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Concept Study: Exploration and Production in Environmentally Sensitive Arctic Areas

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Concept Study: Exploration and Production in Environmentally Sensitive Arctic Areas

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P D L

I N E

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Abstract

The Alaska North Slope offers one of the best prospects for increasing U.S. domestic oil and gas production. However, this region faces some of the greatest environmental and logistical challenges to oil and gas production in the world. A number of studies have shown that weather patterns in this region are warming, and the number of days the tundra surface is adequately frozen for tundra travel each year has declined. Operators are not allowed to explore in undeveloped areas until the tundra is sufficiently frozen and adequate snow cover is present. Spring breakup then forces rapid evacuation of the area prior to snowmelt. Using the best available methods, exploration in remote arctic areas can take up to three years to identify a commercial discovery, and then years to build the infrastructure to develop and produce. This makes new exploration costly. It also increases the costs of maintaining field infrastructure, pipeline inspections, and environmental restoration efforts. New technologies are needed, or oil and gas resources may never be developed outside limited exploration stepouts from existing infrastructure.

Industry has identified certain low-impact technologies suitable for operations, and has made improvements to reduce the footprint and impact on the environment. *Additional improvements are needed for exploration and economic field development and end-of-field restoration.* One operator—Anadarko Petroleum Corporation—built a prototype platform for drilling wells in the Arctic that is elevated, modular, and mobile. The system was tested while drilling one of the first hydrate exploration wells in Alaska during 2003–2004. This technology was identified as a potentially enabling technology by the ongoing Joint Industry Program (JIP) Environmentally Friendly Drilling (EFD) program. The EFD is headed by Texas A&M University and the Houston Advanced Research Center (HARC), and is co-funded by the National Energy Technology Laboratory (NETL). The EFD participants believe that the platform concept could have far-reaching applications in the Arctic as a drilling and production platform, as originally intended, and as a possible staging area.

The overall objective of this project was to document various potential applications, locations, and conceptual designs for the inland platform serving oil and gas operations on the Alaska North Slope. The University of Alaska Fairbanks assisted the HARC/TerraPlatforms team with the characterization of potential resource areas, geotechnical conditions associated with continuous permafrost terrain, and the potential end-user evaluation process.

The team discussed the various potential applications with industry, governmental agencies, and environmental organizations. The benefits and concerns associated with industry's use of the technology were identified. In this discussion process, meetings were held with five operating companies (22 people), including asset team leaders, drilling managers, HSE managers, and production and completion managers. Three other operating companies and two service companies were contacted by phone to discuss the project. A questionnaire was distributed and

responses were provided, which will be included in the report. Meetings were also held with State of Alaska Department of Natural Resources officials and U.S. Bureau of Land Management regulators. The companies met with included ConcoPhillips, Chevron, Pioneer Natural Resources, Fairweather E&P, BP America, and the Alaska Oil and Gas Association.

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Acknowledgment

The authors are thankful to the U.S. Department of Energy (USDOE) for their financial assistance in support of the presented work.

Executive Summary

The Alaskan North Slope offers one of the best prospects for increasing U.S. domestic oil and gas production. However, this region faces some of the greatest environmental and logistical challenges to oil and gas production in the world. A number of studies have shown that weather patterns in this region are warming, and the number of days the tundra is frozen each year has decreased. Operators are not allowed to explore in undeveloped onshore areas until the tundra is sufficiently frozen with sufficient snow depth. Spring breakup then forces rapid evacuation from the area due to snowmelt. Using the best available methods, exploration in remote arctic areas can take up to three years to identify a commercial discovery, and then years to build the infrastructure to develop and produce. This makes new exploration expensive, decreasing the number of fields that could be economical. It also increases the costs of maintaining field infrastructure, pipeline inspections, and environmental restoration efforts. New technologies are needed, or oil and gas resources may never be developed outside limited exploration stepouts from existing infrastructure.

In our study, logistics has been identified as the most expensive barrier to oil and gas exploration on the North Slope. Industry has identified certain low-impact technologies suitable for operations, and has made improvements to reduce the footprint and impact on the environment. *Additional improvements are needed for exploration.* One operator—Anadarko Petroleum Corporation—built a prototype platform for drilling wells in the Arctic that is elevated, modular, and mobile (Figure 1 and Figure 2).[1,2] The system was tested while drilling one of the first hydrate exploration wells in Alaska during 2003–2004. This technology was identified as potentially enabling by the ongoing Joint Industry Program (JIP) Environmentally Friendly Drilling (EFD) program headed by Texas A&M University and the Houston Advanced Research Center (HARC), and co-

Figure 1. 2003 Anadarko/DOE/Noble HOT ICE platform.

Figure 2. HOT ICE platform.

[1] U.S. Department of Energy, Office of Fossil Energy, 'Drilling of U.S.'s First Hydrate Well Underway on North Slope Using Anadarko Petroleum's Innovative 'Arctic Platform'," ***DOE Technline***, April 11, 2003.

[2] Kadster, A.G., Millheim, K.K., and Thompson, T.W.: "The Planning and Drilling of Hot Ice #1 – Gas Hydrate Exploration Well in the Alaskan Arctic," SPE/IADC 92764, Presented at the SPE/IADC Drilling Conference, Amsterdam, The Netherlands, 23-25 February 2005.

funded by the National Energy Technology Laboratory (NETL). The EFD participants believe that the platform concept could have far-reaching applications in the Arctic, both as a drilling and production platform, as originally intended, and as a possible staging area.

The platform can be used for **drilling** or alternatively as **a staging area** to reduce the cost of additional ice pads or, in multi-season deployments, the distance for removing equipment during the summer. Additionally, it may help save on the cost of constructing ice roads over small streams or building thick ice pads on sloping terrain. This study will address such applications, including examples in the NPR-A and Arctic Foothills of Alaska—areas that are considered problematic for any kind of human development, with extremely complicated engineering-geologic conditions. These areas, located in the continuous permafrost zone, are characterized by the following

- Wide occurrence of ice-rich soils with massive areas of ground ice located at different depths (thick and tall ice wedges, buried glacial ice).
- Saturated active-layer thickness usually not more than 0.5–0.6 m.
- High vulnerability of tundra terrain.
- Increased slopes and rougher terrain than the Coastal Plain.
- Fast development of permafrost-related hazardous processes (i.e., thermokarst and thermal erosion).
- Long distance from current infrastructure for oil and gas development.

This project complements work conducted by the EFD program and leverages the accomplishments already achieved. HARC has been collaborating with Texas A&M University and TerraPlatforms, LLC (the Project Team) in the JIP research partnership to identify, test, and adapt technologies for exploiting natural gas resources with a reduced environmental footprint. The collaboration is designed to reduce environmental concerns for ecologically sensitive areas currently open for extraction activities. The JIP addresses not only the engineering challenges facing the energy industry but also the considerable environmental concerns facing preserves and protected areas with mineral extraction activities. Funding for the first phase of the EFD program has been obtained from the Department of Energy NETL and from industry, including BP, Shell, Devon, Conoco, Statoil, Chevron, Anadarko, Noble Corporation, National Oilwell Varco, Halliburton, and MI Swaco.

This report documents an investigation of conceptual designs for logistical support of Arctic activities. The purpose was to consider conceptual designs to improve environmental tradeoffs associated with Arctic operations/logistics and to identify what technology gaps exist. A key part of the effort is outreach and technology transfer to the public, government agencies, industry, and academia associated with exploration and production, and environmental protection in the Arctic.

Objectives and Work Scope

The overall objective of this effort was to investigate conceptual designs for logistical support of Arctic activities. Various conceptual designs and applications to improve environmental tradeoffs associated with Arctic operations/logistics were reviewed, and technology gaps were identified. In addition, the effort documents various potential applications, locations, and conceptual designs for the inland platform serving oil and gas operations on the Alaska North Slope. The University of Alaska Fairbanks assisted the HARC/TerraPlatforms team with the characterization of potential resource areas, geotechnical conditions associated with the continuous permafrost terrain, and the potential end-user evaluation process.

The team discussed the various potential applications with industry, governmental agencies, and environmental organizations. The benefits and concerns associated with industry's use of the technology were identified. In this discussion process, we met with five operating companies (22 people), including asset team leaders, drilling managers, HSE managers, and production and completion managers. Following the Draft Report, four other operating companies and three service companies were either visited or contacted by phone to discuss the project. Some comments by industry were not vetted with senior management, and therefore direct quotes are not contained in this report. A questionnaire was distributed, and responses were provided and included in this report. We also met with State of Alaska Department of Natural Resources officials and Federal BLM regulators. The companies with interviews included in this report include the following:

- ConocoPhillips
- Chevron
- Pioneer Natural Resources
- Fairweather E&P
- BP America
- Alaska Oil and Gas Association

In addition, information was obtained from the Ninth International Conference on Permafrost in Fairbanks in July 2008 and from the United States and Canada Northern Oil and Gas Research Forum October 28–30, 2008, in Anchorage.

Study Area

The Alaska North Slope, Prudhoe Bay, Kuparuk, Milne Point, and other fields are developed primarily in the central Coastal Plain. New resource areas that are in the early stages of exploration and development are NPR-A to the west and the Foothills regions to the south and southwest. Additional exploration is occurring southeast of Prudhoe Bay. Access to these new potential resource areas and the exploration activities are dependent on the development of winter transportation networks and working pads. Through discussions with industry, academia, government agencies, and others, it was determined that the cost to construct ice roads for exploration purposes over 20 miles has hindered exploration activities. This report used the cost of 20 miles as a base, although there have been exceptions to this distance. An initial estimate of 50 miles may be used if an inland platform is used to assist in the staging of equipment and in the construction of the transportation corridor. This extended distance is dependent on the staging of inland platforms resulting in shorter transportation networks (either ice or snow roads). A study area was agreed to in order to focus the platform evaluation effort. The research team decided to focus on additional potential reserves that could be reached by having a 50-mile (80.5 kilometer) corridor compared to a 20-mile (32.2 kilometer) corridor. The study area is illustrated in Figure 3. Existing access routes or points were chosen that have been or currently are used by industry as staging areas or mobilization points. Examples include location such as the Dalton Highway, Kavik Camp (east of the Dalton), or Umiat (southeast of NPR-A). From these mobilization points, areas are shown using the 20- and 50-mile-distance objectives. Some staging areas are points with runway access for year-round access, important for early staging and mobilization before the winter operational season.

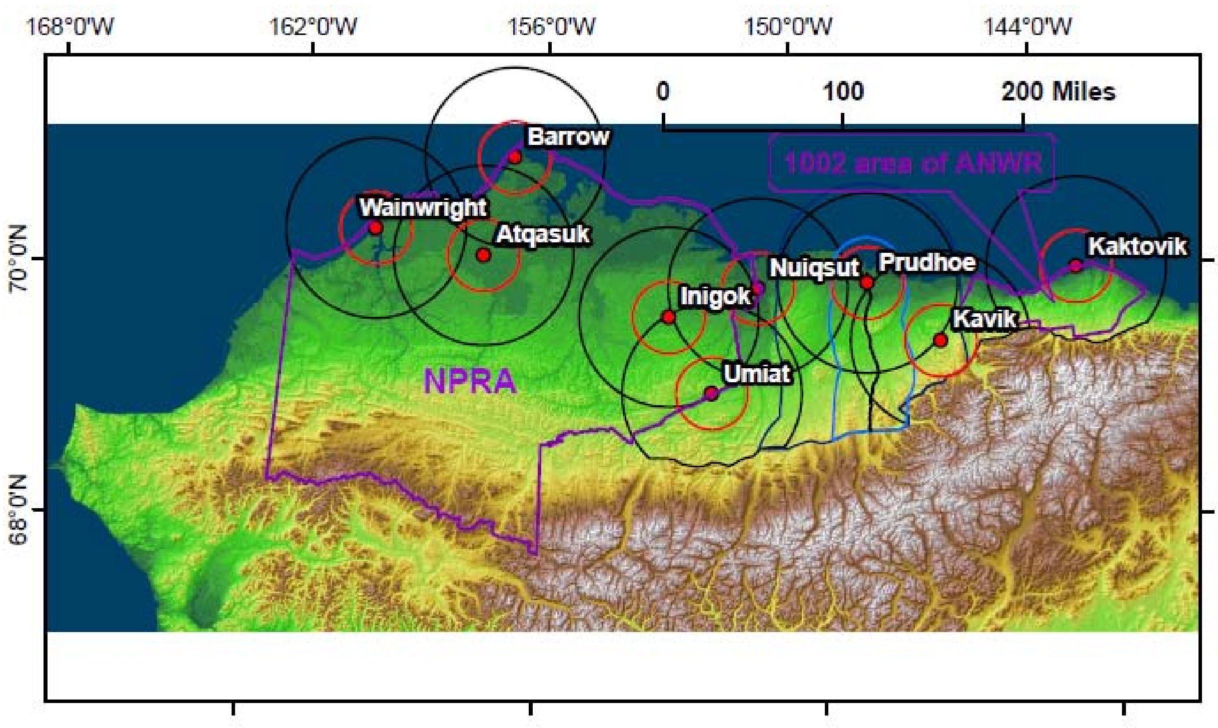

Figure 3. Study area for conceptual design effort. Red (inner) circles have a 20-mile radius. Black (outer) circles have a 50-mile radius. The light and dark blue lines are the respective 20- and 50-mile zones along the Dalton Highway.

Potential Reserves in Study Area

The study area covers three different assessment areas: the National Petroleum Reserve–Alaska (NPR-A), the Central North Slope, and the Arctic National Wildlife Refuge (ANWR). In 2002, the U.S. Geological Survey (USGS) performed a study of NPR-A which complements the 1998 assessment of ANWR, 1002 Area.[3] Figure 4 illustrates the relative sizes of NPR-A and ANWR. ANWR's 2003 Area was evaluated for petroleum potential by the USGS in 1998. The Trans-Alaska Pipeline System (TAPS) and the gather pipelines extending east and west of Prudhoe Bay illustrate the limited extent of existing petroleum infrastructure. Technically recoverable, undiscovered oil beneath the federal part of NPR-A likely ranges between 5.9 and 13.2 billion barrels, with a mean (expected) value of 9.3 billion barrels, as summarized in Table 1.

Figure 4. Map of northern Alaska showing locations and relative sizes of NPR-A and ANWR.

Table 1. Comparison of the 1998 ANWR and 2002 NPRA USGS Assessments. Volumes are technically recoverable oil (mean – ME; 95% confidence limit - F_{95}; 5% confidence limit – F_{05})

	Oil, billions of barrels			Size of area
ENTIRE AREA[1]	F_{95}	Me	F_{05}	(Million acres)
ANWR 1002 Area	5.7	10.4	16.0	1.9
NPRA	6.7	10.6	15.0	24.2
FEDERAL AREA				
ANWR 1002 Area	4.3	7.7	11.8	1.5
NPRA	5.9	9.3	13.2	22.5

[1] Includes Federal and Native lands and State offshore areas.

The USGS assessed the undiscovered oil and gas resources of the central part of the Alaska North Slope (mainly state lands) and the adjacent offshore area. The USGS estimates that there are undiscovered, technically recoverable mean resources of 4.0 billion barrels of oil, 37.5 trillion cubic feet (tcf) of natural gas, and 478 million barrels of natural gas liquids. Figure 5 illustrates the area that the USGS assessed.

In July 2008, the USGS completed an assessment of undiscovered conventional oil and gas resources in all areas north of the Arctic Circle.[4] They estimated the potential of undiscovered oil

[3] USGS: "U.S. Geological Survey 2002 Petroleum Resource Assessment of the National Petroleum Reserve in Alaska (NPRA)," USGS Fact Sheet 045-02, 2002.
[4] USGS: "Circum-Arctic Resource Appraisal: Estimates of Undiscovered Oil and Gas North of the Arctic Circle," USGS Fact Sheet 2008-3049, 2008.

and gas in 33 geologic provinces. The sum of the mean estimates for each province indicated that 90 billion barrels of oil, 1,669 tcf of natural gas, and 44 billion barrels of natural gas liquids may exist in the Arctic, of which approximately 84% is expected to occur in offshore areas. The results are summarized in Table 2.

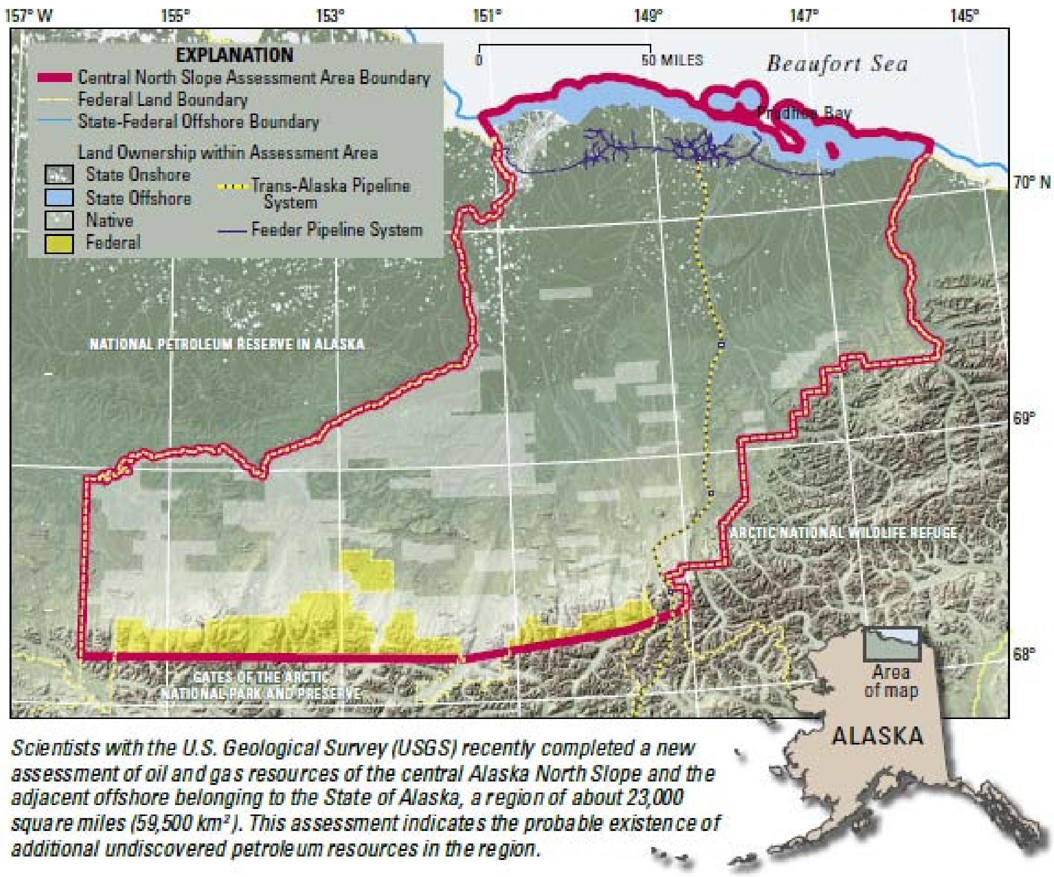

Figure 5. USGS central Alaska North Slope assessment area.

Table 2. Summary of the results of the USGS resource appraisal above the Arctic Circle

[MMBO, million barrels of oil; BCFG, billion cubic feet of natural gas; MMBNGL, million barrels of natural gas liquids; NQA, not quantitatively assessed. Results shown are fully risked mean estimates. For gas accumulations, all liquids are included as NGL (natural gas liquids). Provinces are listed in ranked order of total barrels of oil and oil-equivalent natural gas (BOE).]

Province Code	Province	Oil (MMBO)	Total Gas (BCFG)	NGL (MMBNGL)	BOE (MMBOE)
WSB	West Siberian Basin	3,659.88	651,498.56	20,328.69	132,571.66
AA	Arctic Alaska	29,960.94	221,397.60	5,904.97	72,765.52
EBB	East Barents Basin	7,406.49	317,557.97	1,422.28	61,755.10
EGR	East Greenland Rift Basins	8,902.13	86,180.06	8,121.57	31,387.04
YK	Yenisey-Khatanga Basin	5,583.74	99,964.26	2,675.15	24,919.61
AM	Amerasia Basin	9,723.58	56,891.21	541.69	19,747.14
WGEC	West Greenland-East Canada	7,274.40	51,818.16	1,152.59	17,063.35
LSS	Laptev Sea Shelf	3,115.57	32,562.84	867.16	9,409.87
NM	Norwegian Margin	1,437.29	32,281.01	504.73	7,322.19
BP	Barents Platform	2,055.51	26,218.67	278.71	6,704.00
EB	Eurasia Basin	1,342.15	19,475.43	520.26	5,108.31
NKB	North Kara Basins and Platforms	1,807.26	14,973.58	390.22	4,693.07
TPB	Timan-Pechora Basin	1,667.21	9,062.59	202.80	3,380.44
NGS	North Greenland Sheared Margin	1,349.80	10,207.24	273.09	3,324.09
LM	Lomonosov-Makarov	1,106.78	7,156.25	191.55	2,491.04
SB	Sverdrup Basin	851.11	8,596.36	191.20	2,475.04
LA	Lena-Anabar Basin	1,912.89	2,106.75	56.41	2,320.43
NCWF	North Chukchi-Wrangel Foreland Basin	85.99	6,065.76	106.57	1,203.52
VLK	Vilkitskii Basin	98.03	5,741.87	101.63	1,156.63
NWLS	Northwest Laptev Sea Shelf	172.24	4,488.12	119.63	1,039.90
LV	Lena-Vilyui Basin	376.86	1,335.20	35.66	635.06
ZB	Zyryanka Basin	47.82	1,505.99	40.14	338.95
ESS	East Siberian Sea Basin	19.73	618.83	10.91	133.78
HB	Hope Basin	2.47	648.17	11.37	121.87
NWC	Northwest Canada Interior Basins	23.34	305.34	15.24	89.47
MZB	Mezen' Basin	NQA	NQA	NQA	NQA
NZAA	Novaya Zemlya Basins and Admiralty Arch	NQA	NQA	NQA	NQA
TUN	Tunguska Basin	NQA	NQA	NQA	NQA
CB	Chuckhi Borderland	NQA	NQA	NQA	NQA
YF	Yukon Flats (part of Central Alaska Province)	NQA	NQA	NQA	NQA
LS	Long Strait	NQA	NQA	NQA	NQA
JMM	Jan Mayen Microcontinent	NQA	NQA	NQA	NQA
FS	Franklinian Shelf	NQA	NQA	NQA	NQA
Total		**89,983.21**	**1,668,657.84**	**44,064.24**	**412,157.09**

The average 5%, 50%, and 95% Area of Closure and Trap Depth values for each area of interest are given in Table 3. Each area of interest includes different types of plays, each of which has different 5, 50, 95 probability values. Thus, for each study area of interest, the 5% values for all the play types in that area were averaged, as were the 50% and 95% values. This approach does not take into consideration the likelihood that a particular play type will occur in the area; however, it is sufficient given the overall uncertainty of the area.

Table 3. Average 5, 50, and 95% area of closure and trap depth for each area of interest

average value for oil	Area of Closure* 95%	Area of Closure* 50%	Area of Closure* 5%	Trap Depth** 95%	Trap Depth** 50%	Trap Depth** 5%	Recoverable Oil (mmbo) 95%	Recoverable Oil (mmbo) 50%	Recoverable Oil (mmbo) 5%	Recoverable Gas (bcfg) 95%	Recoverable Gas (bcfg) 50%	Recoverable Gas (bcfg) 5%
Atqasuk--20miles	2.79	5.42	17.17	4.83	7.50	10.17	4.64	50.58	647.95	13.61	139.10	2037.68
Atqasuk--50miles	3.21	6.29	18.29	5.47	8.24	10.76	5.44	58.21	634.03	16.71	158.38	2077.97
Barrow--20 miles	2.83	5.83	15.50	2.67	7.17	9.17	5.62	62.05	361.60	15.78	109.88	583.28
Barrow--50 miles	2.55	5.36	17.09	3.73	6.91	9.73	4.61	54.36	651.73	11.95	121.70	2067.54
Haul Road--20 miles	1.28	3.97	16.84	4.59	7.79	10.77	1.09	23.73	902.32	13.36	172.54	3862.89
Haul Road--50 miles	1.35	3.98	15.83	5.46	8.63	11.60	146.25	387.18	1523.24	13.36	172.54	3862.89
Inigok--20 miles	2.96	5.92	17.75	5.25	7.83	10.33	4.54	52.38	655.68	13.48	147.30	2075.75
Inigok--50 miles	2.54	5.36	19.04	4.63	7.50	10.21	3.65	41.43	883.01	15.12	152.75	2783.14
Kaktovik--20 miles	21.43	33.14	54.86	9.64	10.57	14.93	1452.62	1715.83	3454.28	NA	NA	NA
Kaktovik--50 miles	12.58	20.73	38.00	8.29	10.38	14.02	726.91	1024.21	2235.54	14.85	166.54	3314.90
Kavik--20 miles	1.58	4.27	16.60	5.25	8.67	12.00	243.09	654.03	1850.43	13.52	165.92	3443.73
Kavik--50 miles	1.78	4.92	17.15	5.74	8.93	12.32	153.90	420.27	1544.89	13.27	180.33	4236.39
Nuiqsut--20 miles	1.99	4.23	12.27	5.26	8.29	10.36	2.82	34.14	307.22	12.28	111.59	1314.37
Nuiqsut--50 miles	2.15	4.82	15.96	5.09	7.73	10.29	3.00	37.52	641.52	13.58	142.84	2218.17
Prudhoe--20 miles	1.19	3.63	15.67	2.152	4.82	15.96	1.08	22.79	741.05	14.08	156.36	3113.16
Prudhoe--50 miles	1.31	3.68	16.76	5.04	8.14	10.99	1.12	23.16	915.32	13.76	169.57	3878.84
Umiat--20 miles	2.59	5.53	21.47	3.66	6.94	10.38	2.96	32.76	1123.68	14.55	147.08	3154.68
Umiat--50 miles	2.46	5.52	19.92	4.27	7.38	10.38	3.33	41.01	914.00	15.12	160.84	3014.19
Wainwright--20 miles	2.91	5.73	17.82	4.55	7.27	10.09	4.85	53.29	659.98	13.81	142.44	2020.04
Wainwright--50 miles	3.00	6.23	18.15	4.69	7.54	10.08	4.81	57.25	630.21	13.46	145.16	1948.86

*Area of closure in 1000's of acres
**Trap Depth in 1000's of feet

Study Area Environmental and Geotechnical Information

Oil and gas activities in the Arctic require environmental and geotechnical considerations because of the sensitive nature of the surface tundra and underlying permafrost. The tundra surface grades from the fragile surface vegetation, to underlying peat layers of varying thickness, to mineral soils. The active layer (freezes and thaws seasonally) directly overlies continuous permafrost (frozen more than 2 years) that may extend down 2,000 ft, creating an impermeable layer of frozen earth. Since moisture cannot penetrate the permafrost, almost the entire North Slope is a wetland, which consists of ponds, lakes, and vegetation during the summer, but is frozen and snow-covered the rest of the year. An overview of the permafrost, ground ice, and thermokarst characteristics of Alaska are given in Figure 6, Figure 7, and Figure 8, respectively. [5]

[5] Jorgenson, T., Yoshikawa, K., Kanevskiy, M. and Shur, Y. Institute of Northern Engineering, University of Alaska Fairbanks, 2008.

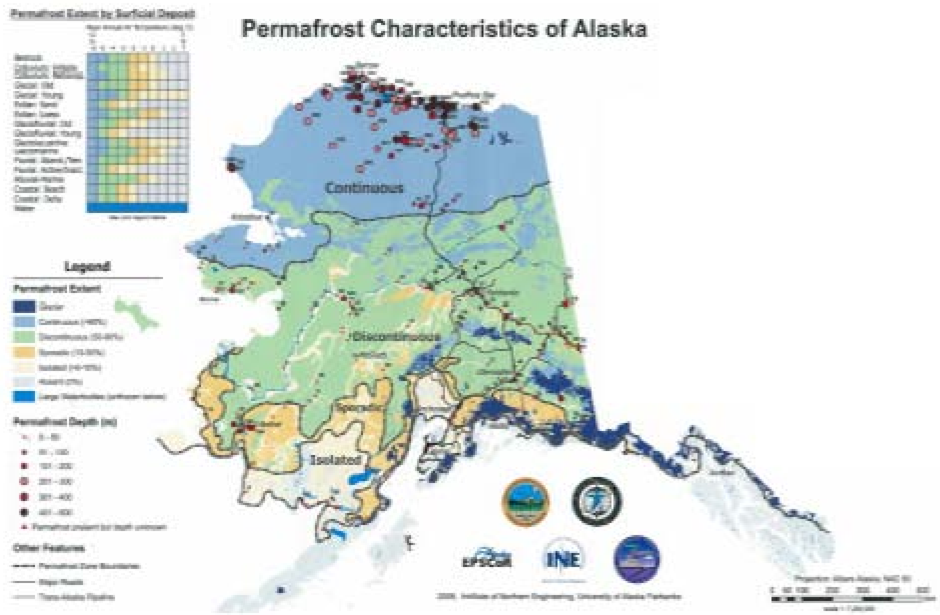

Figure 6. Permafrost characteristics of Alaska.

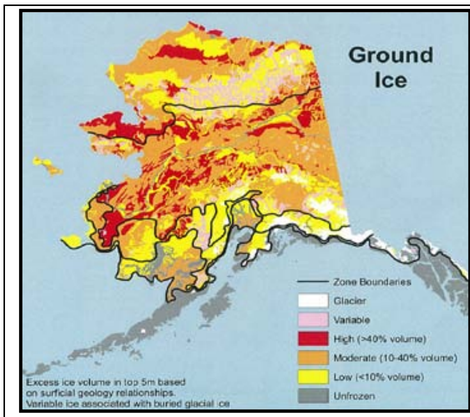

Figure 7. Ground ice across Alaska.

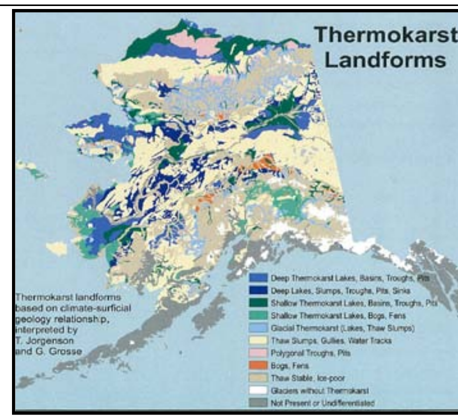

Figure 8. Thermokarst landforms across Alaska.

The UAF/HARC team met at the Ninth International Conference on Permafrost (NICOP) to discuss the inland platform and the environmental and geotechnical characteristics associated with potential applications (Figure 9 and Figure 10).

Figure 9. Tom Williams, TerraPlatforms, greets Brent Sheets, U.S. Department of Energy, at NICOP.

Figure 10. Tom Williams, TerraPlatforms, discusses platform and ground characteristics with Yuri Shur, UAF.

The application of the inland platform may help provide protection to the sensitive tundra surface, as well as help extend the winter operational season. The time window for tundra travel has tended to decrease over time—from about 200 days in the early 1970s to 100 to 120 days today.[6] The Arctic Coastal Plain and Arctic Foothills of Alaska should be considered a problematic area for any kind of human activity, because of extremely complicated environmental and geotechnical conditions. This area, located in the continuous permafrost zone, is characterized by the following conditions:

1. Wide occurrence of ice-rich soils with massive areas of ground ice located at different depths (large ice wedges, buried glacial ice, pingo ice cores).
2. Thin saturated active layer (usually not more than 0.5–0.6 m).
3. High vulnerability of tundra terrain.
4. Fast development of permafrost-related hazardous processes (thermokarsts, thermal erosion, slope processes).

In the study area, Quaternary sediments contain great amounts of ground ice of different types (Black 1983, Carter 1988, Ferrians 1988, Jorgenson et al. 2003, Lawson 1983, Leffingwell 1919, Pullman et al. 2007, Sellmann and Brown 1973, Shur and Jorgenson 1998). Ground ice occurs in two main forms: (1) massive ground ice (large ice wedges, pingo ice cores, buried glacial ice) and (2) porous and segregated ice, forming soil cryostructures.

At some locations of the Arctic Foothills, the thickness of so-called **syngenetic permafrost** with huge ice wedges can reach 30–40 m. The volume of wedge ice in such sediments frequently exceeds 50–60%. In the Arctic Coastal Plain, sediments are also ice-rich, though the occurrence

[6] Godec, M.L. and Johnson, N.: "Quantifying Environmental Benefits of Improved Oil and Gas Exploration and Production Technology," SPE 94388. Presented at the 2005 SPE/EPA/DOE Exploration and Production Environmental Conference, Galveston, TX, 7 – 9 March 2005.

of ice wedges is limited to the top 3–5 m of permafrost. Surface disturbances, such as vegetation destruction due to construction works or vehicle movement, usually result in increasing the active-layer thickness. With massive ice bodies located close to the surface, active layer increases (greater thawing) can trigger development of thermokarsts or thermal erosion. Impacts of these processes on the Arctic environment and engineering designs should be closely considered.

There were four main tasks associated with characterizing the geotechnical information. These included

1. accumulation of basic geotechnical information;
2. assessment of content and distribution of ground ice at the study area;
3. delineation of areas with ice-rich permafrost; and
4. evaluation of potential permafrost-related hazards.

Accumulation of Basic Geotechnical Information (Task 1)

The general geotechnical information for the study area is presented in engineering-geologic maps of northern Alaska, compiled by the U.S. Geological Survey:

- Carter, L.D. 1983. *Engineering-geologic maps of northern Alaska, Teshakpuk quadrangle.* U.S. Geological Survey; Open File Rep. 83-634.
- Carter, L.D., Ferrians, O.J., and Galloway, J.P. 1986. *Engineering-geologic maps of northern Alaska, coastal plain and foothills of the Arctic National Wildlife Refuge.* U.S. Geological Survey; Open File Rep. 86-334. 2 sheets.
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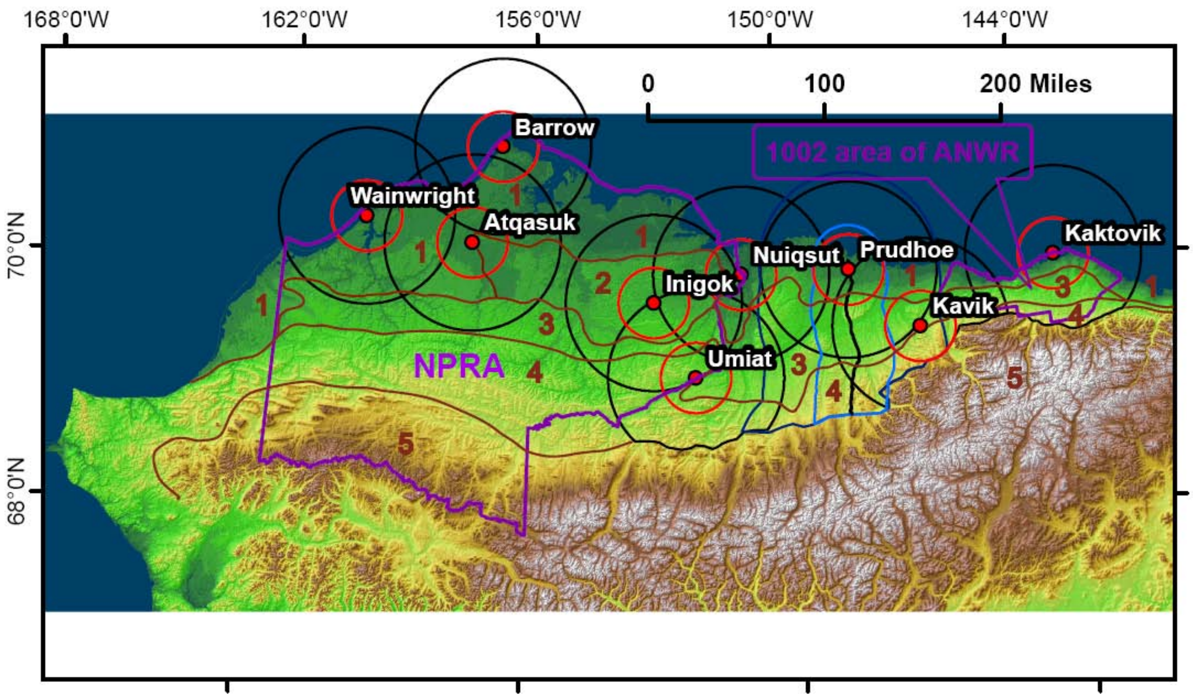
Additional information on permafrost conditions, permafrost-related hazards, and properties of frozen soils for the study area can be found in numerous publications (see the list of references).

Permafrost Conditions

Figure 11 presents a schematic map of permafrost conditions. It was compiled on the basis of our field studies on the Alaska North Slope and an analysis of published information cited above. This map was developed in order to create a base for assessment of content and distribution of ground ice in the study areas (**task 2**), delineation of areas with ice-rich permafrost (**task 3**), and evaluation of potential permafrost-related hazards (**task 4**).



No	Name of the region	Permafrost temperature, °C	Thickness of permafrost, m	Massive ground ice	Permafrost-related hazards
1	Arctic Coastal Plain	–7…–11	200-650	Active ice wedges, pingos	Thermokarst, thermal erosion
2	“Sand Sea”	–5…–8	200-350	Pingos, small active ice wedges	Wind erosion, thermokarst, thermal erosion
3	“Silt belt”	–5…–8	200-550	Huge ice wedges, pingos	Thermal erosion, thermokarst, thaw slumping
4	Arctic Foothills	–5…–7	250-550	Ice wedges	Thermal erosion, slope processes, thermokarst
5	Moderately high mountains	–4…–6	100-300	Buried glacial ice, small ice wedges	Slope processes, thermal erosion

Figure 11. Schematic map of northern Alaska permafrost regions and table listing permafrost characteristics.

Region 1. The Arctic Coastal Plain (Wahrhaftig 1965) is formed by marine, glacio-marine, alluvial, lacustrine, and eolian (windblown) sediments of various compositions (silt, sand, clay, gravel). The sediments contain massive ground ice, which occurs in three main forms: (1) ice wedges, (2) pingo ice cores, and (3) thermokarst-cave ice. Within this area, **ice wedges** are the most common type of massive ground ice, and they can be observed nearly everywhere. Occurrence of ice wedges can be easily noticed due to polygonal tundra surface (Figure 12).

Figure 12. Polygonal tundra, Beaufort Sea coast.

Figure 13. Big ice wedges, Beaufort Sea coast, Point McLeod.

Ice wedges were formed mainly during the Holocene, and most are still active. The upper parts of ice wedges are located no deeper than 10–20 cm beneath the permafrost table (Figure 6). The height of an ice wedge usually does not exceed 4–5 m, while its width can reach 3–5 m. The average volume of ice wedges can be estimated to represent approximately 15% to 25% of exposures at the Beaufort Sea coasts (Kanevskiy et al. 2007). However, these values vary between 1–2% and 40–45% in different sections. The highest ice wedge volume can be observed in coastal bluffs more than 5 m high that have formed in glacio-marine deposits between Point McLeod and Cape Halkett (Figure 13). At such sites, the polygonal network at the surface is dense with 5–7 m of space between ice wedges. Relatively big ice wedges can be observed in the bottoms of old thaw-lake basins, abundant in this area. The lowest ice wedge volume is related to low accumulative surfaces such as coastal marshes, river deltas, and recently drained lake basins. These terrains have large ice-wedge polygons (up to 40 m across) and narrow ice wedges, usually less than 0.5 m wide. No wedges are found in the active eolian sand dunes.

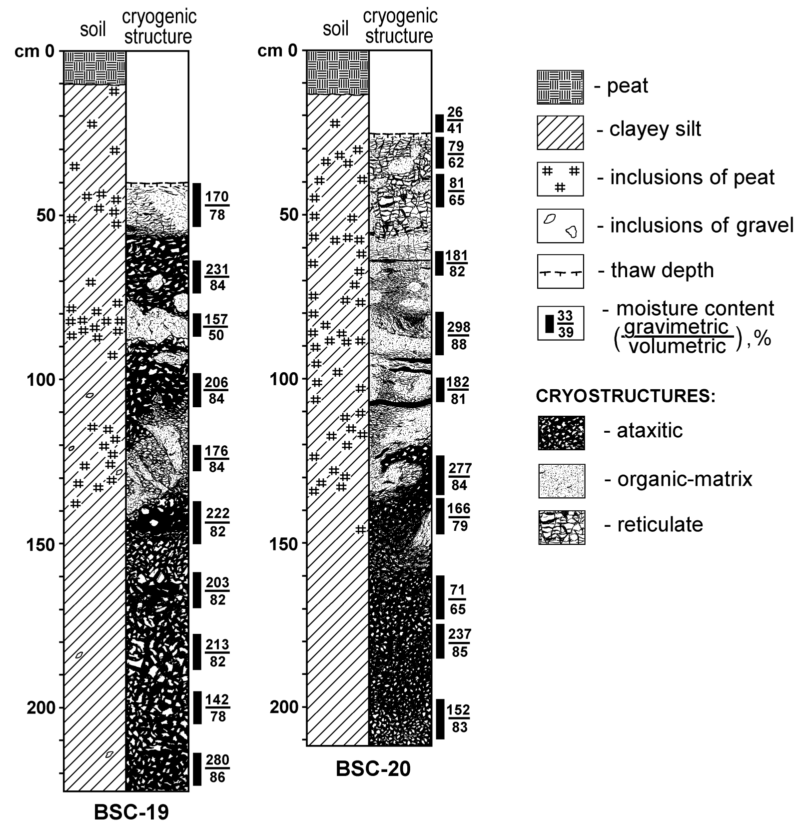


Figure 14. Cryogenic structure of coastal sediments (ice is black), sites #19 and #20, coast of Harrison Bay near Cape Halkett. The height of coastal bluffs is about 2.5 m.

Soils in the Arctic Coastal Plain also contain a lot of segregated ice, forming soil cryostructures (Figure 14). The surface sediments are characterized by a prevalence of the following cryostructures: ataxitic (suspended); reticulate; layered; organic-matrix; porous; and crustal. The ice contents of organic and mineral soils are usually high. The volumetric ice content for sediments with ataxitic cryostructure sometimes reaches 80–95%. Numerous ice lenses and layers up to 10–20 cm thick also can be observed in organic and mineral sediments. Low ice content of sediments is typical for most sands and gravels.

As a result of thawing of ice-rich sediments, numerous thermokarst lakes have formed in this area. Sediments of drained-lake basins also contain a lot of ground ice, which can be reworked by thermokarst processes, resulting in the formation of secondary thaw lakes.

Region 2. "Sand Sea" (Carter 1981) – the area of Arctic Coastal Plain, formed by the Late Pleistocene eolian sands more than 15 m thick. These sediments are relatively ice-poor. At the same time, the majority of more than 1,000 **pingos** with thick ice cores (Figure 15), distinguished in the Arctic Coastal Plain (Carter and Galloway 1979, Ferrians 1988), are located within this area. Pingo formation is connected with injection of water during the freezing of closed taliks (mostly in recently drained lake basins) and occurs only in the areas underlain by thick strata of sands. Relatively small active ice wedges are abundant in this area, especially in the bottoms of numerous drained-lake basins.

Figure 15. Pingo, Prudhoe Bay area.

Region 3. "Silt Belt" (Carter 1988) – the area located along the boundary between the Arctic Coastal Plain and the Arctic Foothills. This region is characterized by the occurrence of thick sequences of ice-rich syngenetic permafrost. Syngenetically frozen sediments are usually characterized by a high content of silt (up to 70–80%); buried organic-rich horizons; high ice content; occurrence of large ice wedges; and a specific set of cryostructures. The width of ice wedges in syngenetic permafrost can reach 3–5 m and even more; wedges often penetrate the whole thickness of silt. Sediments with ice wedges contain a lot of segregated ice as well. At some locations of the "silt belt" of northern Alaska, the thickness of syngenetic permafrost with huge ice wedges can reach 30–40 m. The volume of wedge ice in such sediments frequently exceeds 50–60%. Some of the Late Pleistocene ice wedges are still active. Ice wedges of smaller size are currently developing mainly in floodplains and thaw-lake basins.

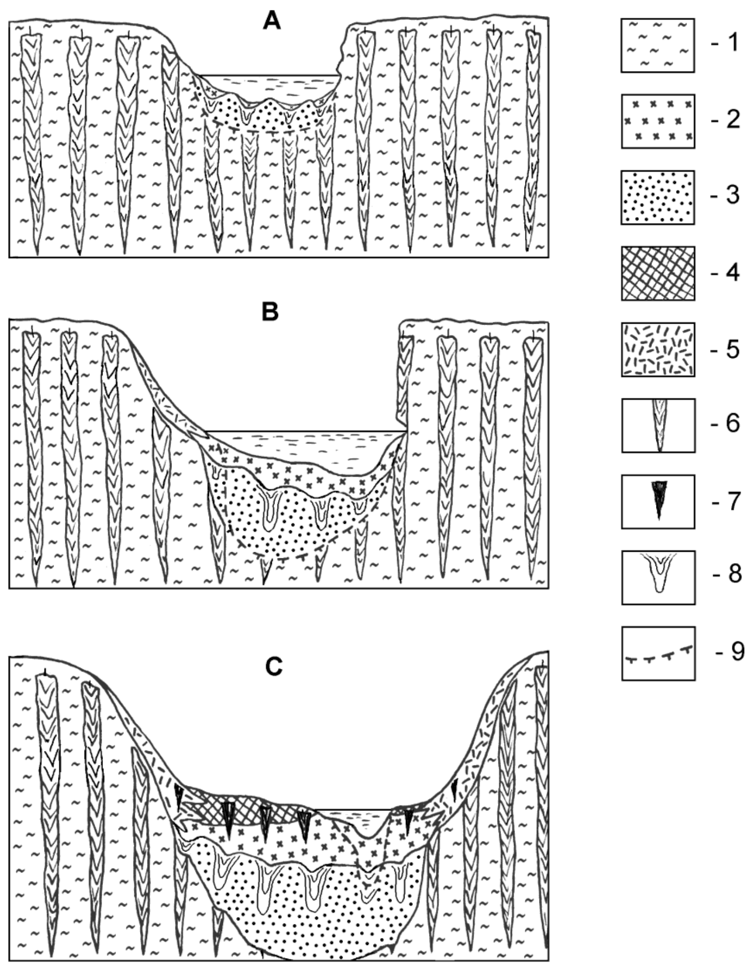


Figure 16. Mechanism of thaw-lake basin formation.

1 – ice-rich silts (Late Pleistocene syngenetic permafrost); 2 – lacustrine sediments; 3 – taberal (thawed and refrozen) sediments; 4 – peat; 5 – slope sediments; 6 – ice wedge (Late Pleistocene); 7 – ice wedge (Holocene); 8 – ice-wedge cast; 9 – thaw bulb; A, B, C – stages of thaw-lake basin formation.

Sections of ice-rich Late Pleistocene syngenetic permafrost within this belt were studied by Livingstone et al. (1958), Williams and Yeend (1979), Lawson (1982, 1983), Carter (1988), Brewer et al. (1993). Cryogenic structures of similar sediments have been studied extensively in Interior Alaska, in the well-known CRREL permafrost tunnel in Fox, located near Fairbanks (Sellmann 1967, Hamilton et al. 1988, Shur et al. 2004, Bray et al. 2006, Kanevskiy et al. 2008). Thawing of these sediments in the study area, which started in the early Holocene, have resulted in formation of large thaw-lake basins up to 20–25 m deep. This process is illustrated in Figure 16.

Region 4. The "Arctic Foothills" (Wahrhaftig 1965) is characterized by relatively thin sediments covering bedrock. However, at some locations (such as river valleys) thicknesses of ice-rich syngenetic sediments can be significant. Figure 17 shows an active thermokarst lake that developed in ice-rich syngenetic permafrost because of thawing ground ice (wedge ice, segregated ice). Holocene and Late Pleistocene ice wedges are abundant in this area. Thermal erosion, slope processes, and thermokarsting are active here. An example of massive ice and thermal erosion is given in Figure 18.

Figure 17. Thermokarst lake, developed in the ice-rich syngenetic permafrost, Arctic Foothills, northern Alaska.

Region 5. Moderately high mountains (Wahrhaftig 1965) – area with exposed bedrock. Ice-rich sediments are localized mostly in gentle slopes and bottoms of valleys. During the Late Pleistocene, this area was glaciated, so the


Figure 18. Massive ice and thermal erosion at the Beaufort Sea coast.

ice wedges are mostly Holocene age; usually they are relatively small. Buried glacial ice and ice-rich glacio-lacustrine sediments also can be found in big glacial valleys (Kreig and Reger 1982, Brown and Kreig 1983). Such processes as solifluction, creep of frozen soils, rock glacier formation, and frost blister formation are active in this area.

There are other impacts to the tundra that may not involve thermokarsting. For example, improper use of vehicles can result in damage to tussock tundra or other vegetation. This may not cause permafrost impacts, but may still produce scars that can last many years. Minimizing off-road travel with the use of environmental platforms could help minimize these potential impacts.

Limitations of Current Technology

Oil and gas operations occasionally create surface disturbance due to construction of drilling sites, campsites, and airstrips; overland transport of equipment and personnel to drilling sites; and gravel mining. Transporting equipment and personnel can cause removal or compaction of tundra, which in turn can cause thawing of permafrost and thermally driven subsidence.

Permanent roads and operational pad infrastructure construction on the Arctic Coastal Plain usually uses gravel and may disturb wetlands and natural drainage patterns, thereby changing fish and wildlife habitat. During project design and permitting processes, measures such as installation of culverts and drainage structures may be taken to minimize impacts. In addition, many areas do not have gravel available, and it must be hauled over long distances, potentially increasing surface disturbances, and making the project uneconomic due to the cost of gravel hauling.

Figure 19. Comparison of inland platform to gravel pad technology.

A comparison of the inland platform to current technology for drilling applications is illustrated in Figure 19. The drillsite (CD3) is located on the Colville Delta and is operated by ConocoPhillips.

Most permanent pads on the Alaska North Slope have been constructed with granular material—gravel and sands—that are hauled in conventional dump trucks on gravel or ice roads. On rare occasions, low-ground-pressure vehicles, that is, Rolligons, are use to haul the material (Figure 20 and Figure 21).

Environmental stipulations restrict most summer construction work on the North Slope. The winter "construction window" must provide for ice road construction, mobilization, well drilling and demobilization. Drilling time is compromised by the length of time it takes to construct ice roads and pads, and by early mobilization and end-of-season demobilization.

Ice Roads and Pads

Because of the absence of permanent gravel roads and the reluctance by regulators and others to allow them to be permitted on the North Slope, ice roads or other environmentally acceptable roads and pads, airstrips, and snow roads are the current technology of choice used for Arctic transportation networks. These winter transportation networks are critical for exploration and development access to sensitive oil and gas exploration areas. Temporary ice roads minimize the need for permanent gravel roads. Industry has been constructing ice roads, pads, and airstrips to reduce potential environmental impacts and restoration costs. One of the primary challenges in maintaining arctic transportation networks and seasonal working pads is the availability of water to build and maintain networks for each winter-operations cycle. Unlike gravel roads, ice roads and pads are rebuilt each winter season. In the past 20 years, there have been three exceptions where ice pads have been kept insulated and used for a second season. There is a limit to how this approach can be maintained for multiple seasons. The cost for construction is approximately $60,000 to $100,000 per mile, and when all environmental studies, permitting, and other associated costs are included, the per-mile cost would be significantly higher. Ice roads can constitute a significant portion of a project's construction budget. It was reported that ice and snow road construction in the Foothills region has been significantly more expensive in the areas where the topography is more uneven.

Figure 20. Close-up of Rolligon low-pressure tires.

Figure 21. Rolligon during platform installation.

The cost to plan, survey, permit, etc. could make the cost per mile significantly higher. The number of river crossings and grade changes also increases the cost. Because of these added costs, permitted ice road routes are usually followed each year, even if a road to another exploration site is longer and more time consuming to build.

Ice roads for exploration purposes that are longer than 25 mi have been constructed but are not typical. When practical or permitted, former military airstrips or ice pad staging areas have been used to decrease the construction distance in multi-year exploration activities. Longer roads are generally built by having midpoint and endpoint ice road construction camps. Staging equipment at these locations during summer months would help start ice road construction the following year at an earlier date. Generally, ice road and pad construction begins during mid to late December when tundra travel is first permitted. There are case-by-case exceptions where efforts are started earlier due to local conditions and additional verification information. The case-by-case examples are difficult to plan for in the budget and logistics planning schedules. It is also important that ambient temperatures are cold enough for relatively fast ice road construction and that river and lake ice is thick enough for crossing and access for winter water use.

Terrain is an important influence in determining ice road construction routes. Ice roads are more hazardous and expensive when made on steep or cross slopes. Routing tends to minimize terrain-slope changes when possible. When building ice roads and pads, the construction process cannot apply cut-and-fill techniques to develop level travel surfaces. Ice road contractors can only “fill” in low areas or side slopes, thus increasing the amount of water needed as well as the time required to build the network.

Ice road transportation networks on the North Slope commonly involve stream and river crossings. The routing of ice road networks takes into account the location of water sources. A segment of the ice road network in the Alpine and northeastern NPR-A oil fields was visited to help evaluate potential new applications of inland platforms and environmental mats to a typical ice road network in this portion of the project study area. A typical ice road is shown in Figure 22.

Figure 22. Ice road in the Alpine field area.

Stream crossings require greater water, ice, and snow volumes to build up the road surface to acceptable design grades, and they increase the time required to build each crossing. These stream crossings can take up the same volume of water as a typical working pad. At the end of the winter operations season, these ice bridges are slotted so they do not dam up water during spring snowmelt flooding. This is an important environmental compliance issue related to early-season fish passage in Arctic streams and rivers. It also helps reduce potential geotechnical erosion and damage to stream areas during snowmelt flooding. Figure 23 shows a stream crossing in the NPR-A during breakup.

Figure 23. Stream crossing during spring breakup.

In areas such as the Kuparuk Foothills, where Chevron built ice roads in the 2007/08 winter season, terrain slopes and limited water supplies resulted in the combined impact of increasing the distances and costs to build the ice road network. The lack of early winter snow cover also reduced the operational time for developing the transportation network, resulting in a decrease in the time available for exploration activities.

Ice Roads –Industry interviews indicated that the construction cost is around $60,000 to $100,000 per mile, with an additional cost of $20,000 to $30,000 per mile for maintenance throughout the drilling season. These costs do not take into account the environmental compliance, permitting, and related costs of the seasonal ice road networks. Snow roads are more commonly used in other arctic regions of the world. Pioneer was able to permit and use a snow road because of a lighter drilling rig and the ability to use temperature sensors in the road to assure regulators that the permafrost was covered and protected. These roads are more expensive (over $100,000 per mile) but are faster to construct, and in areas where there is little or no available water from lakes, it is a viable alternative to using Rolligons. For Pioneer, the snow road was more expensive but allowed them to get to the well location faster and thereby reduced their overall costs. In many areas of the North Slope, there are large shallow lakes, but these lakes are either completely frozen or close to completely frozen by the time (mid to late December) that ice/snow road-construction crews have access to the water sources.

Ice Pads – The typical size of an ice pad for exploration drilling is 500 ft by 500 ft and is typically 1 ft thick. The exploration rigs used in Alaska have typically been large and slow to move. The size has caused operators to construct large ice pads, and in three cases, operators insulated the ice pad to extend drilling to a second season, which becomes time-consuming and expensive. A few new rigs have been constructed that are much smaller, such as the Doyon Akita Arctic Fox 1,000 HP rig being used by Pioneer and FEX, a subsidiary of Talisman, and a similar new arctic Nabors AC modular rig being used by Anadarko and Chevron. These rigs and equipment are still not modular and weigh over a million pounds, although this is nearly three times less weight and half the footprint size as other rigs that have been used on the North Slope. Anadarko is currently utilizing an insulated ice pad for an extended staging area to support their Foothills exploration operations, which is also about 500 ft by 500 ft. This staging area allowed them additional drilling time in 2008 and will increase access time in the next drilling season. An evaluation of the impact of this pad will be conducted in summer 2009.

Exploration in many areas of NPR-A comes with added costs, where it takes up to 2 MM gallons of water per mile to build ice roads. Ice or snow roads over rough terrain require more “fill volume” to be level and meet safety and environmental compliance objectives. These roads are expensive and time-consuming to build. The application of ice chips adds costs but can result in faster construction times, resulting in increased drilling and exploration time.

Assessment of Potential Applications

To identify potential applications, information was gathered through the following sources:

- Meetings held in Anchorage, Alaska, with various industry and government personnel.

- Phone calls to operators and regulators who were unable to meet.
- Developing informative web-based information, in conjunction with the Environmentally Friendly Drilling web site.
- Meetings held in Houston, Texas, with various industry personnel.
- Discussions with attendees at the Ninth International Conference on Permafrost held in Fairbanks, Alaska. These included academia, industry, and government personnel.
- Discussions with Canadian regulators, researchers, and industry.
- Meetings held in conjunction with the Interstate Oil and Gas Compact Commission (IOGCC) annual meeting.
- Follow-up telephone calls and other correspondence.

Based on this information-gathering exercise, the list of potential applications for an inland platform includes the following:

- Construction camps
- River and stream crossings for seasonal ice and snow roads
- Staging areas for construction/logistics support
    - Fueling station
    - Camp storage
    - Drilling equipment storage
    - Spill response equipment storage
- Drilling pads
- Long-term production pads
- Camp for scientific work/summer field work/site cleanup work
- Heliport

These are listed in terms of increasing complexity in Table 4.

Table 4. Potential applications of inland platform

Application	Complexity	Comments
Staging area for logistical support	Low	No facilities for personnel or power requirements will keep design simple, and reduced installation time.
Personnel camps (construction camps, scientific work camps)	Medium	Minimum facilities, power requirements. Short durations.
Exploration drilling pads	Medium-High	Short duration – remove platform after drilling. Use lightweight rig. Maintain mounting posts (?) where future drilling is anticipated.
Production drilling – Long-term production pad	High	Will need to ensure monitoring of permafrost/support interactions.
River crossings for temporary roads	High	Need to investigate ice flows and interactions on supports. How to design topsides. Optional low-profile support sections to leave in place during summer season, quick reset in following years.

Temporary ice roads are currently used between camps and project areas. The ice roads are short roads, usually 3–14 mi, but have been built 30 to 120 mi from the Prudhoe Bay infrastructure. Camps may be located 50 to 70 mi from the gravel-road networks.

In 2002, Golden Valley Electric Association used a 62 mi ice road to cross environmentally sensitive muskeg (sub-Arctic peat bog). State and federal permits required 12 in. of frost and 12 in. of snow on the ground before contractors could move equipment across the terrain. Golden Valley obtained permits from the Alaska Department of Natural Resources to draw water for snowmaking from lakes and rivers earlier in the season, at an additional cost of $1.5 million to $2 million.[7]

Arctic drilling seasons are limited, with approximately 150 drilling days available in recent years (Figure 24). First tundra access is mid to late December, and all activities are normally stopped by May 1. This time has to account for logistical support services that include mobilization and demobilization, which take about 30 days each. The seasonal length for an ice road may be greater if case-by-case opening dates are worked out in specific areas of the North Slope. Addressing these case-by-case issues can involve work not included in project budgets and is subject to variability in early winter weather. A typical operational cycle is shown in Table 5.

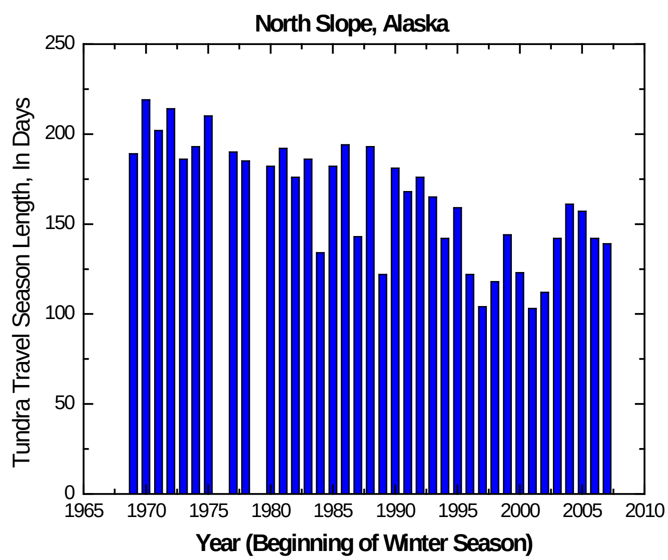


Figure 24. Length of tundra travel opening days for each winter season, show for year of beginning of winter season.

[7] Daniels, S.: "Alaska Contractors Make Ice Road," ***Engineering News – Record***, Vol. 248 Issue 2, p19, 1/21/2002.

Table 5. Winter season operational cycles

Operational Phase	Cost Issues
Tundra-travel opening	Lack of opening forecast tools
Ice/snow road construction starts	Snow/water availability
Mobilization begins	Increased costs if too early or too late
Ice/Road opens	Weather delays, too extreme, too warm
Operational season starts	- -
Demobilization	If too early, lost drilling time, if too late greater risk
Ice/Snow road closedown	Slot stream/river crossings, remove staking
Tundra-travel closing	Lack of forecast tools
Compliance monitoring, reporting	Tundra studies, lake recharge studies

With drilling times of about 30 days, only one, and rarely two, exploration wells can be drilled per season per rig. Prospects 200 mi from infrastructure may be considered unfeasible due to overall costs, logistics, and time constraints. Drilling and testing of one well could require two drilling seasons using today’s technology.[8] Completion of a typical exploration cycle may take three winter seasons. The exploration “cycle” can vary due to the complexity in geology and reservoir characteristics, successful collection and interpretation of seismic data, changing development of production strategies, and need for additional information.

There are a number of exploration prospects 50 to 200 mi from gravel-road networks. Many resource areas are more than 20 mi from staging points along gravel roads or airfields. The exploration phase may allow the use of airstrips to bring in crews and lightweight equipment. The production phase would require pipelines and other resources that would require overland travel. Building ice roads for these distances is neither cost-effective nor time-effective.[9]

The inland platform may be environmentally preferable as part of the set of tools for developing field-operation pads and camp facilities. The use of the platform may solve the problem of limited sand and gravel materials available to build pads for facilities and camps. There are sites where the inland platform would be applicable, which have no suitable native materials nearby. Hybrid combinations of gravel pads and inland platforms could further reduce the “disturbed” tundra footprint of production operations and camps.

The inland platform may enable expanded drilling, completion, and testing, and may enable earlier production to occur. In addition, its use may reduce the risk associated with planning

[8] Safer, R.S.: “Step Change in Remote Exploration,” SPE/IADC 105051. Presented at the 2007 SPE/IADC Drilling Conference, Amsterdam, The Netherlands, 20-22 February 2007.
[9] Shafer, R.S.: “Step Change in Remote Exploration,” SPE/IADC 105051, presented at the SPE/IADC Drilling Conference, Amsterdam, The Netherlands, February 20-22, 2007.

operations. The main barrier envisioned with respect to the potential application of an inland platform is the cost. Other concerns about the platform are related to its durability and longevity. FEX, the Alaska subsidiary of Calgary-based Talisman Energy, supports ideas for state or federal staging locations in remote areas, to enable equipment to be stored close to exploration areas during the summer.[10]

Platform Conceptual Design Basis

The inland platform appears to have several potential applications in the Arctic. For long-term applications, a thermo-pile system similar to that used on the Trans-Alaska Pipeline System (TAPS) may be applicable (Figure 25).

Figure 25. TAPS. Some TAPS technology may be used for the platform design.

The concept of an inland platform to minimize the footprint and environmental impact of a drilling operation has been demonstrated.[11] The platform may be used as a temporary or permanent drilling and production site in ecologically sensitive areas. The modular platform is also suitable as a production platform or pipeline facility in areas without road access. The platform is an effective way of extending operating windows in ecologically fragile areas.

Some of the key design goals for the inland platform include the following:[11]

Modularity: The modular sections of the platform may be fitted together in the field like a Lego™ toy set. The components consist of legs, lower sections shaped similar to "buckets" with isolated leg inserts, and deck sections that fit over the buckets. Additional pieces attach the legs to the buckets and footboards, and there is fencing around the perimeter. The buckets also provide areas for connections and emergency spill containment. This modular approach allows operational flexibility for staging a variety of platforms to meet changing field needs.

The standard size of the bucket is 50 ft long, 12.5 ft wide and 3.5 ft high. Beams are installed to help distribute weight. Two rows of buckets make the pad 100 ft wide, and the pad's length is determined by the space requirements. The 13-3/8 in. diameter pilings provide a 12 ft clear space

[10] Cashman, K.: 'The Explorers 2007: FEX Puts NPR-A Drilling on Pause,' ***Petroleum News***, Vol. 12, No. 46, November 18, 2007.
[11] Kadaster, A.G., and Millheim, K.K.: "Onshore Mobile Platform: A Modular Platform for Drilling and Production Operations in Remote and Environmentally Sensitive Areas," IADC/SPE 87140, presented at the IADC/SPE Drilling Conference, Dallas, TX, March 2-4, 2004.

between the tundra and the platform deck. A key lesson learned from the prototype platform is that all buckets should be made the same size to ensure interchangeability and to speed up the construction time.

Transportability: The components are sized for transport through the North America highway system by semi-trailer trucks and/or by helicopters. The “bucket” modules for the prototype platform were 12½ ft wide by 50 ft long by 3½ ft deep, weighing approximately 10,000 pounds each. Leg sections are made from steel with a diameter of 12–14 in. and length of 24–34 ft, depending on the geotechnical requirements of the site. Deck sections should be constructed to DOT allowances for easy transportation and modular construction requirements. The dimensions of the prototype platform modules proved to be adequate.

Lightweight Construction: The modules are built of aluminum, giving a three-to-one advantage over weight-to-strength ratio in comparison to steel—much less expensive to transport and construct in the field. Decks are designed as 6 in. thick aluminum laminates filled with construction foam for structural strength and insulation, each weighing about 12,500 pounds. They can be easily transported to the site by a Rolligon before being assembled.

Platform Legs: The legs on the prototype platform were 13-3/8 in. OD and designed to be set a minimum of 15 ft into the permafrost by auger or hammer, drilling the permafrost and then freezing the legs in place with a slurry of rock/sand and water. Each leg contains a tube to allow hot water or steam to be injected to allow controlled thawing and easy removal from the permafrost. The tube may be used to circulate refrigerant, similar to the pilings used in the above-ground permafrost regions of TAPS.

Figure 26. Mats used During Platform Construction.

Interlocking Feature: The modules are designed to interlock where any spillage onto the platform decks would be routed and contained within the “bucket” elements of the modules for containment and proper recovery and disposal.

Construction and Other Features: The platform and equipment installation requires the use of a crane. The size depends upon the rig used, but generally a 30-ton crane will be sufficient. During platform and equipment installation, the temporary mats are required as a staging area for crane and installation equipment (Figure 26). The base elevation of the prototype was approximately 12 ft from ground level to allow free and clear passage of native wildlife and to allow summer sun penetration to the tundra grass under the platform. To prevent corrosion issues, dissimilar metals are not allowed to be in contact with each other.

The piling holes are augured by a drill mounted on a Rolligon, and cuttings are captured and used by mixing with water in the slurry along with sand to freeze when the pilings are installed. Depth depends on the area into which it is installed and could be from 10 to 20 ft deep. The pilings are installed end-to-end with some additional load-bearing pilings installed on some buckets mid-way. The first bucket to be installed has 4 pile slots at each corner to ensure stability of the bucket; the other buckets are supported by the first bucket and connected side-by-side or end-to-end. A crane is hauled to the wellsite by a Rolligon and assembled on a mat. The crane unloads the buckets and installs them on the pilings. It is then used to install the drilling rig and equipment onto the platform. This crane is no longer needed until the well is completed and the platform is reconstructed. A smaller crane is designed for installing on the platform in order to lift supplies and smaller equipment as needed onto the platform. It can then be used to remove the drilling equipment onto the Rolligon vehicles for transportation to the next drillsite.

In most cases, time is of the essence in constructing the platform so long as safety and environmental protection are not compromised. The prototype platform was constructed without the advantage of practice prior to installation; hence, as with any first-time construction, there were a few missteps that delayed the construction. The next generation of platform construction and installation will benefit from these lessons learned. It is reasonable to expect that the wellsite could be constructed and equipped in a 30-day time span, depending on size and distance from the staging area. It may be possible to pre-assemble some of the modules from a staging area prior to field installation in order to save construction time.

One of the key platform features is the construction design, which is conducive to utilizing a modular rig, drilling equipment, pumps, logging tools, self-contained mud pits, and water and fuel tanks. Camp and power were transported in containers and installed to maximize space and ease of operation. Some of the equipment and containers were stacked vertically. This allowed the footprint of the platform, which was 100 ft by 100 ft to be only 10% of the size of the ice platforms used today, and every bit as efficient. The two-story 50-man camp was 50 ft by 50 ft on a 62.5 ft by 60 ft platform connected to the drilling platform by a walkway. The camp size was more than adequate for normal exploration activities, and designed for an added scientific crew and visitors to the Hot Ice well location.

Potential Rigs

There are several new rig designs being developed that could be used with the inland platform for drilling operations. Two of the possibilities discussed below are the National Oil Well Varco (NOV) Rapid Rig and the Huisman LOC250/400 Rig.

During the interview process, every operator stated that there is a need for new and innovative drilling systems. Conoco has designed and used a hybrid rig, incorporating coiled tubing drilling, in Canada.[12] In areas where space is a premium, smaller and more efficient rigs and pads should be constructed (like many buildings) going upward. Similar to buildings, this reduces construction costs and provides efficient and cost-effective use of the land while reducing the footprint. This was the case with the Arctic Platform as shown in Figure 1 and Figure 2. Equipment and storage needs were met by utilizing stacked containers. The system included closed-loop fluid containment and a two-story camp. By using a smaller footprint, construction cost and time to install and remove/move the platform is minimized. For exploration purposes, the platform is best suited if it can incorporate new and innovative rig designs such as the NOV Rapid Rig or the Huisman-Itrec LOC rigs. These rigs are lighter, fuel efficient, and easy to transport and assemble. Additionally, they leave a smaller footprint, require a smaller crew, and have built-in environmental safeguards, AC power, and safety improvements such as fully automated pipe handling.

Rapid Rig

In May 2006, NOV rolled out a smaller fully automatic land-drilling rig called the “Rapid Rig.” This rig is a singles rig, as it has the pipe-handling capability to rapidly pickup/laydown, makeup/breakout drillpipe, run casing, and mobilize/demobilize in approximately 8 hours. It utilizes range II or III drillpipe. The Rapid Rig is deployed with a single forklift; it requires no cranes or gin pole trucks and is capable of moving in 16 highway-legal transport loads. The automated rig floor and pipe-handling systems allow operation by a three-person crew. The rig floor has an iron roughneck and stabbing guide, automated pipe slips, AC drawworks rated at 1000 hp and gear-driven with a regenerative dynamic braking system, and topdrive, controlled from a climate-controlled driller’s cabin on the mud pit side.

As illustrated in Figure 27, the footprint of the Rapid Rig is 153 ft by 119 ft. The rig is rated for approximately 11,000 ft and has a hookload rating of 500,000 pounds. The pipe-handling system has a weight limit of 6,000 pounds with a drillpipe capacity of 5.5 in. range III, a drill collar capacity of 8 in. range II, and casing capacity of up to 13-3/8 in. The rig may be transported by a heavy-lift helicopter. Table 6 compares the Rapid Rig to a similar rig—the Ideal Rig.

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[12] Schafer, R.S. “Step Change in Remote Exploration.” SPE/IADC paper presented at the 2007 SPE/IADC Drilling Conference. Amsterdam, The Netherlands, 20-22 February 2007.105051

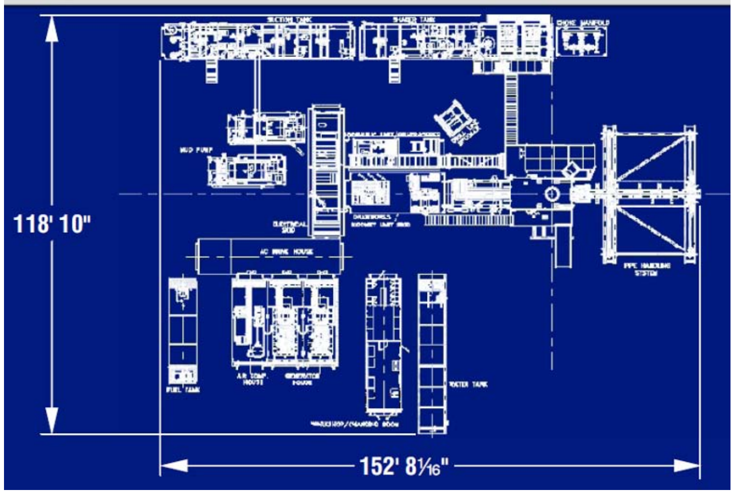

Figure 27. Layout of Rapid Rig.

Table 6: NOV Rapid and Ideal Rig typical specifications

	Rapid Rig	Ideal Rig
Mast Hook Load	250 tons (8 lines)	300 ton
Mast Height	80 ft (telescoping)	142 ft
Base Dimensions	7 ft x 5 ft	12 ft x 12 ft
Wind Rating	70 knot free standing	70 Knot w/ full set back 208 stands of 5.5 inch DP 8 Stands 8 inch DC
Rotary load Rating	250 tons	375 tons (w/ set back)
Drill floor height	20 ft	25 ft
Clear height under floor	17 ft	21 ft 8 inches
Drill Floor Dimensions	16 ft x 17 ft	32 ft x 32 ft
Substructure setback	N/A	250 ton Slingshot
Drawworks Nominal Power	1000 hp	1500 hp
Braking System	Regenerative Dynamic Disk Parking/Emergency Brakes	Disc brakes, Ideal Auto Drilling and Brake control System (IABC)
Top Drive	350 HP, 20,000 ft-lb 250 ton	Optional
Pipe Handling System	6,000 lb range II and III 5.5 pipe 8 inch collars and 13-3/8 inch casing	Optional
Control/instrumentation	SDAQ	SDAQ
Mud System	620 BBLS two tanks 3-panel linear motion shale shaker, Atmospheric Degasser Two Cone Desander	620 BBLS two tanks 2 4-panel high G shale shaker, 1000 GPM Degasser Desander, Desilter
Mud Pumps	2-1000 HP Triplex AC electric Motor Driven	2-1600 HP Triplex AC electric Motor Driven
Power Generation	2- 1350 BHP, 1800 RPM 1750 KVA	3- 1350 BHP, 1800 RPM 1750 KVA
Hydraulic Power	Dual Driven System 70 GPM Diesel, 40 GPM Electric	Dual Driven System 70 GPM Diesel, 40 GPM Electric
Fuel Tanks	Diesel 190 Bbl	400 Bbl cylindrical
Water Tanks	400 Bbl	400 Bbl

Huisman/Drillmar

The Netherlands-based Huisman Special Lifting Equipment BV and Drillmar, Inc. of Houston, through a technology development joint venture, have developed an innovative new rig concept: the LOC250, Land and Offshore Containerized 250 ton hookload rig (Figure 28). The LOC250 is designed to take advantage of today's emerging casing while drilling (CWD) technology to reduce the costs as

Figure 28. Huisman Itrec Rig in south Texas.

well as the environmental impact of drilling a well. The drilling depth capability of the LOC250 is illustrated in Figure 29.

Two of the most important features of the LOC250 rig are its compact size and its ability to be broken down into 17 modules with the shape and the dimensions of standard ISO containers. Within 24 hours (including limited transportation time) and without cranes, a five-man crew with three trucks can demobilize the compact rig and rebuild it in another location. As standard container ships, trains, and oilfield trucks can transport ISO containers rapidly and economically, the LOC250 rig can be used to drill wells anywhere in the world. This has been accomplished by designing the rig in a manner whereby its load-bearing components are in the shape of, or can be pivoted, rotated, or connected into, an ISO container. The container specifications are given in Appendix 2. Figure 30 illustrates the rig during rig-up. The rig may be transported by heavy-lift helicopter.

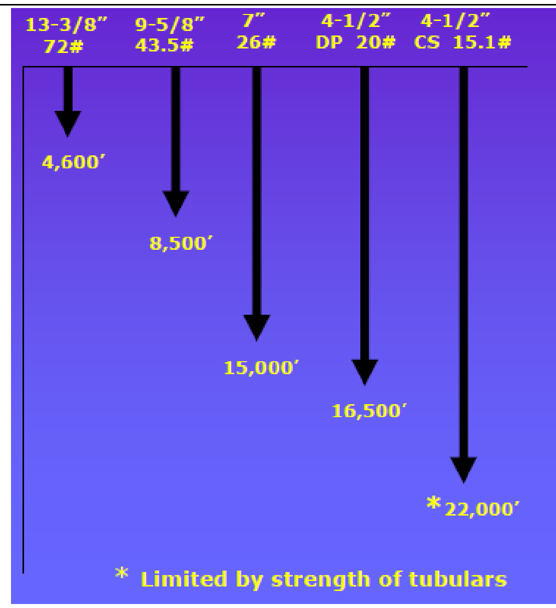

Figure 29. Drilling depths for the LOC250.

The LOC250 is equipped with a fully automated pipe handler, which enables highly efficient handling of both casing and DP. When the pipe handler has upended the tubulars, they are taken over by elevators in the rig. A topdrive is utilized to spin the tubulars in and to torque-up the connections. Fully automated power slips are integrated within the rotary table. The capability to trip DP at 2000 ft/hr makes the LOC250 as efficient as existing conventional DP drilling rigs and more efficient than other specially designed CWD rigs. The DP drilling and CWD processes (including pipe and casing handling) are fully controlled from the control room without personnel on the drill floor. As DP handling is identical to casing handling and uses the same

Figure 30. Huisman Rig during rig-up.

equipment, the same team can carry out both tasks. While a conventional pipe-drilling rig needs a crew of 10, the efficiently designed LOC250 requires a crew of only 5 for full and safe operation.

Statistics show that pipe and material handling cause almost 50% of the recorded accidents during well drilling. The fully automated pipe handling of the LOC250, with its automated drill floor, obviates the need for personnel on the drill floor, thus eliminating the potential for accidents. In addition, the simple rig-assembly process—smaller loads, reduced rig-crew involvement, and improved overview and visibility—effectively mitigates risk for the crew and the potential for accidents and damage during rig moves. The operation of the LOC250 is illustrated in Figure 31.

Figure 31. Huisman LOC250 drawing of operations.

The LOC250 has significantly lower adverse impact on the environment when compared with conventional rigs. Because drilling a well with the LOC250 requires less drilling time and lower mud pump pressures and flow rates, two 800-hp mud pumps are sufficient, compared with three 1000-hp pumps required for conventional DP drilling. This means 45% lower fuel consumption per day when drilling and a reduction in hydrocarbon emissions per well of up to 75%. Solid waste volumes are reduced by up to 30%, as the cascading shaker system provides drier cuttings. Mud and cement costs are reduced by 10 to 20%. Because the LOC250 has only a single 38-m (125-ft) mast, its silhouette does not impact significantly on the horizon. The footprint of the LOC250, at 700 m^2 (7,500 sq ft) is 75% smaller than the 3000 m^2 (32,300 sq ft) required for a conventional rig. Figure 32 illustrates the layout of the LOC250 system for a well pad or platform.

Fidelity Exploration and Production of Texas has already taken delivery of one LOC250. Drillmar has an interest in that company. Additionally, Huisman-Itrec is developing the engineering of the JBF 10,000 drilling “rig of the future,” which is a compact, deepwater semisubmersible that has only 60% of the displacement of fifth-generation semisubs capable of 10,000 ft of water drilling. This will be a fully automated drillpipe-handling

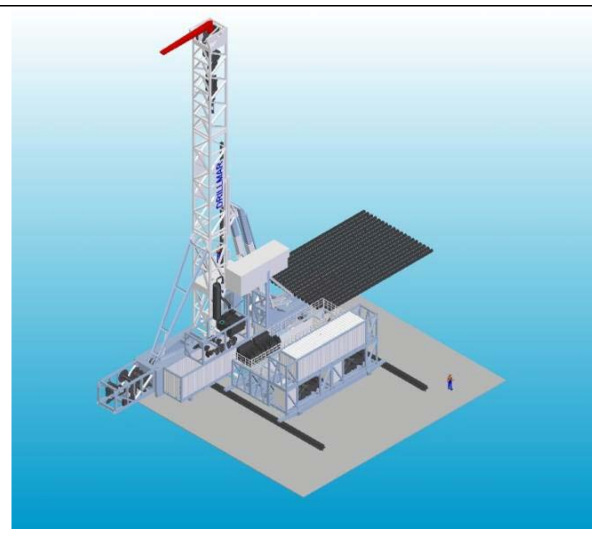

Figure 32. Huisman LOC250 well pad (platform) layout.

system designed to run 135 ft pipe stands in a box mast drilling tower, and features a zero-discharge fluid system[13]. General specifications for the Huisman LOC250 are given in Table 7.

Table 7: Huisman LOC 250 general specifications

Weight and dimensions				
Total transport weight	475	[mton]	524	[Shton]
Number of container units	17			
Containers for loose gear (40′)	4	TBD		
Max. ISO dimensions				
Length	12.2	[m]	40	[ft]
Width	2438	[mm]	8	[ft]
Height standard	2590	[mm]	8′ 6″	
Height high cube without gooseneck	2794	[mm]	9′ 2″	
Height high cube with gooseneck	2896	[mm]	9′ 6″	
Infield rig move	***< 30***	***hours***		

Platform Conceptual Design – Cost Basis

A follow-on engineering study will look at the prototype design, review the Anadarko lessons-learned document, and make improvements to the design. One of the improvements will be to consider alternatives to the deck material sections, speed up the installation process, adapt the pilings to specific areas based on geotechnical data, and make some structural improvements that will accommodate larger rigs and identify ways to speed up the fabrication process. The size of the prototype platform was only 13,750 sq ft. The likely size of a second-generation platform used for either exploration or staging purposes will need to be approximately 30,000 sq ft. For determining a cost for purposes of this report, the estimated expense was based on a platform that will be 100 ft by 300 ft, which utilizes twenty-four 12½ ft by 50 ft buckets.

The cost of fabrication and total assembled can depend on a number of factors, including volume. The material cost for recommended 5083 and 6061 aluminum sheets is $3 per pound. We were able to obtain an estimate of construction time and an average for labor cost, which comes to $92,500 per bucket x 24 = $2,200,000. The cost of the decks is estimated at 24 x $60,000 = $1,440,000.

Handrails, piping, composite grated walkways, and stairs are estimated at $480,000

The next cost is the pilings 13-3/8 x 8-5/8 adjustable steel construction, 35 ft in length. Each leg has tubing to circulate hot fluids or steam. The estimated cost is 60 x $23,000 each = $1,380,000.

[13] Rach, Nina M: "Drilling Market Focus: European Companies Garner Contracts for New Rigs," *Oil and Gas Journal Online* October 17, 2005.

Assuming the platform is constructed in Houston and transported to Dead Horse, the shipping would take 20–25 days, and the cost is approximately$1,080,000, depending on weather:

- Ship to the North Slope:
  - Truck to Seattle
  - Barge to Anchorage
  - Truck to Prudhoe Bay.

Fabrication, testing, and construction time is 4 months.

The time/cost to install in the field will be site-specific and will need to be determined before there is a commercial application.

For exploration purposes, to maximize the application of the platform on a fast-track basis, one scenario to consider is using the rig to drill the first well exploration (well #1) on an ice pad or a mat. While well #1 is being drilled, the platform is installed on the well #2 location. Instead of demobilizing the rig after the first well is being drilled, the rig is moved to well #2 and drilled to the end of the drilling season. We believe this could provide an added 10 to 20 additional drilling days to the back end of the drilling season. When the season closes, the rig stays on this location and as soon as the drilling season opens, the second well is completed and tested. This could add up to 30 days or more on the front end. While this is taking place, a second platform is constructed on the well #3 location so that as soon as the second well is completed, the rig is moved to well #3. The savings of ice roads, demobilization cost, and drilling twice as many wells, without rushing to meet the tundra opening and closing dates, will significantly shorten the time to determine if the play is commercial. In addition, some of the platform can remain on the well location for additional testing, and possibly can be used as a remote completion-and-production area. Because all the buckets are the same, they are interchangeable and thus reduce the configuration complexity from one well location to the other. The more platforms the crew constructs, the shorter the time it will take. In areas of great distance from infrastructure, or where water required for the ice roads and pads is not nearby, the platform may be cheaper and faster to install. This could potentially add two months to the current drilling season in some areas.

For staging area, the platform can be constructed in a central area and, in fact, could even be a well location central in an exploration play. The platform would be constructed to last throughout the exploration activity.

With a two-platform operation, one could also envision the scenario of drill well #1 on an ice pad while setting up platform #1. Well #2 is then drilled on platform #1. Platform #2 is installed where well #3 is drilled. After well #2 is drilled, platform #1 may be moved to the well #4 location, where the rig is over-summered. Then drilling can start early the next winter at the well #4 location.

Complementary Technologies

BP Exploration has used insulated ice pads to extend the drilling season on the Alaska North Slope.[14] BP used pre-fabricated, insulated panels to insulate an underlying ice pad from thawing during the Arctic summer. The survival of the ice pad through the summer made possible an early mobilization of the drilling rig the following October, enabling two exploration wells to be drilled in the same season. The use of the insulated panels increased the season available for well operations from around 100 days to over 150 days.

Composite mats (see Appendix 1) that can be used to protect the Alaskan tundra may complement the use of an inland platform. Composite mat systems formulated from high-performance thermoplastic are engineered to provide safe, cost-effective surfaces for year-round all-weather performance. The system can conform to uneven terrain and is rugged, reusable, and recyclable, being formulated to withstand extreme weather conditions.

Figure 33. Construction of Durabase Road.

The composite mat system has been used to extend the drilling season in Canada by allowing a company to develop locations faster and conduct drilling operations during warm months when the muskeg would otherwise shut down operations. These temporary roads are effective in areas where soil conditions are unstable. Canadian companies have realized that the tight drilling window, as well as strict ecological regulations, would make it impossible to bring in heavy equipment needed for drilling and exploration without the use of mat systems. Mat systems may increase the ability to get into locations earlier and stay later.

[14] Stanley, M.J. and Hazen, B.: "Insulated Ice Pad Technology Enables Extended Season Drilling on Alaska's North Slope," SPE 35686, Presented at the Western Regional Meeting, Anchorage, Alaska, May 22-24, 1996.

For example, Forest Oil, a drilling contractor searching for natural gas in the Alaskan wilderness, has used composite matting for access. In search of oil, Forest Oil faced a challenge in accessing an existing drilling pad originally established in 1969 by Gulf Oil. Forest Oil used a 4000 ft road made from composite mats over Alaskan tundra.

Another example of an application of composite mats is that of City Electric, an Alaskan contractor that needed access to a project site for Chugach Power to keep a project on schedule (Figure 33). Unusually warm seasonal temperatures in Girdwood, Alaska, made the building of an ice road to a work site impossible. Access for the contractor was critical, and the project site was landlocked by tidal marsh/wetlands. An environmentally friendly and safe road was required. The composite map system provided a rapidly deployed solid surface that allowed City Electric to mobilize a 100-ton crane to the work site. The technology enables the contractor to work in summer months while protecting the environment, providing a more productive and safe work situation compared to harsh winter conditions.

Regulatory Issues

Activities within NPR-A require federal (BLM) and state regulatory approvals. Permits require Environmental Impact Assessment and NEPA compliance. Operators noted the difficulty of dealing with various agencies and a need to have a consistent and more streamlined regulatory approval and oversight process. The regulatory bodies include the U.S. Department of Interior, Bureau of Land Management (BLM); U.S. Army Corp of Engineers; U.S. Environmental Protection Agency (NPDES permits); National Marine Fisheries Service; U.S Fish and Wildlife; State of Alaska Oil and Gas Commission; Alaska Department of Environmental Conservation; Alaska Department of Natural Resources (DNR), the Alaska Department of Fish and Game Habitat Division, DNR Division of Coastal and Ocean Management, DNR Division of Mining, Land and Water, and DNR Division of Oil and Gas. In addition, there may be local permitting requirements, such as the North Slope Borough for land use and development.

On federal lands, the BLM attaches mitigation requirements to leases and conditions drilling permits with environmental safeguards. The BLM actively attempts to protect wetland resources.

The State of Alaska and two federal agencies—the Minerals Management Service (MMS) and the Corps of Engineers—regulate oil and gas activities that may affect Alaska's wetlands.

The MMS does not have the authority to regulate activities that occur on coastal wetlands; however, it does address secondary impacts of OCS activities (onshore effects) in its environmental impact statements. The MMS can formally notify lessees of responsibilities and procedures under other federal and state laws included in oil and gas leases (Information to Lessee clauses).

Under Section 404 of the Clean Water Act, the Army Corps of Engineers issues permits for discharge of dredged or fill material into waters of the U.S., including wetlands. Section 401 of the Clean Water Act requires a 404 Permit applicant to obtain a certification that any discharge will comply with state effluent limitations and water quality standards. Section 402 addresses the chemical quality of U.S. waters and associated wetlands, establishes a program that requires a permit for most discharges into surface waters, and can require discharge limits for various pollutants. The Corps regulates most activities related to construction on state and private lands on the Arctic Coastal Plain, and it can issue permits required to construct support facilities for exploration on the OCS through coastal wetlands.

Industry activities on federal lands are primarily regulated by federal land management agencies. The BLM manages the NPR-A, and the MMS oversees activities that occur in waters three or more miles off the coast. Three other federal agencies—the Department of Interior Fish and Wildlife Service, the Department of Commerce National Marine Fisheries Service, and the Environmental Protection Agency—have regulatory authority that may apply to resources affected by activities on federal, state, or private lands.

The State of Alaska owns the land where most current oil and gas activity occurs and has primary responsibility for establishing requirements for how these lands will be restored when activities cease. There are two groups responsible for developing dismantlement, removal, and restoration requirements: the Alaska Department of Natural Resources and the Alaska Oil and Gas Conservation Commission.

- ***Department of Natural Resources –*** manages state lands, including oil and gas leases.
- ***Oil and Gas Conservation Commission –*** issues permits for drilling on state, federal, and private lands. Also includes removal and restoration.

The Alaska Department of Environmental Conservation and the Alaska Department of Fish and Game provide additional regulatory guidance. In addition, the North Slope Borough, the area's local government, can regulate activities on state, native, and municipal lands through zoning ordinances. Corporations own land on the North Slope and can establish environmental and reclamation requirements through contractual arrangements.

In conducting this study, several companies noted that, in addition to the need for regulatory streamlining, attention should be given to new technologies that have been developed and proven, as they could enhance current regulations, some of which were developed and required years before these advances. New technologies include advances in spill prevention, well control, well-testing equipment, and zonal isolation. While not the purpose of this study, it is noted that these concerns should be addressed by state and federal regulators.

Recommendations

There have been a number of studies and research to improve the understanding of oil and gas operations and their impact on tundra[15], ice roads, fresh-water sources[16], and wildlife and their movements. These studies have improved land management practices and use, while improving environmental performance. Improvements have been made in developing more efficient rigs, horizontal and extended-reach drilling, smaller drilling pads, seismic acquisition on monitoring, and drilling and completion fluids. However, there have not been any "step-changing" advances in exploration (drilling) that the majority of participants in this study acknowledged a need for seeing. This report has identified applications for advances to improve access, faster and more efficient drilling and well testing, and development of a new drilling system that would include a modular platform. Additionally, new platform applications are possible for such uses as river crossings, for example, but additional design engineering is required.

A number of barriers were identified outside the scope of this project. It was consistently reported that logistics is the number-one cost and constraint to exploration and production on the North Slope, followed by mobilization and demobilization costs.

Exploration activity is relatively shallow throughout the Alaska North Slope, with wells being drilled 5,000 to 11,000 ft TVD, but even at these relatively shallow depths, they are expensive to drill. The limited drilling season cost depends upon proximity to infrastructure. Comments from industry noted the high cost of exploring in the Arctic, which frequently exceeds the cost of deepwater Gulf of Mexico wells (SP/IADC 10501), and it was stated that a range of 100 to 500 MMB field is the minimum economic commercial limit. Companies make long-term commitments to explore, permit, drill, test, and delineate wells before a commercial discovery is declared and production infrastructure and pipelines are permitted and installed. In many cases, it could take 5 to 9 years from discovery to production. As illustrated in Figure 34, Figure 35, and Figure 36, the use of a platform may improve the logistical support related to drilling operations.

The platform coupled with a more efficient rig and related engines and equipment than is currently used for exploration in Alaska is ideally suited for exploration activities and could significantly speed up the exploration process in potential fields away from infrastructure. What is clear from our findings is that the cost to drill and produce is high, making many discoveries

[15] Guyer, Scott/Bureau of Land Management, Alaska State Office, Anchorage Alaska: **Ice Road Construction and Recovery on Tundra Ecosystems, National Petroleum Reserve, Alaska (NPR-A)** presented at the **United States and Canada Northern Oil and Gas Research Forum: Current Status and Future Directions in the Beaufort Sea, North Slope and Mackenzie Delta,** October 28 to 30, 2008 Anchorage, Alaska.

[16] Daniel White, Institute of Northern Engineering, University of Alaska Fairbanks and Michael Lilly, GW Scientific; Fairbanks, Alaska: **Characterization and Water Use of Alaskan North Slope Lakes** presented at the **United States and Canada Northern Oil and Gas Research Forum: Current Status and Future Directions in the Beaufort Sea, North Slope and Mackenzie Delta,** October 28 to 30, 2008 Anchorage, Alaska.

not commercially viable. The life cycle cost of building a gravel pad, adding production facilities, access cost to the production site, and ultimate reclamation must be considered when determining the commercial value of a discovery. There are a number of marginal fields of 50 to 75 million BOE that cannot be commercially produced by conventional means. In these cases, a platform may be a possible alternative.

The use of an inland platform is an enabling technology in the Arctic. A field, or multiple fields, may be developed and linked together, similar to the way that subsea fields are linked back to centralized offshore locations. This could result in a step-change in how to develop Arctic reserves, in particular, marginal or stranded reserves.

Because only a limited number of lakes are allowed to be used for taking water to build ice roads, haul distance can be a significant cost also. If ice roads are not used, operators rent Rolligons or alternative vehicles, which are expensive to rent and in short supply. On ice roads and in limited off-road travel, mat tracks (alternatives to Rolligons) are used. Bad weather, whiteouts, and high winds, make air lifting problematic. It was reported that Nabors is working on helicopter/air-transportable rigs for arctic exploration.

The cost of dealing with regulatory issues was discussed in the interview process. It was recommended that the multi-agency regulatory bodies streamline the process, and reduce redundancy and duplicative regulations. It was consistently pointed out that the DEC regulations on the oil

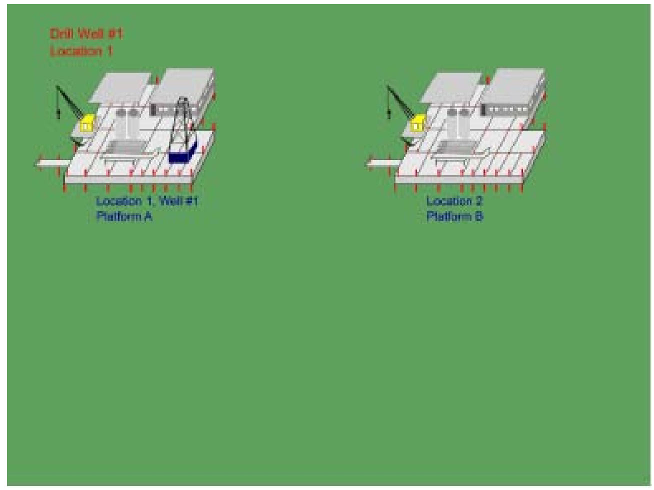

Figure 34. Hop-scotch concept - two platforms set up on locations.

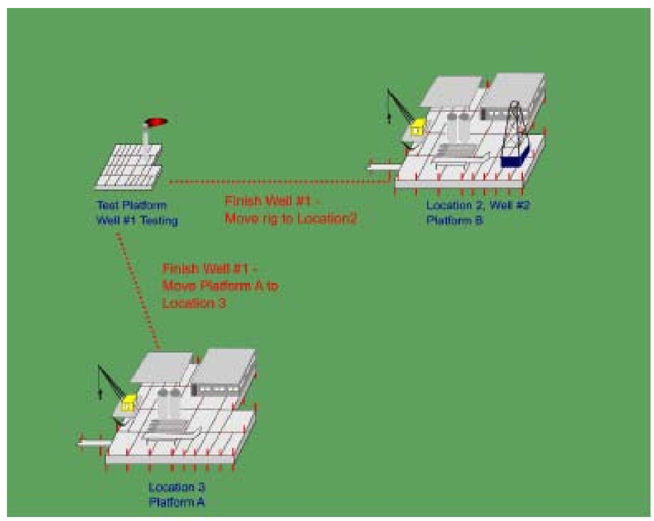

Figure 35. Rig and accessories move to Platform A / Platform B.

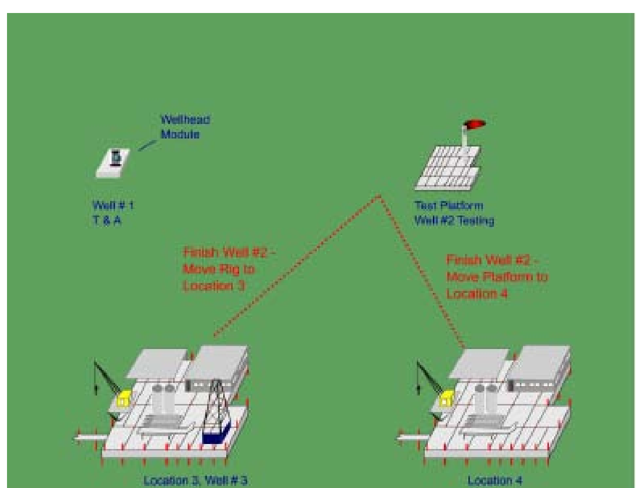

Figure 36. Rig moves to Platform B / Platform A moves to Well 3 /Modules left on Well #1.

spill contingency plan, which require an additional rig plan to intervene in case of a blowout, neither reflect nor take advantage of today's technology related to pore-pressure predictions and detection, and well control. There also were consistent comments related to scheduled and required BOP testing requirements. It was suggested that there be an exchange of ideas and processes with other regulatory agencies, including international arctic environment regulatory bodies.

Companies operating or planning to operate in NPR-A noted and complemented BLM's offer to provide a staging area located near old military airstrips or near other legacy platforms. A gravel road crossing NPR-A would provide the single greatest assistance to exploration logistics. It was also recommended that cuttings disposal was a significant cost, and that a disposal well near one of the NPR-A staging areas would be a major help, reducing long hauls of cuttings to Dead Horse. Environmentally benign cuttings could also be used for permanent pads and roads in areas where gravel is scarce.

There were some concerns expressed by regulators and environmental reviewers of this study about the use of extended insulated ice pads; they believed that the platform offered a more environmentally acceptable alternative. They also expressed support for the platform used as a production facility. The platform could be used as a smaller production facility.

Rig improvements are an area that was consistently mentioned. When discussing the platform in conjunction with new rigs, it was pointed out that this was not just a step change to the way business was conducted. Industry has been reluctant to accept paradigm shifts in the drilling and production process, even when it makes sense.

The inland platform is a technology that may mitigate environmental risks associated with activities in environmentally sensitive areas. Several potential applications could be pursued. As a next step, a detailed engineering study could be performed to develop a design for a site-specific staging area that could be used for logistical support. This would enable various engineering and scientific data to be obtained that could be used in applications that are more complex.

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Appendix 1 – Composite Mats

Performance Data Sheet

DURA-BASE®
Composite Mat System

In an effort to establish performance standards and to explore feasibility for new applications, Newpark Mats & Integrated Services (NMIS) has designed and conducted numerous tests with the DURA-BASE® Composite Mat System. The results viewed by NMIS as most significant are presented in abbreviated form in this document. Anyone having questions regarding the data presented, or issues not addressed here, may contact NMIS at 1-800-446-1972.

General Specifications

Overall Dimensions *(Large Mat)*: 8' x 14' x 4 1/4" (2.44m x 4.27m x 10.8cm)
Surface Dimensions *(Large Mat)*: 7' x 13' (2.13m x 3.96m)
Weight *(Large Mat)*: 1050 lbs. (477 kg)

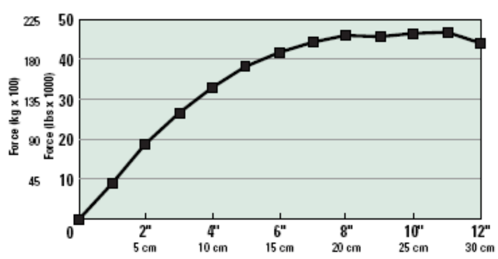
Overall Dimensions *(Small Mat)*: 8' x 7'6" x 4 1/4" (2.44m x 2.29m x 10.8cm)
Surface Dimensions *(Small Mat)*: 7' x 6'6" (2.13m x 1.98m)
Weight *(Small Mat)*: 550 lbs. (250 kg)

Material (primary): High Density Polyethylene
Coefficient of Friction (neoprene on wet mat): 0.6

All published dimensions are nominal.

Strength

Testing has demonstrated mat tolerance to extreme deflection while maintaining high load bearing capacity in pure bending [span = 4 feet (1.2m)]. Pure compressive load capacity is approximately 600 psi (40 kg/cm^2). Compressive loads in excess of 1000 psi (70 kg/cm^2) have been observed in laboratory tests.



NMIS routinely utilizes the mats for unpermitted loads over subgrades of 2 CBR and above.

Traffic

Traffic tests on differing soil conditions have shown the mats to be suitable for an average expected life in excess of 15 years. Fatigue tests have shown no appreciable damage at 60,000 cycles [6 inch (15cm) deflection of 8 foot (2.5m) span].

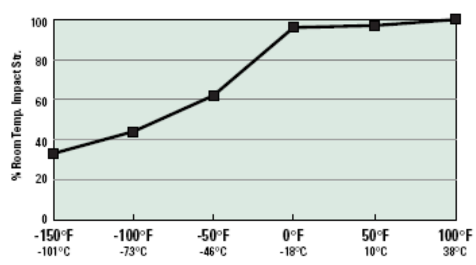
Static Dissipation

Plastics, left untreated, exhibit poor electrical conductivity. This condition, when present in mat material, can lead to a buildup of static charge on the plastic or personnel and result in arcing (mild shock). The DURA-BASE® Composite Mats contain an additive that combines with the plastic and increases the conductivity so a charge may rapidly dissipate, virtually eliminating the potential for static buildup.

Tests have shown the mat surface conductivity to be approximately 10e8 Ohms. The upper limit for a dissipative material is 10e10 Ohms. Field tests have shown the dissipative properties of the composite mat to be equivalent to those of wooden mats.

Temperature Effects

Izod impact tests were conducted to determine the effect of low temperature on material toughness. The results show a transition between -40°F and -4°F (-40°C and -20°C) where the material toughness begins to drop off. All specimens tested above -99°F (-72°C) exhibited signs of ductile failure. The graph presented here shows the impact results relative to room temperature. The impact strength at room temperature of 72°F (22°C) is 2,509 ft-lb/in (134 J/m). DURA-BASE® mats have been successfully employed in environments where -30°F (-34.4°C) temperatures were observed for an extended period of time.



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Appendix 2 – LOC250/400 Transportation Containers

The complete rig consist of a number of standard ISO containers. The weights and dimensions of the containers when transported are:

Weights and dimensions

Number of specific container units		17	[-] (standard delivery)		
Containers for loose gear (40')		6	[-]		
Max. ISO dimensions					
Length 40ft container		12190	[mm]	40	[ft]
Length 20ft container		6055	[mm]	20	[ft]
Width		2438	[mm]	8	[ft]
Max. height (with gooseneck)		2896	[mm]	9½	[ft]
Max. weigth	Approx.	36	[mt]	40	[sht]

The following specific containers are included in the standard delivery:

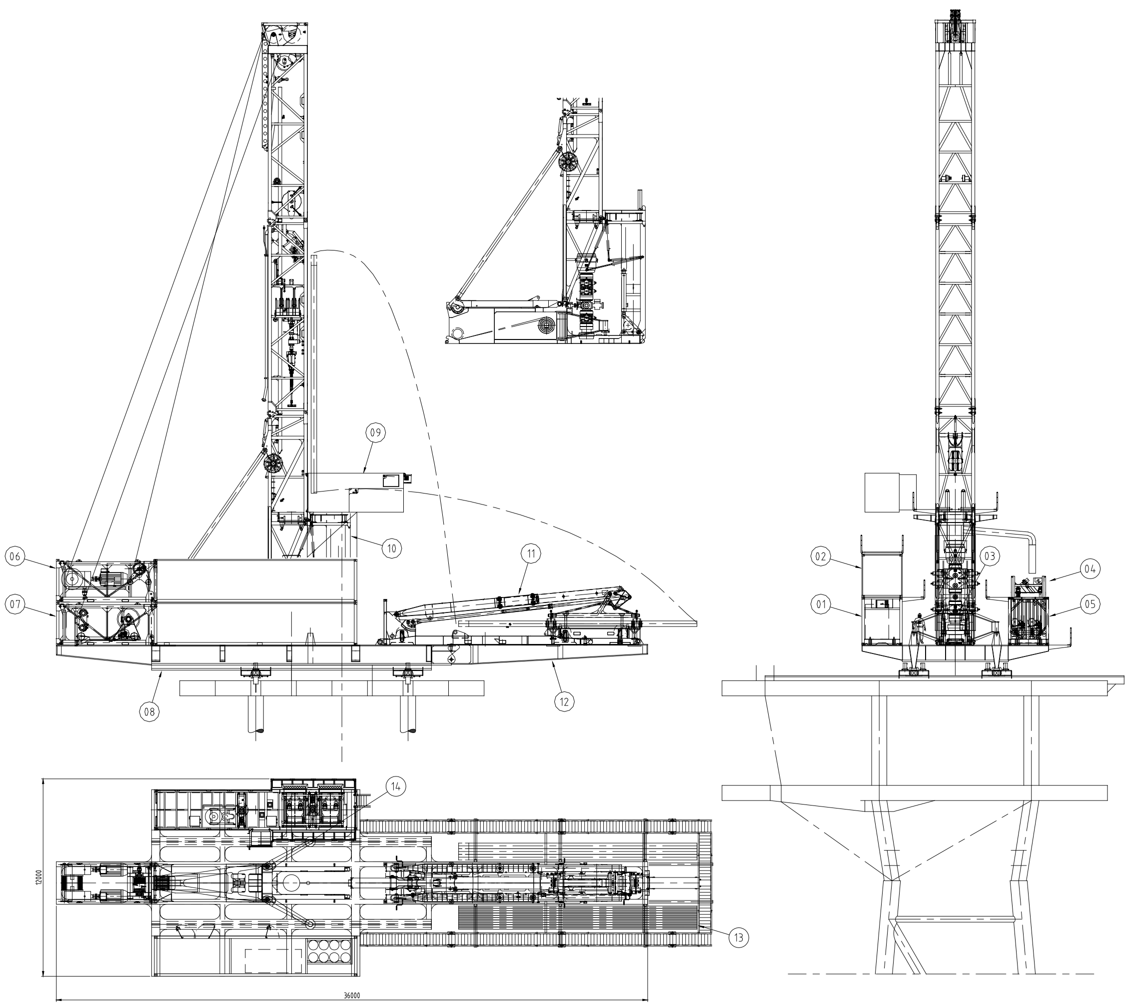
Container name [-]	Abbr. [-]	No. [-]	Size [ft]	Description [-]	Mass [mt]	 [sht]
Base	BASE	1	40	Stabilizers, rig up winch, erection frame	36	40
Drawworks	DWK	1	20	Drawworks, reeving winch, rig up hydraulic power unit (loose item on top)	27	30
Mud pump 1	MP1	1	20	Mud pump 1	27	30
Mud pump 2	MP2	1	20	Mud pump 2	27	30
Mast lower section	MLS	1	40	Rotary table with power slips, standpipe manifold	24	27
Mast middle section	MMS	1	40	Top drive, service loop, kelly hose, large floodlights	29	32
Mast crown section	MCS	1	40	Service crane, tuggers	27	30
Pipe handler	PH	1	40	Pipe handler	28	31
Pipe rack	PR	1	40	Two tilting pipe racks	12	13
Driller's cabin	DC	1	40	Water tank, water pumps, driller's cabin	18	20
Inverters	EPU	1	40	Main electrical distribution and inverters, transformers	28	31
Atmosferic degasser	ATM	1	20	Atmosferic degasser, flow distribution box, choke manifold	18	20
Mud treatment	MT	1	40	Sand trap, shaker tank, degasser tank, shakers, centrifugal degasser, agitators, level sensors	20	22
Active mud	AM	1	40	2 suction tanks, agitators, level sensors	22	24
Mud mix	MM	1	40	Reserve tank and pill pits, agitators, level sensors, mixing hopper, charge/mix pumps, manifold	22	24
Accumulator	ACCU	1	40	BOP control unit, BOP test pump, air compressor and dryer, hydraulic power unit, tool room, high pressure cleaner	28	31
BOP	BOP	1	40	BOP storage, BOP handling, trip tank	46	51
Total		17			439	486

NOTE BOP is including BOP 13-5/8" – 10K , without BOP the mass is 23 mton.

The following specific containers can be delivered as an option:

Container name	**Abbr.**	**No.**	**Size**	**Description**	**Mass**	
[-]	[-]	[-]	[ft]	[-]	[mton]	[sht]
Wire line winch	WLW	1	20	Wire line winch for BHA hoisting	27	30
Mud pump 3	MP3	1	20	Mud pump 3	27	30
Gen set 1	GEN1	1	30	Diesel driven generator 1	19	21
Gen set 2	GEN2	1	30	Diesel driven generator 2	19	21
Gen set 3	GEN3	1	30	Diesel driven generator 3	19	21
Reserve mud 1	RM1	1	40	2 reserve tanks, agitators, level sensors	18	20
Reserve mud 2	RM2	1	40	2 reserve tanks, agitators, level sensors	18	20
Spares storage	SSI	1	40	Insulated space for storing spares	18	20
Spares storage	SS	1	20	Standard dry container for large spares	23	25
Fuel tank	FUEL	1	40	Fuel tank, must be transported empty	10	11

Additionally some standard flat beds are required to handle all loose items such as access stairs and platforms.



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