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GOVERNOR BILL WALKER

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January 2016

Prospective Industry Sponsors for North Slope Geologic Work:

The Alaska Division of Geological & Geophysical Surveys (DGGS) is pleased to submit the enclosed 2016 industry funding proposal for its North Slope program. We are confident you will find our proposed research program beneficial to your company's exploration for petroleum resources in the region.

Since 1994, DGGS has advanced the geologic understanding of North Slope geology and petroleum systems, primarily through stratigraphic studies of potential reservoir and source rock units and geologic mapping. This program was developed in response to the need for high quality, publicly available geologic data to stimulate exploration for hydrocarbons in northern Alaska. Funding for this program is from a balance of state monies and sponsorship by major and independent oil and gas companies. While directed by DGGS, this research effort is a multi-agency collaboration that includes the Alaska Division of Oil & Gas and the United States Geological Survey, among others. We also have a long standing relationship with faculty and students at the University of Alaska Fairbanks and this years' proposal includes funds to support a MS student project.

The following DGGS proposal is organized in three sections. Section I includes a description of the proposed projects for the upcoming 2016 field season, focusing on topics relevant to exploration on Alaska's North Slope. Section II includes a discussion of field logistics, project staff, and proposed budget. Section III briefly reviews project results from prior field seasons, highlighting recent and upcoming publications.

The proposed 2016 field and analytical budget totals approximately $340,000. This request is being submitted to oil and gas companies and Native corporations to solicit participation. Historically, industry contributions have typically ranged from $25,000 - $50,000; we hope your organization will support this years' program at the **requested level of $40,000**, although we will accept participation at any level. If funding is insufficient for the full program as proposed, we will scale back our plans and concentrate on fewer objectives. Funding from industry remains critically important to DGGS's work; such private sector support explicitly demonstrates that improvements in our understanding of the framework petroleum geology is an *investment* in exploration. Furthermore, industry support greatly enhances our ability to seek additional capital monies from the State or other funding agencies that often require leveraged matching resources.

We look forward to expanding DGGS's petroleum-related work, particularly the integration of surface and subsurface geologic data. We trust that your organization will find the proposed work beneficial to your exploration and production objectives. We welcome your input on the planning and scope of our field and analytical program to help ensure our research is aligned with industry needs and our goal of advancing the understanding of North Slope petroleum systems. Please feel free to contact Marwan Wartes at DGGS with questions or comments. Marwan may be reached in Fairbanks at 907-451-5056, or via e-mail at marwan.wartes@alaska.gov.

Sincerely,

S. Masterman

Steven S. Masterman
Director and State Geologist

SUMMARY PROPOSAL FOR THE
ALASKA DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS
NORTH SLOPE PROGRAM:

PETROLEUM-RELATED GEOLOGICAL STUDIES NORTH SLOPE, ALASKA

2016

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INTRODUCTION—Northern Alaska is a world class petroleum province that includes some of the most prospective onshore regions remaining in North America. Despite this potential, the North Slope remains underexplored relative to other sedimentary basins around the world. New exploration ventures are hampered by the limited amount of published geologic data, much of it reconnaissance in nature. This problem is particularly acute for new entrants with limited access to proprietary industry data. In an effort to stimulate exploration for hydrocarbons in northern Alaska, the Division of Geological & Geophysical Surveys (DGGS) initiated a program to acquire and publish high quality geologic data to improve our understanding of the regional petroleum system and entice new exploration investment.

Building on nearly two decades of successful industry support for DGGS Energy programs, we propose a diverse array of petroleum-related studies for the 2016 field season on the North Slope (Fig. 1). Stratigraphic and reservoir quality studies will be conducted on prospective Ellesmerian, Beaufortian, and Brookian units, addressing key components of the petroleum system in northern Alaska. As in previous years, this work will involve close collaboration with geologists from the Alaska Division of Oil and Gas (DOG), the University of Alaska Fairbanks (UAF), and the United States Geological Survey (USGS). All proposed research will focus on economically significant strata and topics relevant to oil and gas exploration in the Brooks Range foothills and North Slope of Alaska.

These include the following:

1. *Controls on the Reservoir Quality of Brookian Units*
2. *Spatial and Temporal Variations of Source Rock Facies in the Hue Shale*
3. *Provenance and Sediment Routing of the mid-Cretaceous Colville Basin*
4. *Paleogene Basin Evolution and Petroleum System*
5. *Tectonic and Stratigraphic Basin Reorganization at the Beaufortian – Brookian Transition*
6. *Factors Influencing Unconventional Shale Oil Potential of the Shublik Formation*

This proposal is organized in three sections. Section I includes a brief description of the proposed projects for the upcoming 2016 field season. Section II includes a discussion of field logistics, project staff, and proposed budget. Section III provides a compilation of noteworthy recent publications from the North Slope Program. As in the past, we welcome your comments and suggestions on any aspect of DGGS's North Slope Energy Program and this proposal.

SECTION I—PROPOSED STUDIES FOR THE 2016 FIELD SEASON

We propose to conduct two to three weeks of focused stratigraphic investigations on the east-central North Slope during the 2016 field season. The DGGS field program is subdivided into six sub-projects, some of which represent a continuation of previous work. Although this proposal is focused around field-related activities, it should be noted that many of the topics listed below will benefit from allied subsurface investigations and leverage existing sample collections. This work plan reflects expressions of interest from past industry sponsors and the resource evaluation needs of the State of Alaska. Each project is listed separately for clarity, but all work is interrelated and shares the common goal of increasing the availability of high quality geologic data pertinent to understanding the North Slope petroleum system.

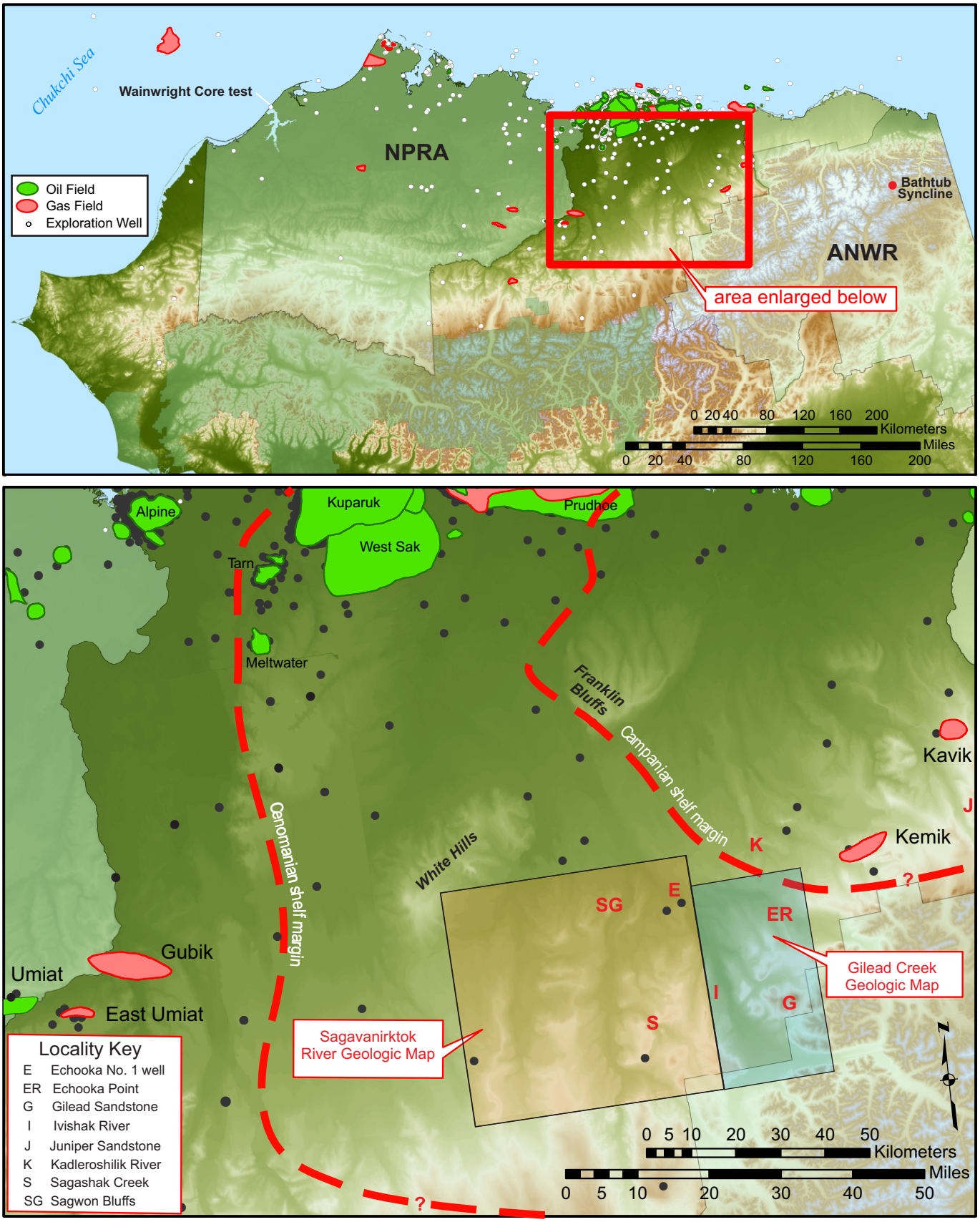


Figure 1. Regional map of northern Alaska (top) illustrating main land status, wells (dots), and oil and gas fields. Fire Creek and Kavik River refer to Shublik localities discussed in text. Enlarged map (bottom) showing key localities (letters), and approximate position of Upper Cretaceous shelf margins.

1. Controls on the Reservoir Quality of Brookian Units

- *Characterize new porosity, permeability, and grain size data from Brookian topset and deepwater sandstones; assess relative importance of variables affecting reservoir viability.*

As the North Slope exploration landscape has matured, the Brookian sequence has received increasing attention, leading to a number of significant discoveries in the last 20 years. Some of the most recent success has benefitted from advanced well stimulation techniques to more efficiently extract hydrocarbons from tighter rocks. Despite these improvements, reservoir quality is a recognized challenge in many Cretaceous sandstones on the North Slope and remains a fundamental risk in exploring for Brookian targets (Reifenstuhl and Loveland, 2004). To reduce this uncertainty, we propose to conduct a robust study of the controls on reservoir quality within both topset and basin floor settings. This work will include standard porosity and permeability measurements combined with detailed compositional and grain size data based on petrographic analyses. In addition to new samples collected in 2016, the proposed work would leverage our large existing collection of outcrop samples (Helmold, 2010), many of which are tied to detailed measured sections.

We also aim to examine relevant available cores to extend our analysis into the subsurface. In particular, we would like to include samples from producing Brookian reservoirs to help establish threshold parameters necessary for successful fields. By combining new petrographic data with our growing database of porosity and permeability and thermal maturity information, we hope to begin quantitatively isolating the most important variables affecting reservoir quality (e.g. burial history, diagenesis, provenance, grain size, etc.; Bloch and Helmold, 1995). For example, elsewhere on the North Slope, maximum burial depth has proven to be a reliable predictor of porosity and permeability (Nelson and Bird, 2005).

An example of the type of work being proposed will be published early in 2016 (Helmold, in review). This study reports on an extensive reservoir quality data set on the mid Cretaceous Nanushuk Formation (Fig. 2) we collected from the continuous shallow core from the Wainwright #1 test well drilled by the USGS (Fig. 1). The interpretations of the controls on reservoir quality are enhanced by companion studies of the detailed sedimentology as well as the regional subsurface context. We anticipate widening this type of analysis to further assess regional trends and improve the ability of explorationists to predict pre-drill risk associated with reservoir characteristics.

2. Spatial and Temporal Variations of Source Rock Facies in the Hue Shale

- *Collect detailed stratigraphic, gamma-ray, and geochronologic information from condensed Brookian basin floor source rock facies; characterize organic geochemistry and correlate with North Slope oils*

The Colville foreland basin largely filled from the southwest to the northeast, resulting in a time-transgressive association of migrating facies belts, with the Hue Shale representing the condensed toes of Brookian clinoforms and starved basin floor deposits (Figs. 2 and 3). The Hue Shale is widely recognized as an important source rock on the North Slope, consisting dominantly of organic-rich paper shale, bentonitic mudstone, and siliceous tuff.

Our mapping across the east-central and eastern North Slope has revealed a distinctive association of facies in the Hue Shale that we interpret as the sequence stratigraphic record of major cycles of

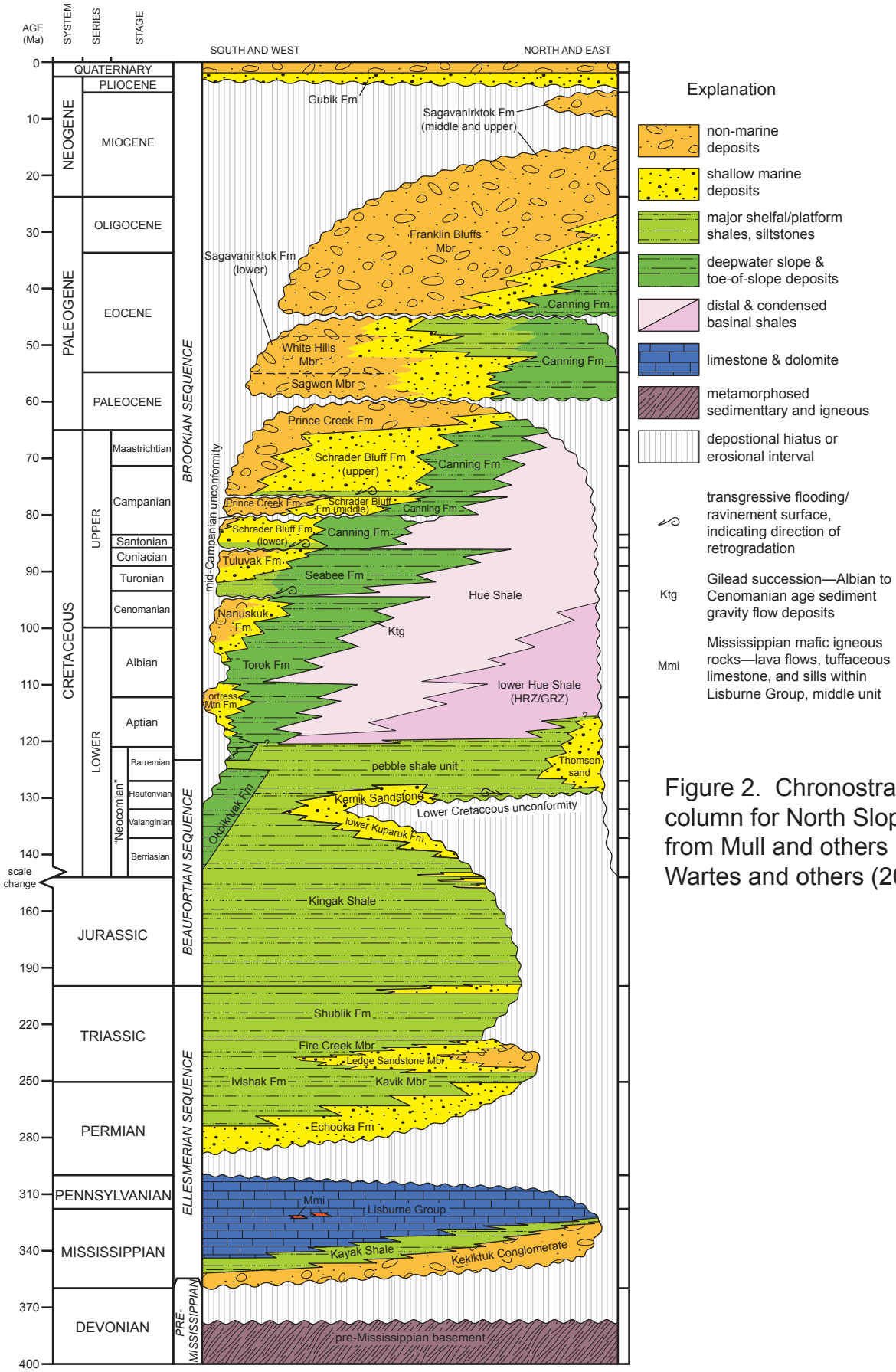
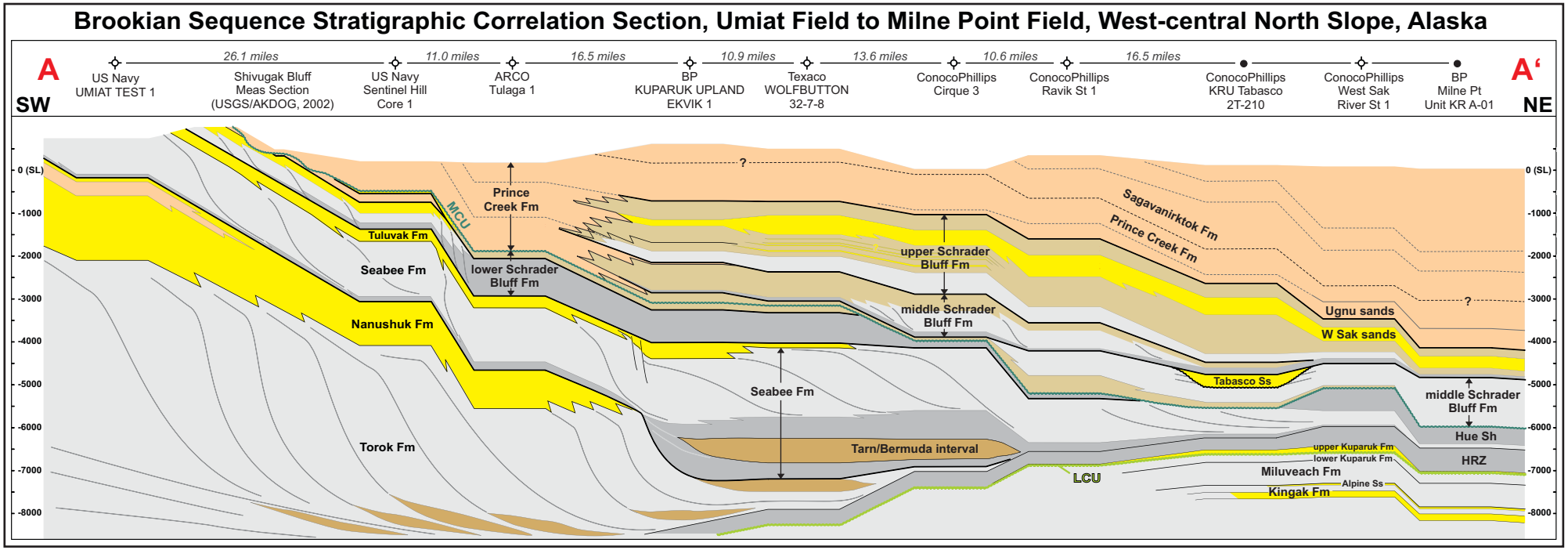
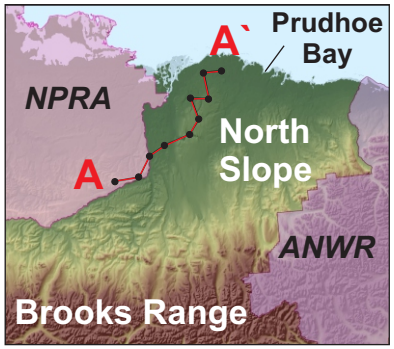


Figure 2. Chronostratigraphic column for North Slope, modified from Mull and others (2003) and Wartes and others (2011).





- nonmarine undifferentiated
- shallow marine to proximal shelf ss.
- distal shelf ss. to sltst.
- toe-of-slope turbidites (sand-prone)
- shelf to slope mudst. to sltst.
- condensed or bentonitic sh.

Figure 3. Brookian sequence stratigraphic cross section, west-central North Slope. This figure is dramatically simplified for page-size display; see Decker (2007) for detailed version which includes annotations, well log curves, facies interpretations, and additional supporting information.

Brookian deposition. This is evident in the Ivishak, and Echooka River areas (Fig. 1), where we recognize an Aptian(?)-Cenomanian lower unit and a Santonian-Campanian upper unit (Fig. 2; Herriott and others, 2011; Wartes and others, 2011; 2014). These intervals are locally separated by distal sandstone of the Seabee Formation, which is often petroliferous. The condensed record preserved in the Hue Shale represents a high resolution record of fluctuating sediment supply that is consistent with our regional sequence stratigraphic framework (Fig. 3, Sheet 1; Decker, 2007). For example, major transgressive episodes recognized on the shelf are recorded in the deep basin by localized starved tongues of Hue Shale extending up the slope. This phenomenon is best seen at "sagashak creek" where Hue Shale facies interfinger with the base of the Canning Formation (LePain and others, 2008; Fig. 1).

We intend to collect additional detailed stratigraphic data from selected exposures of the Hue Shale identified during prior mapping traverses. Particular attention will be paid to recognizing subtle expressions of significant stratal surfaces; this will be aided by the collection of outcrop gamma ray spectral data, which will be particularly useful in recognizing the highly radioactive lowermost parts of the unit (Molenaar and others, 1987; Carman and Hardwick, 1983). In addition, we intend to extend our analysis of the Hue Shale into the subsurface where the wide range of log character may allow for high resolution sequence stratigraphic correlations. Initial pilot work on the Echooka No. 1 well (Fig. 1) was encouraging, yielding fairly robust ties with outcrop data (Decker and others, in press). Finally, we will collect a large set of bentonite and tuff samples for high resolution U-Pb geochronology. Our prior attempts to date some of these air fall volcanic units has generally been successful and suggests it could be a powerful chronostratigraphic tool to correlate widely spaced outcrops.

The Hue Shale is widely recognized as an important source rock, having generated the light oil in the Tarn-Bermuda reservoir (Figs. 1 and 3; Decker, 2011). It is also being actively pursued as an unconventional shale oil target. We will collect additional samples to better characterize the units potential, focusing on source rock richness (total organic carbon), kerogen typing (S2 and HI), and thermal maturity (vitrinite reflectance). Finally, more complex geochemical extract data (biomarkers, carbon isotopes, etc.) will be acquired from selected samples to improve oil-source rock correlations.

3. Provenance and Sediment Routing of the mid-Cretaceous Colville Basin

- *Utilize detrital geochronology and thermochronology to understand regional spatial and temporal variations in the provenance of Nanushuk and Torok formations; build model for exploration fairways based on predicted sandstone composition*

The Colville foreland basin is clearly genetically related to the Brooks Range fold and thrust belt (Mull, 1985; Bird and Molenaar, 1992; Cole et al., 1997). However, it is unclear how much of the Brookian sequence was sourced *directly* from this orogen. Recent provenance work suggests that a substantial volume of the basin fill may be sourced from beyond Alaska, including the Chukotka region of northeastern Russia (Moore et al., 2015). This is supported by regional seismic data on the North Slope that indicate a clear east-northeast progradation of large clinoforms during mid Cretaceous time (e.g. Houseknecht et al., 2009; Houseknecht and Schenk, 2001; Molenaar, 1988). This type of axial dispersal system is common in foreland basins, reflecting the focusing of sedimentation toward the locus of subsidence. However, a transverse contribution to the basin is indicated by regional paleocurrent data from the southern outcrop belt (Huffman et al., 1988). It

remains difficult to ascertain how much sediment is derived from the adjacent thrust belt versus far-travelled detritus.

We seek to resolve the regional patterns in provenance and sediment routing on the North Slope during the mid Cretaceous. These large scale trends are likely to play a significant role in sandstone composition and grain size—key factors influencing the prospectivity of Brookian reservoirs (see related project #1). Previous regional studies have noted spatial variations in sandstone composition, particularly in the Nanushuk Formation. For example, Bartsch-Winkler and Huffman (1988) noted that surface and subsurface samples from the central and east-central North Slope were more quartzose and had less matrix/cement that samples from the western North Slope. In addition the samples from further east recorded a unique lithic grain fraction consisting of more metamorphic rock fragments than those from further west. These observations likely reflect differing bulk provenance feeding the two regions; its possible that the more eastern belt records a higher proportion of sediment derived from the adjacent Brooks Range (Johnsson and Sokol, 2000). This hypothesis builds on suggestions by Molenaar (1985) that the regional net:gross of sandstone in the Nanushuk may reflect the drainage basin geology, with more eastern deltas being supplied by short, sand-laden transverse streams from catchments in the ancestral Brooks Range.

The primary methods we intend to apply in this project are state-of-the-art provenance techniques, such as detrital zircon geochronology. On the North Slope, this technique has already provided important insight into long-standing stratigraphic correlation problems in the Brookian (Wartes, 2008). Interpretations of youngest grain age components are also providing the first absolute age chronology for Nanushuk-Torok shelf-margins (Lease et al, 2014). We will also explore the use of detrital mica $^{40}Ar/^{39}Ar$ thermochronology, which has the potential to record exhumation/cooling ages that are specific to known Brooks Range tectonic events (e.g. Vogl et al., 2002). This method is particularly appropriate for understanding the phyllitic component that appears to be unique to the eastern Torok and Seabee Formations that we've mapped in the Gilead syncline area (Fig. 1). These data will be leveraged with our growing database of standard sedimentary petrography (Helmold, 2010) and chemostratigraphic data (Wright et al. 2011). This provenance information will also be placed in the context of our ongoing stratigraphic studies, including paleocurrent measurements that constrain sediment routing. Ultimately, we aim to build a consistent model for how the composition of Brookian sandstone varies in time and space, allowing for an improved ability to predict where fairways of viable reservoir quality sandstone may be discovered.

4. Paleogene Basin Evolution and Petroleum System

- *Investigate surface and subsurface sequence stratigraphy of Paleogene rcoks; integrate new exhumation data to develop a model of basin evolution, including predicting when sandstone is exported into the deepwater Canning Formation*

A number of independent lines of evidence indicate major episodes of widespread Paleogene exhumation and erosion in northern Alaska, ranging from fission track thermochronology (O'Sullivan and others, 1997), to sonic-porosity log calculations (Burns and others, 2007), and basin filling patterns (Wartes and others, 2011b). These major events are generally regarded as phases of renewed contraction and uplift within the orogenic wedge (Moore and others, 2004; Wallace, 2009). However, recent evaluation and modeling of fission track data from our Sagavanirktok River map area (Fig. 1) indicates that in some areas a significant amount of the recorded cooling cannot be accounted for by tectonic uplift due to structural thickening (Gillis and

others, 2014). Although an alternate mechanism to drive this uplift is unclear, it may prove to be a widespread phenomenon on the North Slope, as evidenced by other recent data from NPRA, which also record uplift well beyond the limit of deformation (Houseknecht and others, 2011). We propose to collect and analyze additional low temperature apatite fission track samples from outcrop and well cuttings to further refine the timing and magnitude of Paleogene exhumation. It seems likely that this major event significantly influenced the region's thermal and fracture history, thus impacting the Cenozoic evolution of the North Slope petroleum system.

Our surface and subsurface stratigraphic studies on the eastern North Slope have provided new insight on Paleocene depositional systems and sequence stratigraphy. At Sagwon Bluffs, near the Dalton Highway, a significant unconformity separates the Maastrichtian to Paleocene Prince Creek Formation from the Paleocene Sagwon Member of the Sagavanirktok Formation (Mull and others, 2003; Figs. 1 and 2). Abrupt changes across this intra-Paleocene surface include 1) increase in grain size, 2) sandstone and clast composition, and 3) reduced sinuosity of fluvial systems (Wartes and others 2011b). These observations are interpreted to reflect increased gradient and sediment supply across the foreland, likely in response to the enigmatic Paleocene uplift noted above.

Our geologic mapping farther east indicates this subaerial unconformity can be correlated basinward. Seismic and well data suggest the correlative Paleocene shelf margin was incised and deeply eroded during a major base level fall, resulting in a regional downward stepping trajectory of toplap surfaces (Decker, 2010; Sheet 1). This surface can be traced into deep-water strata, where significant submarine scouring is evident (Houseknecht and Schenk, 1999). Wells drilled beyond this shelf margin typically exhibit a sharp dislocation in log motif, indicating an abrupt influx of sandstone in slope and basinal facies of the Canning Formation (Wartes et al., 2014; Sheet 1). Several oil-charged slope-channel and slope-apron turbidite systems have been discovered in association with this lowstand systems tract (Badami and Flaxman A-1 pools).

We propose to follow-up on previous reconnaissance-level stratigraphic observations of Paleocene rocks and measure detailed sections to help elucidate the sequence stratigraphic expression of the proposed drop in relative sea level. In particular, we will study a probable down-dip example of this major sequence boundary along the Kadleroshilik River and deeper water examples from the Canning Formation exposed along Juniper Creek and the Canning River (Fig. 1).

5. Tectonic and Stratigraphic Basin Reorganization at the Beaufortian – Brookian Transition

- *Measure detailed stratigraphic sections that span the Early Cretaceous change from rift- to foreland-related subsidence; assess the regional influence of tectonic setting on petroleum systems*

The Early Cretaceous evolution of the North Slope includes an unusual juxtaposition of tectonic settings with the coeval development of the Colville flexural foreland basin and the rift-related opening of the Arctic Ocean basin (Hubbard et al, 1987). These tectonic modes are widely recognized as drivers for the Brookian and Beaufortian sequences, respectively (Moore and others, 1994; Fig. 2). Despite this framework, the nature of the transition remains poorly understood, especially outside of the well-characterized producing areas. Given the time-transgressive nature of much of the stratigraphy, it is possible that the change in polarity of the basin may occur at different times, in different places. Furthermore, it is possible that the tectonic settings are interfering with one another, such as through forebulge enhancement of the composite barrow arch (e.g. Coakley

and Watts, 1991). The Cenozoic exhumation of the northeastern Brooks Range provides a unique opportunity to examine the Beaufortian-Brookian transition in many widely spaced outcrops. Our previous mapping traverses identified a number of key exposures that will be re-visited in order to collect additional detailed sedimentologic and stratigraphic data.

The Hauterivian Kemik Sandstone, equivalent to the prolific Kuparuk "C" sandstone in the subsurface (Carman and Hardwick, 1983), will be examined in detail. We will acquire additional measured sections and compile data on the variability of lithofacies and trace fossil assemblages to better reconstruct the broader depositional system. Previous mapping demonstrated that distinct facies belts are difficult to correlate to one another, in part due to Tertiary thrusting which telescoped this shelf (Wartes et al., 2011a; Wallace et al., 2014). Our reconnaissance observations have raised the possibility that some of the facies belts may have been controlled by Hauterivian extensional faults, some or most of which were inverted by Brookian compression. Neocomian normal faulting is a well-established depositional control on the Barrow Arch, but the southern extent of this tectonic style is not known. Alternatively, irregular paleotopography, such as incised valleys inherited from the LCU may have controlled accommodation and the spectrum of net sand-to-gross interval observed across the Kemik outcrop belt.

The organic-rich pebble shale unit overlies the Kemik and our recent work has notably increased our understanding of this transgressive assemblage (van der Kolk et al, 2015). We located several thin bentonites within rare exposures of the pebble shale; precise geochronology of these airfall units would provide much needed control of the age of the Beaufortian-Brookian transition. Past work by DGGS also identified other units that are tentatively considered correlative to the pebble shale, but lie further south and offer the opportunity to assess the potential time-transgressive nature of the switch to Brookian deposition. These exposures include the phosphatic manganiferous shale in the Cobblestone Creek area of the inner Brooks Range foothills (Mull et al., 2009; Wartes and Decker, 2008; Fig. 1) and possible analogues in the eastern Brooks Range at Bathtub Ridge (Detterman et al, 1975; Camber and Mull, 1986; Fig. 1). These units are only known from reconnaissance stratigraphic and mapping work, yet warrant detailed sedimentologic and stratigraphic examination.

We've recognized exposures of the basal Brookian at a number of localities, particularly along the Ivishak and Echooka Rivers (Decker et al., 2008; Fig. 1), and at Gilead syncline (Reifenstuhl, 1991; Herriott et al., 2011; Fig. 1). Further east, Wartes and others (2011a) applied the name Juniper sandstone to an enigmatic belt of probable correlative deep-water strata in the Kavik River area (Fig. 1). Finally, several key exposures are reported from ANWR, including the Arctic Creek unit (Mull and Decker, 1993; Fig. 1) and the Bathtub Graywacke (Detterman et al., 1975; Fig. 1). Our primary goal at these exposures is to collect detailed measured sections and associated data to improve our understanding of their age, depositional setting, facies, and sequence stratigraphic context.

6. Factors Influencing Unconventional Shale Oil Potential of the Shublik Formation

- *Integrate new sedimentary facies data from outcrop and core with geochemistry, mineralogy, pore types, and mechanical properties; develop a sequence stratigraphic model predicting favorable settings for unconventional development*

The presence of multiple widespread, organic rich source rocks on the North Slope has led to the recognition that the region may host commercially viable shale oil systems (Houseknecht and others, 2012, Decker, 2011). However, key aspects of this unconventional play remain poorly constrained in northern Alaska, particularly the mechanical properties of the potential units. The rapid development of shale-hosted hydrocarbons around the world has drawn attention to the important role of brittleness or ductility on the ultimate production of hydrocarbons from the targeted rocks (Slatt, 2011).

The main source rock of interest in northern Alaska is the Upper Triassic Shublik Formation (Fig. 2). This heterogeneous unit includes organic rich mudstone, sooty shale, calcareous sandstone and siltstone, and phosphatic limestone. The Shublik was deposited on a low relief shelf characterized by episodes of nutrient upwelling (Kelly and others, 2007; Parrish and others, 2001). The formation averages approximately 2-3% total organic carbon and is known to have generated the oil that migrated into many of the conventional accumulations on the North Slope (Decker, 2011).

Despite the importance of the Shublik Formation in the North Slope petroleum system, many important aspects of its regional stratigraphy, geochemistry, and thermal maturity remain poorly constrained (see wide range of estimated undiscovered shale oil resources in the recent USGS assessment published by Houseknecht and others (2012)). In collaboration with Michael Whalen at UAF, DGGS has supported investigations of the detailed sedimentology and sequence stratigraphy of the Shublik (see Kelly and others, 2007). Building on this past work, we are currently supporting MS student April Knox in a detailed study of the unconventional reservoir potential of the Shublik Formation. Work to-date has included high resolution outcrop sampling of the most complete sections in ANWR. In addition, the valuable cores from the Merak #1 and Alcor #1 wells drilled by Great Bear Petroleum have been logged and sampled. Ongoing and future work is focusing on thermal maturity, standard petrography, SEM imaging, inorganic and organic geochemistry, and classification of pore types (Knox and Whalen, 2015). This work will improve our understanding of microfacies, bioturbation fabrics, mineralogy, and diagenesis—all aspects that likely contribute to the unit's mechanical behavior and suitability as an unconventional reservoir. To better understand the mechanical properties of the Shublik, a representative suite of samples will be subjected to appropriate laboratory analyses to ascertain parameters such as Young's modulus, Poisson's ratio, compressive and tensile strength, and compressibility. These tests will also provide information on dynamic properties while under stress, including compressional and shear velocities. The stratigraphic, petrologic, and mechanical data will be placed within a sequence stratigraphic context, allowing for the prediction of where favorable facies belts may be found (e.g. Slatt and Abousleiman, 2011).

SECTION II—LOGISTICS / REVIEW MEETINGS / BUDGET / STAFF

BASE CAMP—Pending final logistical arrangements, DGGS will deploy a field party during the latter part of June and early part of July. Most of our team will work daily out of a base camp at either the Kavik River airstrip, or Happy Valley. If we are permitted for work in ANWR, we will likely consider an extended spike camp in order to conserve expensive helicopter round-trips and to limit air traffic within the refuge.

SPONSORS TOUR—DGGS has periodically led a two-day sponsor's tour in the field to share new results and visit key localities. These tours are an excellent forum for discussing North Slope

petroleum geology, and depending upon sponsor interest and available funding, we look forward to the opportunity to host field tours in future seasons.

MEETINGS AND CONFERENCES—DGGS is always seeking forums for the timely release of new data and interpretations. In previous years, we have given a series of presentations at meetings of the Alaska Geological Society and the American Association of Petroleum Geologists, among others. Based on feedback from sponsoring companies we've also instituted occasional two day technical review meetings. These meetings were held in Anchorage in 2007, 2008, and 2010. The Pacific Section AAPG meeting is currently scheduled to be held in Anchorage in the spring of 2017; it is anticipated that DGGS would have a significant presence at this conference. As always please feel free to offer suggestions on how DGGS can best convey new results and successfully stimulate discussion on the petroleum geology of northern Alaska.

BUDGET AND REQUESTED CONTRIBUTIONS—The costs associated with operating a remote field program continue to increase, largely due to expenses associated with helicopter services. The field and analytical budget we propose for the 2016 field season will require funding for field operations and analytical services of approximately $340,000. This request is being submitted to oil and gas companies and Native corporations to solicit participation. We hope that your organization will support our program at the requested level of $40,000, and welcome your input into the planning of the program. If your support cannot be at this level, we will accept participation at a reduced level. If funding is insufficient for the full program as proposed, we will scale back our plans and concentrate on fewer objectives. In past years, DGGS has successfully sought supplementary monies to support North Slope field studies through Capital Improvement Project grants from the State of Alaska and federal grants through the USGS. However, the financial support of sponsoring companies remains vital to the success of our geological work on the North Slope. A detailed summary of the proposed project budget is included in Table 1.

PROJECT STAFF—Although this program is led by principal investigators at DGGS, it remains a multi-agency collaborative effort. As was true in previous years, this program has assembled a team with an excellent cross-section of expertise to address the topics outlined in this proposal. The geologists listed below are expected to participate in various aspects of field, subsurface, or analytical work described in this proposal.

Marwan Wartes (DGGS)—Clastic sedimentology, basin analysis, and tectonics
Trystan Herriott (DGGS)—Clastic sedimentology and stratigraphy
Paul Decker (DOG)—Stratigraphy, structural geology, subsurface, and petroleum geology
David LePain (DGGS)—Clastic sedimentology and sequence stratigraphy
Robert Gillis (DGGS)—Structural geology and thermochronology
Nina Harun (DGGS)—Sedimentology and petrology
Ken Helmold (DOG)—Reservoir quality and basin modeling
Diane Shellenbaum (DOG)—Seismic stratigraphy and data processing
Michael Whalen (UAF)—Carbonate sedimentology, stratigraphy, and geochemistry
April Knox (UAF)—MS student, Shublik Formation project

In addition, we also anticipate informal collaboration with the USGS. State and Federal cooperation has been very successful in previous years' work in northern Alaska, leveraging our collective resources and staff expertise. Many of our proposed topical studies are closely allied with ongoing USGS work associated with their regional petroleum assessments.

Table 1: Proposed budget for DGGS 2016 field and analytical studies in northern Alaska. In addition to industry support, we will continue to aggressively seek other state and federal funding to defray the operational costs listed below.

Budget Category	Unit Cost	Unit	No. Units	Outside Receipts
100 Salaries				
Graduate Student Research Intern	43,000	year	1	43,000
Subtotal				$43,000
200 Field Expenses				
Charter flights (staff and equipment)	6,000	one-way	2	12,000
lodging & meals	250	person/day	100	25,000
Spike camp perdiem	63	person/day	10	630
Bell 206B3 Helicopter (daily + 4 hrs/day)	4,250	day	20	85,000
Helicopter ferry (206B3 between Bethel and North Slope)	2,650	one-way	2	5,300
Helicopter fuel (30 gal/hr x 4 hr/day x 12 days)	10	gallon	2000	20,000
Subtotal				$147,930
300 Analytical Expenses & Contracts (preliminary)				
Thin sections	30	sample	100	3,000
Grain size and point count analysis	350	sample	75	26,250
Porosity and permeability	100	sample	40	4,000
Total organic carbon (TOC)	25	sample	50	1,250
Rock-eval 6	40	sample	50	2,000
Vitrinite reflectance/kerogen typing	160	sample	50	8,000
Extract geochemistry	1,050	sample	5	5,250
Isotopic analysis-oil	730	sample	5	3,650
Major and trace element geochemistry	150	sample	50	7,500
Micropaleo--palynology	250	sample	25	6,250
Micropaleo--foraminifera	200	sample	10	2,000
Megafossil ID	175	sample	10	1,750
U/Pb detrital zircon geochronology	1,100	sample	20	22,000
U/Pb zircon geochronology (tuff/bentonite)	900	sample	15	13,500
Apatite fission track thermochronology	1,000	sample	10	10,000
Ar/Ar detrital mica thermochronology	1,000	sample	12	12,000
Rock mechanics / strength	1,400	sample	5	7,000
Subtotal				$135,400
400 Miscellaneous Supplies & Travel				
Air photos & Topo maps	500	one-time	1	500
Handheld GPS	600	one-time	1	600
Mountain tent	600	one-time	1	600
Miscellaneous field equipment (batteries, sample bags, etc.)	1,250	one-time	1	1,250
Report production, distribution, and computer support	2,500	one-time	1	2,500
Travel to GMC or other core facility	1,500	person	2	3,000
AAPG annual meeting	4,000	person	2	8,000
Subtotal				$16,450
Project Total				**$342,780**

SECTION III—RESULTS OF RECENT WORK

We typically publish the results of our work through peer-reviewed DGGS publications or occasionally in appropriate scientific journals. To expedite communication of our interim data and interpretations, we also regularly give presentations at industry and geological conferences. A list of publications stemming from the industry-supported North Slope program in the last ~20 years is attached to this proposal, and can also be found here:
http://www.dggs.alaska.gov/sections/energy/sponsors-proposals.php

A number of products from the North Slope program have been published recently, or will be released soon. The list on the following two pages is subdivided into categories including, 1) geologic maps, 2) topical studies, 3) presentations, and 4) graduate theses:

Geologic Maps

Herriott, T.M., Wartes, M.A., Decker, P.L., Gillis, R.J., Shellenbaum, D.P., Mauel, D.J., and Helmold, K.P., 2015, Geologic map of the Umiat-Gubik area, central North Slope, Alaska - Integration of fieldwork and subsurface data in a region of known oil and gas accumulations (poster): Alaska Division of Geological & Geophysical Surveys, 1 sheet. doi:10.14509/29442

Gillis, R.J., Decker, P.L., Wartes, M.A., Loveland, A.M., and Hubbard, T.D., 2014, Geologic map of the south-central Sagavanirktok Quadrangle, North Slope, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigation 2014-4, 24 p., 2 sheets, scale 1:63,360. doi:10.14509/29138

Wartes, M.A., and Weakland, J.R., 2012, Geologic basins and energy resources of Alaska: Alaska Division of Geological & Geophysical Surveys Miscellaneous Publication 146, 1 sheet, scale 1:3,700,000. doi:10.14509/24064

Wartes, M.A., Wallace, W.K., Loveland, A.M., Gillis, R.J., Decker, P.L., Reifenstuhl, R.R., Delaney, P.R., LePain, D.L., and Carson, E.C., 2011, Geologic map of the Kavik River area, northeastern Brooks Range, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigation 2011-3A, 14 p., 1 sheet, scale 1:63,360. doi:10.14509/22602

Topical Studies

Decker, P.L. and LePain, D.L., *in review*, Subsurface relationships of Albian-Cenomanian shallow marine to nonmarine topsets of the Nanushuk Formation, northwestern NPRA: DGGS Report of Investigations 2016-X-1

LePain, D.L. and Decker, P.L, *in review*, Lithofacies analysis of the Wainwright #1 continuous core, western Arctic Slope, Alaska: Transition from lower to upper delta plain environments in the Nanushuk Formation: DGGS Report of Investigations 2016-X-2

Helmold, K.P., *in review*, Sedimentary petrology and reservoir quality of Lower Cretaceous Nanushuk sandstones, USGS Wainwright #1 test well, western North Slope, Alaska, DGGS Report of Investigations 2016-X-3

Decker, P.L., LePain, D.L., Wartes, M.A., Gillis, R.J., Mongrain, J.R., Kirkham, R.A., and Shellenbaum, D.P., *in revision*, Sedimentology, Stratigraphy, and Subsurface Expression of Upper Cretaceous Strata in the Sagavanirktok River Area, east-central North Slope, Alaska: Alaska Division of Geological and Geophysical Surveys Preliminary Interpretive Report 2016-X

Shimer, G.T., Benowitz, J.A., Layer, P.W., McCarthy, P.J., Hanks, C.L., and Wartes, M.A., 2016, $^{40}Ar/^{39}Ar$ ages and geochemical characterization of Cretaceous bentonites in the Nanushuk, Seabee, Tuluvak, and Schrader Bluff formations, North Slope, Alaska: Cretaceous Research, v. 57, p. 325-341.

van der Kolk, D.A., Whalen, M.T., and Wartes, M.A., 2015, Source-rock potential of the Lower Cretaceous Pebble shale unit, northeastern Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2015-1, 37 p. doi:10.14509/29401

Dumoulin, J.A., and Whalen, M.T., 2015, Reconnaissance investigation of the Lisburne Group in the Cobblestone Creek area, Chandler Lake Quadrangle, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2015-2, 18 p. doi:10.14509/29403

Flaig, P.P., and van der Kolk, D.A., 2015, Depositional environments of the Prince Creek Formation along the east side of the Toolik River, Sagavanirktok Quadrangle, North Slope, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2015-4, 17 p., 1 sheet. doi:10.14509/29407

Wallace, W.K., Wartes, M.A., Decker, P.L., Delaney, P.R., Gillis, R.J., Loveland, A.M., and Reifenstuhl, R.R., 2014, Interpretations of seismic reflection data and structural cross sections for the Kavik River map area, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigation 2011-3B, 19 p., 3 sheets. doi:10.14509/25399

Houseknecht, D.W., and Wartes, M.A., 2013, Clinoform Deposition Across a Boundary Between Orogenic Front and Foredeep – an Example from the Lower Cretaceous in Arctic Alaska: Terra Nova, v. 25, p. 206-211.

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Presentations (selected examples)

Herriott, T.M., Wartes, M.A., Decker, P.L., Gillis, R.J., Shellenbaum, D.P., Mauel, D.J., and Helmold, K.P., 2015, Geologic map of the Umiat-Gubik area, central North Slope, Alaska - Integration of fieldwork and subsurface data in a region of known oil and gas accumulations: Geological Society of America, Cordilleran Section Annual Meeting.

Knox, A.R. and Whalen, M.T., 2015, Petrographic and microfacies analysis of the Shublik Formation, northern Alaska: Implications for an Unconventional Resource System: Geological Society of America Cordilleran Section Meeting, v. 47, no. 4, p. 22.

Wartes, M.A., Decker, P.L., Gillis, R.J., Herriott, T.M., and LePain, D.L., 2014, Predicting deep-water reservoirs in the Brookian Sequence: Underexplored plays on the North Slope, Alaska (presentation): Alaska Geological Society Technical Conference, Anchorage, AK, May 15, 2014: Alaska Division of Geological & Geophysical Surveys, 46 p. doi:10.14509/29545

Wartes, M.A., Decker, P.L., Gillis, R.J., Herriott, T.M., and LePain, D.L., 2013, Predicting Deep Water Reservoirs in the Brookian Sequence: Underexplored Plays on the North Slope, Alaska: American Association of Petroleum Geologists 3P Arctic Conference.

Wartes, M.A., 2012, Stratigraphy of Northern Alaska, with an Emphasis on the Cretaceous – Cenozoic Foreland Basin: Alaska Geological Society Fold & Thrust Belt Workshop, Anchorage, AK.

Decker, P.L., 2011, Source-reservoired Oil Resources, Alaskan North Slope: September Luncheon Lecture, Alaska Geological Society, Anchorage, AK.

Wartes, M.A., Decker, P.L., Houseknecht, D.W., Gillis, R.J., and LePain, D.L., 2011, Foreland Basin Response to Paleocene Rejuvenation in the Brooks Range, Northern Alaska: AAPG 3P Polar Petroleum Potential Meeting, Halifax, Nova Scotia, Canada

Recent DGGS-Supported Student Theses Completed

Hutton, E., 2014, Surface to Subsurface Correlation of the Shublik Formation: Implications for Triassic Paleoceanography and Source Rock Accumulation: University of Alaska, Fairbanks MS Thesis.

Wentz, R., 2014, Fracture Characteristics and Distribution in Cretaceous Rocks Near the Umiat Anticline, North Slope of Alaska: University of Alaska, Fairbanks MS Thesis, 171 p.

Sanders, C., 2014, Structure and Kinematics of the Big Bend Anticline Area, Umiat A-4 Quadrangle, Brooks Range Foothills, Alaska: University of Alaska, Fairbanks MS Thesis.

Shimer, G., 2013, Sedimentology and Stratigraphy of the Nanushuk Formation and Related Foreland Basin Deposits, North Slope, Alaska: University of Alaska, Fairbanks Ph.D. Thesis.

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