with Simbirskites sp. collected since Imlays study, the pelecypod fauna is apparently longer ranging than previously believed and is now dated as Valanginian to Albian (J.W. Miller, written commun., 1985). Megafossil data from the Kemik are given in table 1.

A Hauterivian to Barremian microfauna has been recovered from shales interbedded with the Kemik and from the overlying pebble shale unit (Michael B. Mickey, written commun., 1979 and 1981). Microfossil data are given in table 2.

Table 1. Megafossil data from Ignek Valley Member of Kemik Sandstone.

[Identifications and ages reported by J.W. Miller, written commun., 1981, and 1986 (ages revised). Environments by R.C. Allison, written commun., 1986.]

Locality no.	Stratigraphic position	Location	Township and range	Fauna	Environment	Age reported	Date of report
76AMu15-1 (M7419)	Upper half of Kemik Sandstone	North side of Sadlerochit Mountains	N½, sec. 19, T. 4 N., R. 30 E.	Astarte ignekensis Imlay, 1961 Thracia stelcki McLearn, 1945	5 to 230 m Intertidal to 135 m	Early Cretaceous (Valanginian to Albian)	6/2/81 (4/8/86)
76AMu27-4 (M7420)	Upper part of Kemik Sandstone	Tributary of Katakturuk River, north side of Sadlerochit Mountains	SE¼, sec. 6, T. 3 N., R. 28 E.	Astarte ignekensis Imlay, 1961	5 to 230 m	Early Cretaceous (Valanginian to Albian)	6/2/81 (4/8/86)
80AMu12 (M7421)	------do------	Hogback ridge, upper Ignek Creek, south side of Sadlerochit Mountains	SW¼, sec. 27, T. 3 N. R. 26 E.	Astarte ignekensis Imlay, 1961 Ditrupa cornu Imlay, 1961	5 to 230 m Below wave base	Early Cretaceous (Valanginian to Albian)	6/2/81 (4/8/86)
80AMu14-10 (M7422)	------do------	Katakturuk River, south side of Sadlerochit Mountains	E½, sec. 3, T. 2 N., R. 27 E.	Astarte ignekensis Imlay, 1961	5 to 230 m	Early Cretaceous (Valanginian to Albian)	6/2/81 (4/8/86)
80AMu17 (M7423)	Top of Kemik Sandstone	Marsh Creek, north side of Sadlerochit Mountains	SW¼, sec. 18, T. 4 N. R. 30 E.	Astarte ignekensis Imlay, 1961 Entolium utukokense Imlay, 1961 Panope(?) kissoumi (McLearn, 1945)	5 to 230 m Pelagic, quiet water Intertidal (?) to 20 m	Early Cretaceous (Valanginian to Albian)	6/2/81 (4/8/86)
80AMu19-3 (M7424)	Float from upper part of Kemik Sandstone	------do------	SW¼, sec. 18, T. 4 N. R. 30 E.	Camptonectes dettermani Imlay, 1961	Pelagic, quiet water	Early Cretaceous (Valanginian to Albian)	6/2/81 (4/8/86)
80AMu22 (M7425)	Upper half of Kemik Sandstone	------do------	SE¼, sec. 13, T. 4 N., R. 29 E.	Astarte ignekensis Imlay, 1961	5 to 230 m	Early Cretaceous (Valanginian to Albian)	6/2/81 (4/8/86)
84AMu112-13 (M8063)	Float from upper part of Kemik Sandstone	Last Creek, east end of Sadlerochit Mountains	NE¼, sec. 11, T. 3 N. R. 31 E.	Cucullaea (= Dicranodonta) dowlingi (McLearn, 1919) Veniella sp.	High energy nearshore High energy nearshore	Early Cretaceous (Valanginian to Albian)	4/10/85
84AMu113-6 (M8057)	75 ft above base of Kemik Sandstone	Echooka River	SW¼, sec. 36, T. 1 S., R. 13 E.	Arctica(?) sp.	Neritic	Early Cretaceous (Neocomian)	4/10/85
84AMu113-5 (M8058)	65 ft above base of Kemik Sandstone	------do------	---do---	Cylindroteuthis sp.	Open ocean	Late Jurassic (probably reworked)	4/10/85

84AMu113-3 (M8059)	Float, near base of Kemik Sandstone	------do------	---do---	Simberskites sp. (1) Entolium sp. Arctica sp.(?)	Open ocean Pelagic, quiet water Neritic	Early Cretaceous (Hauterivian)	4/10/85
84AMu113-2 (M8080)	Float, as above	------do------	---do---	Astarte ignekensis Imlay, 1961	5 to 230 m	Early Cretaceous (Valanginian to Albian)	4/10/85
84AMu113-1 (M8061)	15 ft below base Kemik Sandstone	------do------	---do---	Probably Pleuromya sikanni (McLearn, 1945) (fragment only)	Quiet water	Probably Early Cretaceous (Valanginian to Albian)	4/10/85

(1) Group of Simberskites (Speetoniceras) speetonensis or subinversis, Pavlov, Early Hauterivian (J.H. Callomon, written commun., 1986).

Table 2. Microfaunal and palynological data from pebble shale unit, Kemik Sandstone, and Kingak Shale, Arctic National Wildlife Refuge.

[Microfossil identifications and dating by M.B. Mickey of Anderson, Warren, and Associates, written commun., 1979, Biostratigraphics, Inc., written commun., 1981; and oral commun., 1986 (revised age). Palynology by Hideyo Haga of Biostratigraphics, Inc., written commun., 1981. Fl, flood; A, abundant; C, common; F, frequent; R, rare.]

Locality no.	Stratigraphic position	Location	Township and range	Fauna	Age reported	Environment	Date of report
PEBBLE SHALE UNIT							
76AMu64	Shale, 15 ft above contact with Marsh Creek Member of Kemik Sandstone	Last Creek	NE¼, NE¼ sec. 11, T. 3 N., R. 31 E.	Ammodiscus sp. (small) (F), Gaudryina tailleuri (F), Haplophragmoides cf. excavatus (F), H. coronis (F), H. duoflatis (R), arenaceous spp. (F), round quartz grains (A).	Early Cretaceous (Hauterivian to Barremian)	Outer neritic to bathyal	5/17/79 (4/11/86)
76AMu64-1	Shale, 5 ft above contact with Marsh Creek Member of Kemik Sandstone	---do---	---do---	Ammobaculites alaskensis (F), A. reophacoides (F), Gaudryina tailleuri (R), Haplophragmoides inflatigrandis (F), H. goodenoughensis (F), Bathysiphon sp., arenaceous spp. (large) (C), round quartz grains (A).	---do---	---do---	5/17/79 (4/11/86)
80AMu7-4	Shale, 6 ft above top of Ignek Valley Member of Ignek Valley Member of Kemik Sandstone	Ignek Creek	NW¼, sec. 19, T. 3 N., R. 25 E.	Bathysiphon scintillata (F), Conorboides cf. umiatensis (R), Glomospira corona (R), G. subarctica (F), Glomospirella arctica (F), Haplophragmoides duoflatis (F), H. coronis (F), H. inflatigrandis (F, round quartz grains (R).	---do---	Probable neritic	5/22/81
80AMu8-4	Shale, composite sample 30-45 ft above top of Ignek Valley Member of Kemik Sandstone	---do---	W½, sec. 27, T. 3 N., R. 25 E.	Ammodiscus mackenziensis (R), Bathysiphon scintillata (R), Gaudryina tailleuri (F), Haplophragmoides duoflatis (F), H. coronis (R), Trochammina squammata (R), arenaceous spp. (F), round quartz grains (R).	---do---	Outer neritic to middle bathyal, turbid	5/22/81
80AMu14-12	Shale, 10 ft above top of Ignek Valley Member Kemik Sandstone	Upper Katakturuk River	Center of N½, sec. 3, T. 2 N., R. 27 E.	Bathysiphon scintillata (F), Conorboides cf. umiatensis (R), Gaudryina tailleuri (R), Glomospirella arctica (R), Haplophragmoides duoflatis (F), H. coronis (F), H. inflatigrandis (F), Trochammina cf. sablei (R), arenaceous spp. (large, coarse) (F), round quartz grains (R).	---do---	Middle neritic to upper bathyal, turbid	5/22/81

80AMu16-18	Shale, 1 ft above contact with Marsh Creek Member of Kemik Sandstone	Marsh Creek	SE¼, sec. 19, T. 4 N. R. 30 E.	Ammodiscus sp. (very small) (R), Gaudryina subcretacea (F), G. cf. tailleuri (R), Haplophragmoides coronis (C), Thuramminoides sp. (R).	---do---	Middle to outer neritic, turbid	5/22/81
80AMu16-18A	Shale, same location as above, composite sample 20-40 ft above 80AMu16-18	------do------	---do---	Ammobaculites reophacoides (R), Conorboides cf. umiatensis (R), Gaudryina tailleuri (F), Haplophragmoides duoflatis (F), H. inflatigrandis (R).	---do---	Outer neritic to middle bathyal	5/22/81
80AMu21	Shale, uncertain position above Ignek Valley Member of Kemik Sandstone	------do------	NE¼, sec. 13, T. 4 N., R. 29 E.	Ammodiscus mackenziensis (R), A. cf. elongatus (R), Bathysiphon scintillata (R), Gaudryina tailleuri (F), G. tappanae (F), Glomospira subarctica (R), Haplophragmoides duoflatis (F), H. coronis (C), Thuramminoides sp. (R), arenaceous spp. (large, coarse) (F), rounded quartz grains (F).	---do---	Outer neritic to middle bathyal, turbid	5/22/81
KEMIK SANDSTONE							
76AMu29-2	Ignek Valley Member of Kemik, shale interbedded with sandstone (same location as 80AMu7-2)	Ignek Creek	NW¼, sec. 19, T. 3 N., R. 25 E.	Ammobaculites reophacoides (R), Gaudryina tailleuri (F), G. milleri(?) (R), Haplophragmoides duoflatis (R).	Early Cretaceous (Neocomian)	Possible outer neritic to upper bathyal	5/17/79
76AMu65-1	Mudstone and shale facies of Kemik, brown sandy shale	Southeast side of Sadlerochit River valley	NW¼, sec. 7. T. 2 N. R. 31 E.	Ammodiscus canui (F), Haplophragmoides kingakensis (F), arenaceous spp. (large, coarse) (C), round quartz grains (FL).	Jurassic to Neocomian (possibly Neocomian)	Marine	5/17/79 (4/11/86)
76AMu113-1	Mudstone and shale facies of Kemik	Tributary of Kavik River	NE¼, sec. 6, T. 1 S., R. 24 E.	Ammodiscus mackenziensis (R), Bathysiphon scintillata (R), Gaudryina tailleuri (R), Glomospira corona (R), Glomospirella arctica (F), Haplophragmoides duoflatis (F), H. coronis (F), H. inflatigrandis (R), round quartz grains (C).	Early Cretaceous (Neocomian)	Probable outer neritic to upper bathyal, turbid	5/17/79
80AMu7-2	Ignek Valley Member of Kemik, shale interbedded with sandstone approximately 30 ft below base of upper sandstone unit	Ignek Creek	NW¼, sec. 19, T. 3 N. R. 25 E.	Bathysiphon scintillata (F), Gaudryina subcretacea (R), G. tappanae (F), Haplophragmoides coronis (C), H. goodenoughensis (R), Lituotuba gallupi (R), echinoid spines (R), arenaceous spp. (C), rounded quartz grains (R).	Early Cretaceous (Hauterivian to Barremian)	Outer neritic to middle bathyal, turbid	5/22/81

80AMu7-2 (Palynology)	------do------	------do------	---do---	Lycospora spp. (R, reworked). Batioladinium pelliferum (R), Chlamydophorella nyei (R), Cyclonephelium distinctum (A), Oligosphearidium complex (C), Gardodinium trabeculosum (R), Operculodinium(?) spinigerum (R), Tenua anaphrissa (F).	Early Cretaceous (Neocomian)	Marine	5/22/81
80AMu27-6	Marsh Creek Member of Kemik, silty mudstone inter-bedded with sand near base of Kemik	Tributary of Katak-turuk River	NE¼, sec. 32, T. 4 N., R. 28 E.	Ammobaculites reophacoides(R), Gaudryine tailleuri (R), Hep-lophragmoides duoflatis (C), H. coronis (F), arenaceous spp. (F).	Probably Early Cretaceous (Neo-comian, undiffer-entiated)	Middle to outer neritic, turbid	5/22/81
80AMu16-17	Marsh Creek Member of Kemik, composite from shale interbeds 15 ft and 45 ft below top	Marsh Creek	SE¼, sec. 19, T. 4 N., R. 30 E.	Ammodiscus cf. elongatus (R), Bathysiphon scintillata (F), Gaudryina tailleuri (R), Glo-mospira subarctica (R), Haplo-phragmoides duoflatis (F), H. coronis (R), H. inflatigrandis (F), H. goodenoughensis (R), Thuramminoides sp. (R), arena-ceous spp. (large,coarse) (F), rounded quartz grains (F).	Early Cretaceous (Hauterivian to Barremian)	Middle neritic to upper bathyal, turbid	5/22/81
KINGAK SHALE							
76AMu65-3	Black clay shale	Southeast side of Sadlerochit River	NW¼, sec. 7, T. 2 N.	Ammodiscus cheradospirus (R), A. orbis (R), Gaudryina milleri (R), G. leffingwelli (R), Glomospira pattoni (R), Haplophragmoides canui (R), H. kingakensis (R), Bathysi-phon sp. (R), round quartz grains (F).	Late Jurassic (Oxfordian)	Outer neritic to bathyal	5/17/79
76AMu113-2	Shale 100 ft below top of Kingak shale	Tributary of Kavik River	SE¼, sec. 35, T. 1 N., R. 23 E.	Ammobaculites reophacoides (F), Gaudryina tailleuri (R), Glomospirella arctica (F), Haplophragmoides inflati-grandis (R), H. duoflatis (F), H. goodenoughensis (F), Trochammina squamata (R), arenaceous spp. (F), round quartz grains (C).	Early Cretaceous (Neocomian)	Probable outer neritic to upper bathyal, turbid	5/17/79
80AMu23	Shale 200 yds north of 80AMu16-18 and 80AMu16-18A	Marsh Creek	SE¼, sec. 19, T. 4 N.,	Ammodiscus cf. orbis (R), Haplophragmoides sp. (R), Lituotuba irregularis (R), Cenosphaera spp. (F) (pyritized), Dictyomitra sp. (R) (pyritized), Spongodis-cus spp. (F) (pyritized).	Probable Early to Middle Jurassic	Open marine	5/22/81

Paleoenvironment

R.C. Allison (written commun., 1986) reported that the Kemik megafauna is dominated by a few species---a characteristic of a boreal paleogeographic setting. Allison reports that some of the same taxa are reported in much lower latitude faunas, where they can have much larger shells; this suggests marginal living conditions for part of the Kemik fauna, possibly including seasonal ice. The fauna indicates open ocean conditions in a shallow shelf environment, however, a number of taxa have relatively thin shells that suggest a subtidal environment below heavy wave surge except during storms. The abundant *Astarte ignekensis* was probably transported by storms and mechanically concentrated. Two heavy shelled forms collected in this study, *Cucullaea* (*Dicranodonta*) *dowlingi* and *Veniella* sp., represent a high energy nearshore environment, but only one specimen of each form was found. The environmental interpretations of the megafauna are included in table 1.

DESCRIPTION OF FACIES

Two major facies are represented in the Kemik Sandstone. The massive cross-bedded sandstone facies is most abundant in Ignek Valley and in the Canning River valley (fig. 11). The burrowed pebbly-siltstone facies of the Marsh Creek Member is exposed along the north flank of the eastern Sadlerochit Mountains (fig. 12). Burrowed siltstone beds are interbedded with the cross-bedded sandstone facies, and regional stratigraphic and geographic relationships indicate that the two members were deposited in close proximity to each other. A third correlative facies that consists dominantly of shale, mudstone, and one thin sandstone bed is present south of the Ignek Valley Member (fig. 13). Although quite different facies are represented by the cross-bedded sandstone and burrowed siltstone trends, both are overlain by a section consisting of the pebble shale unit and the pyroclastic rocks of the Upper Cretaceous Colville Group. The shale and mudstone facies is overlain by the pebble shale unit and Albian turbidites. Combined, the three Kemik facies define a regional depositional setting that is limited both in its areal distribution and in time.

The correlation of the burrowed siltstone, cross-bedded sandstone, and mudstone-shale facies of the Kemik is based on an assumption that the overlying pebble shale unit is a precise chronostratigraphic unit. Unfortunately, available paleontologic data are not sufficiently precise to prove or disprove this assumption; the three Kemik facies and the pebble shale unit are all dated as Hauterivian-Barremian (table 2). However, each Kemik facies is overlain at a sharp contact by the pebble shale unit without evidence of interfingering with the underlying strata. The relationships suggest rapid marine transgression in which the pebble shale unit represents an effective time line. Major characteristics of each of the three Kemik facies are described below.

Cross-bedded Sandstone Facies (Ignek Valley Member)

Sandstone constitutes over 80 percent of the beds in most of the sections in the cross-bedded sandstone facies. The sandstone has generally uniform grain size but exhibits a wide range of bedding characteristics that

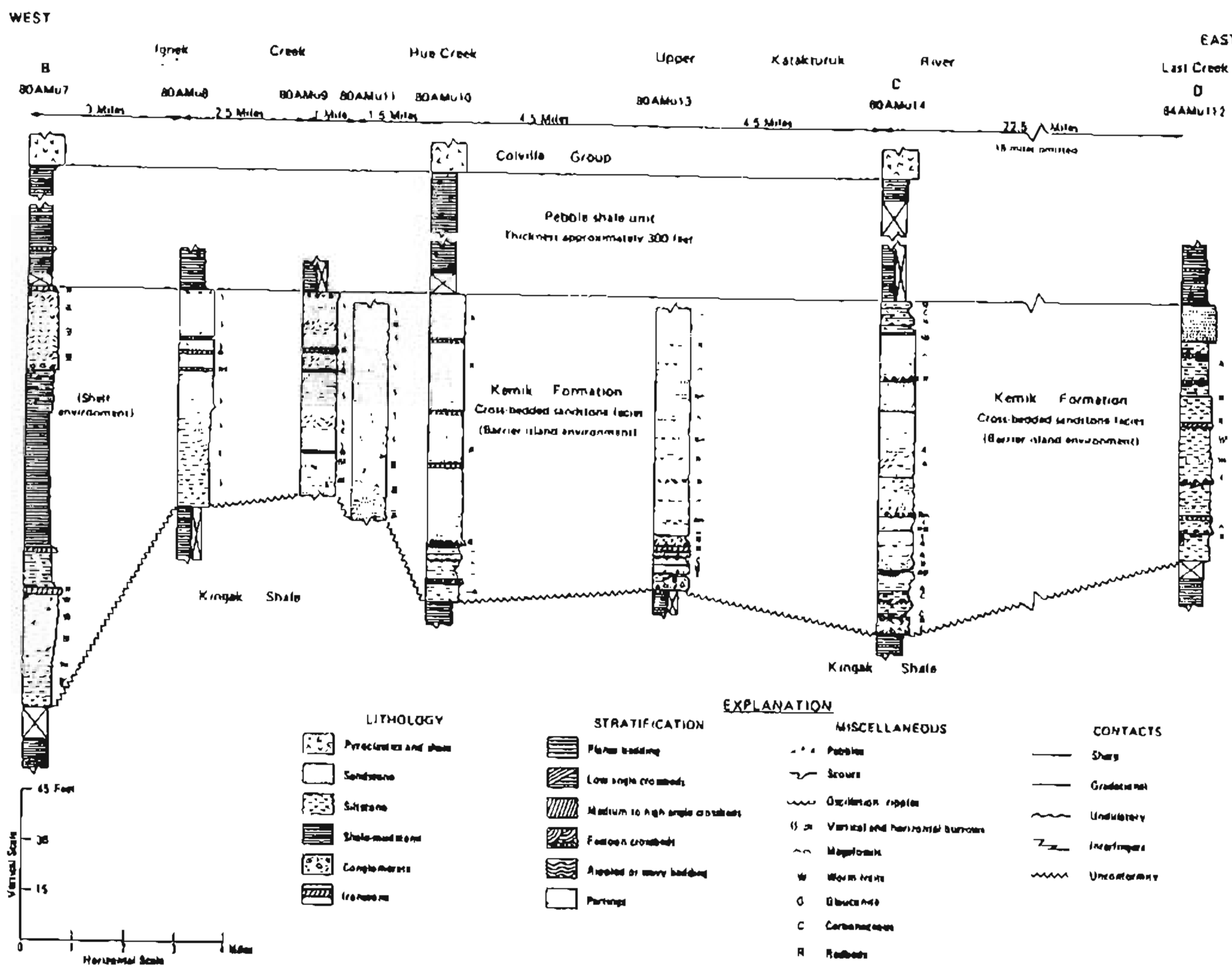

Figure 11. Stratigraphic cross section correlating measured sections of cross-bedded sandstone facies of the Ignek Valley Member of the Kemik and overlying and underlying strata in Ignek Valley. See figure 2 for location of section.

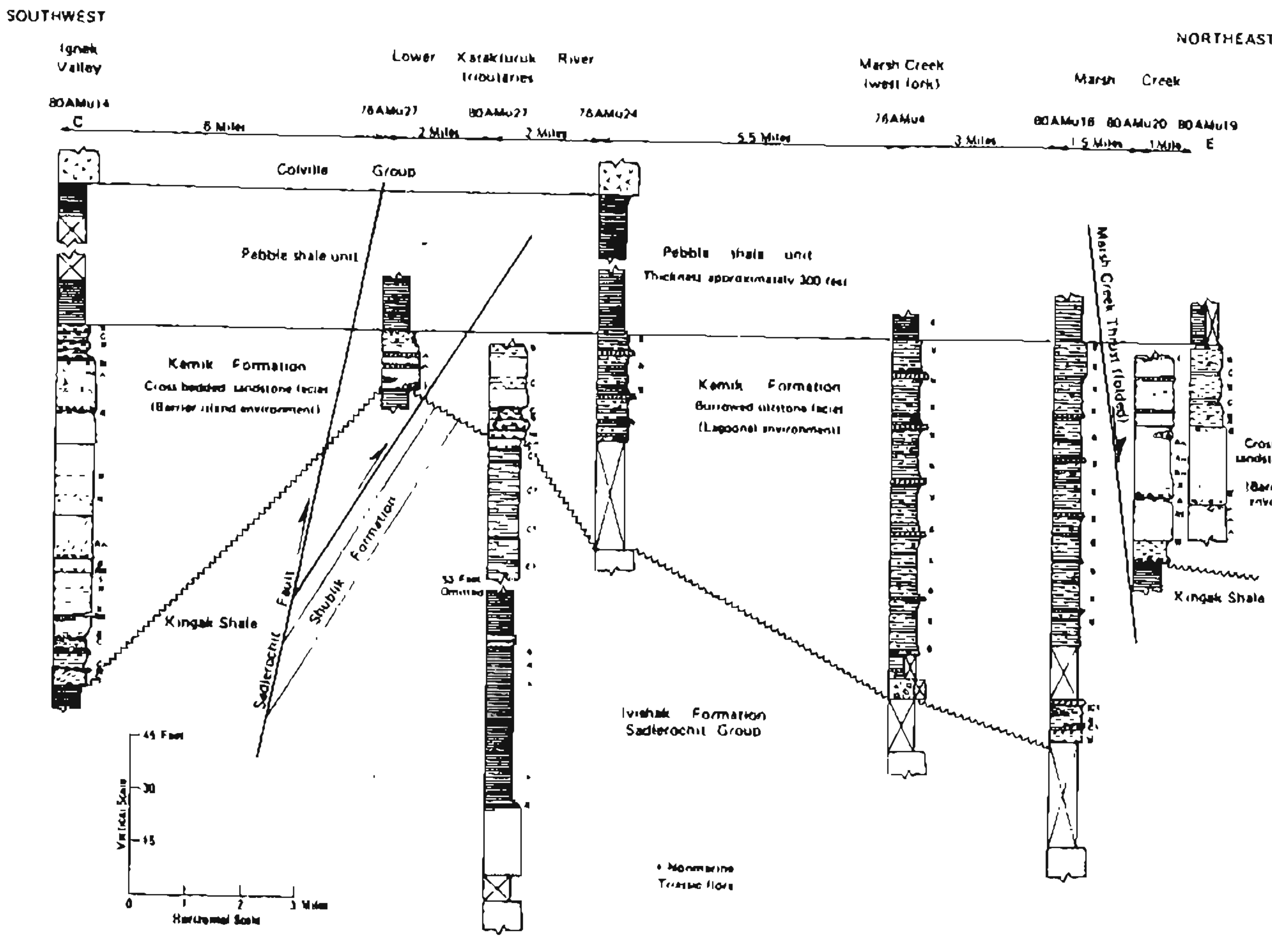

Figure 12. Stratigraphic cross section correlating burrowed pebbly siltstone facies of the Marsh Creek Member of the Kemik on north side of eastern Sadlerochit Mountains with cross-bedded sandstone facies of the Ignek Valley Member of the Kemik in Ignek Valley and Marsh Creek areas, and showing overlying and underlying strata. Location and direction of relative movement of major faults are shown diagrammatically. See figure 2 for location of section and figure 11 for explanation of symbols.

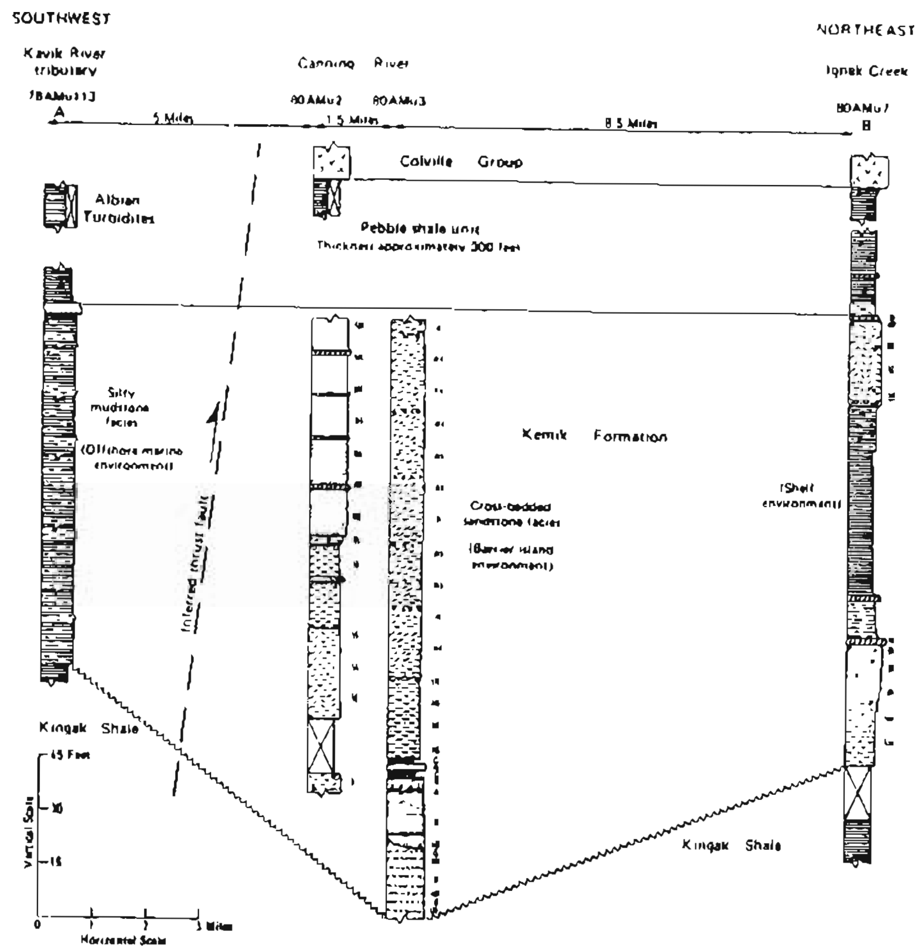

Figure 13. Stratigraphic cross section of Kemik Formation correlating offshore marine silty mudstone facies in Kavik River area with cross-bedded sandstone of the Ignek Valley Member on Canning River and shelf sandstone deposits at west end of Ignek Valley, showing overlying and underlying strata. See figure 2 for location of section and figure 11 for explanation of symbols.

include both primary depositional features and features that result from bioturbation.

Individual bed sets typically have sharply defined bases that truncate the underlying beds. Many of these bed bases are marked by conglomerate layers that range from lags only one pebble thick to pebble conglomerate beds as much as 2 ft thick (fig. 14). These conglomerate zones typically grade upward into sandstone characterized either by planar laminations or small- to large-scale low-angle cross-lamination (figs. 15 and 16). Isolated matrix-supported pebbles are present in many beds. Convolute bedding is present at a few localities (fig. 17). Some of the thick sandstone beds exhibit no internal bedding features except for scattered large vertical burrows up to 20 in. long; these are found throughout the sandstone facies but are less numerous in the upper half of the sections. Some beds, particularly in the lower part of the section, were so intensely bioturbated that all internal bedding features were destroyed; these beds fracture with an irregular surface that weathers in marked contrast to the conchoidally fractured laminated and cross laminated beds (fig. 19). Individual beds in the cross-bedded sandstone facies range up to several feet in thickness.

The lower portion of most of the sections in the cross-bedded sandstone facies of the Ignek Valley Member consists mostly of siltstone, mudstone, and carbonaceous shale (fig. 20) with minor amounts of conglomerate. Both vertical and horizontal burrowing is widespread and results in crude irregular bed boundaries, although scattered rippled bedding surfaces are present (fig. 21). Red- and yellow-weathering hematite- or siderite-cemented beds and zones of ironstone concretions up to 2 ft thick are common throughout the cross-bedded sandstone facies, and result in the distinct banded appearance of most exposures. The top of some sections of the cross-bedded sandstone facies contains a few feet of interbedded carbonaceous silty shale and siltstone with abundant vertical burrows (fig. 22).

Rocks of the cross-bedded sandstone facies of the Kemik Sandstone are best exposed near the headwaters of the Katakturuk River in a 100-ft-thick section that is here designated as the type section of the Ignek Valley Member of the Kemik Formation (fig. 2, locality 80AMu14, fig. 7). At this locality, the stream cuts across both limbs of a small west-plunging syncline (fig. 23); the best exposure of the section is on the east side of the stream on the south limb of the syncline. However, the best exposures of both the basal and upper contacts are found on the west side of the stream on the north flank of the syncline.

At the Katakturuk syncline section, the Ignek Valley Member unconformably overlies a 2-in.-thick, greenish gray to yellow clay at the top of the Kingak Shale. The basal Kemik, best exposed on the north flank of the syncline, is marked by a 1.5-ft-thick conglomerate bed that grades upward into 13 ft of dark-brownish-gray siltstone in undulatory beds 6 in. to 2 ft thick and interbedded carbonaceous mudstone (fig. 20). The siltstone interfingers upward into a 1-ft-thick bed of pebble conglomerate that forms the top of the interval. The individual siltstone beds appear generally featureless but contain a few traces of low-angle medium-scale cross-beds and some large vertical burrows (Skolithos) up to 3/8 in. in diameter and several inches

Figure 14. Conglomerate at base of bioturbated sandstone bed in Ignek Valley Member truncates underlying faintly laminated sandstone. Bioturbatation in overlying sandstone is suggested by irregular weathering surface and absence of laminations.

Figure 15. Conglomerate layer grades upward into laminated sandstone with broad sweeping low-angle cross laminations; top of bed is bioturbated, a few vertical burrows are visible. Base of overlying laminated sandstone bed (at bottom of knife) truncates underlying burrowed sandstone and is marked by bedding discontinuity with scattered pebble lags. Knife is 4 in. long.

Figure 16. Close up view of small-scale cross lamination etched in relief on sandstone in Ignek Valley Member. Matrix supported chert pebble in upper center is ½ in. diameter.

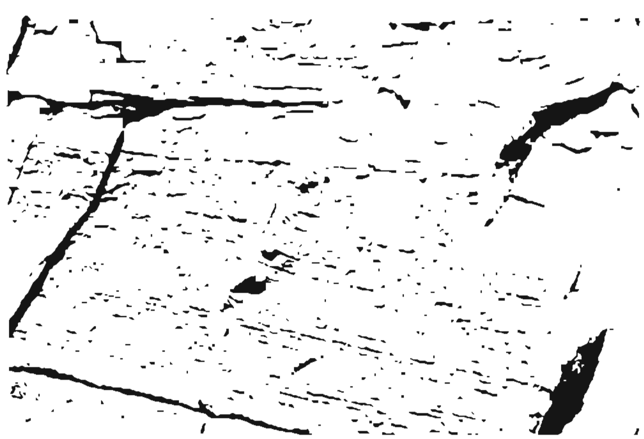

Figure 17. Close up view of convolute bedding at base of bed scoured into underlying laminated sandstone in Ignek Valley Member. Convolute structures probably formed by dewatering of sand deposited rapidly during storm event. Knife handle is 4 in. long.

Figure 18. Large vertical burrows in homogeneous sandstone in Ignek Valley Member.

Figure 20. Carbonaceous shale and mudstone (by hammer) interbedded with bioturbated siltstone in lower part of section at Ignek Valley type section (fig. 7). Bed contacts are generally irregular.

Figure 21. Oscillation ripples at top of very fine grained faintly laminated sandstone bed in Ignek Valley Member type section (fig. 7) are filled by red muddy siltstone. Overlying and underlying beds are intensely bioturbated.

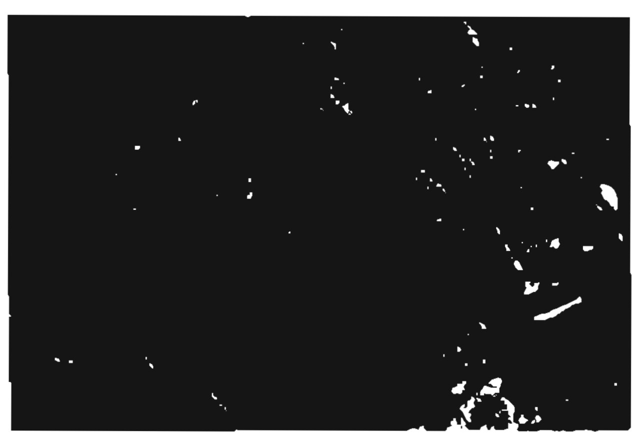

Figure 22. Intensely burrowed siltstone beds at top of type section of Ignek Valley Member section (fig. 7) have pseudo-columnar fracturing controlled by vertical burrows.

Figure 23. View east to small syncline in Kemik Sandstone near headwaters of Katakturuk River in Ignek Valley. Type section of Ignek Valley Member (fig. 7) is located east of stream on south limb of syncline. Ignek Mesa (left center skyline) is formed by Kemik near axis of Ignek Valley syncline. Kingak Shale underlies covered slopes between Ignek Mesa and syncline. South-dipping Middle and Upper Triassic Shublik Formation forms low cuesta (left) on south flank of Sadlerochit Mountains; north-dipping dip slopes of Lower Triassic Ivishak Formation form north flank of eastern shublik Mountains (right skyline). Kps---pebble shale unit; Kk---Ignek Valley Member of Kemik Formation; Jk---Kingak Shale; T s---Shublik Formation; T Ps---Ivishak Formation of Sadlerochit Group.

long. On the south limb of the syncline this siltstone interval thins to 5 ft, and the upper conglomerate thins from 1 ft to 3 in. The upper bedding surface of the conglomerate is gently undulatory and contains interference ripples and scattered worm trails.

On both the south and north limbs of the syncline the conglomerate at the top of the basal Kemik interval is overlain by 5 ft of interbedded reddish-brown-weathering mudstone and carbonaceous siltstone that contains small-scale trough cross-bedding. The top of the reddish brown-weathering zone is a scoured surface overlain by 3 ft of siltstone similar to that at the base of the Kemik. This siltstone also has a sharp upper boundary, and is separated from overlying sandstones by a thin carbonaceous shale bed.

Seventy-five ft of massive beds of gray to light-gray, fine to very fine-grained sandstone make up most of the remainder of the crossbedded sandstone facies of the Ignek Valley Member of the Kemik. Some of the beds have no visible bedding and have a homogeneous appearance except for the presence of occasional large vertical burrows (Skolithos). Beds in the lower part of the interval have features that range from fine planar lamination to low-angle cross-lamination that may represent hummocky cross-stratification (fig. 24) (Dott and Bourgeois, 1982). Some beds in the upper part of the interval have cross lamination with dips up to 25°. Interbedded reddish-brown to yellowish brown silty horizons that are gradational with the gray sandstone give the outcrop a distinct banded appearance. Scattered pelecypods, mostly Astarte ignekensis, occur in one of the reddish brown silty zones. Sandstone beds range from 4 ft to 12 ft thick and typically have sharp bases that in some cases are marked by thin pebble-conglomerate layers that truncate the underlying bed. These massive sandstone intervals fracture to form distinctive smooth conchoidal surfaces on which bedding details are etched in relief. At the syncline section, the uppermost cross-bedded sandstone beds have numerous large vertical burrows; the top 2 in. has scattered chert pebbles up to 1 in. in diameter. This pebbly interval is gradational with the underlying sandstone but has a sharp contact at the top. It is overlain by 5 to 10 ft of dark-gray carbonaceous shale with interbeds of intensely burrowed gray siltstone (fig. 22). In turn, the shale and siltstone interval is overlain at a sharp contact by the pebble shale unit.

In summary, the cross-bedded sandstone facies of the Ignek Valley Member characteristically is a shallowing- and coarsening-upward sequence that generally grades upward from siltstone at the base to fine-grained sandstone at the top. Burrowing is abundant at the base and becomes less conspicuous upward except at the top of the sequence, which in some places contains a thin interval of burrowed siltstone beneath the overlying pebble shale unit. West of the Katakturuk syncline section, the cross-bedded sandstone facies is generally thinner and contains more homogeneous sandstone and burrowed silt-stone beds. In addition, the cross-bedded sandstone beds are thinner and less prominent, and the conglomerate intervals are less numerous.

An anomalous section that consists of two distinct intervals of sandstone and siltstone crops out at the west end of Ignek Valley (80AMu7). The upper interval, 25 ft thick, consists of wavy irregular-bedded siltstone in beds up to 3 ft thick. In contrast to localities to the east, large

Figure 24. Unburrowed cross-laminated sandstone in Ignek Valley Member overlies burrowed sandstone (lower right), and may be hummocky cross-stratification. Scale is 8 in. long.

curved horizontal burrows are numerous; no vertical burrows were observed. The unit has a sharp base with a lag deposit of black chert pebbles and cobbles up to 4 in. in diameter. Scattered matrix-supported chert pebbles are present throughout the interval, but no tripolitic chert was observed. This upper interval is separated from a lower sandstone-siltstone interval by 65 ft of fissile to silty shale that contains scattered ironstone nodules. The lower interval consists of 35 ft of very fine grained sandstone that grades downward into siltstone. The interval contains abundant horizontal burrows and a few large vertical burrows. Matrix-supported pebbles are abundant in the top of the horizon. Although the base is covered, the lower sandstone-siltstone interval appears to grade downward into the underlying Kingak Shale. In general, depositional features in both of these intervals suggest shelf deposition in deeper water than in sections to the east.

With one exception, the cross-bedded sandstone of the Ignek Valley Member is best developed along an approximate S. 80° W. trend that extends from the east end of the Sadlerochit Mountains at Last Creek through Ignek Mesa, the upper Katakturuk River, Ignek Creek, and Hue Creek, to west of the Shublik Mountains at the Canning River (fig. 3). Additional thinner exposures are present along this trend west of the Canning River. The exception to this linear trend are exposures along Marsh Creek, on the north side of the eastern Sadlerochit Mountains. These exposures have been displaced 8 - 10 mi northward by thrust faulting. The relationship of this displaced Kemik facies to the surrounding rocks is discussed in a later section of this report.

Burrowed Siltstone Facies (Marsh Creek Member)

Rocks of the burrowed siltstone facies are exposed in stream cuts at five localities along the north side of the Sadlerochit Mountains between the Katakturuk River on the west and the Sadlerochit River on the east (fig. 12). The facies is also present at a small outcrop on Last Creek on the south side of the eastern Sadlerochit Mountains. The burrowed siltstone facies is about 100 ft thick, but because the rocks are less resistant than the cross-bedded sandstone facies of the Kemik, outcrops are generally not as good. The best exposure of the burrowed siltstone facies is on the west fork of Marsh Creek (fig. 2, locality 76AMu4; and fig. 8) and is designated the type section for the Marsh Creek Member of the Kemik Sandstone. Neither the top nor the base is well exposed at this locality, however, the upper contact with the pebble shale unit is fairly well exposed in a section on Marsh Creek (fig. 2, locality 80AMu16, and fig. 25). The upper part of the Marsh Creek Member of the Kemik, the pebble shale unit, and Colville Group pyroclastics are well exposed in a section near the head of a small tributary of the Katakturuk River (fig. 2, locality 76AMu24 and fig. 26).

Along the north side of the eastern Sadlerochit Mountains, the Kingak Shale has been truncated, and the burrowed pebbly siltstone of the Marsh Creek Member of the Kemik unconformably overlies the Lower Triassic Ivishak Formation; at Last Creek it unconformably overlies the Middle and Upper Triassic Shublik Formation. The basal contact is not well exposed at most localities, but only a thin covered interval separates the basal Marsh Creek Member from the top of Triassic rocks. On the west fork of Marsh Creek, the

Figure 25. View east to Marsh Creek Member of Kemik Sandstone on a small eastern tributary of Marsh Creek (locality 80AMu16). Triassic Ivishak Formation forms resistant outcrop on right. Basal Kemik consists of 8 ft of irregularly bedded, faintly laminated, burrowed, conglomeratic siltstone and very fine grained sandstone. Slope to left is underlain by partially exposed burrowed shaly pebbly siltstone and mudstone of the burrowed siltstone facies. Sharp contact with pebble shale on shoulder of ridge spur to left. Marsh Creek thrust trends down covered slope at extreme left. Kps---pebble shale unit; Kkbs---Kemik Formation, burrowed pebbly siltstone facies; Jk---Kingak Shale; T i---Ivishak Formation.

Figure 26. View northeast to burrowed pebbly siltstone facies of Marsh Creek Member of Kemik Sandstone, pebble shale unit, and pyroclastics of Colville Group exposed at head of tributary of Katakturuk River (locality 76AMu24) on north side of Sadlerochit Mountains. Numerous pebble to boulder size clasts are present in pebble shale unit near helicopter. Ivishak Formation is in right foreground. Kc---Colville Group pyroclastics; Kps---pebble shale unit; Kkbs---Marsh Creek Member of Kemik Formation, burrowed pebbly siltstone facies; T i---Ivishak Formation.

base of the Marsh Creek Member contains 5 ft of chert pebble conglomerate and sandstone, and at Marsh Creek the basal 8 ft consists of burrowed siltstone and very fine grained sandstone with pebble conglomerate lenses. Upward the sections consist of interbedded black mudstone and dark-gray argillaceous siltstone to argillaceous very fine-grained sandstone. Matrix-supported chert and quartz pebbles are common throughout the section. On a small tributary of the Katakturuk River (locality 80AMu27) a narrow 2 ft-deep channel contains chert boulders up to 15 in. diam.

Beds in the Marsh Creek Member are from 1 to 3 ft thick, all contacts within the unit are gradational and no internal bedding features are visible. The rocks appear to have been thoroughly bioturbated and large-diameter vertical burrows (Skolithos) are common in the siltstone beds (fig. 27). Some of the burrows seem to be U-shaped burrows (Arenicolites) with the paired vertical segments about 3 in. apart. No megafossils have been found in the burrowed pebbly siltstone facies of the Kemik; however, a microfauna has been recovered from mudstone interbeds.

In an unbroken sedimentary sequence, the burrowed pebbly siltstone facies of the Marsh Creek Member is overlain at a sharp contact by the pebble shale unit, which in turn is overlain by the shale, bentonite, and red-weathering pyroclastics of the Colville Group (fig. 24). However, in the Marsh Creek area, because of faulting, this sequence is not present.

Shale and Mudstone Facies

A shale and mudstone facies of the Kemik Sandstone is well exposed at only one locality, at the headwaters of a small tributary of the Kavik River (figs. 2 and 13, locality 76AMu113). It overlies Kingak Shale and consists of soft, silty, burrowed mudstone and shale with scattered 1-in.-thick, platy, micaceous siltstone beds that typically contain convolute lamination. A single 3-ft-thick brownish-gray, quartzose sandstone bed caps the section; it weathers to the characteristic light-gray and reddish-brown banded character of the Kemik and is overlain by the pebble shale unit, which in turn is overlain by Albian turbidites. The facies is also present southwest of the Sadlerochit River in poor exposures that overlie Kingak Shale and underlie the pebble shale unit and Albian turbidites (fig. 2, locality 76AMu65).

INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS

The depositional environments of the Kemik Sandstone can be interpreted from the generalized facies characteristics that are summarized below:

Cross-bedded sandstone facies (Ignek Valley Member):

1. Sharply defined erosional base typically with a basal conglomerate; overlies a regional unconformity that dies out southward.

2. Facies generally coarsens upward, and consists of siltstone at the base and fine-grained sandstone at the top.

Figure 27. Close up view of burrowed pebbly siltstone in Marsh Creek Member.
Knife is 4 in. long.

3. Individual beds have sharply defined bases that truncate the underlying beds; thin conglomerate layers form the base of many beds, and matrix-supported pebbles are common.

4. Base of the sequence is represented by the Cruziana and Skolithos ichnofacies; top of the sequence contains only the Skolithos ichnofacies.

5. Internal bedding features within the lower beds commonly have been obliterated by bioturbation, but upward in the section, planar lamination and broad-sweeping low-angle cross-lamination are well preserved in many places. Thin beds with small-scale high-angle cross-lamination are also present.

6. A sparse megafauna that consists mostly of pelecypods is present, generally in red mudstone and siltstone beds. Interbedded shales contain a calcareous microfauna.

7. The cross-bedded sandstone facies can be traced for over 60 mi along a long linear trend with a maximum inferred width of about 10 mi.

Burrowed pebbly siltstone facies (Marsh Creek Member):

1. Sharply-defined erosional base with basal conglomerate; unconformably overlies Triassic rocks.

2. Beds have gradational contacts.

3. No internal bedding features due to pervasive bioturbation; trace fossils Skolithos and Arenicolites, representative of the Skolithos ichnofacies, are common.

4. No megafossils are present, but some interbedded shales contain a calcareous microfauna.

5. Matrix-supported pebbles are common in the siltstone.

Mudstone and shale facies:

1. Thin interbeds of mudstone, shale, and burrowed siltstone.

2. Convolute bedding in thin siltstones.

3. Contains a calcareous microfauna.

The general characteristics of the three major Kemik facies and their regional distribution suggest deposition in a barrier island complex that flanked a back barrier subtidal lagoon to the north. General characteristics of barrier-island and lagoonal systems are summarized by Reinson (1984). The cross-bedded sandstone facies consists of a generally shallowing and coarsening upward suite of rocks that records a transition upward from inner shelf to shoreface and beach environments. Reinson summarizes evidence that suggests that long linear barrier bars, as interpreted in the Kemik, are indicative of a microtidal coastline with less than 6 ft of tidal range. The more intensely burrowed sandstone in the lower part of the cross-bedded sandstone sequence probably represents repetitive cycles of storm dominated deposition below fair weather wave base. Upward in the cross-bedded sandstone section the more numerous laminated and cross-bedded intervals are interpreted to represent deposition in shallower shoreface to beach environments. The mudstone and shale facies is interpreted to have been deposited in an offshore environment seaward from the barrier island complex.

In the lagoon, fluctuating brackish water to marine conditions are suggested by the interbedded unfossiliferous burrowed pebbly siltstone and black mudstone, which in some cases contains a calcareous microfauna. The isolated matrix-supported pebbles and sand grains in the burrowed siltstone facies may be dropstones rafted in by kelp or by seasonal floating ice. R.C. Allison (written commun., 1986) suggests that part of the megafauna indicates a marginal habitat not incompatible with floating ice. In addition, paleomagnetic data (Irving, 1979; and Witte and others, this volume) indicate that the Brooks Range had a high paleolatitude of between 75° and 80° N during the Neocomian to Albian; this is also compatible with seasonal ice during deposition of the Kemik Sandstone and also the overlying pebble shale unit.

Although no statistical study has been made, the abundance and size of the conspicuous white tripolitic-chert pebbles in the interpreted barrier island sequence appears to decrease from northeast to southwest. Tripolitic-chert pebbles are not present in the lagoonal deposits, which contain only gray- and black-chert pebbles. These relationships suggest a strong component of longshore drift from northeast to southwest along the barrier island trend.

Although a shallowing and coarsening upward sequence characterizes most of the cross-bedded sandstone facies, in some locations the top of the section contains a few feet of thinly interbedded mudstone and burrowed siltstone. These beds may represent local breaching and destruction of the barrier island. However, there does not appear to have been any significant amount of lateral migration of the barrier-island complex. Although there are indications of minor lateral intertonguing of the interpreted barrier-island and lagoonal deposits, regional stratigraphic superposition of thick sections of the cross-bedded sandstone facies over burrowed siltstone deposits, or burrowed siltstone over cross-bedded sandstone deposits, has not been observed. Deposition of the barrier island complex appears to have been dominantly by vertical accretion along a relatively narrow trend, followed by rapid submergence of the coastline, during which the overlying pebble shale unit transgressed over the entire area. However, the interpretation of relatively narrow facies trends in the Sadlerochit and Shublik Mountains area may be accentuated by thrust telescoping of facies into belts narrower than their original depositional extent. The effects of faulting on the Kemik Sandstone in the Sadlerochit and Shublik Mountains area are discussed in the following section of this report.

STRUCTURAL RELATIONSHIPS

Regional geologic mapping of the Mt. Michelson Quadrangle (Reiser and others, 1971) suggests that structural deformation of the Kemik Sandstone is relatively straightforward; the formation is deformed by broad folds and cut by high-angle reverse faults along the north flanks of the Shublik Mountains and Sadlerochit Mountains (fig. 3). However, structure in the Kemik is locally more complex and suggests greater regional complexity than is obvious from regional-scale mapping. Stratigraphic complications due to faulting were first noted by Leffingwell (1919) along the west bank of the Canning River and along Marsh Creek on the north side of the eastern Sadlerochit Mountains. In addition, examination of some of the better exposures in Ignek Valley and at Last Creek suggest thrust fault repetition. Some of these structural complications and their implications are discussed below.

Canning River

West of the Shublik Mountains along the west bank of the Canning River (fig. 13, locality 80AMu3), three resistant outcrops of the cross-bedded sandstone facies of the Kemik project into the river. Two of the sandstone bodies dip northward; the third is overturned. All are separated by poorly exposed Kingak or pebble shale intervals. The sandstones are probably repeated by east-west trending thrusts or high-angle faults, but exposures are too limited to determine the structural relationships.

Ignek Valley

Multiple sandstone and siltstone intervals are present at several localities in Ignek Valley. At the west end of the valley two lithologically distinct siltstone intervals are present (fig. 2, locality 80AMu7) and have been discussed previously. To the east up Ignek Valley (localities 80AMu8, 80AMu11) the relationship between multiple sandstone units cannot be determined with confidence because of poor exposures. However, extensive fracturing of some beds and the apparent repetition of distinctive lithologies suggest thrust repetition of the Kemik and pebble shale. Small offsets in the Kemik outcrops (fig. 4) on the divide between upper Ignek Creek and the Katakturuk River can also be interpreted as minor thrust imbrication of the Kemik and pebble shale. This small-scale thrust faulting can either be interpreted as out-of-the-syncline thrusting (Dahlstrom, 1970) related to formation of the Ignek Valley syncline, or may be a consequence of regional thrusting.

Last Creek

Two significant exposures on the south side of Last Creek, at the east end of the Sadlerochit Mountains (fig. 2, locality 76AMu64 and 85AMu112), suggest thrust telescoping of a section of Kingak Shale and the cross-bedded sandstone facies of Kemik over the burrowed siltstone facies of Kemik and the pebble shale unit (fig. 28). A linear almost east-west trending ridge on the south side of the creek is formed by the Shublik Formation unconformably overlain by a section consisting of an estimated 50 ft of the burrowed siltstone facies of the Kemik and pebble shale unit (76AMu64). The section dips

Figure 28. View northeast to Kemik exposures on south side of Last Creek. Thrust imbricated cross-bedded sandstone facies of Ognek Valley Member of Kemik on ridge at left center overlies Kingak Shale. Burrowed pebbly siltstone facies of Marsh Creek Member and pebble shale unit unconformably overlie Shublik Formation on distant ridge at right. Probable folded thrust juxtaposes the two contrasting Kemik facies. Kps---pebble shale unit; Kkbs---burrowed siltstone facies of Kemik; Kkcs---cross-bedded sandstone facies of Kemik; Jk---Kingak Shale; T s---Shublik Formation.

about 15° E. About 200 yds southwest and across a covered topographic swale, a conspicuous resistant dip slope formed by the cross-bedded sandstone facies of the Kemik dips about 30° SE. This section consists of two thrust imbricated sandstone intervals separated by pebble shale, and overlies a poorly exposed section of about 200 ft of Kingak Shale that overlies Shublik Formation.

These localities are along the apparent eastern extension of the Sadlerochit fault; a major fault that forms the northern front of the western Sadlerochit Mountains. Reiser and others (1971) mapped a N. 75° W. trending high angle fault separating the two Kemik exposures at Last Creek. However, an alternate interpretation is that the fault is a folded thrust that has juxtaposed the two Kemik facies. The locality has not been mapped in detail and warrants further investigation.

Marsh Creek Area

Mapping along the north flank of the eastern Sadlerochit Mountains shows that the Mesozoic stratigraphic sequence in this area consists of the Lower Triassic Ivishak Formation of the Sadlerochit Group unconformably overlain by the burrowed pebbly-siltstone facies of the Marsh Creek Member of the Kemik Sandstone, as discussed above; this facies of the Kemik, in turn, is overlain by the pebble shale unit and the organic shale, bentonite, and red-weathering pyroclastics of the Colville Group. This normal sequence is well exposed at the head of a small tributary of the Katakturuk River on the north flank of a gentle west-plunging anticlinal nose (fig. 2, locality 76AMu24, and figs. 3, 12, and 26).

At the mountain front in the Marsh Creek area, 9 mi east of the Katakturuk River (fig. 2, locality 80AMu16), anomalous stratigraphic relationships were first noted by Leffingwell (1919), who mapped intersecting normal faults to explain the relationships he observed. Here, as elsewhere along the front of the eastern Sadlerochit Mountains, beds here recognized as the burrowed pebbly-siltstone facies Marsh Creek Member of the Kemik Sandstone (and a thin basal unit of cross-bedded sandstone) unconformably overlie sandstone of the Ivishak Formation (figs. 3 and 25); the Shublik Formation and Kingak Shale are absent beneath the unconformity. However, downstream along Marsh Creek, the Kingak Shale, the cross-bedded sandstone of the Ignek Valley Member of the Kemik and the pebble shale unit are present (fig. 2, sections 80AMu19, 80AMu20, and fig. 5).

The regional distribution of Kemik facies indicate that the Kingak Shale, the Ignek Valley Member of the Kemik, and the pebble shale unit are part of a folded thrust sheet emplaced by thrusting over the Marsh Creek Member of the Kemik and pebble shale (fig. 3); the fault is here named the Marsh Creek thrust. At Marsh Creek, the north-dipping thrust zone is probably located about 100 yds north of the mountain front in a covered interval that overlies the pebble shale unit (fig. 29). An exposure of black clay shale about 100 yards further downstream contains an Early to Middle Jurassic microfauna (table 2, locality 80AMu23). On the thrust sheet, between Marsh Creek and its west fork (fig. 30), the Ignek Valley Member is folded into gently northeast plunging synclines and anticlinal noses (fig. 31), and in

Figure 29. View east to Marsh Creek, at Sadlerochit Mountains front, showing location of autochthonous burrowed siltstone facies of Marsh Creek Member and allochthonous cross-bedded sandstone facies of Ignek Valley Member Kemik, and approximate location of folded Marsh Creek thrust fault. Fold axes in cross-bedded sandstone trend about N. 45° E. and plunge gently NE. A---autochthonous burrowed siltstone facies of Marsh Creek Member of Kemik, and pebble shale unit (fig. 25); Kkcs---cross-bedded sandstone facies of Ignek Valley Member of Kemik; Jk---Kingak Shale; T Ps---Sadlerochit Group; IPMl---Lisburne Group.

Figure 30. View to northeast of pebbly siltstone of Marsh Creek Member of the Kemik Formation and Ivishak Formation exposed in west fork of Marsh Creek, and allochthonous cross-bedded sandstone of Ignek Valley Member of the Kemik in dark ridge across upper center. Tundra covered slopes between ridge and creek are underlain by Kingak Shale; Marsh Creek thrust trends across center of photo. Ignek Valley Member of Kemik is folded into broad syncline. Colville Group exposures in distance are north of folded Marsh Creek thrust. Kc---Colville Group pyroclastic rocks; Kkcs---cross-bedded sandstone facies of Ignek Valley Member of Kemik Formation; Kkbs---burrowed pebbly siltstone facies of Marsh Creek Member of Kemik Formation; Jk---Kingak Shale; T i---Ivishak Formation.

Figure 31. View north to gently folding allochthonous cross-bedded sandstone of the Ignek Valley Member of the Kemik Formation west of Marsh Creek. Anticlinal and synclinal axes plunge northeast. High level gravels cap flat-topped hill in center.

the hills east of Marsh Creek, a number of Kemik imbricates are present (fig. 5). Regional stratigraphic and structural relationships suggest that these imbricates are part of a more extensive thrust sheet that has been subsequently folded by uplift of the Sadlerochit Mountains.

THRUST SHEET EMPLACEMENT

Major thrusting in the northeastern Brooks Range is not readily apparent, in contrast to the central and western Brooks Range where several hundred miles of shortening of allochthons during the Early Cretaceous part of the Brooks Range orogeny has been reported (Mull, 1982; Mayfield and others, 1983). In the northeastern Brooks Range, regional relationships mapped by Reiser and others (1971 and 1981) in the northeastern Brooks Range show a pattern of regional anticlinoria in which pre-Mississippian basement rocks are exposed beneath the broadly warped and unfaulted basal Mississippian clastic rocks and unconformity. No obvious major allochthons of late Paleozoic and early Mesozoic rocks have been mapped. The Mesozoic and Tertiary deformation of Triassic and older rocks in these uplifts seems to have had a major vertical component although some thrust detachment within the Mississippian Kayak Shale is suggested by the presence of tight folding of Lisburne and Sadlerochit, particularly in the Third Range and Franklin Mountains to the south (see Reiser and others, 1971). The Sadlerochit and Shublik Mountains are similar in form but smaller than the regional anticlinoria. Both ranges are composed of Mississippian to Triassic rocks folded into regional doubly plunging anticlines that are broken along their north flanks by south-dipping high-angle reverse faults which involve pre-Mississippian basement rocks (fig. 3). Although the Sadlerochit and Shublik high-angle reverse faults are inferred to sole into a regional decollement with depth (Rattey, 1985; Kelley and Molenaar, 1985), close similarities in the stratigraphy of both ranges and the adjacent valleys suggest that there is no major crustal shortening along these faults. In a 39-mi transect from the Sadlerochit Mountains south into the Franklin Mountains, Leiggi and Russell (1985) reported about 2 mi of shortening within the Sadlerochit Mountains and calculated only 14 mi of total shortening across the length of the transect.

Because of these broad regional structural relationships, Mull and Kososki (1977) suggested that the imbricated sheet of Kemik and Kingak in the Marsh Creek area were emplaced by gravitational gliding off the north flank of the Sadlerochit Mountains. Documented gravitational movement of much larger allochthons, such as the Heart Mountain detachment in Wyoming (Hauge, 1985), suggests that gravity could play a role in Brooks Range deformation in addition to the effects of compressional tectonics. However, subsequent evaluation of stratigraphic and structural relationships in the eastern Sadlerochit Mountains area suggests that there is more evidence for regional thrusting of the Kemik than was previously recognized. In addition to the allochthonous rocks in the Marsh Creek area, anomalous stratigraphic relationships southeast of the Sadlerochit Mountains suggest that the allochthonous Kingak and Kemik in the Marsh Creek area are part of a regional folded thrust sheet.

Mapping in Ignek Valley, including the apparently minor imbrications of Kemik and pebble shale, does not suggest a major detachment within the Kingak in that area. However, on the southeast side of the Sadlerochit Mountains, between Last Creek (fig. 2, locality 84AMu112) and Ignek Mesa (locality 80AMu15), a distance of 18 mi, no Kemik is exposed (fig. 3). Much of this distance is along the valley of the Sadlerochit River, and it is possible that the Kemik has been eroded and buried by alluvium. However, both at Ignek Mesa and Last Creek, the Kemik is composed of the resistant cross-bedded sandstone of the Ignek Valley Member, which forms prominent exposures in other glaciated and alluvial valleys such as the Canning River valley. The absence of Kemik between Last Creek and Ignek Mesa can be explained in part by a thrust fault in the Kingak Shale along the southeast flank of the Sadlerochit Mountains, trending westward up the valley of the Sadlerochit River.

Additional evidence for a thrust fault in the Sadlerochit River valley is found east of the confluence of the Kekiktuk and Sadlerochit Rivers. Turbidites capping the ridge tops in the area of locality 76AMu65 are on trend with rocks dated as Albian (Reiser and others, 1971; Detterman and others, 1975). The area is anomalous because rocks of this age and lithology are not present along strike in Ignek Valley. In addition, the Albian turbidites are overlain by a section of organic shale and bentonite of probable Late Cretaceous age (fig. 2, locality 78AMu7) that contains none of the prominent red-weathering silicified pyroclastics that are typical of the Upper Cretaceous in Ignek Valley and on the north side of the Sadlerochit Mountains. A section of Kingak Shale, the mudstone and shale facies of the Kemik, and probable pebble-shale unit underlies the Albian turbidites; no Kemik Sandstone is present. These apparently anomalous stratigraphic units on strike with and in close proximity to the "normal" stratigraphic succession associated with the Kemik in Ignek Valley suggests thrust telescoping of Lower and Upper Cretaceous rocks above a detachment zone in the Kingak Shale adjacent to the eastern Sadlerochit Mountains; the fault is here named the Sadlerochit River thrust.

The Sadlerochit River thrust is inferred to have been continuous with the Marsh Creek thrust. At least 10 mi of northward movement along this thrust is interpreted to have displaced a portion of the cross-bedded sandstone facies trend (barrier island) of the Ignek Valley Member northwestward over the lagoonal deposits of the Marsh Creek Member of the Kemik in the Marsh Creek area. Subsequent uplift of the Sadlerochit and Shublik Mountains, which folded of the thrust sheet, is also a necessary inference. The sequence of events inferred in this interpretation is illustrated in figure 32.

REGIONAL CORRELATIONS

The Kemik Sandstone correlates with several sandstone bodies in the subsurface of northern Alaska. The Put River Sandstone at Prudhoe Bay (Jamison and others, 1980), the Cape Halkett sandstone (informal name) in the National Petroleum Reserve in Alaska, the upper Kuparuk River Formation (Paris and Masterson, 1985), and reported sandstone and conglomerate in the subsurface of the Point Thompson area west of ANWR all overlie the regional mid-

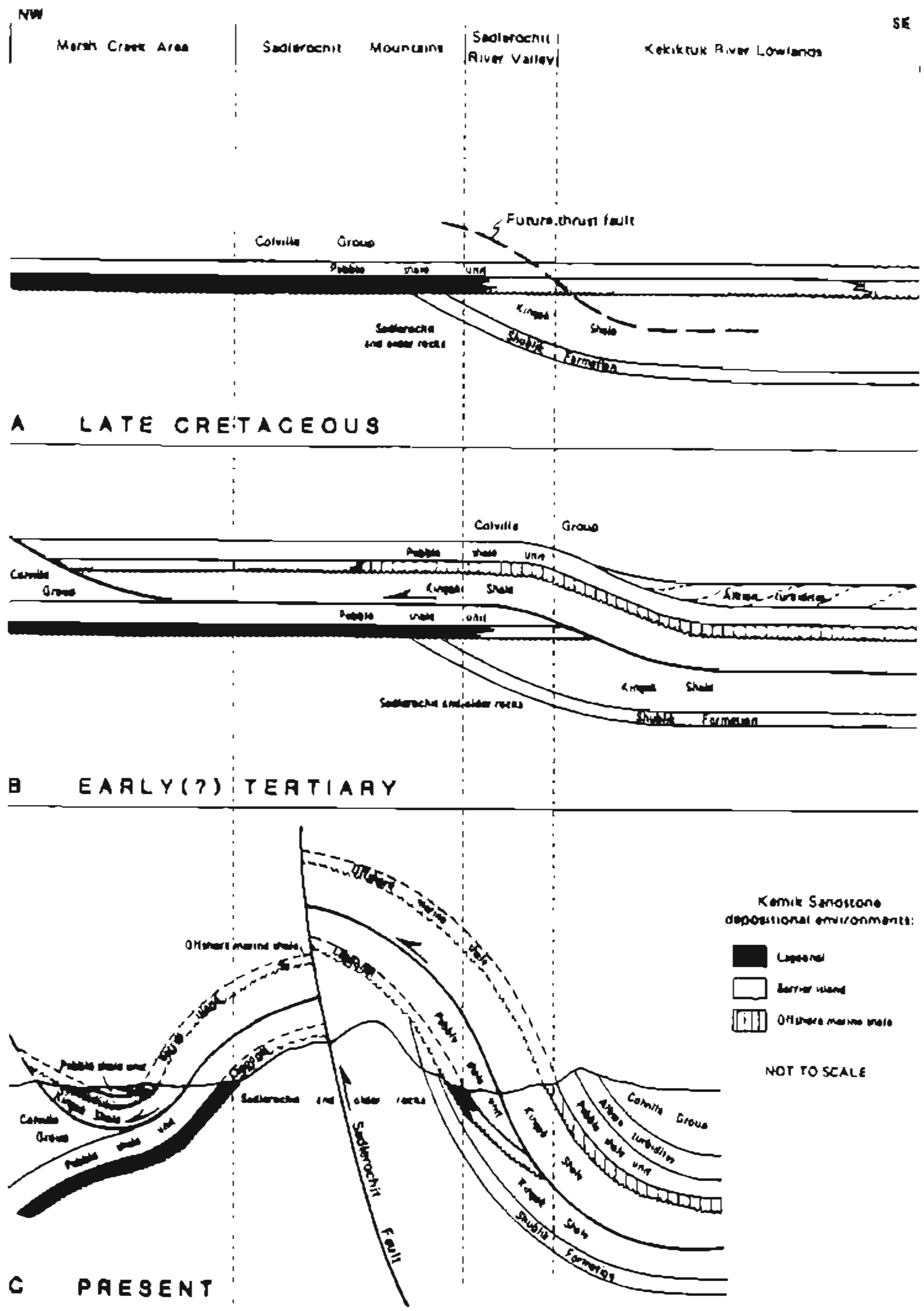

Figure 32. Diagram illustrating stages in structural evolution of eastern Sadlerochit Mountains. A---distribution of lagoonal, barrier island, and offshore marine deposits of Kemik Formation unconformable on older beds, at end of Cretaceous. B---distribution of telescoped strata after thrusting in early Tertiary time. C---Present distribution of strata after uplift of Sadlerochit Mountains in late(?) Tertiary time. Diagrams are not to scale; vertical exaggeration accentuates structural relationships and facies contrast.

Neocomian unconformity. Although all four of these sandstone units and the Kemik occupy the same stratigraphic position above the unconformity, all appear to be isolated bodies separated by areas in which the pebble shale unit rests directly on the unconformity.

In the northern Richardson Mountains and Mackenzie Delta area of Canada, 200 to 250 mi east of the Sadlerochit Mountains, a similar major regional unconformity is reported (Dixon, 1982). This unconformity is overlain by the Mount Goodenough Formation, a dominantly shale and mudstone unit of Late Hauterivian to Barremian (and possibly Aptian) age (Jeletsky, 1980; Dixon, 1982) that contains *Simbirskites* sp. in its lowermost beds. In some areas, the Mount Goodenough Formation has a basal transgressive conglomerate and bioturbated sandstone unit that contains matrix-supported clasts. The Mount Goodenough Formation in Canada and pebble shale unit in northern Alaska thus occupy comparable stratigraphic positions above a regional unconformity. These data suggest that the Kemik Formation is correlative with the basal clastics in the Mount Goodenough Formation.

However, a possible alternative correlation is suggested by the reported Early Hauterivian age of the *Simbirskites* sp. collected in this study from the Kemik on the Echooka River (J.H. Callomon, written commun., 1986; and table 1). In the Mackenzie Delta area, the unconformity at the base of the Mount Goodenough Formation is underlain locally by a shale section and by the Kamik Formation of Middle to Late Valanginian to Middle Hauterivian age (Dixon, 1982). (The Kamik Formation is also known informally as the Parsons Sandstone, a gas productive interval in the Mackenzie Delta.) The Kemik on the Echooka River is thus apparently coeval with the upper part of the Kamik Formation of the Mackenzie Delta area. Dixon reports that the upper Kamik consists of barrier island deposits in which offshore, shoreface, tidal channel, and lagoonal subenvironments have been recognized. This correlation of the Kamik Formation of the Mackenzie Delta with the Kemik Sandstone of northeastern Alaska is plausible only if the base of the pebble shale unit rather than the base of the Kemik represents the mid-Neocomian unconformity.

PALEOGEOGRAPHY AND TECTONIC IMPLICATIONS

Evidence discussed above permits some generalized conclusions on the paleogeography and tectonic setting that controlled deposition of the Kemik Sandstone.

The development of an unconformity and deposition of the relatively thin Kemik Sandstone following the deposition of the Kingak Shale is indicative of an abrupt change in depositional patterns in northern Alaska. Uplift of a local sediment source is indicated. The superposition of the marine pebble shale unit over all three Kemik facies suggests rapid subsidence of the area following the relatively brief period of uplift, erosion, and clastic deposition represented by the Kemik.

Regionally the Kemik Sandstone was deposited near the northern margin of the Arctic Alaska plate. The margin of this plate is thought to have been an extensional (Atlantic style) plate margin developed during the early stages of opening of the Canada Basin of the Arctic Ocean (Mull, 1982; Grantz and

May 1982; May and Grantz, 1983). Examination of other rifted margins (Lowell and Genik, 1972; Falvey, 1974) indicates that such margins are characterized by a sequence of events consisting of: 1) regional uplift prior to rifting, 2) rifting and truncation of downdropped, uplifted, and rotated fault blocks formed during continental breakup, and 3) rapid subsidence of the margin as plate spreading progresses. The stratigraphic sequence and distribution of the Kemik Sandstone and other correlative units in northern Alaska suggests that they were deposited adjacent to an extensional plate margin during a period of continental breakup.

SUMMARY AND CONCLUSIONS

The Kemik Sandstone in the northeastern Brooks Range was previously considered a member of the Kongakut Formation. In order to simplify the understanding of the Lower Cretaceous stratigraphy, the Kemik is here revised and raised to formation rank on the north side of the Brooks Range.

The Kemik Sandstone consists of very fine to fine-grained quartzose sandstone deposited in a shallow shelf setting as a barrier island complex south of a back barrier lagoon in which pebbly siltstone was deposited. The barrier-island complex can be traced along a linear trend of about S. 80° W. for over 80 mi from the Sadlerochit Mountains on the east to the Echooka River on the west. Construction of the barrier-island complex seems to have been dominated by vertical accretion with little lateral migration. The Kemik is Early Hauterivian in age and overlies a regional mid-Neocomian unconformity that in outcrop truncates rocks as old as Early Triassic. This unconformity is present in the subsurface throughout northern Alaska. A similar regional unconformity that may be slightly younger is present in the northern Richardson Mountains and Mackenzie Delta area of Canada. Regional relationships suggest that the unconformity and truncation both in northern Alaska and the Mackenzie Delta area developed during the early stages of rifting and continental breakup of the Arctic Alaska plate prior to opening of the Canada Basin. The Kemik and other coeval but separate sandstone intervals were probably derived from and deposited on the margins of uplifted blocks along the extensional margin. The overlying pebble shale unit of Hauterivian-Barremian age transgressed rapidly over both the barrier-island and lagoonal deposits of the Kemik.

A displaced sequence composed of the pebble shale unit, the barrier island complex of the Kemik, and Jurassic Kingak Shale is thrust over a sequence of pebble shale, lagoonal deposits of the Kemik, and the Lower Triassic Ivishak Formation on the north flank of the eastern Sadlerochit Mountains. This allochthonous section has been displaced as much as 10 mi north or northwestward by an inferred regional thrust fault that has been folded by later uplift of the Sadlerochit Mountains.

The barrier-island complex of the Kemik, named the Ignek Valley Member may be a potential objective for hydrocarbon exploration in ANWR. It is up to 100 ft thick and consists dominantly of very fine-grained sandstone that may have reservoir potential in the subsurface. It is overlain by the organic-rich pebble shale unit and underlain by the Kingak Shale, both of which have hydrocarbon source rock potential. Exploration for the barrier-island complex in the subsurface will be complicated by its possible narrow linear development and probable rapid facies changes to beds without reservoir potential both to the north and south of the barrier island complex. Exploration may also be complicated by structural telescoping of facies.

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