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RESERVOIR CHARACTERIZATION STUDY: POROSITY AND PERMEABILITY OF 148 TERTIARY TO MISSISSIPPIAN AGE OUTCROP SAMPLES, EAST-CENTRAL BROOKS RANGE FOOTHILLS AND NORTH SLOPE, ALASKA

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Reservoir Characterization Study: Porosity and Permeability of 148 Tertiary to Mississippian Age Outcrop Samples, east-central Brooks Range Foothills and North Slope, Alaska

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Abstract

This reservoir characterization pilot study (148 samples) is based on the Division of Geological & Geophysical Surveys (DGGS) surface geologic mapping (1987–2003), facies analysis, measured stratigraphic sections, regional stratigraphic correlations, petrography, porosity and permeability data, and limited subsurface data. The sample suite is from the North Slope and Brooks Range foothills belt, and addresses 11 siliciclastic rock units and one carbonate unit. Data yield critical reservoir characteristics and petroleum-resource information relevant to oil exploration for Prudhoe Bay satellite fields, new play-type evaluations, and surface and subsurface stratigraphic correlations.

The stratigraphy sampled and corresponding ages include: Tuluvak Formation (Turonian to Coniacian), Schrader Bluff Formation (Coniacian to Maestrichtian), Nanushuk Formation (Albian to Cenomanian), Gilead sandstone (Albian to Cenomanian), Torok Formation (Albian), Fortress Mountain Formation (Albian), Cobblestone Sandstone (Albian), Okpikruak (Berriasian to Barremian), Karen Creek Sandstone (Lower Triassic), Otuk Formation (Triassic and Jurassic), Siksikpuk Formation (Permian), and Lisburne Limestone (Carboniferous).

Outcrop samples are from the Brookian, Beaufortian, and Ellesmerian sequences; part of the parautochthonous Paleozoic and Mesozoic mountain front and foothills belt. The foreland basin succession (Brookian) lies north of the Brooks Range fold-and-thrust belt, and progrades north, onlapping the south flank of the Beaufort sill, which separates the Colville Basin from the Canada Basin in the Arctic Ocean. Stratigraphy is part of the 600-mi-long and 30- to 220-mi-wide Colville Basin. To the north, in the subsurface, these strata form the reservoir and hydrocarbon source rocks for Prudhoe Bay and its satellite fields.

Porosity and Klinkenberg permeability data range from the relatively high Tuluvak sandstone (8 to 19 percent and 0.5 to 8,000 millidarcy [mD]), Nanushuk (3 to 14 percent and 0.005 to 247 mD), Gilead sandstone (5 to 6 percent and 0.001 mD), Fortress Mountain (3 to 8 percent and 0.1 to 12 mD), Cobblestone Sandstone (2 percent and 0.001 mD), to the relatively low Lisburne Limestone (1.4 to 2.8 percent and 0.1 to 0.4 mD).

Introduction

This reservoir characterization pilot program analyzed 148 outcrop samples during the 1999–2002 geologic mapping and stratigraphy projects in the Brooks Range Foothills and North Slope. Hundreds of samples were collected from the Sagavanirktok, Philip Smith Mountains, Chandler Lake, and Umiat quadrangles. The 148 samples selected for porosity, permeability, and petrography are representative of the targeted rock units. The total number of samples collected and analyzed for petrophysics was limited by time and budget constraints.

This program was funded by the Division of Oil and Gas, the Division of Geological & Geophysical Sur-

veys, the federal STATEMAP program, and a consortium of oil companies, including Anadarko Petroleum, ConocoPhillips Alaska, Alberta Energy Company, BP Alaska, Exxon-Mobil, and Chevron.

Analyses perfoemed include porosity and permeability (P&P), grain density, grain volume, bulk volume, sample weight, and capacity for flow to nitrogen. Detailed petrography and point counts (400 framework grains per thin section) were completed on 20 thin sections. Additionally, more than 100 thin sections from the P&P sample set were examined. The permeability results are reported as 'air' permeability for all samples. 'Klinkenberg' permeability is also reported for the majority of samples. Samples with only air permeability analytical data are from Core Laboratories (Denver, Colorado). Samples with air permeability and Klinkenberg permeability analyses are from Precision Core Analysis (Denver, Colorado). Analyses are reported in millidarcy units (md) and percent of the total rock volume.

Plug samples were cut into right cylinders, weighed, and analyzed for oil and water saturation using the Dean Stark method. For this method, the plugs were placed in a Dean Stark distillation unit and suspended over boiling toluene. Water and toluene vapors were cooled in a distillation tower and collected in a tube where the water separated from the toluene by its differential density. Extracted oil remained in the toluene. Saturations were calculated using the measured water volume and a gravimetrically derived oil volume. To determine the grain volume, the samples were dried and cleaned, weighed, and injected with helium in individual Coberly–Stevens Boyle's Law porosimeters. Grain density and porosity were also determined for each sample. To assess permeability, nitrogen gas was forced through the samples. Klinkenberg-corrected values for permeability were also determined using the testing parameters during measurement. Sample remnants are archived at the State of Alaska Geologic Materials Center in Eagle River, Alaska.

List of rock units and ages studied

Tuluvak Formation (Turonian to Coniacian)

Schrader Bluff Formation (Coniacian to Maestrichtian)

Nanushuk Formation (Albian to Cenomanian)

Gilead sandstone (Albian to Cenomanian)

Torok Formation (Albian)

Fortress Mountain Formation (Albian)

Cobblestone Sandstone Member of the Fortress Mountain Formation (Albian)

Okpikruak Formation (Berriasian to Barremian)

Karen Creek Sandstone Member of the Otuk Formation (Lower Triassic)

Otuk Formation (Triassic and Jurassic)

Siksikpuk Formation (Permian)

Lisburne Limestone (Carboniferous)

Tuluvak Formation facies analysis

The Upper Cretaceous Tuluvak Formation (Mull and others, 2003) was the original focus of this reservoir characterization study. Consequently, the following addresses this particularly viable reservoir unit.

The Tuluvak Formation combines rocks previously mapped as the Ayiyak Member of the upper part of the Seabee Formation with the overlying Tuluvak Tongue of the Prince Creek Formation (lower part of the Prince Creek Formation). The Tuluvak Formation, as newly designated, is a relatively coherent sandstone package, which crops out discontinuously to a thickness of 590 feet locally, and represents a thickening- and coarsening-up sand package recognizable at seismic scale. The Tuluvak is conformably underlain by the Upper Cretaceous (Cenomanian and Turonian) age Seabee Formation. The Tuluvak is conformably overlain by the Schrader Bluff Formation (Santonian to Maestrichtian age). The Tuluvak

Formation is typically well sorted, chert and quartz-rich, and records deposition in shallow-marine to nonmarine settings, as prodelta, delta-front, coarse-grained lower delta plain and laterally associated shoreface and foreshore beach.

The Tuluvak Formation internal stratigraphic succession is consistently organized in coarsening and thickening-upward cycles, 30 to 80 feet. Three out of four of our measured sections contain marine megafossils (local Inoceramids to 7 inches) or marine indicators in the lower portion of the sections. All four measured sections grade upward into nonmarine coarse siliciclastics and conglomerate. The sections average greater than 90 percent net sand. Basal marine sandstone, where present or observed, is typically tuffaceous, but much less so than the underlying Shale Wall Member of the Seabee Formation. The overlying Schrader Bluff Formation, where present, contains locally abundant tuffaceous sandstone and tuffaceous layers.

To address reservoir characteristics, lateral continuity, facies distribution, and correlation, we measured four stratigraphic sections across some 30 miles of the foothills belt. These four new sections are in the Chandler Lake and Umiat quadrangles, and lie within 25 miles of each other. The Shale Wall Bluff section is 425 feet thick and contains five coarsening- and thickening-upward cycles. The Ayiyak Mesa syncline section, 15 miles south of the Shale Wall Bluff section, is 125 feet thick with evidence of subaerial exposure near its base. The Nanushuk River–May Creek syncline section is 540 feet thick, poorly exposed, organized in six thickening-upward successions, and includes an apparent Glossifungites surface near its base. This section is 11 miles southeast of the Ayiyak Mesa syncline section. The May Creek syncline section is part of an eastern extension of the May Creek syncline structure, and is a 195-foot-thick succession of conglomeratic shoreface deposits capped by coarse fluvial deposits. The May Creek syncline section is 6 miles due east of the Nanushuk River–May Creek syncline section and on the north side of May Creek.

Tuluvak Formation outcrop samples (27) from the central Brooks Range Foothills contain excellent porosity (average ~15 percent) and permeability (0.5–8,000 md), making the Tuluvak a potential exploration objective. Petrographically the Tuluvak framework grains comprise quartz (10 to 70 percent) and chert (15–70 percent) and minor, sedimentary and volcanic lithic grains. Pore filling is typically by quartz overgrowths, with local minor siderite and calcite.

Regionally, the Tuluvak Formation thins and fines eastward. Based on lithologic and stratigraphic similarities to the Tuluvak Formation, very fine sandstone strata of Coniacian age, east of the Sagavanirktok River on the small., unnamed creek that lies between the Ivishak River and the Sagavanirktok River may represent the distal correlative deposits. This interpretation places the Coniacian–Santonian shelf edge in the area of the current Kuparuk and Toolik rivers.

Future reservoir characterization studies

This project will continue in conjunction with the North Slope–Brooks Range Foothills program. The range and scope of sampling, analysis, and integration into the regional geologic framework will be partly a function of industry funding.

Reference cited

Mull, C.G., Houseknecht, D.W., and Bird, K.J., Revised Cretaceous and Tertiary Stratigraphic Nomenclature in the Colville Basin, Northern Alaska, U.S. Geological Survey Professional Paper 1673, Version 1.0, http://pubs.usgs.gov/pp/p1673.

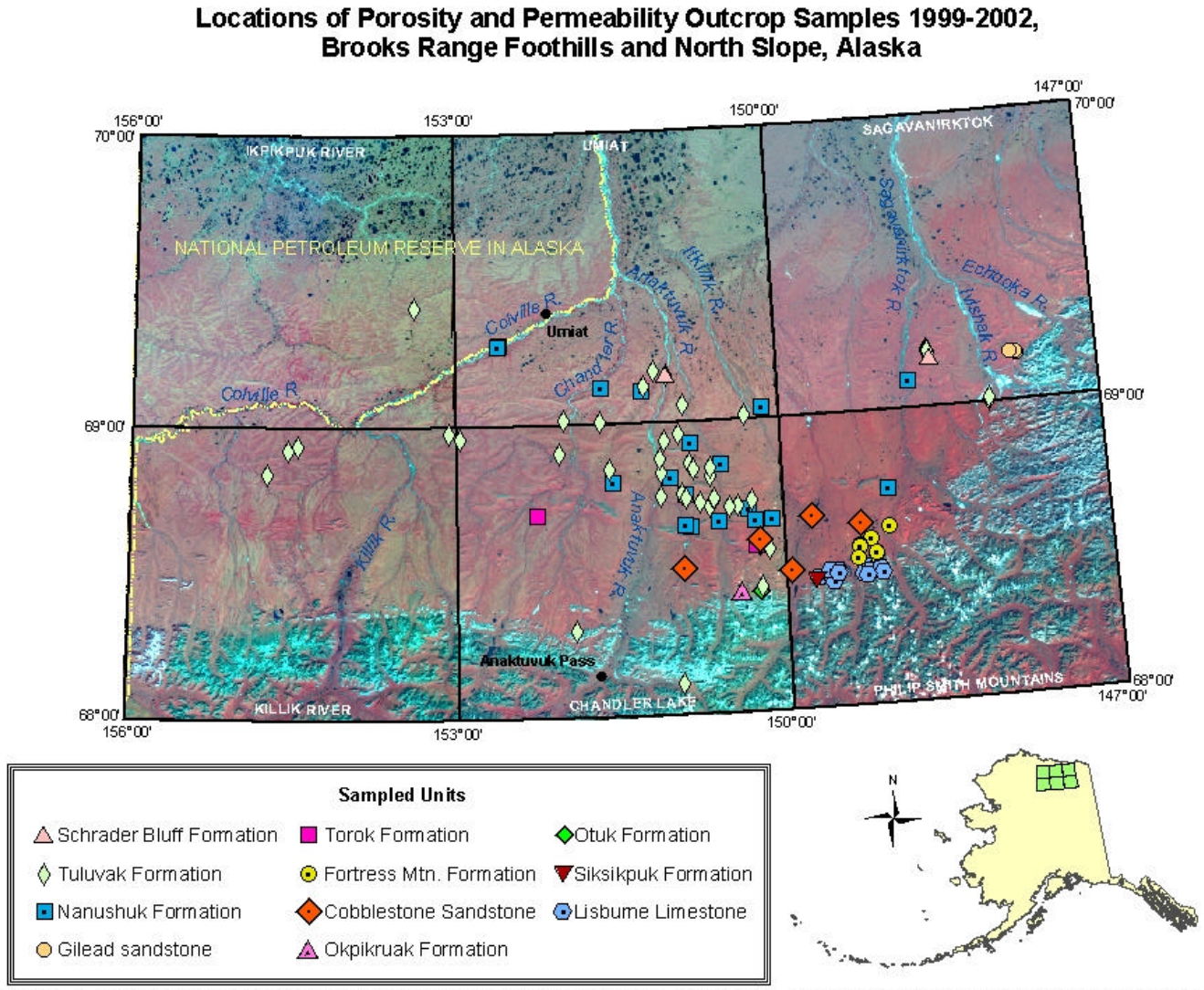

Figure 1. Satellite image showing locations and geologic formations of porosity and permeability samples from 1999-2002, Brooks Range Foothills and North Slope, Alaska.

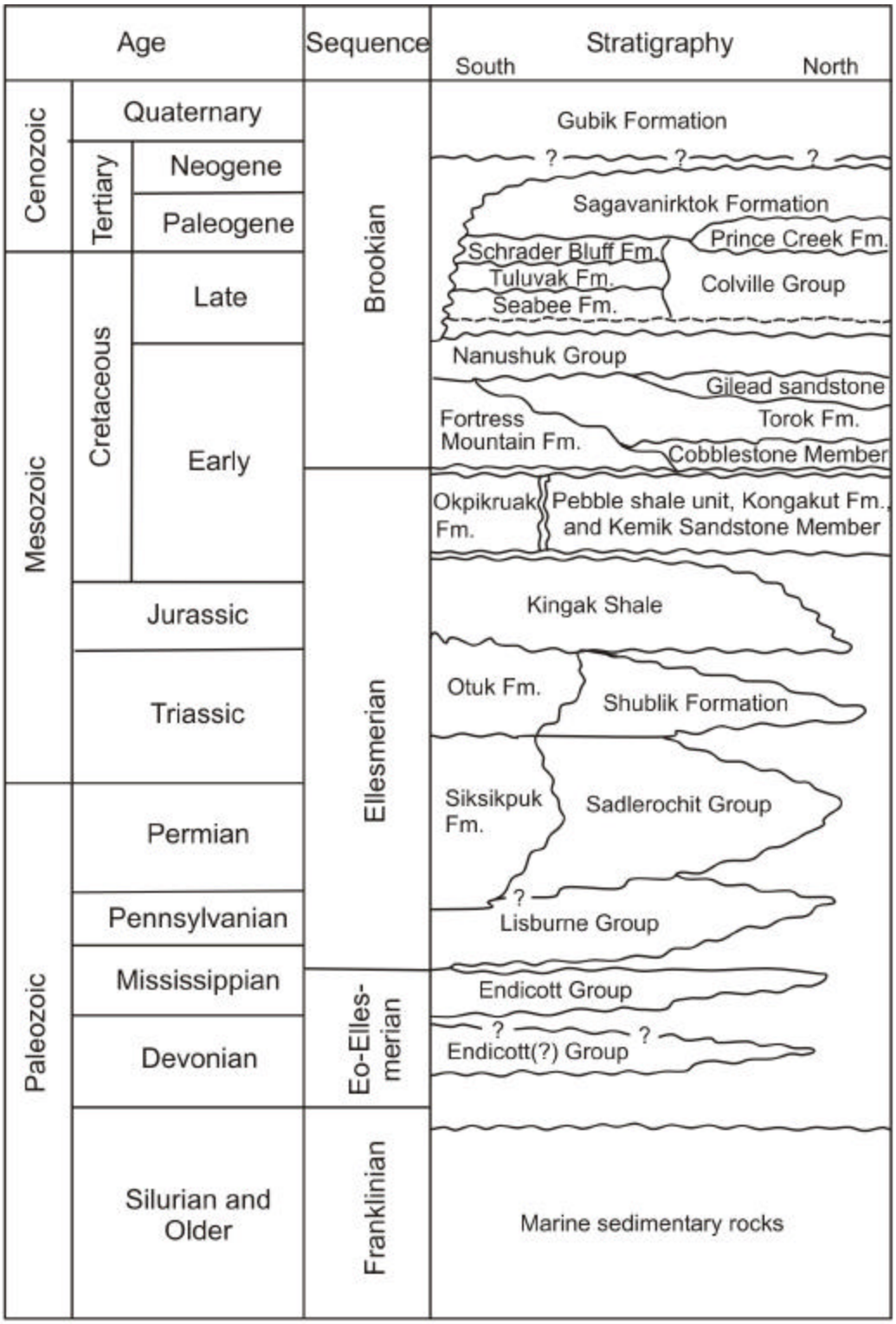

Figure 2. Schematic stratigraphy of the central North Slope, Alaska (modified from Grantz and others, 1988).

Figure 3. Porosity and permeability of outcrop samples from 11 rock units, North Slope, Alaska.

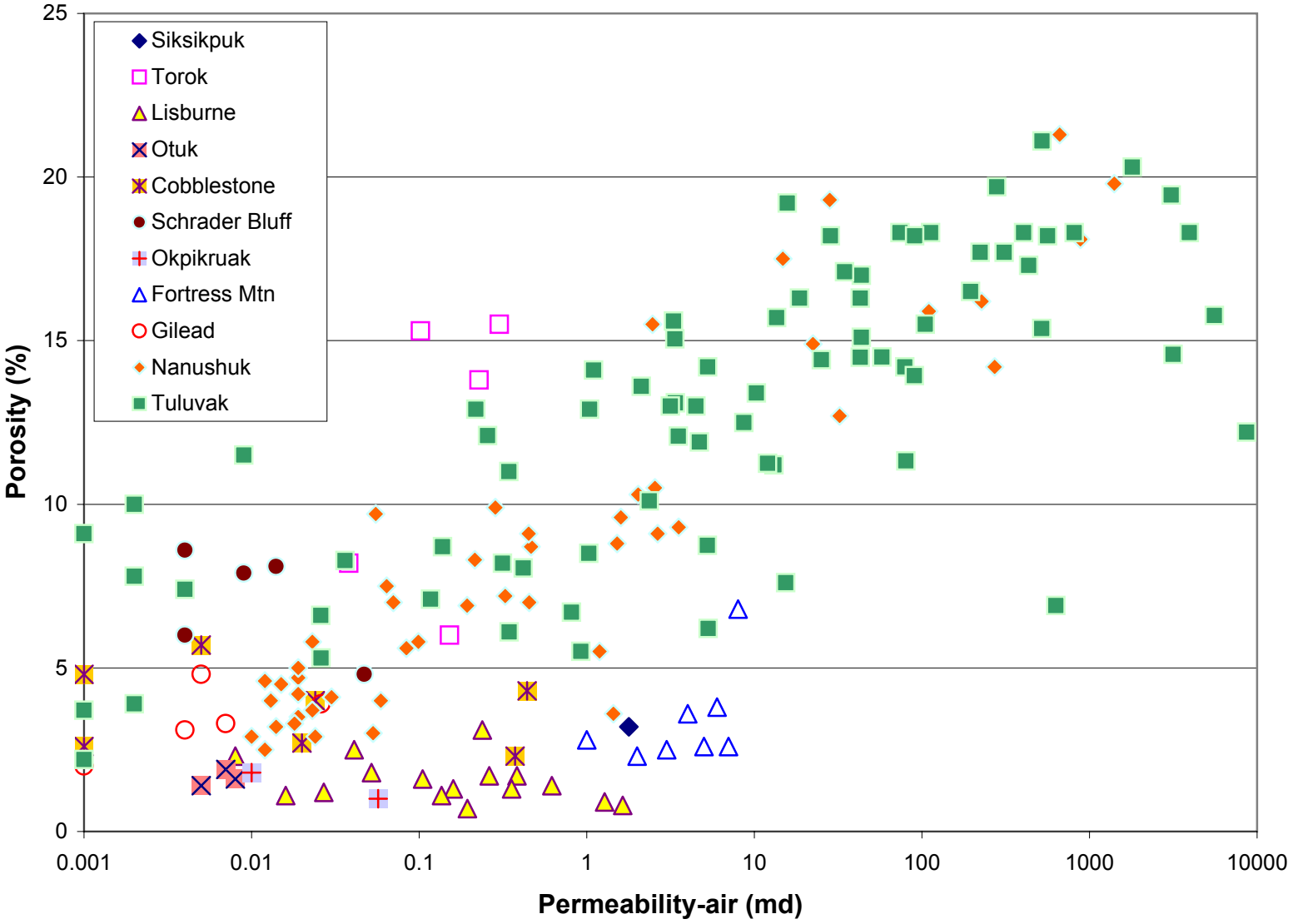

Figure 4. Porosity and permeability of Schrader Bluff Formation outcrop samples, North Slope, Alaska.

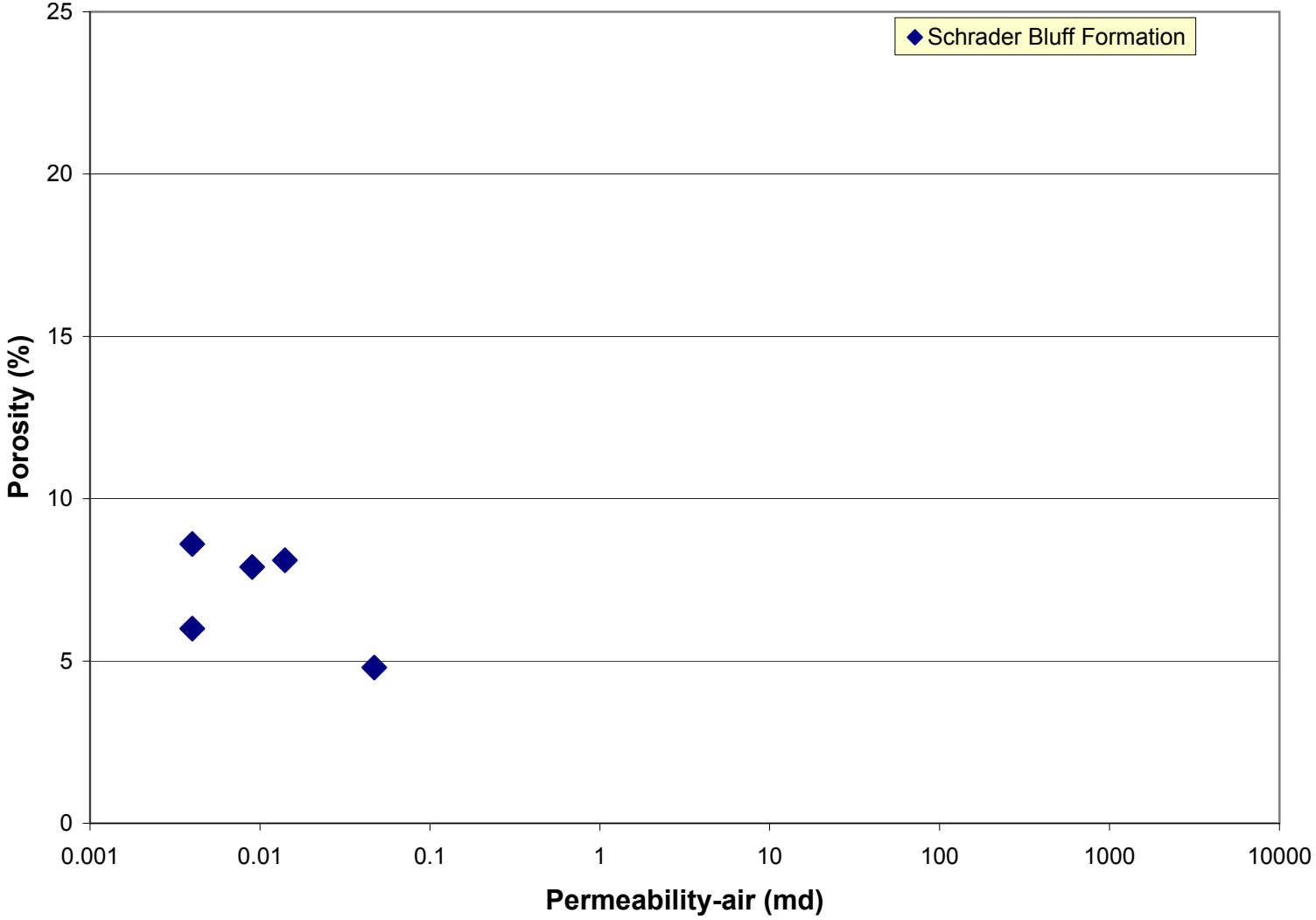

Figure 5. Porosity and permeability of Tuluvak Formation outcrop samples, North Slope, Alaska.

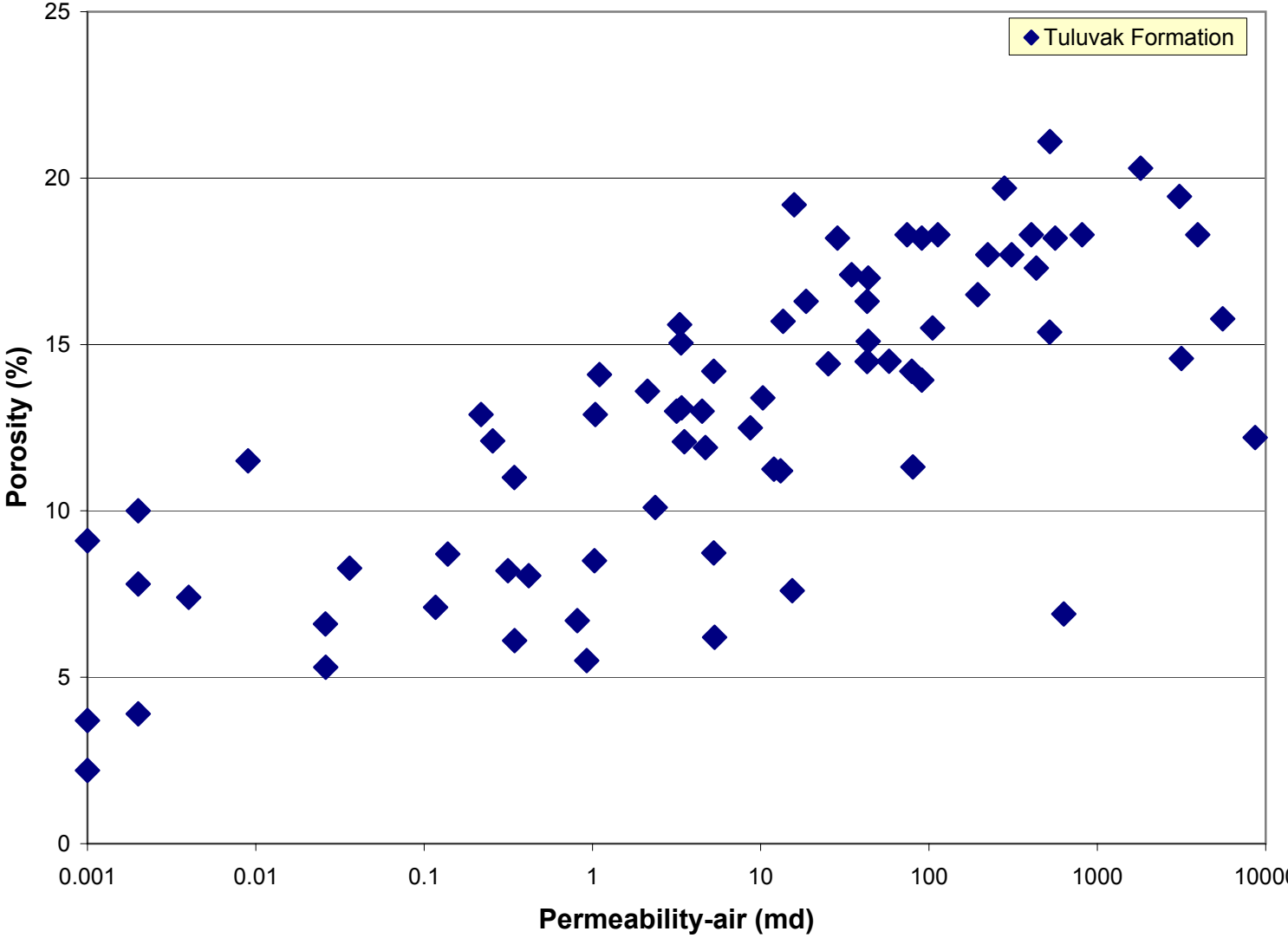

Figure 6. Porosity and permeability of Nanushuk Formation outcrop samples, North Slope, Alaska.

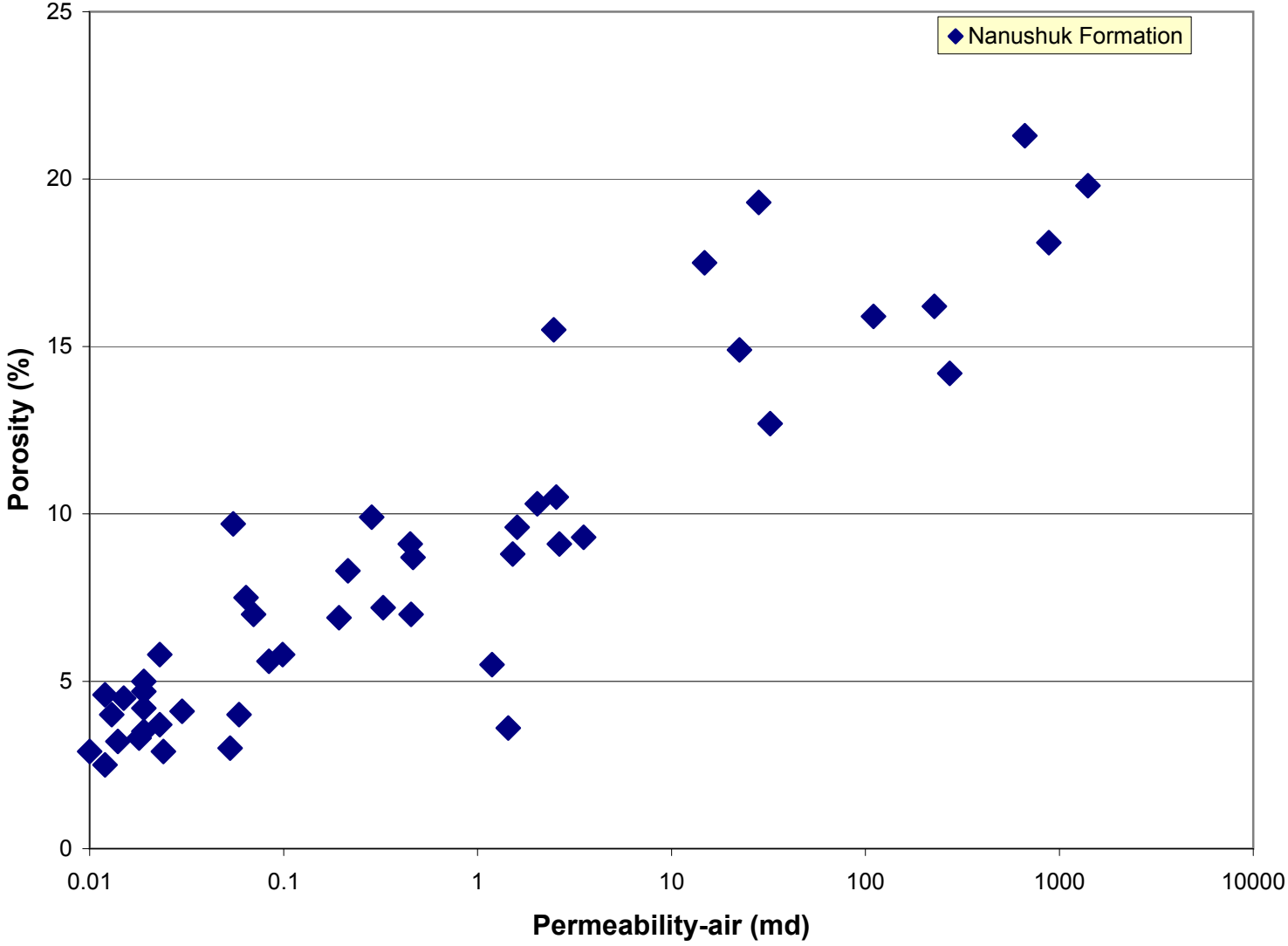

Figure 7. Porosity and permeability of Gilead sandstone outcrop samples, North Slope, Alaska.

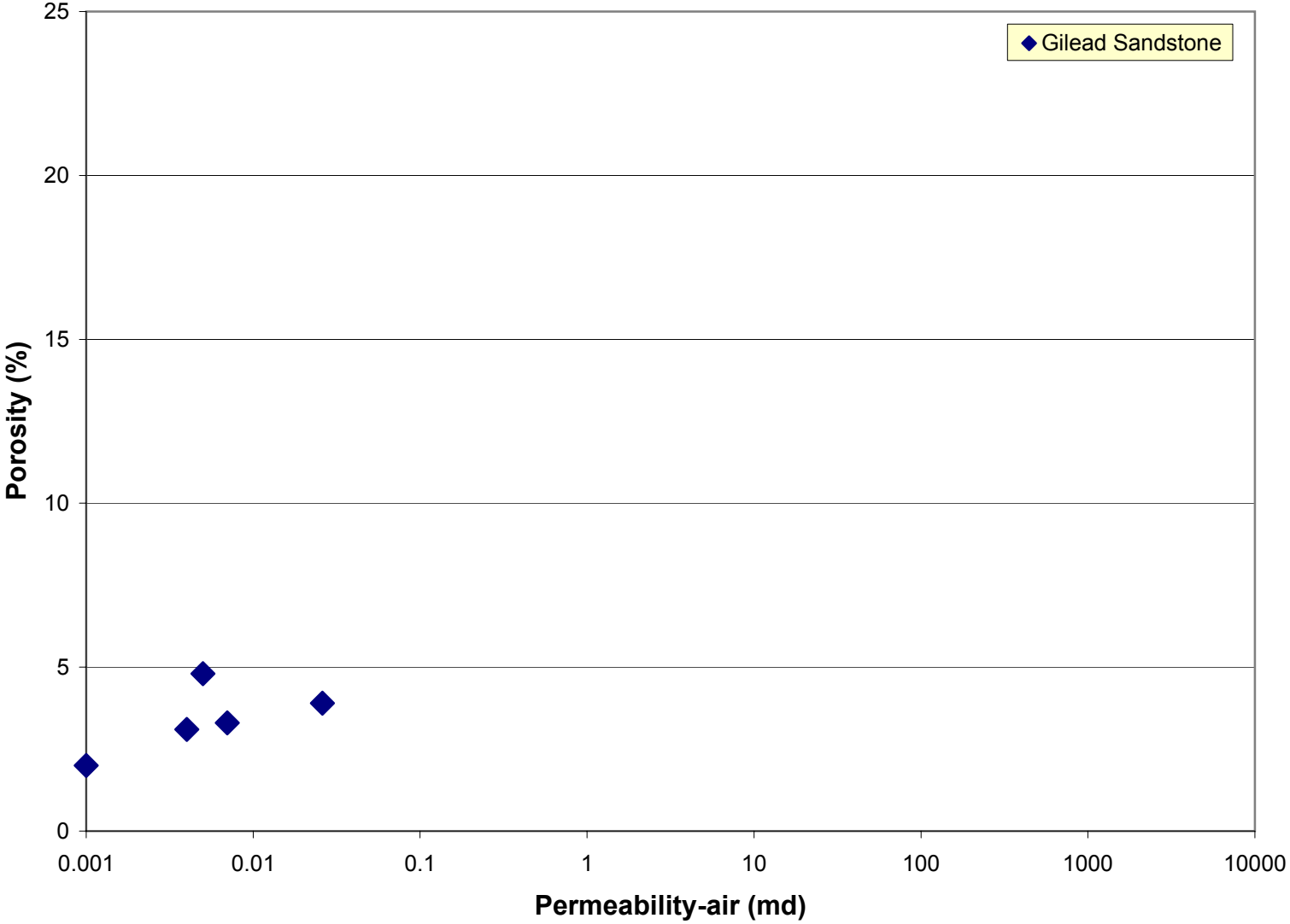

Figure 8. Porosity and permeability of Torok Formation outcrop samples, North Slope, Alaska.

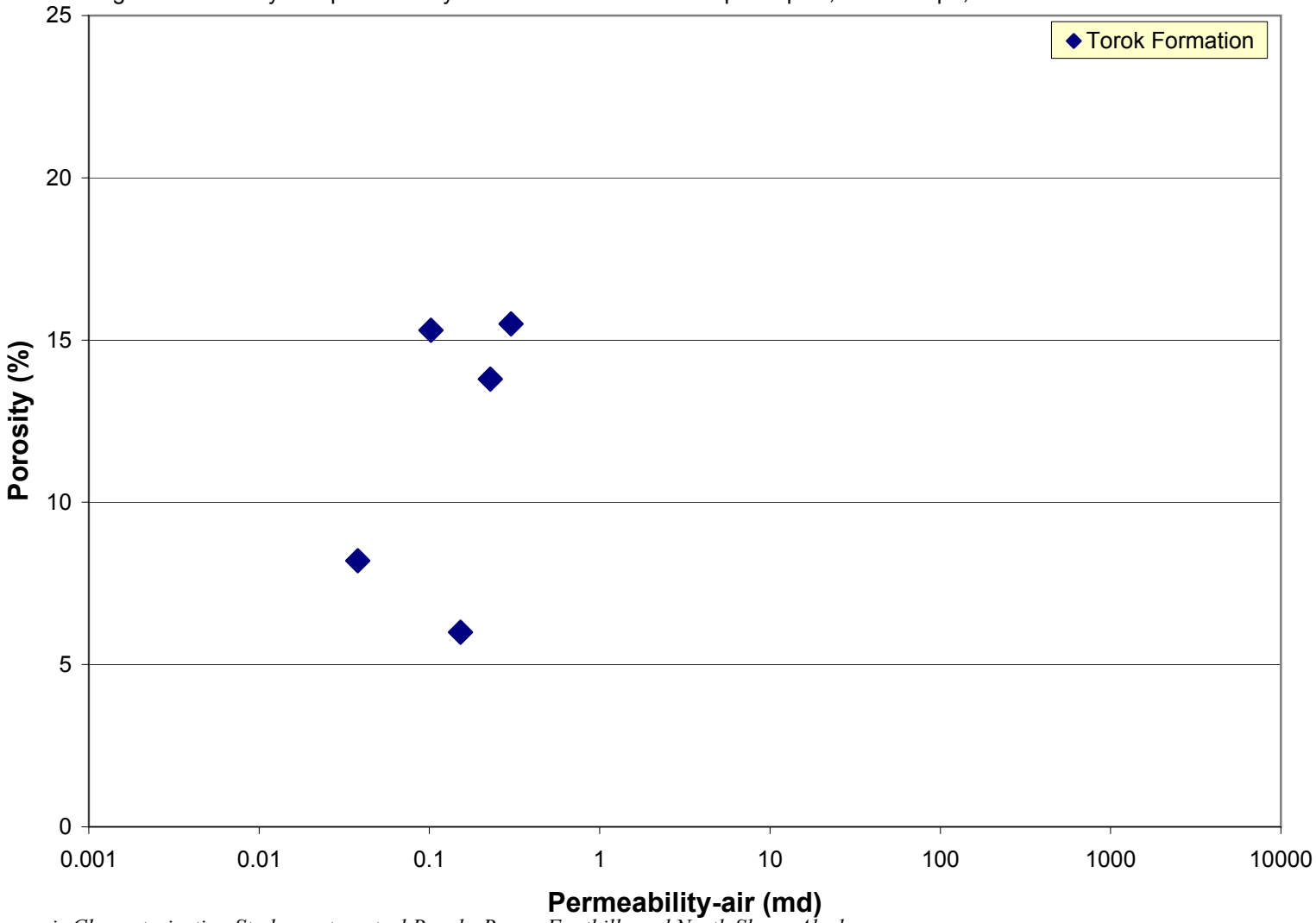

Figure 9. Porosity and permeability of Fortress Mountain Formation outcrop samples, North Slope, Alaska.

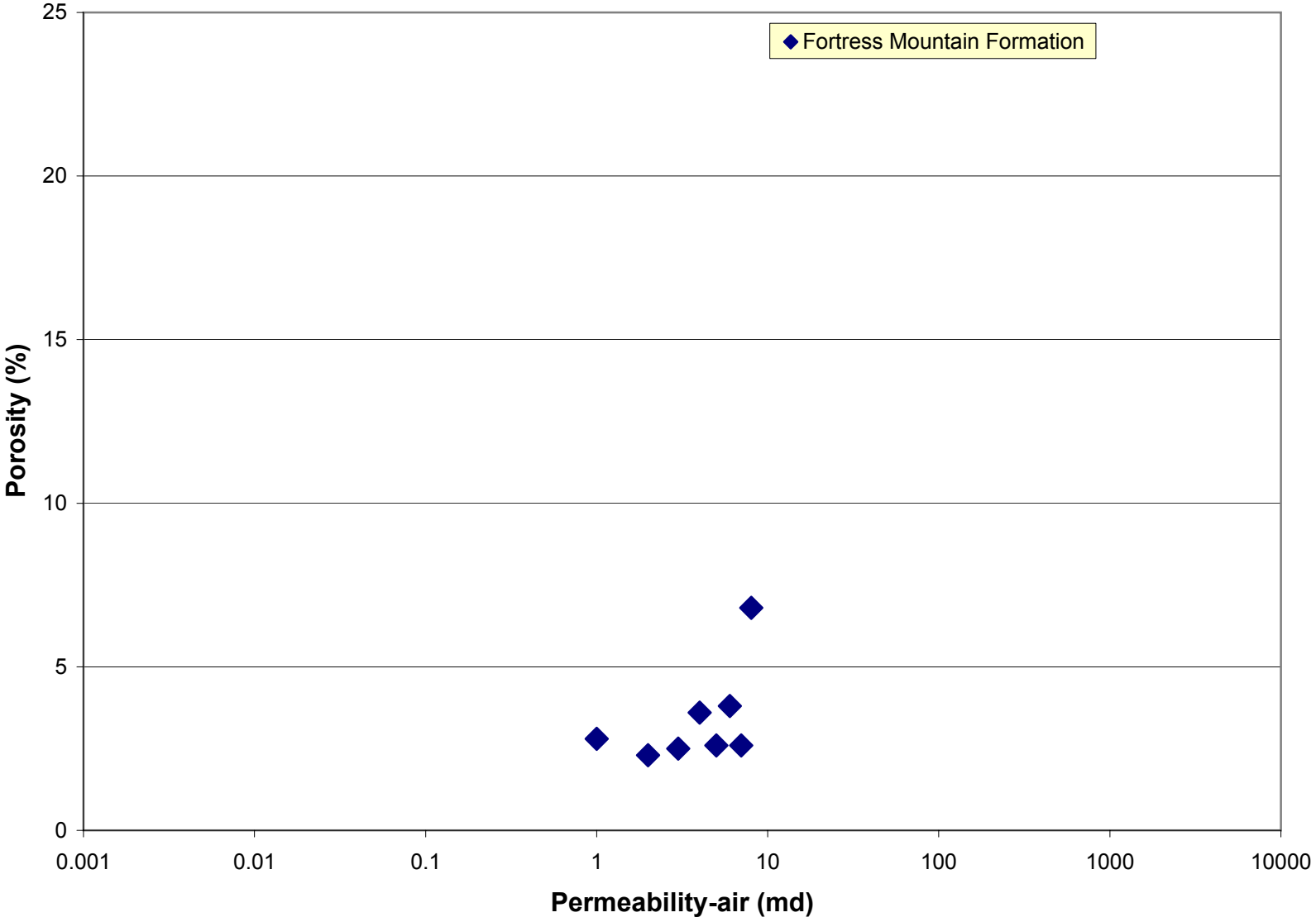

Figure 10. Porosity and permeability of Cobblestone Sandstone outcrop samples, North Slope, Alaska.

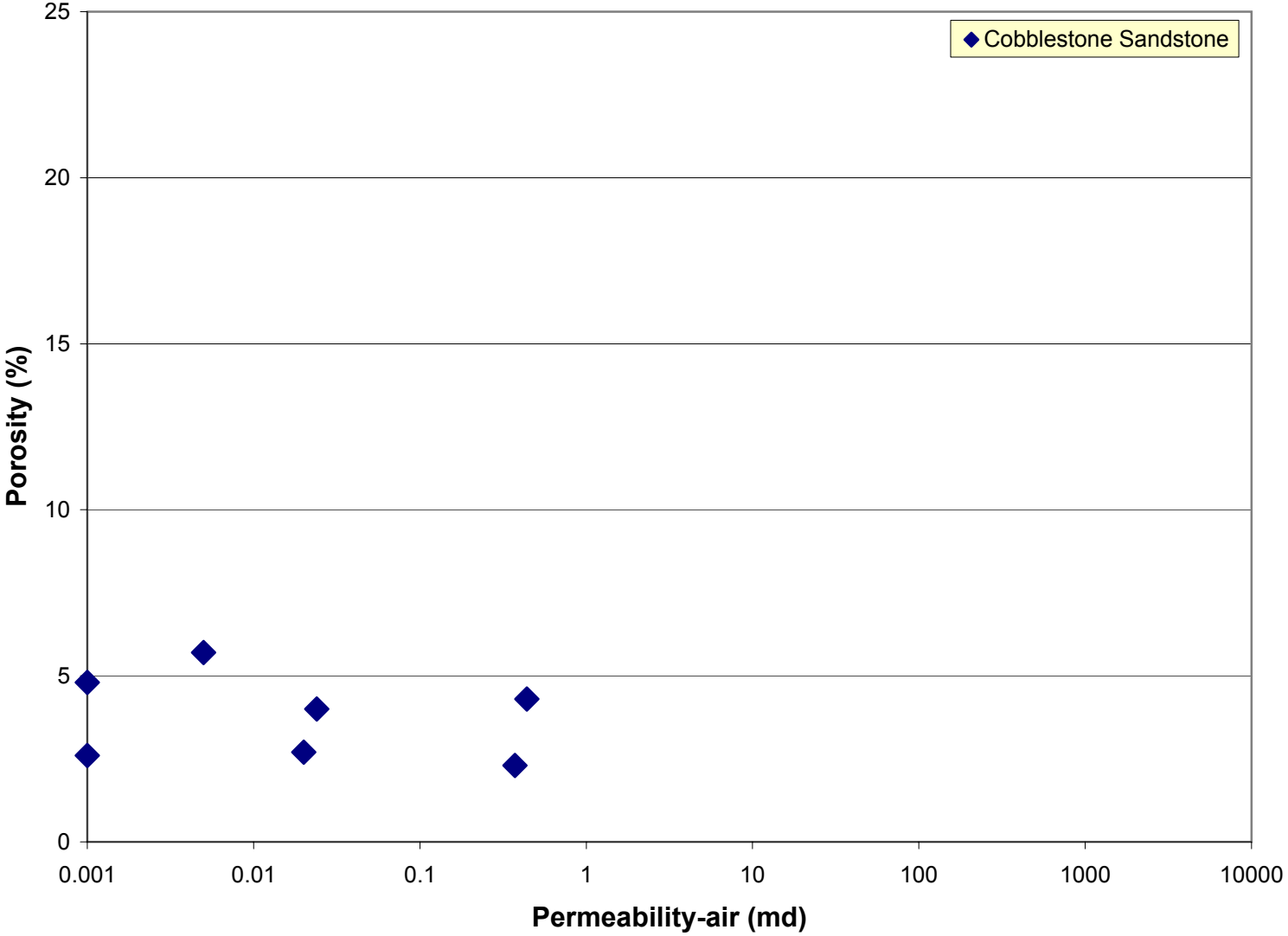

Figure 11. Porosity and permeability of Siksikpuk and Okpikruak Formations from outcrop samples, North Slope, Alaska.

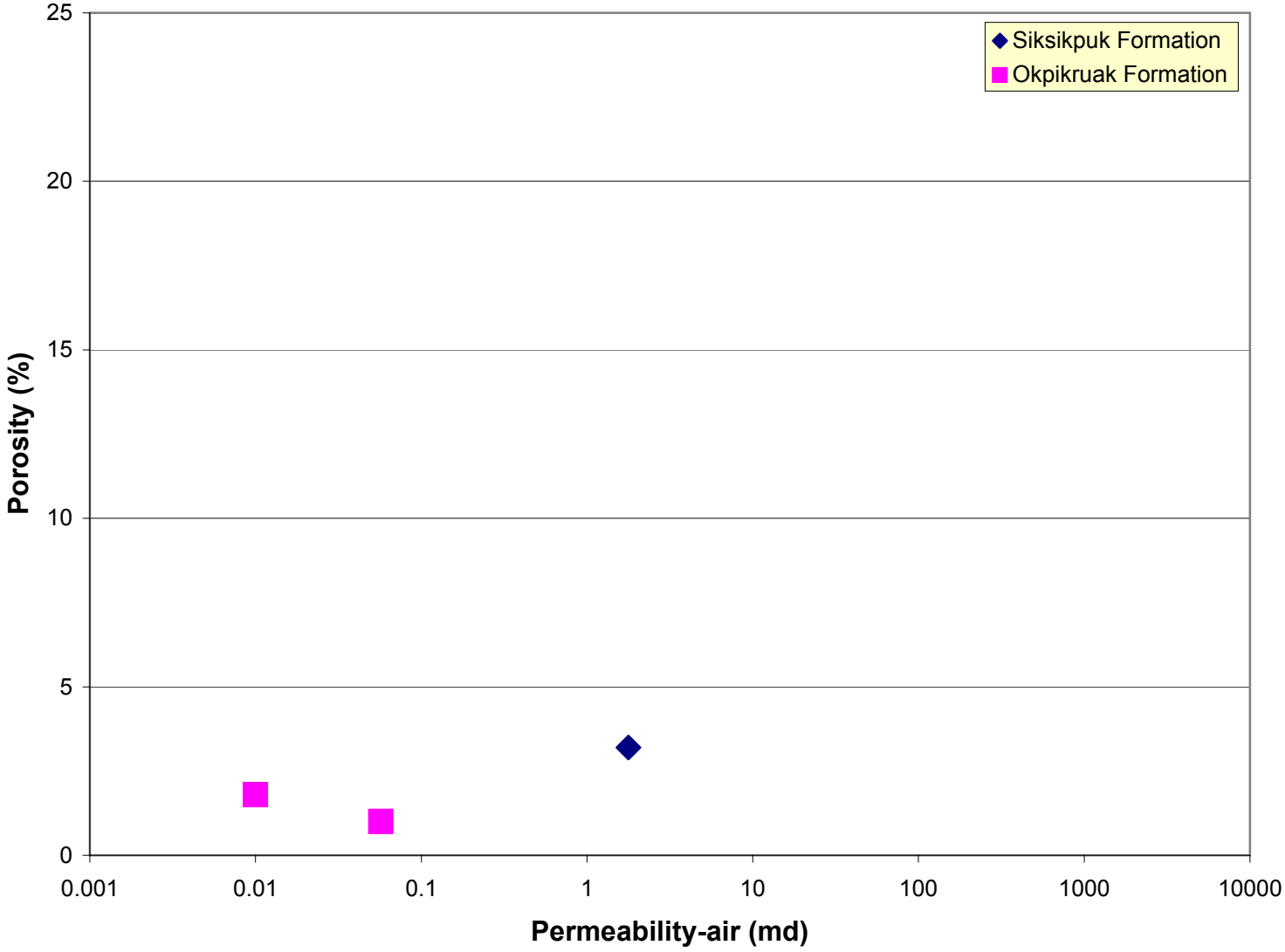

Figure 12. Porosity and permeability of Otuk Formation outcrop samples, North Slope, Alaska.

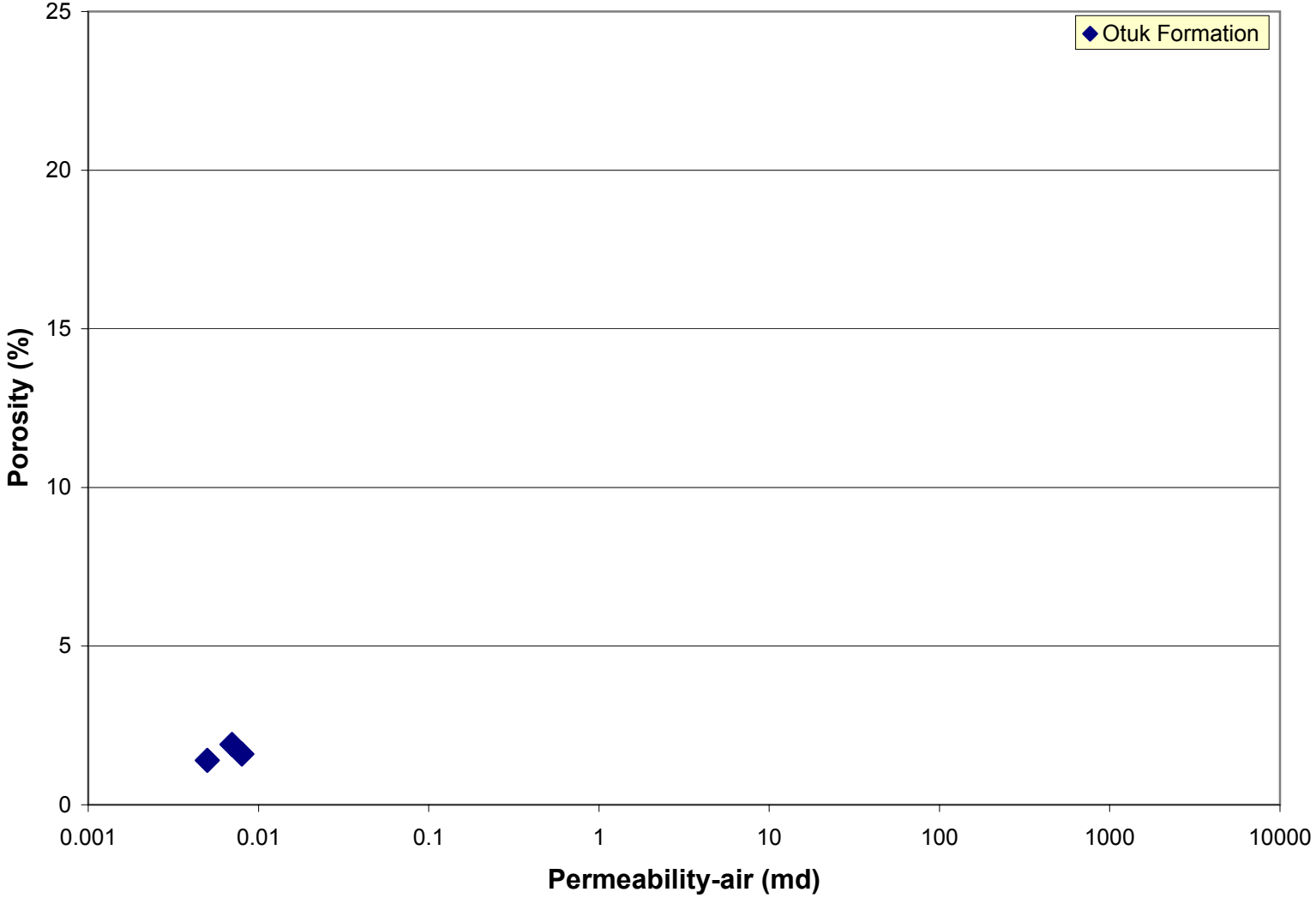

Figure 13. Porosity and permeability of Lisburne Limestone outcrop samples, North Slope, Alaska.

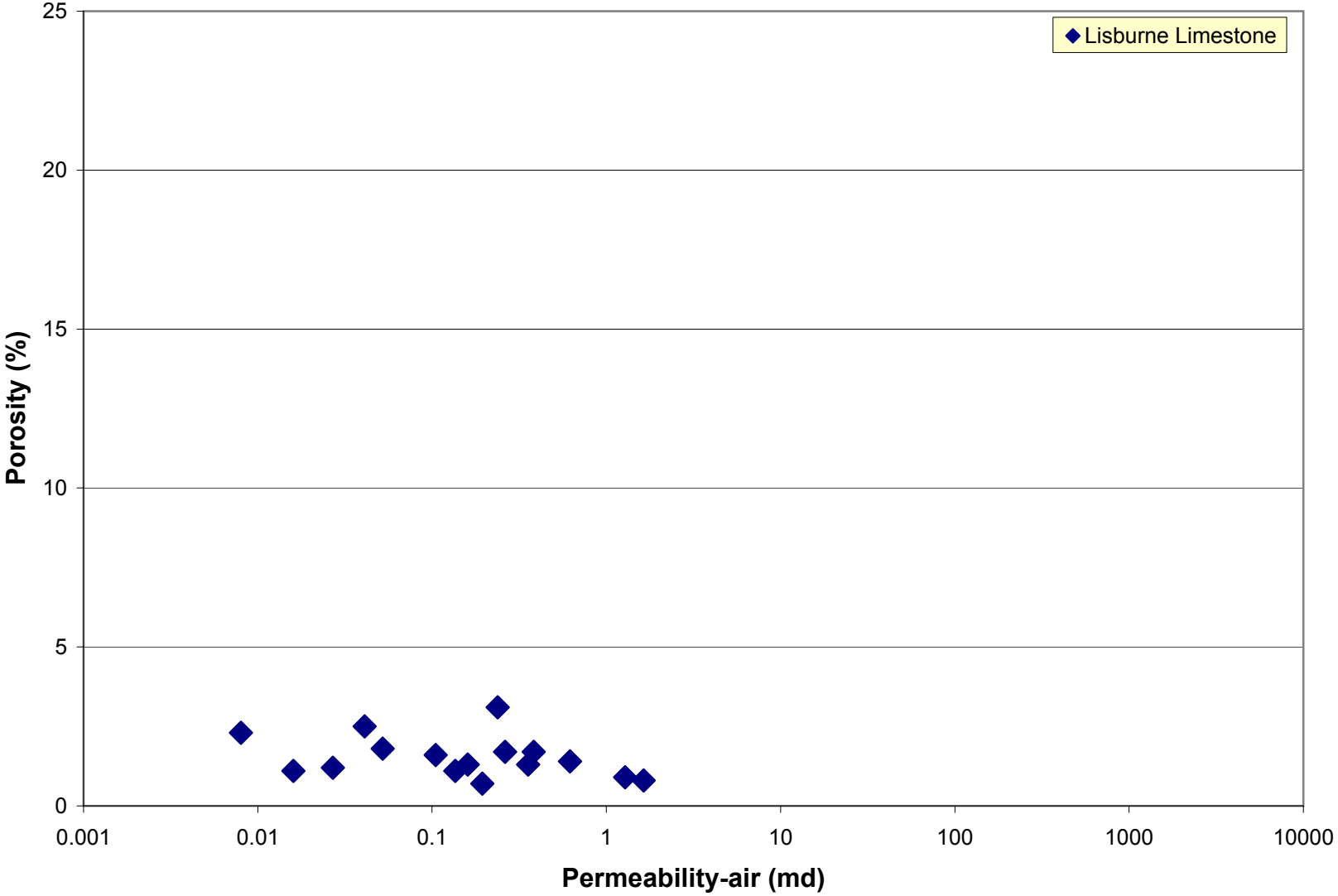

Table 1. Porosity and Permeability of 148 outcrop samples (1999-2002), from 11 formations, Brooks Range Foothills and North Slope, Alaska

Sample	Permability Air	Permability Klinkenberg	Helium Porosity	Grain Density	Sample Description	Rock unit (Fm= Formation)	General location	Lat	Long
	(md)	(md)	(%)	(g/cc)					
99Mu40	Unsuitable		21.8	2.63		Prince Creek Fm	Toolik River, Sag quad.	n/a	n/a
01RR24-5B	0.004		6.0	2.52	V fine grained ss, siltstone, parallel, crossbedded, pelecypods	Schrader Bluff Fm	Schrader Bluff, type locality, Umiat A-2, N end section	69.15845	-151.01887
01RR24-100B	0.009		7.9	2.44	V fine, lt gray, parallel bedded, pelecypod, tuffaceous ss	Schrader Bluff Fm	Schrader Bluff type locality, Umiat A-2	69.15845	-151.01887
02RR10A	0.014	0.005	8.1	2.69	V thin bed, f/m ss, 5cm pelecypods, burrows, xbeds	Schrader Bluff Fm.	South end 'Sagashak Creek' exposure, Sagavanirktok A-3	69.16345	-148.54728
01RR24-107B	0.004		8.6	2.51		Schrader Bluff Fm	Schrader Bluff type locality, Umiat A-2	69.15845	-151.01887
01RR28-100	0.047		4.8	2.71	Sandy sltstn w/limey layers, tuffaceous, bioturbated	Schrader Bluff Fm	Tuluga River	69.15845	-151.01887
01RR-19B	0.256	0.166	12.1	2.64	Fine-grained, v lt gray, mod sort, well rnded, qtz-chrt ss	Tuluvak Fm	May Creek Syncline	68.70564	-150.40149
01RR-20A	4.70	3.67	11.9	2.69	Fine-grained, fluvial? Ss with wood debris	Tuluvak Fm	May Creek Syncline	68.72272	-150.27466
01RR-48B	8660	8440	12.2	2.63	Marine, low-angle, cross-bedded pebbly sandstone	Tuluvak Fm	Ayiyak Mesa Syncline	68.87494	-151.10324
01RR-22B	79.1	68	14.2	2.65	Fine and med ss, plane-parallel bedded	Tuluvak Fm	Ayiyak Mesa Syncline	68.81130	-150.64305
01RR-22C	74.0	63.4	18.3	2.66	Rippled, v dk gry to greenish ss	Tuluvak Fm	Ayiyak Mesa Syncline	68.81130	-150.64305
01RR-22E	57.8	48.7	14.5	2.65	Very light gray ss with pebble lag at base of 1 meter bed	Tuluvak Fm	Ayiyak Mesa Syncline	68.81130	-150.64305
01RR08-1B	3.38	2.56	13.1	2.67	Thin-bedded, marine, tuffaceous ss with organics	Tuluvak Fm	Ayiyak Mesa Syncline 'butte'	68.83685	-150.80341
01RR08-22B	0.813	0.507	6.7	2.67	Med-crs ss with crossbedding and local carbonate cement	Tuluvak Fm	Ayiyak Mesa Syncline	68.83685	-150.80341
01RR08-29A	43.5	36.3	17.0	2.64	Med ss, top of marine section? Minor organics	Tuluvak Fm	Ayiyak Mesa Syncline	68.83685	-150.80341
00RR164C	34.6	28.8	17.1	2.66	Light gray, fine-grained, trace tripolitic chert, marine? Ss	Tuluvak Fm	Ayiyak Mesa Syncline	68.83000	-156.64000
00RR165F	113	99	18.3	2.65	Basal ss, friable, very porous, med to coarse grained	Tuluvak Fm	Ayiyak Mesa Syncline	68.85000	-156.83000
01RR1-100	1.10	0.857	14.1	2.70	Fine-grained, marine ss	Tuluvak Fm	Shale Wall Bluff,	69.05646	-150.86952
01RR1-119	280	255	19.7	2.67	Pebbly sandstone, marine?	Tuluvak Fm	Shale Wall Bluff,	69.05646	-150.86952
01RR2-0B	0.924	0.682	5.5	2.73	V lt gray marine ss; white & orange brown wx, bioturbated	Tuluvak Fm	Nanushuk River measured section w/glossyfungites	68.70417	-150.66098
01RR2-43B	0.117	0.068	7.1	2.70	Dk gray, fine & v fine bioturbated marine ss, w/ pelecypods	Tuluvak Fm	Nanushuk River measured section w/glossyfungites	68.70417	-150.66098
01RR2-180B	1.04	0.803	12.9	2.67	Lt gry, med gray, brn & orng wxd, med-crs fuvial? Ss; wood	Tuluvak Fm	Nanushuk River measured section w/glossyfungites	68.70417	-150.66098
01RR4B	0.138	0.082	8.7	2.68	Light gray, fine and medium, ss; plane & crossbedded	Tuluvak Fm	Nanushuk River north of Arc-Kayak measured sect	68.72920	-150.62256
01RR24-400B	16.		19.2	2.67	Fine-grained, well sorted, 10 m thick ss; local bentonite	Tuluvak Fm	Type locality Schrader Bluff Fm, Umiat A-2	69.15845	-151.01887
01RR24-600C	310.		17.7	2.66	Fine and medium grained pebbly ss; 2-5 meter beds	Tuluvak Fm	Type local Schrader Bluff Fm (N end), Umiat A-2	69.15845	-151.01887
01RR24-700B	0.345		6.1	2.67	Fine grained ss with organic debris	Tuluvak Fm	Type locality Schrader Bluff Fm, Umiat A-2	69.15845	-151.01887
01RR27-75B	1.03		8.5	2.60	Marine ss, Inoceramid debris	Tuluvak Fm	Shale Wall Bluff, south end anticline	69.01284	-150.30060
01RR27-40B	3.30		15.6	2.69	Cross bedded ss, shell debris	Tuluvak Fm	Shale Wall Bluff, south end anticline	69.01284	-150.30060
01RR27-80	4.48		13.0	2.68	Brown-weathering calc-ss	Tuluvak Fm	Shale Wall Bluff, south end anticline	69.01284	-150.30060
01RR28-0	195.		16.5	2.64	Pebbly ss & conglomerate, non-marine fluvial w/ wood debris	Tuluvak Fm	Tuluga River	68.30000	-157.19000
01RR28-40	44.		15.1	2.65	Pebbly ss & conglomerate, non-marine fluvial w/ wood debris	Tuluvak Fm	Tuluga River	68.30000	-157.19000
01RR08-32A			8.8	2.62	Noncalcareous matrix supported bebble cgl., cross beds	Tuluvak Fm	Ayiyak Mesa syncline	68.83685	-150.80341
01MU15	812.		18.3	2.64	lt gray to brown gray ss	Tuluvak Fm	Anaktuvuk R. N side Outpost Mtn	69.17743	-151.12925
01MU25	562.		18.2	2.65	mg ss with scattered chert and qtz	Tuluvak Fm	N side Racetrack basin,	68.95947	-150.93073
01MU33C			10.1	2.64	drk gray silty mudstone	Tuluvak Fm	May Ck syncline W of Nanushuk R	68.55362	-150.13777
01MU33	8.7		12.5	2.65		Tuluvak Fm	May Ck syncline W of Nanushuk R	68.55362	-150.13777
01MU36	29.		18.2	2.65		Tuluvak Fm	SW flank of Kayak Mtn anticline	68..75178	-150.90872
01MU38	91.		18.2	2.66	fg ss, probably marine	Tuluvak Fm	NW flank of Kayak Mtn anticline	68.10635	-150.96013
01DL15-186	0.343	0.231	11.0	2.65	Ss toe of slope? Strong Hydrocarb. odor	Tuluvak Fm?	"Sagashak" Ck	69.18780	-148.56547

Sample	Permability	Permability	Helium	Grain	Sample	Rock unit	General location	Lat	Long
	Air	Klink	Porosity	Density	Description	(Fm= Formation)			
	(md)	(md)	(%)	(g/cc)					
01DL11A-13.2	2.36	1.77	10.1	2.71	Ss toe of slope?	Tuluvak Fm?	"Sagashak" Ck	69.19668	-148.57419
01DL11A-18.8	5.26	3.77	14.2	2.71	Ss toe of slope? mod. Hydrocarb. odor	Tuluvak Fm?	"Sagashak" Ck	69.19668	-148.57419
99MU64	631	588	6.9	2.63		Tuluvak Fm	N of Kayak Mtn.	n/a	n/a
99MU65	405	372	18.3	2.65		Tuluvak Fm	N flank Shale Wall anticline	n/a	n/a
99MU82	1806	1722	20.3	2.63		Tuluvak Fm	S flank Big Bend anticline	n/a	n/a
00MU28	3.16	2.48	13	2.66	fine grain lt brn ss	Tuluvak Fm	Kayak Mtn-Rooftop syncline	68.42585	-150.20987
99MU43-1	105	91.8	15.5	2.65		Tuluvak Fm	Tuluvak, May Creek syncline	n/a	n/a
02RR20A	5559	5388	15.77	2.63	well-sorted granule conglomerate	Tuluvak Fm		68.70445	-150.47707
02RR20B	3153	3033	14.58	2.62	conglomerate, better cemented than 20A	Tuluvak Fm		68.70445	-150.47707
02RR20C	42.9	36.1	14.49	2.66	fine to med grained ss, well-sorted	Tuluvak Fm		68.70445	-150.47707
02RR21B	0.0259	0.0112	6.6	2.7	lt-med gray, fine to med grained, planer bedded	Tuluvak Fm	Aiyak Mesa	68.82728	-151.09360
02RR23B	3078	2960	19.45	2.65	fine-med grained ss, crossbeds	Tuluvak Fm		68.93767	-151.06247
02RR25B	25.2	20.6	14.42	2.65		Tuluvak Fm	Willow Creek	68.75315	-150.90582
02RR26B	0.419	0.2889	*8.05*	*2.65*	float, very coarse ss	Tuluvak Fm	S flank Kayak Mountain	68.73818	-150.87695
02RR27A	90.4	78.3	*13.93*	*2.64*		Tuluvak Fm		68.72100	-150.74347
02RR27B	80.3	68.8	*11.32*	*2.63*		Tuluvak Fm		68.72100	-150.74347
02RR29B	520	482	*15.37*	*2.63*	~10% pebbles, poorly sorted, well to subrounded clasts	Tuluvak Fm	Aiyak Mesa	68.90060	-152.02775
02RR29C	5.25	3.97	*8.74*	*2.63*	granule to pebble conglomerate	Tuluvak Fm		68.90060	-152.02775
02RR30B	223	201	*17.7*	*2.63*	lt gray coarse ss with granules and pebbles locally	Tuluvak Fm	VABM Cove (780')	69.01493	-151.98722
02RR31B	0.0361	0.0167	*8.28*	*2.65*	black coaly material	Tuluvak Fm	Niakogon Bluffs, SE knob	69.00543	-151.65000
02MU4	3.52	2.75	*12.08*	*2.64*	pebble conglomerate, fluvial	Tuluvak Fm	N flank Kanayut River anticline	68.74450	-151.10835
02MU6-1	3.36	2.65	*15.05*	*2.66*	ss rubble from top of bluff	Tuluvak Fm	Kanayut Bluff	68.73428	-150.61537
01DL15-161.5	0.030	0.013	9.3	2.72			"Sagashak" Ck	69.18780	-148.56547
01DL18-7	0.005	0.001	4.1	2.64			"Sagashak" Ck	69.17869	-148.53766
01DL22-118	0.059	0.03	10.7	2.68	Shelf deposited ss		"Sagashak" Ck	69.15393	-148.50077
01DL22-122	0.093	0.052	11.9	2.68	Shelf or shallow marine ss		"Sagashak" Ck	69.15393	-148.50077
01DL22-134.5	0.012	0.004	7.5	2.66	Shoreface ss		"Sagashak" Ck	69.15393	-148.50077
01RR-18C	0.019	0.008	4.7	2.70	Fine, bioturbated, ss, toe of slope? Coniacian to Santonian	Tuluvak equivalent?	"Sagashak" Ck pelecypods	69.18657	-148.55890
01RR-48A	15.4	11.9	7.6	2.64	Granule, pebbly ss w/ mnr cgl, low angle crossbeds, marine	Tuluvak Fm	Ayiyak Mesa Syncline	68.87494	-151.10324
02RRIC	0.002	0.001	3.9	2.95	Thin-bedded, fine grained ss with 3% organics	Tuluvak equivalent	NW end 'Sagashak Creek' exposure, Sagavanirktok A-3	69.00333	-148.01058
02RRID	0.001	0.001	3.7	2.73	Medium bedded, fine grained ss, siliceous, minor organics	Tuluvak equivalent	NW end 'Sagashak Creek' exposure, Sagavanirktok A-3	69.00333	-148.01058
02RRIF	0.002	0.001	10	2.63	Laminated, fine ss, cross beds, erosion, 4% organics, volcanics	Tuluvak equivalent	NW end 'Sagashak Creek' exposure, Sagavanirktok A-3	69.00333	-148.01058
02RR2A	0.001	0.001	9.1	2.53	Med-dark gray, bioturbated, faulted, fractured, paleophycus	Tuluvak equivalent	NW end 'Sagashak Creek' exposure, Sagavanirktok A-3	69.00322	-148.01009
02RR2B	0.001	0.001	2.2	2.7	Thin-bedded, fine grained ss with 3% organics, local pyrite	Tuluvak equivalent	NW end 'Sagashak Creek' exposure, Sagavanirktok A-3	69.00322	-148.01009
02RR2D	0.002	0.001	7.8	2.72	Slickensides common	Tuluvak equivalent	NW end 'Sagashak Creek' exposure, Sagavanirktok A-3	69.01550	-148.01009
02RR6-1	0.009	0.003	11.5	2.5	Light gray, med ss, recumbent fold, siltstone & silty shale local	Tuluvak equivalent	Mid' 'Sagashak Creek' exposure, Sagavanirktok A-3	69.18452	-148.54802
02DL01	0.315	0.209	8.2	2.71	U. fine grnd, friable ss.	Tuluvak equivalent	NW end 'Sagashak Creek' exposure, Sagavanirktok A-3	69.19005	-148.56838
02DL02-C	0.004	0.001	7.4	2.78	Tan-brown, uv fine grnd ss.	Tuluvak equivalent	Sagashak Creek', Sagavanirktok A-3	69.18850	-148.56580
02DL02-D	0.026	0.011	5.3	2.72	Light gray, uv fine grnd ss.	Tuluvak equivalent	Sagashak Creek', Sagavanirktok A-3	69.18850	-148.56580
02RR32B	522	482	21.1	2.64	V lt gray, m-crs ss & cgl, 5m section, fluvial cut/fill	Tuluvak	Outpost Mtn syncline, Umiat Quad.	69.12518	-151.22632
02RR33B	3940	3800	18.3	2.63	Ss, peb cgl (lenses), peb ss, 3m section, v poor sorted	Tuluvak	Outpost Mtn syncline, Umiat Quad. North flank	69.17742	-151.12953

Sample	Permability	Permability	Helium	Grain	Sample	Rock unit	General location	Lat	Long
	Air	Klink	Porosity	Density	Description	(Fm= Formation)			
	(md)	(md)	(%)	(g/cc)					
02MU21	5.31	3.97	6.2	2.63	Wh to gr pea gravel cgl	Tuluvak	Wolf Creek anticline, Ikpikpuk R. quad	69.41082	-153.36712
02MU24	42.9	35.6	16.3	2.66	Wh qtz pbl-cbl cgl, mostly disaggregated, w ss lens in cgl	Tuluvak	VABM Ji,. NE Killik R. quad	68.93857	-154.44908
02MU25	0.218	0.139	12.9	2.67	Msv thick cbl to boldr cgl, abund wh qutz cobbles, w ss lenses.	Tuluvak or uppermost Nanush	Aupuk Ck., NE Killik R. quad	68.92405	-154.54632
02MU26	434	399	17.3	2.64	Qtz cbl cgl, white qtz, w some ss lenses	Tuluvak	Upper Aupuk Ck., NE Killik R. quad	68.83908	-154.73328
02MU32	13.6	10.8	15.7	2.7	Tuluvak, mostly rubble, f grns ss, gn gr, wh speckled w Macronicnus	Tuluvak	E of Killilk River, NE Killik R. quad	n/a	n/a
02MU34	18.6	14.5	16.3	2.65	Gr pebble cgl, mostly cht clasts, some ss lenses	Tuluvak	S Fork Ninuluk Ck, NE Killik R. quad	68.95587	-152.94837
02MU33	10.3	7.94	13.4	2.65	Med to crs grnd qtz ss, froable, 80+% ang to subang qtz grains.	Tuluvak or uppermost Nanush	S Fork Ninuluk Ck, NE Killik R. quad	68.97925	-153.05520
02MU33A	2.12	1.57	13.6	2.67	Med to crs grnd qtz ss, froable, 80+% ang to subang qtz grains.	Tuluvak or uppermost Nanush	S Fork Ninuluk Ck, NE Killik R. quad	68.97925	-153.05520
01MU21B	1404.		19.8	2.63	Marginal marine? ss	Nanushuk (top?)	N flank of Big Bend anticline, east of Chandler River,	69.12095	-151.64150
01RR25B	0.465		8.7	2.64	Pebbly ss to conglomerate, non marine, growth fault?, overthrust	Nanushuk Fm	Syncline east of Kanayut R.	68.63625	-150.84405
01MU41	2.64		9.1	2.65	massive, thick fluvial congl/ss	Nanushuk Fm	W of Anaktuvuk R	68.79655	-151.55533
01MU16	227.		16.2	2.66	med grained, subrounded qtz and blk chert	Nanushuk Fm	Anaktuvuk R, S flank Big Bend anticline	69.03510	-150.14495
01MU20	884.		18.1	2.65	ss, fg-mg, friable, qtz, chert	Nanushuk Fm	Big Bend anticline	69.10667	-151.26197
01MU39	1.52		8.8	2.65	ss, mg qtz, chert, forms thick rubble	Nanushuk Fm	N of lower Kanayut River.	68.80502	-151.01572
00DL24-51.5	0.030	0.014	4.1	2.72		Nanushuk Fm	Arc Mtn, shoreface, delta-front, prominent HC odor	68.65400	-150.59500
01MU30	1.60		9.6	2.65	coarse grained lithic sandstone with floating chert	Nanushuk Fm	Top N flank Arc Mtn anticline	68.69085	-150.32060
01MU35	0.193		6.9	2.64	ss, mg, well laminated, abundant chert and qtz	Nanushuk Fm	SW flank of Kayak Mtn anticline	68.74563	-150.88067
00DL22-234	0.215	0.136	8.3	2.72	siltstone	Nanushuk Fm	Rooftop Ridge	68.84000	-156.56000
00DL22-244.4	32.3	26.7	12.7	2.65	siltstone	Nanushuk Fm	Rooftop Ridge	68.84000	-156.56000
01DL31-21.2	0.023	0.01	3.7	2.74		Nanushuk Fm	Ch Lk. C-2; Kanyut R.; Arc Mtn trend	68.64108	-150.90267
01DL31-129	0.014	0.005	3.2	2.73		Nanushuk Fm	Ch Lk. C-2; Kanyut R.; Arc Mtn trend	68.64108	-150.90267
01DL31-184	0.013	0.005	4.0	2.70		Nanushuk Fm	Ch Lk. C-2; Kanyut R.; Arc Mtn trend	68.64108	-150.90267
01DL31-266.6	0.053	0.027	3.0	2.71		Nanushuk Fm	Ch Lk. C-2; Kanyut R.; Arc Mtn trend	68.64108	-150.90267
01DL31-285.6	0.454	0.319	7.0	2.66		Nanushuk Fm	Ch Lk. C-2; Kanyut R.; Arc Mtn trend	68.64108	-150.90267
01DL31-298.3	0.084	0.046	5.6	2.65		Nanushuk Fm	Ch Lk. C-2; Kanyut R.; Arc Mtn trend	68.64108	-150.90267
01DL31-303.8	3.53	2.74	9.3	2.65		Nanushuk Fm	Ch Lk. C-2; Kanyut R.; Arc Mtn trend	68.64108	-150.90267
01DL31-335.2	0.326	0.218	7.2	2.67		Nanushuk Fm	Ch Lk. C-2; Kanyut R.; Arc Mtn trend	68.64108	-150.90267
01DL31-384.5	0.099	0.055	5.8	2.67		Nanushuk Fm	Ch Lk. C-2; Kanyut R.; Arc Mtn trend	68.64108	-150.90267
01DL27-3.0	272	247	14.2	2.63	sandsone	Nanushuk Fm	Chand C-1	68.65230	-150.10861
01DL27-9	0.285	0.187	9.9	2.67	sandstone	Nanushuk Fm	Chand C-1	68.65230	-150.10861
01DL27-20	2.03	1.52	10.3	2.68	sandstone	Nanushuk Fm	Chand C-1	68.65230	-150.10861
01DL27-28	2.55	1.96	10.5	2.67	sandstone	Nanushuk Fm	Chand C-1	68.65230	-150.10861
01DL29-E	0.015	0.005	4.5	2.74	green-gray ss with faint hydrocarbon odor	Nanushuk Fm	Chand C-1	68.64923	-150.25633
01DL30B	0.064	0.033	7.5	2.65	sandstone	Nanushuk Fm		68.72887	-149.01860
01DL23-139.5	0.019	0.008	3.5	2.72	thin-bedded ss with interbedded siltstone	Nanushuk Fm	PSM C-5 @ Slope Mtn section	68.72887	-149.01860
01DL23-156.8	0.024	0.01	2.9	2.71	"	Nanushuk Fm	PSM C-5 @ Slope Mtn section	68.72887	-149.01860
01DL23-159.8	1.44	1.06	3.6	2.72	"	Nanushuk Fm	PSM C-5 @ Slope Mtn section	68.72887	-149.01860
01DL23-185.5	0.019	0.008	4.7	2.73	"	Nanushuk Fm	PSM C-5 @ Slope Mtn section	68.72887	-149.01860
01DL23-240.6	0.018	0.007	3.3	2.67	"	Nanushuk Fm	PSM C-5 @ Slope Mtn section	68.72887	-149.01860
01DL23-305	0.059	0.03	4.0	2.68	"	Nanushuk Fm	PSM C-5 @ Slope Mtn section	68.72887	-149.01860

Sample	Permability	Permability	Helium	Grain	Sample	Rock unit	General location	Lat	Long
	Air	Klink	Porosity	Density	Description	(Fm= Formation)			
	(md)	(md)	(%)	(g/cc)					
01DL23-338	0.019	0.007	4.2	2.72	"	Nanushuk Fm	PSM C-5 @ Slope Mtn section	68.72887	-149.01860
01DL02-4.1	0.012	0.004	4.6	2.72		Nanushuk Fm	Sag. R. south of Lupine well	69.09280	-148.76997
01DL02-41.6	1.19	0.929	5.5	2.71		Nanushuk Fm	Sag. R.	69.09280	-148.76997
01DL02-47.2	0.019	0.007	5.0	2.72		Nanushuk Fm	Sag. R.	69.09280	-148.76997
01DL02-174.6	0.012	0.004	2.5	2.73		Nanushuk Fm	Sag. R.	69.09280	-148.76997
01DL02-224.5	0.023	0.01	5.8	2.72		Nanushuk Fm	Sag. R.	69.09280	-148.76997
01DL02-336.6	0.070	0.037	7.0	2.72		Nanushuk Fm	Sag. R.	69.09280	-148.76997
99MU41	0.45	0.3	9.1	2.7		Nanushuk Fm	Sag River, Ice Cut, southern Sag quad.	n/a	n/a
99MU42	0.01	0	2.9	2.73	Marine	Nanushuk Fm, base	Arc Mtn	n/a	n/a
00Mu65	110	96.1	15.9	2.66		Nanushuk Fm, top	N flank of Rooftop Ridge anticline	68.92127	-150.82667
02DL29A	14.8	11.8	17.5	2.7	Fn-med grnd ss from base of incision fill	Nanushuk Formation	North bank of Colville River, Umiat B-5	69.27370	-152.57500
02DL30-0.7	0.055	0.028	9.7	2.71	inoceramus fragments	Nanushuk Formation	North bank of Colville River, Umiat B-5	69.27240	-152.58830
02DL30-5.8	28.2	23	19.3	2.69	Lt gray, lower fine-grained, well sorted, minor white mica & FeOx	Nanushuk Formation	North bank of Colville River, Umiat B-5	69.27240	-152.58830
02MU27	22.4	18	14.9	2.64	Tan f grns cglatic ss	Nanushuk	Kurupa anticline	n/a	n/a
02MU31	663	618	21.3	2.66	F to crs grainesd qtz ss w stron petroleum odor.	Uppermost Nanushuk	Umiat, upstream from Umiat Mtn. Strong petroleum odor, light staining.	n/a	n/a
02DL30-33.5	2.47	1.86	15.5	2.72	Lt gray, lower fine-grained, well sorted, minor white mica & FeOx	Nanushuk Formation	North bank of Colville River, Umiat B-5	69.27240	-152.58830
02MU23	Sample not suitable		13.3	2.71	Msv cglatic ss, abund wh qtz cobbles	Uppermost Nanushuk ?	SW of Killik Bend, NE Killik River quad	n/a	n/a
01DL01A-4.8	0.007	0.002	3.3	2.71	Ss, base of slope, amalgamated turbidites?	Gilead sandstone		69.15804	-147.72813
01DL01A-119.5	0.026	0.011	3.9	2.70	Ss, base of slope, high density turbidites?	Gilead sandstone		69.15804	-147.72813
01DL01B-29.2	0.001	<1.001	2.0	2.68	Ss, shelf Ss, above storm wave base?	Gilead sandstone		69.16428	-147.74435
01DL01J-0.5	0.004	0.001	3.1	2.72	Ss, shelf Ss, above storm wave base?	Gilead sandstone		69.16442	-147.79236
01DL01J-10.5	0.005	0.001	4.8	2.72	Ss, shelf Ss, above storm wave base?	Gilead sandstone		69.16442	-147.79236
02DL23-66	0.301	0.199	15.5	2.71	Uvf-lf ss with outsized grains to cse grn size of black and white chert	Torok Formation	East bank of Chandler River, opposite confluence with Torok Creek	68.69230	-152.25010
02DL23-83	0.228	0.145	13.8	2.68	Green-gray, lf grnd ss, slightly friable, with strong hydrocabon odor	Torok Formation	East bank of Chandler River, opposite confluence with Torok Creek	68.69230	-152.25010
02DL23-107	0.102	0.058	15.3	2.73	Lf grnd ss, slight hydrocarbon odor in beds few decimeters upsection	Torok Formation	East bank of Chandler River, opposite confluence with Torok Creek	68.69230	-152.25010
Oil Stained Toro	0.152	0.092	6	2.5					
01MU10	0.038	0.018	8.2	2.76	lt gray shale, micaceous	Torok Fm	May Creek	68.56380	-150.26342
01RR-39B	0.001	<0.001	2.8	2.73	Dk grn, dk gry, f ss w/ pebbles to 3 mm, tasmanite, marine	Fortress Mtn Fm	Atigun Gorge	68.51000	-149.17000
01RR-40B	0.001	<0.001	2.3	2.69	Fine, med & crs ss and cgl, cross bedded, braided stream	Fortress Mtn Fm	Atigun Gorge	68.51306	-149.17117
01RR-41B	0.001	<0.001	2.5	2.68	Dk grn dk-gray, med-crs, ss peb ss, cgl, parallel bedded	Fortress Mtn Fm	Atigun Gorge	68.56167	-149.21175
01RR-44	0.015	0.005	3.6	2.69	Crs-med cgl and ss, bioturbated, space cleavage	Fortress Mtn Fm	Atigun Gorge	68.60000	-149.04000
01RR-45	0.200	0.125	2.6	2.69	Fine grained ss w/ rare chert pebble to 2 cm, calc layers	Fortress Mtn Fm	Atigun Gorge	68.54000	-149.32000
01RR-46	<0.002	<0.001	3.8	2.68	Conglomerate, med and crs ss, thin to med bedded, marine?	Fortress Mtn Fm	Atigun Gorge	68.53592	-149.31989
01RR-42B	0.009	0.003	2.6	2.66	Massive cgl, organized bedding: 0.3 to 2 m, cobbles to 10 cm	Fortress Mtn Fm	Atigun Gorge	68.49830	-149.33597
								n/a	n/a
01RR32B	0.032		6.8	2.70	Debris flow, basal Fortress Mtn Fm?, clasts to 25 cm, chaos	Fortress Mtn Fm?	W Anaktuvuk R; S of Fortress Mtn Fm, Ch Lake Quad	68.49403	-150.93370
01RR-49A	0.001	<0.001	2.6	2.70	Pebbly ss, w/ white carbonate veining, event deposit, burrowed	Cobblestone ss?	Itkillik/Itikmalak River	68.47135	-149.95230
01MU1	0.001	<0.001	4.8	2.71		Cobblestone ss		68.61937	-149.30730
01MU8	0.005	0.001	5.7	2.68	Debris flow	Cobblestone ss	Toolik Lake, E side of Itkillik Valley	68.55067	-147.79733

Sample	Permability	Permability	Helium	Grain	Sample	Rock unit	General location	Lat	Long
	Air	Klink	Porosity	Density	Description	(Fm= Formation)			
	(md)	(md)	(%)	(g/cc)					
01RR26-62	0.440		4.3	2.70	Very coarse ss with mud rip ups to 2-5 cm clasts; organics	Cobblestone ss	Cobblestone Creek; measured section	68.58160	-150.23209
01RR26-21B	0.020		2.7	2.71	Fine, med & crs ss, event deposit, w/ organics, loads, grooves	Cobblestone ss	Cobblestone Creek; measured section	68.58160	-150.23209
01-RR26-1B	0.024		4.0	2.71	Fine and med ss	Cobblestone ss	Cobblestone Creek; measured section; base	68.58160	-150.23209
01RR31B	0.373		2.3	2.72	Melange, cgl, ss, siltstone, v immature, disorganized, organics	Cobblestone ss	Nanushuk River in mountains	68.49403	-150.93370
01RR29B	0.057		1.0	2.70	Dk gry- v dk gry fine/med graywacke, 30 cm beds, turbidites	Okpikruak Fm	Perigrine Ck	68.41070	-150.40679
99MU46	0.01	0	1.8	2.71		Okpikruak Fm	Perigrine Ck	n/a	n/a
00MU27-2	0.007	0.002	1.9	2.71		Otuk, Karen Ck. Fm.		68.40665	-150.25253
00MU27-4	0.005	0.001	1.4	2.72		Otuk Fm		68.40665	-150.25253
01MU11	0.008	0.002	1.6	2.71	limey shale	Otuk Fm	N side May Creek Tributary	68.55895	-150.25132
01RR-52	1.78	1.18	3.2	2.69	V light gray, sandy lime-wacke, below Lisburne	Siksikpuk Fm	Phillip Smith Mtns B-5	68.43531	-149.73009
01RR-13A	0.160	0.097	1.3	2.72	Medium gry, lt gry, medium bedded, micrite? mid Lisburne	Lisburne Limestone	Phillip Smith Mtns B-5	68.44091	-149.69980
01RR-15A	0.008	0.003	2.3	2.71	Light brownish gray, fossiliferous, fetid, limestone at thrust	Lisburne Limestone	Phillip Smith Mtns B-5, 'lower' Lisburne	68.45257	-149.61197
01RR-16	0.383	0.262	1.7	2.71	Black-v dk gry, vermicular fossils, fetid, limestone; horn coral	Lisburne Limestone	Phillip Smith Mtns B-5	68.45357	-149.58129
01RR-16A	0.262	0.171	1.7	2.72	Black-v dk gry, vermicular fossils, fetid, limestone; med bedded	Lisburne Limestone	Phillip Smith Mtns B-5	68.45357	-149.58129
01RR-21C	0.618	0.434	1.4	2.65	V dk gry to brownish black, thin to med bed, fossil dissolution	Lisburne Limestone	Phillip Smith Mtns B-5; 'middle' unit	68.43907	-149.57447
01RR7A	0.041	0.02	2.5	2.70	Very light gray tabulate? Coral wackestone to limestone	Lisburne Limestone	Phillip Smith Mtns B-5	68.45664	-149.52922
01RR6A	1.28	1.01	0.9	2.71	Very light gray wackestone to limestone; highly fractured	Lisburne Limestone	Phillip Smith Mtns B-5	68.46000	-149.52891
01RR35A	0.194		0.7	2.71	Massive, light gray limestone, abundant chert nodules	Lisburne Limestone	Phillip Smith Mtns B-4	68.44489	-149.29651
01RR38A	0.016		1.1	2.69	Overturned, very light gray, massive bedding	Lisburne Limestone	Atigun Gorge	68.46630	-149.22390
01PP30A	1.64		0.8	2.70	Nodular blk chert beds 10-60cm thick; gry-blck silty limestone; fetid	Lisburne Limestone	Phillip Smith Mtns B-4	68.45674	-149.19771
01PP07A	0.238		3.1	2.73	Brownish dark gray flaky limestone, ('middle' unit)	Lisburne Limestone	Phillip Smith Mtns B-5	68.42316	-149.56159
01PP38A	0.136		1.1	2.70	Massive, overturned	Lisburne Limestone	Phillip Smith Mtns B-4	68.45508	-149.22736
01RR23A	0.105		1.6	2.75	Brownish dark gray flaky limestone, ('middle' unit)	Lisburne Limestone	E of Galbraith, 'middle' Lisburne	68.46343	-149.60367
01RR36B	0.052		1.8	2.70	Fetid limestone, bryozoan, coral, dead oil?	Lisburne Limestone	Phillip Smith Mtns B-4	68.45963	-149.13769
01HA41	0.356		1.3	2.71	Dark gray, bedding .3 m, crinoids, minor chert, packstone	Lisburne Limestone	Phillip Smith Mtns B-4, 'middle' unit, Atigun Gorge	68.44336	-149.11628
01RR33A	0.027		1.2	2.71	Very light gray, thin bedded to platey, crinoid, byozoa, spicule,	Lisburne Limestone	Atigun Gorge, south side	68.44222	-149.25600
01RR-17A			2.9	2.70	Massive, light gray, orange-brn wxing, with solution wxing	Lisburne Limestone	Phillip Smith Mtns B-5	68.45339	-149.52371
02RR16A	13.1	10.4	11.2	2.83	dolomite, dead hydrocarb.	Lisburne Limestone	Tiglukpuk Creek	68.29793	-151.91668
02RR16B	12	9.42	11.25	2.84	non hydrocarb	Lisburne Limestone		68.29793	-151.91668
NOTE: Many of the above samples were of sandstone lenses in thick conglomerate; samples probably not representative of unit as a whole									