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# SUMMARY REPORT ON THE GEOLOGY AND HYDROCARBON POTENTIAL OF THE FOOTHILLS OF THE NORTHWESTERN DELONG MOUNTAINS, WESETERN BROOKS RANGE, ALASKA

by
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**SUMMARY REPORT ON THE GEOLOGY AND HYDROCARBON POTENTIAL OF THE FOOTHILLS OF THE NORTHWESTERN DELONG MOUNTAINS, WESTERN BROOKS RANGE, ALASKA**

This report contains a summary of the major conclusions and discoveries in a project investigating the geology of the western Brooks Range and Arctic Slope of northern Alaska. Informally termed, the Tingmerkpuk project, the objective is to expand the data base for evaluation of potential hydrocarbon exploration objectives of the future in the western part of the Colville basin, including the western part of the National Petroleum Reserve, Alaska (NPRA). The project includes geologic mapping and acquisition of data concerning the stratigraphy, paleontology, organic geochemistry, and tectonic evolution of the foothills of the western DeLong Mountains. The most significant interpretations and conclusions summarized in this report are based upon analytical data and interpretations contained within the reports listed below.

Field operations and analytical studies for the Tingmerkpuk project were partially funded by grants from Anadarko Petroleum Corporation, ARCO Alaska, Inc, (now Phillips Alaska, Inc.) Arctic Slope Regional Corporation, BP Exploration Inc., North Slope Borough, Phillips Petroleum Company, the U.S. Geological Survey, and Alfred James III.

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June 2000

# SUMMARY REPORT ON THE GEOLOGY AND HYDROCARBON POTENTIAL OF THE FOOTHILLS OF THE NORTHWESTERN DELONG MOUNTAINS, WESTERN BROOKS RANGE, ALASKA

By C.G. Mull

## INTRODUCTION

The Alaska Division of Geological and Geophysical Surveys, in collaboration with the U.S. Geological Survey, the Alaska Division of Oil and Gas, and University of Alaska, Fairbanks, is engaged in an ongoing study of the hydrocarbon potential of northern Alaska. As part of a collaborative effort to evaluate the subsurface geology of the western part of the North Slope, surface geological studies have been carried out in the foothills of the northwestern DeLong Mountains of the western Brooks Range. The studies include mile to inch (1:63,360) geological mapping in parts of the DeLong Mountains and Misheguk Mountain 1:250,000 quadrangles, study of the depositional environment of the the Tingmerkpuk Sandstone--a rock unit of Neocomian age that is coeval with the oil-productive Kuparuk River Formation on the central Arctic Slope, and collection of samples for micropaleontologic, organic geochemical, and apatite fission track (AFTA) analysis.

Field operations have been supported by grants from Anadarko Petroleum, ARCO Alaska (now Phillips Alaska, Inc.), Arctic Slope Regional Corporation, BP Exploration, Phillips Petroleum Company, North Slope Borough, the U.S. Geological Survey, and Alfred James III.

The conclusions summarized in this report are based upon published analytical and interpretive reports by Crowder and others (1994), Dow (1998, 2000), Dow and Talukdar (1995), Elder (1998), LePain and others (1999 and 2000 in press), Mickey and Haga (1995, 1998, 2000), Mickey and others (1995), Mull (1995), Mull and others (2000), Reifenstuhl and others (1998), and Wartes and Reifenstuhl (1998). Details of the stratigraphy, structure, paleontology, and organic geochemistry of the rocks of the foothills of the northwestern DeLong Mountains are discussed and illustrated in many of these references and are not repeated here.

Many of the conclusions summarized here have also been presented in abstracts for a number of public oral presentations and posters at professional and technical meetings. These include presentations by Crowder and others (1995), Grow and others (1995), LePain and others (1999), Mowatt and others (1995), Mull (1997), Mull and others (1995a, 1995b, and 1999), and Wartes (1997).

## FRAMEWORK GEOLOGY AND EVOLUTION OF THE FOOTHILLS OF THE NORTHWESTERN DELONG MOUNTAINS

The foothills of the northwestern DeLong Mountains straddle the northern flank of the Brooks Range orogenic belt and the southern part of the Colville basin, a Cretaceous foreland basin that lies north of the Brooks Range. The Colville basin overlies a relatively thin, regionally south-dipping section of Carboniferous to earliest Cretaceous (lower Neocomian) platform sediments that are coeval with rocks exposed in thrust sheets in the DeLong Mountains, 40 km (25 mi) south of the map area. This sequence of platform sediments is succeeded upward by a Lower Cretaceous (upper Neocomian to Aptian) section of dominantly orogenic sediments derived from the Brooks Range thrust. These rocks, in turn, are overlain by a thick section of mid-Cretaceous (Aptian-Albian to Cenomanian) foreland basin deposits of the Torok Formation and Nanushuk Group. These rocks fill the Colville Basin and form most of the surface exposures

of the southern part of the Brooks Range foothills foldbelt (figs. 1 and 2). (See also regional map in Mull and others, 1987, or Moore and others, 1994).

On the western Arctic Slope, the Nanushuk Group is a complex of deltaic sediments >3000 m.-thick termed the Corwin delta (Ahlbrandt and others, 1979, Huffman and others, 1985). The Nanushuk overlies >2500 m of pro-delta shale of the Torok Formation and prograded generally eastward across the Colville basin (Chapman and Sable, 1964; Mull, 1985, Huffman, 1985, and Molenaar 1985) from a dominant source in the area of the Herald arch beneath the present Chukchi Sea (Mull, 1979). This foreland basin fill extends northward and underlies most of the northern foothills belt and coastal plain of northern Alaska.

Most of the surface exposures in the northern part of the DeLong Mountains foothills consist of the relatively competent Nanushuk Group and relatively incompetent shale of the Torok Formation (Fig. 1). The relatively resistant Nanushuk is regionally deformed into a series of long, linear, relatively broad gentle synclines and narrow anticlines. These structures are formed above a decollement in the shales of the Torok, which is generally exposed only in the cores of the anticlines (see Chapman and Sable, 1960, Mull and others, 1987).

Regional structural and stratigraphic relationships in the DeLong Mountains are indicative of a major Early Cretaceous (Neocomian) orogenic event characterized by extensive north-vergent thrust faulting and juxtaposition of far-travelled allochthons (Mull, 1982, Mayfield and others, 1988, Moore and others, 1994). However, stratigraphic data in the area of Coke Basin and Tupikchak syncline in the center of the map area of figure 1 (discussed below) also suggest mid-Cretaceous (Aptian-Albian) deformation. In addition, post-Cenomanian orogenesis is indicated by deformation of the foreland basin deposits of the Nanushuk Group above the inferred decollement within the Torok Formation. Apatite fission track analysis of a number of Cretaceous sandstones collected in the course of this mapping project also indicates significant early Tertiary uplift in the DeLong Mountains foothills belt (John Murphy, 1997 written communication).

## SUMMARY OF MAJOR CONCLUSIONS

Major discoveries resulting from the studies of the hydrocarbon potential of the foothills of the northwestern Brooks Range include data and interpretations on 1) hydrocarbon source rock potential, 2) uplift and deformation of the Surprise Creek area and a new potential hydrocarbon exploration play in the Brooks Range foothills, 3) origin and depositional environment of the Tingmerkpuk sandstone (Neocomian), 4) tectonic evolution of the northwestern DeLong Mountains foothills.

### 1. Hydrocarbon source rocks

Significant organic-rich oil- and gas-prone Late Triassic, Early Jurassic, and Early Cretaceous (Hauterivian-Barremian) source rocks are present in the western part of the DeLong Mountains foothills in the vicinity of the headwaters of Thetis Creek (Fig. 1). These Triassic, Jurassic, and Lower Cretaceous rocks contain shale or limestone beds with total organic carbon (TOC) of up to 21%TOC and hydrogen index (HI) values as high as 560 HI, indicative of high quality oil- and gas-prone source rocks (Mull and others, 2000, Dow, 2000). Indicators of thermal maturity show that in the western part of the area, some of these rocks are thermally mature with 420-430°TMax and vitrinite reflectance values of 0.6 to 1.19 Ro, capable of generating both liquid and gaseous hydrocarbons. In the central part of the area near the Kukpowruk River (Fig. 1), Jurassic and Neocomian rocks coeval with the rocks of the Thetis Creek area are thermally overmature for generation of liquid hydrocarbons and could be the source of undiscovered migrated liquid and gaseous hydrocarbons in the subsurface of the Colville Basin to the north.

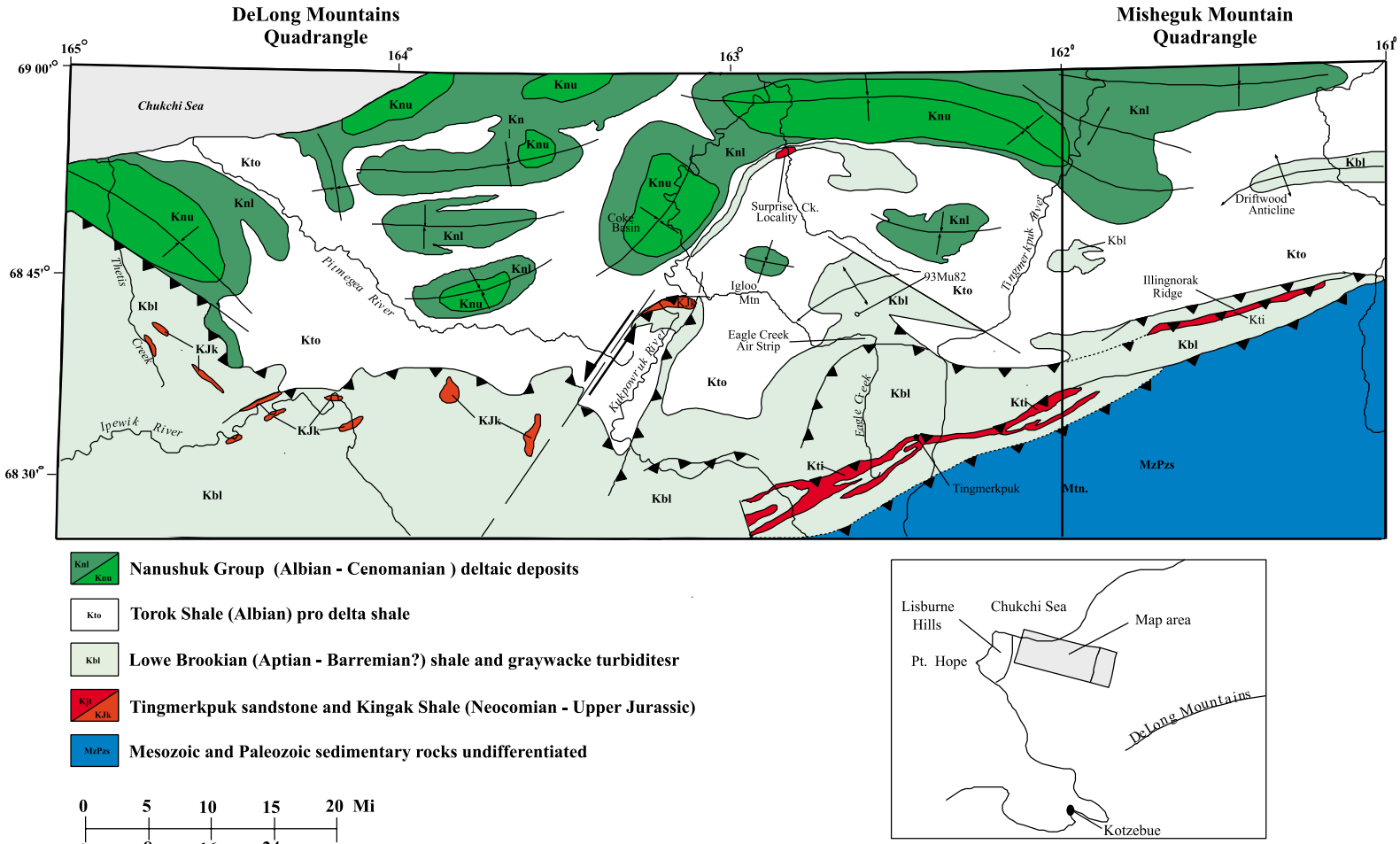


Figure 1: Generalized geologic map of the northwestern DeLong mountains and foothills, western Brooks Range, Alaska

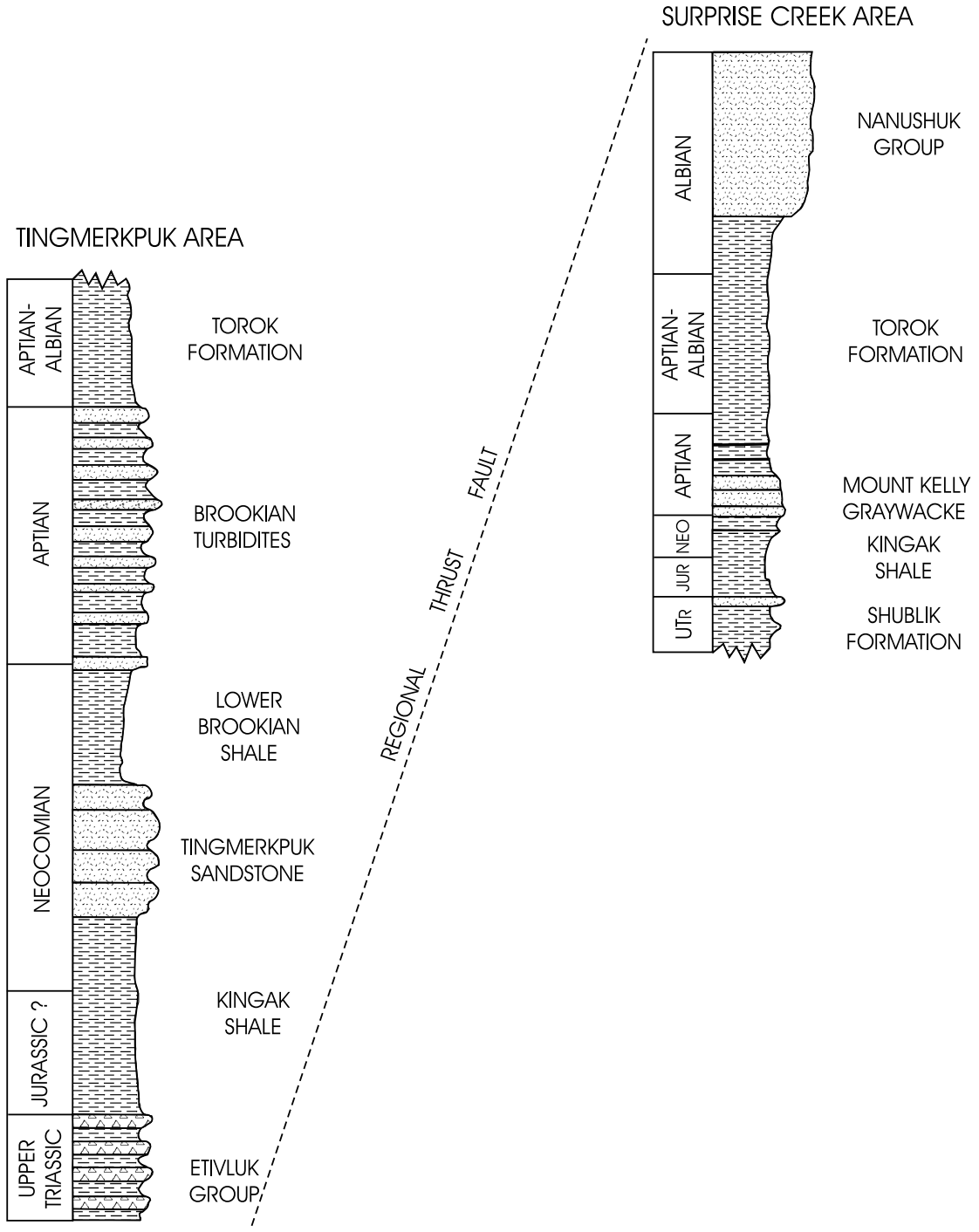


Fig. 2 Generalized composite stratigraphic columns, Tingmerkpuk Mountain and Surprise Creek areas, northwestern DeLong Mountains.

In the eastern part of the map area (fig. 1), Neocomian shales in the Kingak Formation, Tingmerkpuk sandstone, and overlying basal Brookian section on the thrust sheets of the western DeLong Mountains contain 1.2- 1.84% TOC and dominantly Type II/III mixed marine and terrigenous kerogen that is both oil and gas prone (Mull, 1995). The overlying Aptian-Albian shales (Brookian) contain to 1.06-1.3% TOC that is gas-prone Type III terrigenous kerogen. In the thrust belt outcrops in the western DeLong Mountains all of these shales have vitrinite reflectance values that range from 1.17 to 1.57% Ro, indicating that they are now mostly thermally overmature for generation of oil and gas (Dow and Talukdar, 1995, and Mull, 1995). However, the geochemical data suggest that these rocks may also have been a fair oil and gas source prior to deep burial and thermal maturation, and could also be the source of migrated hydrocarbons in other parts of the Colville basin.

Regional map and facies relationships suggest that the organic-rich, oil-prone Triassic, Jurassic, and Lower Cretaceous source rocks of the Thetis Creek area are probably structurally overridden to the east by the thrust sheets of the northwestern DeLong Mountains. If valid, this structural interpretation suggests that the deeply buried source rocks in the southern part of the Colville basin are probably richer than otherwise suggested by the quality of the coeval thrust faulted source rocks exposed in the adjacent DeLong Mountains. Rich source rocks deeply buried beneath the overriding thrust sheets of the DeLong Mountain are probably now thermally overmature. However, during the earlier stages of burial and thermal maturation, such rocks should have been the source of significant volumes of liquid hydrocarbons that were generated and migrated into shallower portions of the Colville basin to the north.

## 2. The Surprise Creek locality: source rocks, early uplift, and potential hydrocarbon exploration plays

An anomalous exposure of the Upper Triassic Shublik Formation, Jurassic-Neocomian Kingak Shale, and Aptian-Albian Mt. Kelly Graywacke is present at a locality known as Surprise Creek (fig. 1), near the leading edge of the Coke Basin-Tupikchak thrust fault (Wartes, 1997, Mull and others, 2000). At this locality, near the southern edge of the Brooks Range foothills, and north of the DeLong Mountains thrust belt, Upper Triassic and Jurassic source rocks underlie thick deltaic sandstones of the Nanushuk Group (Albian to Cenomanian). They are exposed in an area in which an extremely thick section of Torok prodelta shale (Albian) and lower Brookian (Albian-Aptian) graywacke turbidites normally overlies the Kingak and Shublik (fig. 2) (Mull, 1995). The Shublik at Surprise Creek is a rich source rock with up to 4.6% total organic carbon (TOC) with Type II oil-prone kerogen. Shale in the Kingak is also a fair source rock with 1.8% TOC and Type II/III oil and gas prone kerogen (Dow and Talukdar, 1995, Dow, 1998, Mull and others, 2000). Thermal maturation data at this locality show that the Kingak and part of the Shublik are thermally mature at peak oil generative capacity, with vitrinite reflectance values of 0.74% to 1.16% Ro (Dow, 1998, Mull and others, 2000). This level of thermal maturity is substantially lower than expected for rocks that were apparently structurally uplifted from the depths of the Colville basin. Regional surface and subsurface data suggest that Jurassic and Triassic strata in the southern part of the Colville Basin are at a depth of >5 km (see Mull and others, 1987, Howell and others, 1992, Moore and others, 1994, Fuis and others, 1997). Rocks at this depth should be thermally overmature for the generation of oil and well into the zone of dry gas generation, with vitrinite reflectance values of >2.0 Ro (Howell and others, 1992). The thermal maturity data suggest that the Shublik and Kingak at Surprise Creek had a residence time at depth that was significantly less than for coeval rocks in the Colville Basin or for the coeval rocks exposed in the thrust sheets in the Brooks Range to the south.

Marine sandstones that typically form the base of the Nanushuk Group appear to pinch out locally in close proximity to the leading edge of the Coke Basin-Tupikchak thrust along the southeast flank of Coke Basin and south flank of Tupikchak syncline (Mull and others, 2000). The exposures of Triassic and Jurassic source rocks at Surprise Creek occur on this thrust plate. On both the southeast flank of Coke Basin and on the south flank of Tupikchak syncline, fluvial sandstones and conglomerates characteristic of the upper Nanushuk appear to directly overlie the prodelta shales of the Torok. At these locations, lower Nanushuk marine sandstone are absent. This stratigraphic relationship contrasts markedly with the stratigraphy in adjacent areas 4 mi to the south and southeast, where the basal marine sandstones of the Nanushuk are >1000 ft. thick.

In addition to the local pinchout of marine beds of the lower Nanushuk, the southeast flank of Coke Basin is also maked by a structural anomaly in which the basal nonmarine beds in the Nanushuk are locally vertical to slightly overturned where they are in proximity to the Coke Basin-Tupikchak thrust fault (Mull and others, 2000). The steep dips in this Nanushuk section progressively decrease up-section to ~20°NW, as well as along strike both to the northwest and southwest. Aerial photographs show that a number of resistant beds in a thick interval in the lower part of the upper Nanushuk pinch out between the Kukpowruk River valley and the area of overturned outcrops to the northeast. The outcrop relationships suggest stratigraphic onlap and deposition of fluvial clastics and coals onto a relatively positive area.

Significant changes in thickness of the Nanushuk over a relatively short distance are also evident in the mapping of laterally persistent beds of the upper Nanushuk in both the western end of Tupikchak syncline and northeast Coke Basin, where numerous resistant beds clearly pinch out laterally (Mull and others, 2000). Inasmuch as changes in thickness of similar magnitude over short distances have not been observed elsewhere in the Nanushuk outcrop belt, these relationships may be suggestive of tectonic control on deposition related to uplift along the Coke Basin-Tupikchak thrust synchronous with deposition of the Nanushuk Group.

The lateral extent of the area of thrust sheets containing thermally mature Triassic and Jurassic source rocks uplifted synchronous with deposition of the Nanushuk Group is unknown. However, regional relationships suggest that other areas characterized by early uplift of thrust sheets with Triassic source rocks may be present along the southern edge of the Colville basin. The emplacement of north-vergent thrust sheets with organic-rich Upper Triassic and Jurassic source rocks into proximity with potential Cretaceous reservoir rocks may result in more favorable hydrocarbon migration pathways than previously interpreted. These relationships in the Surprise Creek area may have important implications that suggest potential for significant hydrocarbon exploration plays to the east, in the southern part of the Colville basin and northern part of the Brooks Range thrust belt (Mull and others, 2000).

**3. The Tingmerkpuk sandstone (informal name)**

The Tingmerkpuk sandstone (Neocomian) is about 390 ft. thick and consists of about ~60% net sandstone that is very fine-to medium grained and was deposited in an outer shelf setting (LePain and others, 2000 in press). It is present on north-vergent thrust sheets for over 60 miles along an east-northeast strike trend in the northwestern DeLong Mountains (figs. 1 and 2). Inasmuch as it is a compositionally and texturally mature sandstone, it might be considered a possible reservoir rock if present in the subsurface.

Paleontologic data suggest that the Tingmerkpuk sandstone straddles the Lower Cretaceous unconformity (LCU) (Mickey and others, 1995, LePain and others, 2000). The lower part contains lower Neocomian (Valanginian) pelecypods as well as Valanginian foraminifera and palynomorphs (Mickey and others, 1995, Elder, 1998). Upper Neocomian (Hauterivian-

Barremian) palynomorphs characteristic of the rocks that overlie the LCU are abundant in some of the interbedded shales in the upper part of the Tingmerkpuk. The Tingmerkpuk is thus coeval with the Kuparuk River Formation, which constitutes the major reservoir in the giant Kuparuk River and Point McIntire oil fields on the northern flank of the Colville Basin.

Petrographic study shows that the Tingmerkpuk consists of ~96% monocrystalline quartz (Reifenstuhl and others, 1997). These compositionally and texturally mature sandstones are petrographically nearly indistinguishable from the Kuparuk River Formation in the Kuparuk River field and also from Kuparuk River sands in the Tunalik test well in the northwestern part of the National Petroleum Reserve in Alaska (NPRA) (M.D. Wilson, oral communication, 1998). The Tingmerkpuk appears to have very little visible porosity; however, measured porosities up to 11% are reported (Reifenstuhl and others, 1997), although the permeability is very low (< 0.4 md.) Most of the porosity reduction appears to be due to pressure solution suturing due to compaction. Although the Tingmerkpuk in outcrop appears to have very little reservoir potential, improved reservoir potential in the subsurface may be possible in areas in which early migration of hydrocarbons could inhibit compaction and cementation.

Detailed mapping of the Tingmerkpuk in its type locality on Tingmerkpuk Mountain in the northern part of the DeLong Mountains thrust belt (fig. 1) reveals the presence of two parallel thrust-juxtaposed belts (Reifenstuhl and others, 1997, LePain and others, 2000). The northern belt consists of the thick bedded Tingmerkpuk sandstones described above; the southern belt consists of more thinly bedded, very fine grained sandstone and siltstone, with a much higher percentage of shale interbeds. The interval thickness for the Tingmerkpuk in both the northern and southern facies belts appears similar. Petrographic modal analyses of the sands from both the northern and southern facies belts reveal no significant compositional difference in the framework grains of both facies belts (Reifenstuhl and others, 1997). The relative distribution of the sands and the petrographic data suggest that the sands in the southern facies belt were deposited in a more distal depositional setting than the more proximal, thicker and coarser sands in the northern belt. These data are thus suggestive of a northern source for the Tingmerkpuk sands.

The source of the sand in the Tingmerkpuk is an enigma; several alternatives have been proposed and are discussed by LePain and others (2000). Although the Tingmerkpuk is coeval with the Kuparuk River Formation in the Tunalik test well in NPRA, these two sandstone units are unlikely to be physically continuous in the subsurface. The Tingmerkpuk is over 200 miles south of the Barrow arch, which was the source of the shelf sands in the Kuparuk River Formation, and subsurface control and seismic interpretations in western NPRA indicate that the Kuparuk River thins basinward to the south from the Tunalik test well. Conventional models for deposition of shelf sands suggest that it is unlikely that shelf sands of the Kuparuk River at Tunalik could be continuous with the outer shelf sands of the Tingmerkpuk. The Kuparuk River sands in the Tunalik area would have had to be dispersed southward across a broad shallow marine shelf and intervening slope and basinal area to reach the depositional area of the Tingmerkpuk.

From consideration of all presently available data, we suggest that the Tingmerkpuk sands may have been shed southward from an unrecognized paleotopographic high beneath what is now the southern Colville Basin or beneath the thrust sheets of the northwestern DeLong Mountains (LePain and others, 2000). This speculative interpretation may have other implications concerning the tectonic evolution and hydrocarbon potential of the Colville basin and Brooks Range orogenic belt.

## 4. Evolution of the northwestern DeLong Mountains foothills

1. **Late Triassic:** Deposition of thin-bedded limestone and organic-rich shales of the Shublik Formation.

2. **Jurassic:** Deposition of black shales of the lower part of the Kingak Formation.

3. **Early Neocomian (Berriasian-Valanginian):** Thrust faulting in DeLong Mountains. Deposition in incipient southern Colville basin of upper part of Kingak Shale of the Surprise Creek area, and the lower part of the Tingmerkpuk sandstone of the thrust belt, coeval with deposition of orogenic sediments of Okpikruak Formation to the south, derived from Brooks Range orogenic belt.

4. **Late Neocomian (Hauterivian-Barremian):** Deposition of upper Tingmerkpuk sandstone and overlying distal lower Brookian sediments in Colville basin foredeep, coeval with deposition of proximal upper Okpikruak Formation to south, derived from Brooks Range thrust belt.

5. **Early Aptian**: Deposition of northward prograding, upward-thickening and coarsening sequence of lower Brookian sediments derived from thrust belt. Possible beginning of north-vergent thrusting and uplift of thrust sheet of Shublik and Kingak formations exposed at Surprise Creek.

6. **Mid-Aptian**: Deposition of northward prograding Mt. Kelly Graywacke Tongue of Fortress Mountain Formation. Probable ongoing north-vergent thrusting Shublik and Kingak formations on Coke Basin-Tupikchak thrust, and deposition of upper part of Mt. Kelly Graywacke on thrust plate.

7. **Late Aptian**: Deposition of eastward prograding pro-delta shale of Torok Formation, syndepositional with continued movement and uplift of leading edge of Coke Basin-Tupikchak thrust.

8. **Late Aptian to Albian**: Prograding deposition of lower Nanushuk marine to locally nonmarine sandstones and coal syndepositional with and overlapping Coke Basin-Tupikchak thrust in Surprise Creek area. Deposition of thick lower Nanushuk marine sandstones in adjacent areas.

9. **Albian to Cenomanian:** Deposition of complete Nanushuk deltaic section across map area.

10. **Early Tertiary**: Renewed deformation and development of regional folds in Nanushuk above decollement in shales of Torok Formation. Formation of local backthrust at triangle zone on south flank of Tupikchak syncline, and south-vergent deformation of Shublik, Kingak, and upper part of Mt. Kelly Graywacke at Surprise Creek.

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