STRATIGRAPHY OF BURGER J (OCS-Y-2321), BLOCK 6912, CHUKCHI SEA

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TABLE OF CONTENTS

FIGURES

Figure 1 Northern Alaskan and Chukchi Sea Jurassic - Cretaceous palynological zones of Bujak Research International (2003a, b) plotted against the ICS 2012 time scale. Note the local subdivision of Zone K6 in the Chukchi Sea.

Figure 2 Late Aptian to Cenomanian Arctic zonation showing Albian subzones and their calibration with North Sea and northwest European stages and ammonite zones.

RANGE CHARTS (APPENDIX A)

Micropaleontological range chart in StrataBugs format: Plot showing lithostratigraphy, age, palynological zones and micropaleontological assemblages, plus interpreted depositional environments. Taxa are arranged by highest occurrence (tops) within major groups.

Palynological range chart in StrataBugs format: Plot showing lithostratigraphy, age, palynological zones and micropaleontological assemblages, plus interpreted depositional environments. Taxa are arranged by highest occurrence (tops) within major groups.

1. INTRODUCTION

The Burger J well is located on lease OCS-Y-2321, Block 6912, in the Chukchi Sea. It was drilled on the Burger J prospect by the "Polar Pioneer" semi-submersible drilling rig and spudded at approximately 71° 10' 24.03"N, 163° 28' 18.522"W on 30th July 2015. Total depth was reached at 6800 ft in the last week of September 2015 (public information and press releases from Shell Gulf of Mexico Inc.).

1.1 MATERIAL AND METHODS

Material

This report is based on micropaleontological and palynological analysis of 100 composite cuttings samples, which were selected by the operator between 1512 ft and 6800 ft (TD).

Analyzed samples are listed in Section 5 of this report.

All depths in the report are based on depths listed on the sample bags. These are assumed to indicate depth below the drill floor, which was 76 ft above mean sea level (BSEE daily reports, public version).

In this report, the North American convention of using the top of the marked depth on the sample bag as the reference point is followed. The "top" event can therefore be no higher in the well than the top sample depth marked on the bag, but the actual "top" could occur at an intermediate depth down to the bottom depth marked on the sample bag.

Processing and analysis

Samples were processed for palynology and micropaleontology by Malcolm Jones at Palynological Laboratory Services Ltd in North Wales.

Micropaleontological fossil picking and analysis were undertaken by Paul Connell. Palynological analysis was undertaken by Jonathan Bujak. No other biostratigraphic consultants or technical staff were involved in any aspect of this work.

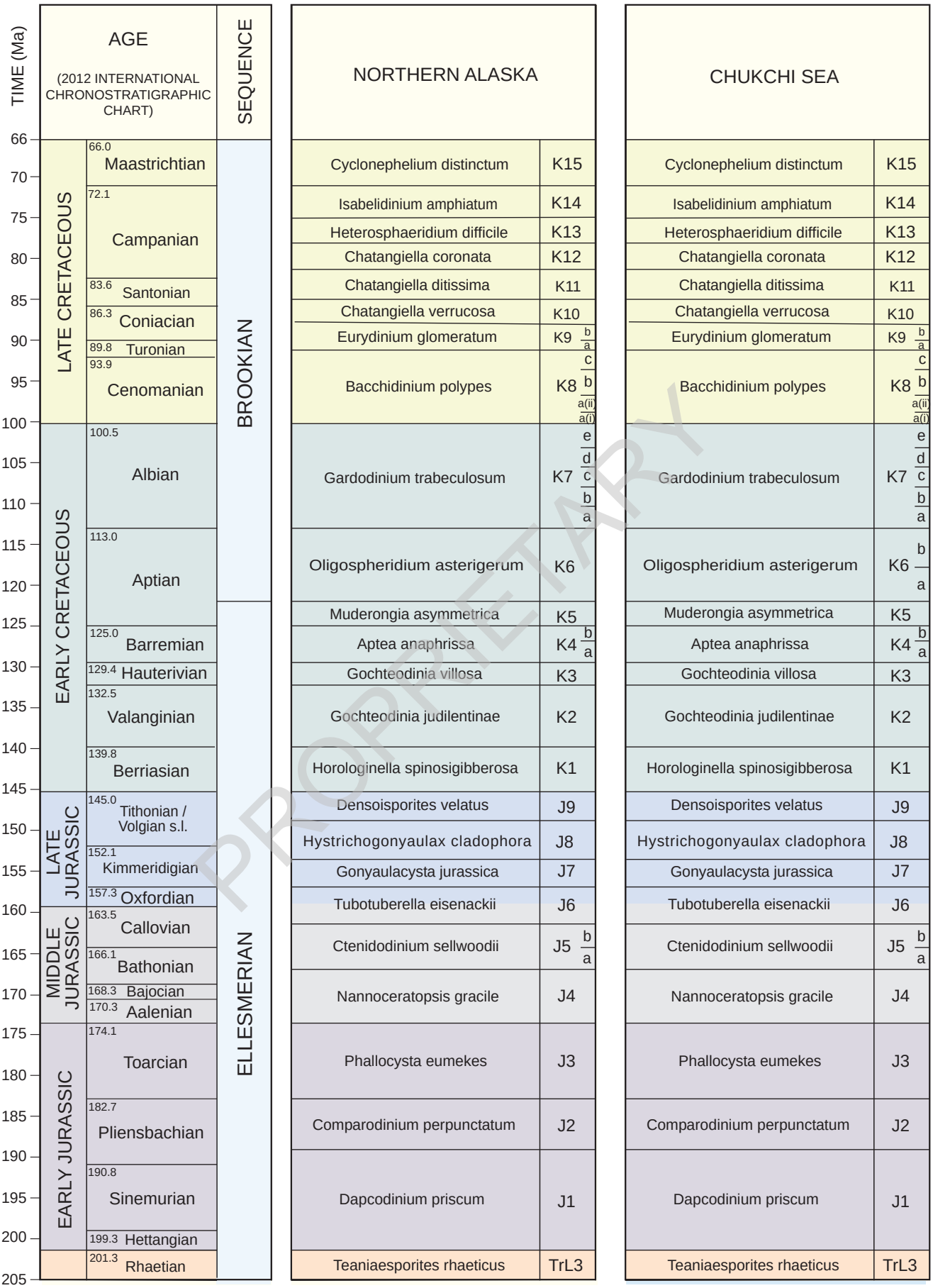

Figure 1. Northern Alaskan and Chukchi Sea Jurassic - Cretaceous palynological zones of Bujak Research International (2003a, b) plotted against the ICS 2012 time scale. Note the local subdivision of Zone K6 in the Chukchi Sea..

DINOCYST BIOEVENT (Note: [1] not all bioevents occur in both the North Sea and Arctic regions; [2] some bioevents show minor diachronism between the two regions; [A] indicates Arctic range			ARCTIC ZONE *	ARCTIC SUBZONE *	NORTH SEA DINO ZONE **	NORTH SEA MFS	AMMONITE ZONE	ABSOLUTE AGE (Ma) (Gradstein et al. 2012)	STAGE
top	occurrence	Epiplosphaera spinosa	K8A	K8A	CEN1		MANTELLI	96.7	EARLY CENOMANIAN
top	occurrence	Senoniasphaera 'reticulata'							
top	occurrence	Sidridinium borealis							
top	occurrence	Ovoidinium scabrosum	K7	LATE K7E	ALB17		DISPAR	100.5	LATE ALBIAN
top	occurrence	Aptea polymorpha							
top	sporadic	Dingodinium cerviculum [A]							
top	consistent	Cyclonephelium brevispinosum							
top	occurrence	Chichaouadinium vestitum [A]							
top	consistent	Senoniasphaera microreticulata [A]							
top	occurrence	Luxadinium propatulum [A]							
top	occurrence	Pseudoceratium / Endoceratium turneri							
top	common	Pterodinium grande		EARLY K7E	ALB16	MFS		103.0	
top	occurrence	Litosphaeridium arundum			ALB15				
top	occurrence	Gonyaulacysta cretacea / helicoidea [A]							
top	influx	Litosphaeridium siphoniphorum							
top	occurrence	Leptodinium modicum [A]			ALB14				
top	occurrence	Leptodinium? hyalodermopsis [A]							
top	occurrence	Lunatadinium dissolutum [A]							
top	occurrence	Protoellipsodinium spinocristatum							
top	occurrence	Endoscrinium turneri		LATE K7D	ALB13		INFLATUM	106.4	
top	occurrence	Endoscrinium rostratum [A]							
top	occurrence	Carpodinium granulatum							
top	occurrence	common / consistent Luxadinium primulum [A]			ALB12				
top	consistent	Oligosphaeridium totum totum [A]							
top	frequent	Cribroperidinium edwardsii							
top	occurrence	Odontochitina singhii		EARLY K7D	ALB11				
top	influx	Oligosphaeridium complex							
top	base	Litosphaeridium siphoniphorum							
top	occurrence	Apteodinium granulatum							
top	occurrence	Apteodinium grande							
top	occurrence	Scriniodinium heikei		LATE K7C	ALB10		LAUTUS	107.0	MIDDLE ALBIAN
top	occurrence	Systematophora cretacea							
top	occurrence	Gardodonium trabeculosum [A]							
top	occurrence	Ellipsoidictyum imperfectum							
top	occurrence	Cauca parva							
top	occurrence	Pseudoceratium expolitum [A]		EARLY K7C	ALB9			107.6	
top	occurrence	Cyclonephelium brevispinosum 'extremum' [A]							
top	occurrence	Pseudoceratium retusum [A]							
top	influx	Systematophora silyba							
top	occurrence	Microdinium opacum [A]		LATE K7B	ALB8		LORICATUS	108.2	
top	occurrence	Microdinium setosum							
top	occurrence	Tehamadinium tenuiceras			ALB7				
top	occurrence	Leptodinium cancellatum [A]							
top	occurrence	Stephodinium spinulosum							
top	occurrence	Impagidinium verrucosum [A]		EARLY K7B	ALB6		DENTATUS	108.8	
top	occurrence	Escharisphaeridia rudis [A]							
top	occurrence	Kleithriasphaeeridium simplicispinosum	K7	LATE K7A	ALB5		MAMILLATUM	110.8	EARLY ALBIAN
top	occurrence	Occisucysta tentoria							
top	occurrence	Impagidinium alectrolophum							
top	influx	Ellipsoidictyum imperfectum							
top	occurrence	Kiokansium prolatum		EARLY K7A	ALB4		TARDEFURCATA	112.0	
top	occurrence	Cyclonephelium compactum (extreme ornament)							
top	influx	Cauca parva							
top	common	Kiokansium prolatum			ALB3				
top	common	Kiokansium polypes							
top	occurrence	Ellipsoidictyum inaffectum subsp. elongataum			ALB2	MFS			
base	common	Surculosphaeridium longifurcatum							
top	occurrence	Occisucysta echinata			ALB1				
top	occurrence	Dingodinium albertii							
top	occurrence	Aldorfia vectensis							
top	occurrence	Protoellipsodinium clavulum	K6	K6C	APT18		JACOBI	113.0	LATE APTIAN
top	occurrence	Achomosphaera verdieri							
top	occurrence	Cerbia tabulata							

** Arctic zonation (Bujak Research International 2003a, b)

* North Sea scheme of Duxbury (2001) renamed with alphanumeric notation

Figure 2. Late Aptian to Cenomanian Arctic zonation showing Albian subzones and theit calibration with North Sea and northwest European stages and ammonite zones.

1.2 BIOSTRATIGRAPHIC ZONATION

Mesozoic (Figure 1)

During the Triassic to Maastrichtian, the Arctic Ocean was connected to the Pacific Ocean, permitting continuous interchange of marine fauna between the two oceans. Relatively low latitudinal thermal gradients of the greenhouse climate also resulted in warmer Arctic air and sea-surface temperatures (SST) than those of the present bipolar icehouse climate. Arctic Mesozoic strata therefore contain abundant populations of dinoflagellates, which were the major phytoplankton during this time.

The Arctic Ocean was centred on the North Pole throughout most of the Mesozoic, enabling an Arctic Basin-wide scheme for the Arctic, except for the Oligocene to Recent of the Barents Sea which was influenced by warmer waters of the Gulf Stream.

The Mesozoic Arctic Ocean was fringed by land inhabited by diverse plant communities, as indicated by the presence of abundant pollen and spores in many Arctic and circum-Arctic sediments. The Mesozoic palynological zonal scheme used in this report is therefore based on a combination of dinoflagellates, pollen and spores, but with marine taxa providing most of the zonal markers as they are less prone to local facies control and diachronism.

Arctic dinoflagellate assemblages include several distinctive endemic populations, plus more cosmopolitan taxa that permit correlation into lower latitudes and calibration of the Arctic zones with absolute time. The zonal scheme used in this report is summarised in Figures 1 and 2, based on extensive analysis of wells and surface sections by Jonathan Bujak (Bujak Research International, 2003a, b). Several Mesozoic zones are subdivided into subzones, with Albian subzones being particularly significant to the present study,

Albian Subzones (Figure 2)

The Albian *Gardodinium trabeculosum* Zone (K7) is subdivided into five subzones. Most of the taxa that define the subzones are dinoflagellate cysts that have relatively wide geographic distribution. The stratigraphic ranges of these species can therefore be compared with those in northwest Europe (e.g., Duxbury 2001), and there is sufficient similarity to permit correlation

with northwest European Ammonite zones. Some of the Alaskan biomarkers have slightly different stratigraphic ranges from their North Sea / northwest European distribution and these are noted in Figure 2.

Foraminifera

Despite the long history of micropaleontological analyses undertaken in Alaska and the adjacent Beaufort-Mackenzie and Sverdrup basins, no comprehensive microfossil zonation scheme for the Lower Cretaceous strata has been published.

The early monograph reports of Tappan (1962) and Bergquist (1966) largely neglected the pre-Albian strata in Alaska and there have been no further detailed publications. Detailed research in the Yukon and Sverdrup basins by Chamney (1969, 1971, 1978), Fowler and Braun (1993), Hedinger (1994), Souaya (1976) and Wall (1983) have resulted in well-illustrated monographs with modern foraminiferal taxonomy.

The large compilation of biostratigraphic data from many Alaskan wells, including all of those in the Chukchi Sea, by Mickey *et al*. (2006) utilised a system of F-Zones to subdivide the micropaleontological succession. Unfortunately the microfossil taxonomy remained unrevised from the original analytical work in the early 1990's and the defining details of the zones were never published. Our review of their well data was unable to recognise consistent criteria for the definition of the F-Zones.

The taxonomy utilised in this report draws on the compilations mentioned above as well as the available Russian literature (Dain, 1972; Bulynnikova *et al*., 1990) which deals with the, frequently rich, microfossiliferous Barremian to Volgian strata of the northern basins of Siberia.

The assemblages, which have been recognised in this well are based on the characteristic microfossils from each interval, are tabulated in Section 2 of this report. These assemblages mainly reflect the lithostratigraphy, so that they have limited chronostratigraphic significance.

1.3 REPORT FORMAT

The report is divided into the following six sections and Appendix A.

- Section 1 discussed the examined material and methodology.
- Biostratigraphic results of the study are summarised in Section 2 and include a four-fold degree of confidence for each zonal assignment that ranges from 1 (highest) to 4 (lowest).
- Section 3 documents the biostratigraphic subdivision of the well in more detail, including lists of the bioevents used to recognise individual zones and subzones, plus environmental interpretations.
- Section 4 lists the lithostratigraphic subdivision of the well based on the biostratigraphic succession. Depths are approximate because well logs were not provided for the study.
- Section 5 tabulates the examined samples and their paleontological analyses.
- Section 6 lists an abbreviated bibliography.
- Micropaleontological and palynological range charts are provided in Appendix A.

2. SUMMARY OF RESULTS: BURGER J (OCS-Y-2321)

2.1 PALYNOLOGICAL ZONATION: BURGER J (OCS-Y-2321)

1512 ft **highest examined sample**

1512-3480 ft ***Gardodinium trabeculosum* Zone K7 (Albian) [1]**

- 1512-1590 ft Subzone K7d (late Albian) [2]
- 1590-1950 ft Subzone K7c (middle Albian) [3]
- 1950-3210 ft Subzone K7b (middle Albian) [3]
- 3210-3480 ft Subzone K7a (early Albian) [3]

3480-5280 ft ***Oligosphaeridium asterigerum* Zone K6 (Aptian) [2]**

- 3480-3930 ft Subzone K6b (late Aptian) [2]
- 3930-5280 ft Subzone K6a (late part of the Early Aptian) [4]

---------- 5280 FT (APPROXIMATE): BROOKIAN UNCONFORMITY----------

5280-5790 ft ***Aptea anaphrissa* Zone K4 (late Hauterivian to Barremian) [2] with common reworked K2 (Valanginian) taxa**

------- 5790 FT (APPROXIMATE): LOWER CRETACEOUS UNCONFORMITY-------

5790-6570 ft ***Gochteodinia judilentinae* Zone K2 (Valanginian) [2]**

6570-6800 ft (TD) ***Horologinella spinosigibberosa* Zone K1 (Berriasian) [3]**

2.2 MICROPALEONTOLOGICAL ASSEMBLAGES: BURGER J (OCS-Y-2321)

1512 ft **highest examined sample**

1512-1590 ft no assemblage recognisable

1590-2130 ft **megaspores**

2130-3930 ft ***Haplophragmoides topagorukensis* / *Gaudryina tailleuri***

3930-4980 ft ***Bathysiphon brosgei***

4980-5280 ft **radiolaria**

---------- 5280 FT (APPROXIMATE): BROOKIAN UNCONFORMITY----------

5280-5790 ft ***Recurvoides* ex gr. *stschekuriensis* / *Haplophragmoides concavus***

------- 5790 FT (APPROXIMATE): LOWER CRETACEOUS UNCONFORMITY-------

5790-5850 ft **no assemblage recognisable**

5850-6050 ft ***Glomospira* / *Haplophragmoides***

6050-6570 ft ***Cribrostomoides infracretaceous* / *Labrospira goodenoughensis***

- 6050-6080 ft *Recurvoides* sub-assemblage
- 6080-6140 ft *Epistomina caracolla anterior* sub-assemblage
- 6140-6290 ft *Verneuilinoides neocomiensis* sub-assemblage
- 6290-6570 ft *Trochammina* / *Gaudryina* sub-assemblage

6570-6800 ft (TD) ***Cribrostomoides canui***

- 6630-6800 ft Ostracods / *Pseudolamarckina* sub-assemblage

NOTES

1. The base of each zonal interval is listed down to the top of the highest sample assigned to the underlying zone, consistent with other Bujak Research Arctic reports. It is possible that the horizon occurs in the gap between the examined samples.

2. The degree of confidence is shown in square brackets [1-4] after each zonal assignment:
   - Confidence level 1: highest confidence level
   - Confidence level 2: medium confidence level
   - Confidence level 3: lower confidence level
   - Confidence level 4: lowest confidence level

3. BIOSTRATIGRAPHIC RESULTS: BURGER J (OCS-Y-2321)

3.1 INTRODUCTION

1. This section of the report discusses the biostratigraphic succession interpreted from the palynological and micropaleontological data shown on four range charts in Appendix A.
2. The zonal subdivision of the well is documented below in order of increasing downhole depth, using the Bujak Research International zonal scheme shown in Figures 1 and 2.
3. The base of each zonal and subzonal interval is listed down to the highest sample assigned to the underlying zone.
4. A confidence level is assigned to each zone in square brackets from 1 (highest) to 4 (lowest). Each zonal bioevent listed within each zone or subzone is followed by the type of microfossil in curved brackets, i.e., Palynomorphs (P): (A) algae, (D) dinocysts, (F) fungi and (S) spores and pollen. Microfauna: (F) foraminifera, (O) ostracoda, (R) radiolaria (M) miscellaneous microfossils and minerals.
5. Age-diagnostic species and other significant taxa are listed for each zone and subzone in order of their highest occurrence observed in the well.

3.2 BIOSTRATIGRAPHIC SUBDIVISION: BURGER J (OCS-Y-2321)

Sea bed to 1512 ft: not examined

1512-3480 ft: *Gardodinium trabeculosum* Zone K7 (Albian) [1]

1512-1590 ft Subzone K7d (late Albian) [2]

Diagnostic palynomorphs:

1512 ft top *Bacchidinium polypes* (D) Zone 8 and older
top *Vitreisporites pallidus* (P) Zone 8 and older
top *Apteodinium grande* (D) Subzone K7d and older
top *Chichaouadinium vestitum* (D) Subzone K7e and older
top *Chlamydophorella nyei* (long horn) (D) Subzone K7d and older
top *Endoscrinium turneri* (D) Subzone K7e and older
top *Leptodinium? hyalodermopsis* (D) Subzone K7e and older
top *Luxadinium primulum* (D) Subzone K7e and older
top *Luxadinium propatulum* (D) Subzone K7e and older
top *Oligosphaeridium totum totum* Subzone K7d and older
top *Ovoidinium scabrosum* (D) Subzone K7e and older
top *Protoellipsodinium spinocristatum* (D) Subzone K7e and older
top *Pseudoceratium turneri* (D) Subzone K7e and older
top *Senoniasphaera microreticulata* (D) Subzone K7e and older

Lithology:

The washed residue from the only sample in this interval consists of fine grade, well sorted, sub-angular, loose sand and a few lumps of crystalline pyrite.

Palynology:

Palynomorphs in the interval have fair to good preservation with some broken specimens. Dinocysts comprise 15% of the palynological assemblage, with some probably representing the

cysts of nearshore marine dinoflagellates that were washed into non-marine locations during storm surges.

Micropaleontology:

No foraminifera were recovered from this sample; the only biogenic material consists of abundant coal fragments and carbonised woody debris.

Paleoenvironment:

Nonmarine to marginal marine coastal swamp if *in situ*, but could be deeper, inner neritic if re-deposited as a debris flow. The presence of dinocysts and miospores may indicate deposition in salt water creeks within a marginal marine environment.

Stratigraphic comments:

Age and lithology are typical of the Nanushuk Group and probably represent a lowstand deposit, or a debris flow sourced from the coastal swamps.

1590-1950 ft: Subzone K7c (middle Albian) [3]

Diagnostic palynomorphs:

1590 ft	top *Cauca parva* (D) Subzone K7e and older
	top *Ellipsoidictyum imperfectum* (D) Subzone K7e and older
	top *Gardodinium trabeculosum* (D) Subzone K7e and older
1680 ft	top *Cyclonephelium brevispinum 'extremum'* (very short spines) (D) Subzone K7e and older
1770 ft	top *Systematophora cretacea* (D) Subzone K7e and older

Lithology:

The washed residue is dominated by fine-grained, sub-angular, well-sorted, loose sand, which occasionally occurs as well-cemented fragments, and is accompanied by minor amounts of hard, dark-brown dolomite, and a buff to light-brown sandy mudstone. The sand is generally finer grained than in the overlying interval.

Palynology:

Palynomorphs in the interval have fair to good preservation with some broken specimens. Dinocysts comprise 12-15% of the palynological assemblage, with some probably representing the cysts of nearshore marine dinoflagellates that were washed into non-marine locations during storm surges.

Micropaleontology:

No foraminifera were recovered from this interval. The only microfossils consist of small, brown to dark-brown plant megaspores. Compared to the overlying interval there is a noticeable decrease in the amount of coal and carbonized vegetation fragments.

Paleoenvironment:

Nonmarine to transitional; possibly strand line rather than swamp if the assemblages are *in situ*, otherwise inner neritic, or deeper if redeposited as a debrite.

Stratigraphic comments:

Typical of the Nanushuk Group strata and possibly a regressive sequence.

1950-3210 ft: Subzone K7b (middle Albian) [3]

Diagnostic palynomorphs:

1950 ft	top *Microdinium setosum* (D) Subzone K7b and older
	top *Tehamadinium tenuiceras* (D) Subzone K7b and older
2130 ft	top *Stephodinium spinulosum* (D) Subzone K7b and older marker

Diagnostic foraminifera:

2130 ft	highest occurrence of foraminifera including *Gaudryina tailleuri* (F)
2220 ft	top *Ammodiscus rotalarius* (F)
2310 ft	top *Haplophragmoides topagorukensis* (F)

Lithology:

The washed residues consist of a monotonous series of light-brown, variably sandy, and variably carbonaceous mudstones with common amounts of fine-grained sand which is occasionally seen as well-cemented fragments. Minor amounts of light-brown dolomite, as seen above, and light-gray limestone occur infrequently. Light-gray to light-brownish gray mudstone appear below 2670 ft. Minor amounts of oilwell cement were seen at 3030 ft. Crystalline pyrite occurs in every sample with peak of common amounts at 2490 ft and 2580 ft.

Palynology:

Palynomorphs in the interval have good preservation with some broken specimens. Dinocysts comprise 9-17% of the palynological assemblage, except in the cuttings sample at 2310-2340 ft where they only comprise 3% of the assemblage. Some of the dinocysts may represent the cysts of nearshore marine dinoflagellates that were washed into non-marine locations during storm surges.

Micropaleontology:

Low numbers of light-brown, thin-walled, agglutinated foraminifera occur in most samples below 2130 ft. The most commonly occurring species are *Haplophragmoides chapmani* and *Haplophragmoides topagorukensis*, which are the only foraminifera below 2580 ft. Maximum numbers and diversity occur at 2400 ft which also marks the deepest occurrence of *G. tailleuri*, *Saccammina* spp. and the highest occurrence of frequent *H. topagorukensis*. A single specimen of a very small, calcareous benthonic foraminifer, *Gavelinella* spp. occurs at 2490 ft. With the exception of *Saccammina*, all the genera in this interval are considered to be mobile epi-lithic, possibly epi-phytal, browsers.

Fragments of coal occur in almost every sample and fluctuate from rare to abundant, particularly at 2670 ft where there are common amounts of carbonised vegetation.

Paleoenvironment:

The top of the interval was possibly deposited in nonmarine to transitional environments if the assemblages are *in situ*, but shallow marine, inner shelf conditions are suggested by the relative abundant and diverse foraminifera between 2130 ft and 2490 ft. Below 2580 ft, the restricted

Haplophragmoides biofacies suggests nearshore, transitional environments with brackish influence. Environmental conditions were probably strongly influenced by rapid short-term variations in salinity and current velocity in shifting channels within a marsh to nearshore setting. Ubiquitous pyrite suggests reducing conditions below the sediment-water interface.

Stratigraphic comments:

The interval probably represents an initial transgressive sequence reaching a local maximum flooding event at about 2490 ft and thereafter a regressive sequence until the disappearance of marine influences above 2130 ft which marks the onset of a lowstand sequence.

3210-3480 ft: Subzone K7a (early Albian) [3]

Diagnostic palynomorphs:

3210 ft	top *Impagidinium alectrolophum* (D) Subzone K7a and older
	top *Kleithriasphaeridium simplicispinosum* (D) Subzone K7a and older
	top *Occisucysta tentoria* (D) Subzone K7a and older
3315 ft	top *Occisucysta echinata* (D) Subzone K7a and older

Diagnostic foraminifera:

3315 ft	deepest occurrence of rare *Haplophragmoides chapmani* (F)

Lithology:

The three samples in this interval are composed of variably brown-colored, sandy mudstone that occasionally grades to clean, fine-grained sandstone. Rare fragments of cemented, well-sorted sandstone and light-brown, firm limestone also occur. Pyrite is rare and fragments of oilwell cement are rare to frequent at 3315 ft and 3390 ft.

Palynology:

Palynomorphs in the interval have good to good preservation with some broken specimens. Dinocysts comprise 18-19% of the palynological assemblage, with some possibly representing

the cysts of marine dinoflagellates that were washed into non-marine locations during storm surges.

Micropaleontology:

Low numbers of small agglutinated foraminifera occur in all three samples. *H. topagorukensis* is the most common, particularly at 3315 ft, plus rarer *H. chapmani* and single occurrences of *Saccammina* and *Ammodiscus rotalarius*. Plant megaspores are absent, but carbonised, woody vegetation is abundant at 3315 ft and 3390 ft.

Paleoenvironment:

Probably nearshore, shifting channels in a marsh, with marine, inner neritic influences.

Stratigraphic comments:

The local foraminiferal maximum at 3315 ft may represent the most marine influence within this shallow water facies. It was not possible to recognise the subtle boundary between the more marine Torok Formation and the overlying, less marine Nanushuk Group in this well. Either the influx of carbonised vegetation at 3390 ft or the uphole consistent occurrence of megaspores above 3030 ft in the overlying interval are possible candidates, and the boundary is picked at the early-middle Albian horizon between palynomorph zones K7a and K7b.

3480-5280 ft: *Oligosphaeridium asterigerum* Zone K6 (Aptian) [2]

3480-3930 ft: Subzone K6b (late Aptian) [2]

Diagnostic palynomorphs:

3480 ft	top *Cerbia tabulata* (D) Zone K6 and older marker
	top *Oligosphaeridium asterigerum* (D) Zone K6 and older marker
3660 ft	top *Achomosphaera verdieri* (D) Zone K6 and older marker
	top *Protoellipsodinium clavulum* (D) Zone K6 and older marker

Lithology:

This interval is composed of brown sandy mudstone which grades into muddy sandstone with variable amounts of carbonaceous debris, as in the overlying intervals. The appearance of very fine flakes of white mica is the only difference. Frequent to common amounts of pyrite are only present in the top two samples at 3480 ft and 3570 ft.

Palynology:

Palynomorphs in the interval have good to excellent preservation, with dinocysts comprising 18-24% of the palynological assemblage. Miospores comprise both water and wind-borne pollen and spores that were transported to the depositional site.

Micropaleontology:

Rare and single specimens of *H. topagorukensis* occur in decreasing numbers downhole. Carbonised vegetation is frequent to common in the top three samples, but very rare in the deepest two samples at 3750 ft and 3840 ft. The deepest sample, at 3840 ft, is almost barren and only one indeterminate agglutinated foraminifer plus a few megaspores were recovered. Fragments of coal are frequent to common in all samples.

Paleoenvironment:

The upper part of the interval may have been deposited in an inner neritic environment; the lower part was probably deposited in a nearshore, transitional environment.

Stratigraphic comments:

The uphole biofacies development suggests a transgressive sequence that culminates with the local microfaunal maximum at 3315 ft in the overlying interval. The base of the interval is probably coincident with a sequence boundary which overlies a deeper marine biofacies of the underlying interval.

3930-5280 ft: Subzone K6a (late part of the Early Aptian) [4]

Diagnostic palynomorphs:

3930 ft	top *Oligosphaeridium asterigerum* abundance (D) Subzone K6a and older marker

Diagnostic foraminifera:

3930 ft	top *Bathysiphon brosgei* and *Hippocrepina barksdalei* (F)
4290 ft	top rare occurrences of *Conorboides umiatensis* (F)
4980 ft	top *Parvicingula* spp. (R)
	top common to abundant loose, quartz pebbles (M)
	top pyrite 'sticks' (M)
5010 ft	top *Verneuilinoides borealis* (F) and top 'round browns' (M)
5220 ft	base consistent occurrences of *Pseudodictyomitra* spp. (R),
	isolated occurrence of *Hedbergella aptiana* (F)
5250 ft	re-appearance of *Gaudryina tailleuri* (F),
	base *Haplophragmoides topagorukensis* (F)

Lithology:

This interval can be divided into two sections based on the lithology and biofacies.

The upper section down to 4200 ft is much sandier than the overlying interval and the washed residues are dominated by fragments of moderately well-cemented, fine-grained, subangular, quartzose sand. Below 4290 ft, a medium to dark gray, micromicaceous mudstone occurs in addition to the medium brownish gray, sandy mudstone. Pyrite is frequent to abundant down to 4380 ft, but is almost absent from 4470 ft to 4920 ft. In the same section, the mudstones are richly carbonaceous and abundant coal fragments occur from 4560 ft to 4740 ft.

The lower section from 4980 ft downwards consists of brown, silty, carbonaceous, mudstone accompanied by poorly sorted and occasionally well-cemented, sandstone. The grain size ranges from very fine to coarse with scattered very coarse, well-rounded, subspherical quartz grains. In the washed residue there are common to abundant well-polished quartz grains larger than 500 microns. At the same depth, pyrite reappears in abundance and remains abundant throughout the remainder of the section. Crystalline lumps, plus small, finely crystalline spheres and discoids

occur with frequent cylindrical pyrite 'sticks'. This lower section is also characterized by the occurrence of a minor component of hard, light-gray to dark grayish brown, non-calcareous fragments which are possibly tuffaceous. Some of the larger mudstone fragments below 5190 ft seem to be veined with a white, non-calcareous mineral.

Palynology:

Palynomorphs in the interval have good to excellent preservation, with dinocysts mostly comprising more than 20% of the palynological assemblage, and reaching a peak of 32% between 4020-4140 ft, and a minimum of 16% in the cuttings samples at 44709-4500 ft and 5100-5130 ft. Miospores comprise both water and wind-borne pollen and spores that were transported to the marine depositional site.

Micropaleontology:

The upper section from 3930 ft to 4920 ft is sparsely fossiliferous and the agglutinated foraminifera are mainly *H. topagorukensis, B. brosgei* and *H. barksdalei*.

The following additional events also occur:

4020 ft isolated occurrence of *Pseudodictyomitra* spp. (R) and shelly debris (M)

4560 ft local base *B. brosgei*

4650 ft local base *H. topagorukensis*

The samples from 4740 ft to 4920 ft, which contain common to abundant coal fragments and carbonaceous debris, are devoid of foraminifera and only yielded a single megaspore.

The section below 4980 ft is marked by the reappearance of *H. topagorukensis* and *B. brosgei*, but very few agglutinated foraminifera occur between 5040 ft and 5190 ft. The section is further characterized by the occurrence of the pyritized nassellarian radiolaria *Parvicingula, Pseudodictyomitra, Archaeodictyomitra* and *Xitus*. These genera were probably assigned to *Lithocampe* in older Chukchi well reports. It is possible that the small, finely crystalline spheres and discoids are pseudomorphs after radiolaria, but the lack of any surface ornament precludes a confident assignment. The other characteristic microfossil which occurs throughout this section is

the small, smooth sphere, which may be the algal cyst reported as 'round browns' in modern oceanographic reports.

The most interesting event in this section is the recovery of a few pyritized planktonic foraminifera at 5220 ft which are assigned to *Hedbergella aptiana.* This species characterized the early Aptian in northern Europe and southern Russia. As far as can be ascertained, there are no previous reports of planktonic foraminifera from the Early Cretaceous of the Arctic region.

A few specimens of *H. topagorukensis* and a few calcareous benthonic foraminifera reappear in the samples from 5190 ft to 5280 ft.

Paleoenvironment:

Within the section 3830 ft to 4650 ft, the presence of *Bathysiphon* and *Hippocrepina* reflect marine, outer neritic water depths, with suboxic conditions below the sea bed being indicated by the presence of abundant pyrite. The reappearance of abundant coal fragments in the lower half of the section, below 4560 ft, may reflect a return to nearshore conditions, but the event probably represents a substantial debrite flow sourced from the coastline.

Within the section from 4980 ft to 5280 ft deeper, outer neritic to upper bathyal water depths are indicated by the agglutinated foraminifera and the presence of bathypelagic, nassellarian radiolaria. Fluctuations in lithology and biofacies are consistent with debris flows and frequent scouring of the substrate.

Stratigraphic comments:

The marked discontinuity between 4950 ft and 4980 ft may reflect a sequence boundary within the Torok Formation or a tectonic slide plane.

There is no palynological evidence for the early Aptian *Muderongia asymmetrica* Zone K5, indicating that the lower boundary of this interval represents a significant unconformity at the base of the Brookian sequence.

The presence of abundant, coarse, well-rounded quartz grains could suggest the 'Pebble Shale' but large, cemented, rock fragments indicate that they are associated with influxes of poorly sorted sand.

5280-5790 ft: *Aptea anaphrissa* Zone K4 (late Hauterivian to Barremian) [2]

Diagnostic palynomorphs:

5280 ft	top *Aptea anaphrissa* (D) Zone K4 and older marker
	top *Muderongia asymmetrica* (D) Zone K4 and older marker
	top *Muderongia tetracantha* (D) Zone K5 and older marker
	top *Subtilisphaera perlucida* (D) Zone K5 and older marker
5310 ft	top *Kleithriasphaeridium fasciatum* (D) Zone K4 and older marker

Diagnostic foraminifera:

5280 ft	top *Haplophragmoides concavus* (F),
	top *Recurvoides* ex gr. *stschekuriensis sensu* Fowler & Braun 1993 (F),
	top *Recurvoides* ex gr. *canningensis* (F)
5310 ft	top *Lagena hauteriviana hauteriviana* (F)
5426 ft	top *Labrospira goodenoughensis* (F)
5610 ft	top *Lenticulina saxocretacea* (F)

Lithology:

The interval is characterized by the occurrence of dark-gray to almost black, laminated, non-calcareous and occasionally micromicaceous, mudstone. Larger fragments contain isolated, coarse, well-rounded quartz grains that sometimes do not have high sphericity. Mudstone and sandy conglomeratic lithofacies occur locally. The shallowest five samples also contain fragments of highly calcareous, reddish brown mudstone that is shot through with white anastomosing veins. Lighter gray, carbonaceous and micromicaceous sandy mudstones, which grade to poorly sorted argillaceous sandstones, are present in variable proportions in all samples. Pyrite is ubiquitous and occurs as crystalline lumps, small spheres, small discoids and 'sticks'. Framboidal pyrite lumps are mostly rare, but a slight increase was noted in the deepest three samples. Dark-green, oviform pellets/peloids are common in the deepest sample at 5780 ft.

Palynology:

Palynomorphs in the interval have good to excellent preservation, with dinocysts comprising 52-72% of the palynological assemblage, except in the cuttings sample at 5280-5310 ft where they

comprise 43% of the assemblage. Miospores comprise both water and wind-borne pollen and spores that were transported to the marine depositional site. Common specimens of palynomorphs that characterize palynomorph Zone K2 (Valanginian) are interpreted to be reworked in this interval**.**

Micropaleontology:

The rich and diverse foraminiferal assemblages are dominated by dark-brown, fine-grained agglutinated foraminifera, particularly species of *Recurvoides*, with diverse but individually sparse, calcareous benthonic foraminifera. A few nassellarian radiolaria also occur, plus two occurrences of possible planktonic foraminifera, a single specimen of *Hedbergella aptiana* at 5310 ft, and a specimen tentatively assigned to *Hedbergella tushepsensis* at 5580 ft. Megaspores and 'round browns' occur throughout.

Allowing for taxonomic revisions, the entire assemblage is comparable with those in adjacent wells and published studies in Alaska and Arctic Canada (Wall, 1983; Fowler & Braun, 1993; Mickey *et al*.,2006). The highest occurrence of *Lagena hauteriviana hauteriviana* may indicate an age no younger than Middle Barremian. There is no available publication of a well-calibrated microfauna that would allow recognition of Hauterivian strata in this well.

The most common, age-diagnostic and correlative agglutinated foraminiferal species are listed above. Other frequently occurring taxa include *Gaudryina tailleuri*, *Haplophragmoides lobatoloculare*, and undifferentiated specimens of *Recurvoides*. Very few of the species are considered to be adapted to filter feeding, and most are mobile, epilithic morphotypes. Many of the specimens of agglutinated foraminifera are either nearly opaque, deformed or broken, which often precludes their confident identification, and such specimens are recorded as 'indet frag/crushed agglut forams' on the range charts.

Approximately 20 species of calcareous benthonic foraminifera were recognised, although many occur in only a few samples. The scattered occurrences of taxa that occur regularly in the underlying Valanginian mudstones suggests that many of the calcareous benthonic foraminifera are reworked in this interval. A distinct, and possibly *in situ*, sub-assemblage occurs below 5610

ft which comprises *Lenticulina saxocretacea, Lenticulina macrodisca, Lenticulina muensteri* and *Conorboides walli.*

Paleoenvironment:

Marine, bathyal water depths with near normal conditions of salinity and dysoxic to oxic conditions at the sea bed. Some of the fragments of dark gray mudstone have the appearance of a diamicton. The sandy beds are probably basin-floor, turbidite fan deposits. The pellets/peloids recovered from the deepest sample may indicate a starved horizon.

Stratigraphic comments:

The underlying interval at 5790 ft is dated as Valanginian, indicating the presence of a significant stratigraphic break at the base of this interval which marks the base of the 'Brookian Sequence', also known as the Lower Cretaceous Unconformity. The interval is a highstand deposit with little sequential change to indicate variation in depositional regime.

5790-6570 ft: *Gochteodinia judilentinae* Zone K2 (Valanginian) [2]

Diagnostic palynomorphs:

5790 ft	top *Batioladinium micropodum* (D) Zone K2 and older marker
	top *Gochteodinia villosa* (D) Zone K3 and older marker
	top *Muderongia* cf. *M. simplex sensu* Brideaux & McIntyre 1980 (D) Zone K2 and older marker
	top *Nelchinopsis kostromiensis* (D) Zone K2 and older marker
	top *Oligosphaeridium* sp. GE of Brideaux & McIntyre 1980 (D) Zone K2 and older marker
	top *Oligosphaeridium vasiforme* (D) Zone K2 and older marker
	top *Paragonyaulacysta borealis* (D) Zone K2 and older marker
	top *Stiphrosphaeridium dictyophorum* (D) Zone K2 and older marker
	top *Tubotuberella uncinata* (D) Zone K2 and older marker
5820 ft	top *Cymososphaeridium validum* (D) Zone K2 and older marker
	top *Egmontodinium expiratum* (D) Zone K2 and older marker

5850 ft top *Gochteodinia judilentinae* (D) Zone K2 and older marker

5880 ft top *Oligosphaeridium diluculum* (D) Zone K2 and older marker

5910 ft top *Apteodinium spongiosum* (D) Zone K2 and older marker

5990 ft top *Parvocavatus spinosum* (D) Zone K2 and older marker

Diagnostic foraminifera:

5850 ft top *Cribrostomoides infracretaceous* (F)

6050 ft top *Saracenaria valanginiana* (F),

top common *Labrospira goodenoughensis* (F)

6080 ft top *Epistomina caracolla anterior* (F)

6110 ft top *Uvigerinammina* sp.1 of Wall 1983 (F),

top common to abundant *Cribrostomoides infracretaceous* (F)

Lithology:

This interval can be subdivided into four sections: an upper mudstone; an upper sandstone; a middle mudstone; and a lower sandstone.

The upper mudstone occurs in the top two samples and consists of grey to brown, occasionally micromicaceous, variably sandy, mudstone together with dark gray, mudstone with coarse sand grains.

The upper sandstone which is picked in the cuttings samples from 5850 ft to 6050 ft is gray to white, quartzose, medium to fine-grained, occasionally with coarse 'floating' grains, well-sorted, hard, occasionally loose, and with a white argillaceous matrix. Crystalline pyrite is common to abundant throughout and pyrite 'sticks' are relatively rare. This section is attributed to the 'Burger Sandstone' (Craig & Sherwood, 2004; Sherwood, 2012).

The underlying section, from 6050 ft to 6410 ft, is composed of light-grayish brown to brown, silty, occasionally pyritic mudstone, grading to fine-grained, argillaceous sandstone which is composed of varicoloured grains. The mudstone becomes noticeably less sandy below 6290 ft. Pyrite 'sticks' and crystalline pyrite become abundant below 6290 ft and are accompanied by small pyrite spheres.

The lower sandstone is picked from 6410 ft to the base of the interval at 6560 ft. Compared to the upper sandstone it is much more argillaceous and micromicaceous. Fragments of a relatively clean sandstone occur at 6440 ft and 6470 ft.

Palynology:

Palynomorphs in the interval have good to excellent preservation. Dinocysts comprise 52-77% of the palynological assemblage in the upper part of the interval from 5790-6500 ft, decreasing in the lower part to 47-49% from 6500-6570 ft. Miospores comprise both water and wind-borne pollen and spores that were transported to the marine depositional site. Reworked Late Jurassic palynomorphs occur sporadically in this interval and mostly represent Kimmeridgian to early Volgian Zones J7 and J8.

Micropaleontology:

The upper mudstone contains indeterminate fragments of agglutinated foraminifera, a few *Lenticulina muensteri* and a specimen of *Geinitzinita arctocretacea*.

Recovery from the 'Burger Sandstone' was sparse but diverse. The agglutinated foraminifera are composed of white specimens of *Glomospira subarctica*, *Glomospira variabilis* and *Glomospirella arctica*. White, coarse-grained and occasionally large *Haplophragmoides* occur below 5910 ft. The most characteristic feature is the occurrence of calcareous tubes which are attributed to *Ditrupa*.

The microfauna from the middle mudstone is dominated by a rich and diverse assemblage of agglutinated foraminifera with a diverse and consistently occurring assemblage of calcareous benthonic foraminifera. *Inoceramus* debris and shelly fragments occur in every sample below 6140 ft. In addition to the listed diagnostic taxa, *Bathysiphon vitta*, *Glomospira subarctica*, *Recurvoides* ex gr. *canningensis* and undifferentiated *Recurvoides* occur in all samples, together with regular occurrences of the calcareous benthonic foraminifera *Saracenaria pyramidata*, *Lenticulina muensteri*, *Astacolus strombecki* and undifferentiated fragments of *Dentalina*/ *Nodosaria*. Most of the scattered occurrences of these taxa in the overlying late Hauterivian to Barremian, 'Pebble Shale Unit' probably represent reworking. In the highly pyritic mudstones

below 6290 ft, the microfauna is dominated by *C. infracretaceous* and a suite of small finely agglutinated species of *Trochammina, Gaudryina* and *Haplophragmoides cushmani*.

In the lower sandstone section, calcareous benthonic foraminifera are sparse and the agglutinated foraminifera are reduced in numbers and diversity. Coarse-grained *Haplophragmoides*, similar to those seen in the lower part of the 'Burger Sandstone', reappear between 6500 ft and 6500 ft. *Ditrupa* tubes are absent.

Paleoenvironment:

The limited microfauna and the worm tubes in the 'Burger Sandstone' are consistent with relatively shallow marine conditions and inner to middle neritic water depths. For the underlying thick mudstone, a deep, outer neritic to upper bathyal environment with relatively tranquil conditions is suggested by the rich and diverse microfaunas, but with strongly dysoxic conditions within the substrate, particularly for the section below 6290 ft. Deposition of the lower sandstone probably took place in a similar deep-water environment.

Stratigraphic comments:

The lower sandstone is probably a lowstand fan deposit overlain by a transgressive sequence of deep marine mudstones which are separated from the overlying 'Burger Sandstone' by a sequence boundary marking the start of a regressive sequence. This sequence is terminated upwards by a return to transgressive conditions marked by the mudstone cap. The presence of pellets/peloids at the upper boundary of the interval suggests prolonged sediment starvation.

6570-6800 ft (TD): *Horologinella spinosigibberosa* Zone K1 (Berriasian) [3]

Diagnostic palynomorphs:

6570 ft	top *Paragonyaulacysta capillosa* (D) Zone K1 and older marker
	top *Priodinium alaskense* (D) Zone K1 and older marker
6630 ft	top *Atopodinium prostatum* (D) Zone K1 and older marker
	top *Horologinella spinosigibberosa* (D) Zone K1 and older marker

Diagnostic foraminifera:

6570 ft top *Cribrostomoides canui* (F)

6630 ft top *Pseudolamarckina* spp. (F)

6660 ft top regular occurrences *Schuleridea* spp. (O)

6690 ft top *Ammobaculites alaskensis* (F)

Lithology:

The upper part of the interval is very sandy. In the underlying samples, the mudstones are dominated by dark gray colors in contrast to the brownish gray colors of the overlying interval. Pyrite is common and the small 'sticks' occur in floods below 6630 ft.

Palynology:

Palynomorphs in the interval have good to excellent preservation, with dinocysts comprising 46-53% of the assemblage. Miospores comprise both water and wind-borne pollen and spores that were transported to the marine depositional site.

Micropaleontology:

The microfaunal change at the top of this interval is marked by the appearance and sustained occurrence of frequent to common *C. canui* and the almost complete disappearance of *C. infracretaceous*. Only agglutinated foraminifera and *Ditrupa* tubes occur in the sand-rich samples at 6570 ft to 6600 ft. From 6300 ft to the base of the well at 6800 ft, the agglutinated foraminifera are composed of diverse and moderately abundant assemblages dominated by *C. canui, L. goodenoughensis, B. vitta* and species of *Saccammina* and *Recurvoides*. The only consistently present calcareous benthonics are *L. muensteri, Pseudolamarckina* and small polymorphinids. Other notable events in this interval are the regular occurrences of ostracoda below 6660 ft and the occurrence of frequent numbers of species of *Ammobaculites* and small *Gaudryina* below 6690 ft.

Paleoenvironment:

Marine, outer neritic to shallow upper bathyal water depths with strongly dysoxic conditions within the substrate. Some of the ostracoda have eye tubercles which may indicate that deposition was within the photic zone.

Stratigraphic comments:

If the *Ditrupa* tubes recovered at the top of the interval are *in situ*, the interval would appear to be a regressive sequence. There may be a sequence boundary at the top of this interval, below the lowstand fan sandstone, at the base of the overlying Valanginian interval.

4. LITHOSTRATIGRAPHIC PICKS: BURGER J (OCS-Y-2321)

The following lithostratigraphic picks are based on ages assigned to the well section in the present study. Depths are based on the observations of cutting samples and are approximate because well logs were not provided for the study

1512 FT: LOWER BROOKIAN SEQUENCE (top not seen)

1512 ft: Nanushuk Group

3210 ft: Torok Formation

5280 FT: RIFT SEQUENCE

5280 ft: Pebble Shale Unit

5790 ft: Kuparuk equivalent

6800 ft: Total Depth

5. SAMPLES ANALYSED, BURGER J (OCS-Y-2321)

No.	Sample interval	Paleo	No	Sample interval	Paleo	No	Sample interval	Paleo
1	1,512-1,530	M P	35	4,560-4,590	M P	69	5,850-5,880	M P
2	1,590-1,620	M P	36	4,650-4,680	M P	70	5,880-5,910	M P
3	1,680-1,710	M P	37	4,740-4,770	M P	71	5,910-5,940	M P
4	1,770-1,800	M P	38	4,830-4,860	M P	72	5,960-5,970	M P
5	1,860-1,890	M P	39	4,920-4,950	M P	73	5,990-6,000	M P
6	1,950-1,980	M P	40	4,980-5,010	M P	74	6,020-6,050	M P
7	2,040-2,070	M P	41	5,010-5,040	M P	75	6,050-6,080	M P
8	2,130-2,160	M P	42	5,040-5,070	M P	76	6,080-6,110	M P
9	2,220-2,250	M P	43	5,070-5,100	M P	77	6,110-6,140	M P
10	2,310-2,340	M P	44	5,100-5,130	M P	78	6,140-6,170	M P
11	2,400-2,430	M P	45	5,130-5,160	M P	79	6,170-6,200	M P
12	2,490-2,520	M P	46	5,160-5,190	M P	80	6,200-6,230	M P
13	2,580-2,610	M P	47	5,190-5,220	M P	81	6,230-6,260	M P
14	2,670-2,700	M P	48	5,220-5,250	M P	82	6,260-6,290	M P
15	2,760-2,790	M P	49	5,250-5,280	M P	83	6,290-6,320	M P
16	2,850-2,880	M P	50	5,280-5,310	M P	84	6,320-6,350	M P
17	2,940-2,963	M P	51	5,310-5,340	M P	85	6,350-6,380	M P
18	3,030-3,060	M P	52	5,340-5,370	M P	86	6,380-6,410	M P
19	3,120-3,150	M P	53	5,370-5,400	M P	87	6,410-6,440	M P
20	3,210-3,240	M P	54	5,400-5,423	M P	88	6,440-6,460	M P
21	3,315-3,330	M P	55	5,426-5,460	M P	89	6,470-6,480	M P
22	3,390-3,420	M P	56	5,460-5,490	M P	90	6,500-6,510	M P
23	3,480-3,510	M P	57	5,490-5,520	M P	91	6,530-6,540	M P
24	3,570-3,600	M P	58	5,520-5,550	M P	92	6,560-6,570	M P
25	3,660-3,690	M P	59	5,550-5,580	M P	93	6,570-6,600	M P
26	3,750-3,780	M P	60	5,580-5,610	M P	94	6,600-6,630	M P
27	3,840-3,870	M P	61	5,610-5,640	M P	95	6,630-6,660	M P
28	3,930-3,960	M P	62	5,640-5,670	M P	96	6,660-6,690	M P
29	4,020-4,050	M P	63	5,670-5,700	M P	97	6,690-6,720	M P
30	4,110-4,140	M P	64	5,700-5,730	M P	98	6,720-6,750	M P
31	4,200-4,230	M P	65	5,750-5,760	M P	99	6,750-6,780	M P
32	4,290-4,320	M P	66	5,780-5,790	M P	100	6,780-6,800	M P
33	4,380-4,410	M P	67	5,790-5,820	M P			
34	4,470-4,500	M P	68	5,820-5,850	M P			

Paleo analysis M Micropaleontology
P Palynology

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APPENDIX A: RANGE CHARTS

Micropaleontological range chart in StrataBugs format

Plot showing lithostratigraphy, age, palynological zonal intervals and micropaleontological assemblages; taxa arranged by highest occurrence (tops) within major groups

Palynological range chart in StrataBugs format

Plot showing lithostratigraphy, age, palynological zonal intervals and micropaleontological assemblages; taxa arranged by highest occurrence (tops) within major groups

Palynological and micropaleontological range charts were also supplied digitally in excel format.

Well Name : BURGER J (OCS-Y-2321)

Interval Various
Scale : 1:5000
Chart date: 16 February 2016

Micropaleontological chart
prepared by Paul Connell for Bujak Research International
Chukchi Sea

Jonathan Bujak
UK

Text Keys
*1 Absolute abundance (100mm=200 counts)

Well Name : BURGER J (OCS-Y-2321)

Interval Various
Scale : 1:5000
Chart date: 17 February 2016

Palynological chart
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