



Ice Gouging: Identification and Analysis

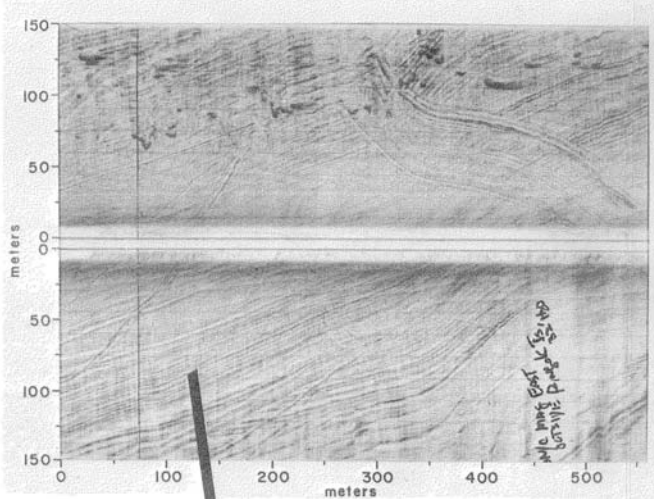
Arctic Technologies Workshop
October 2009



Ice Gouge Analysis

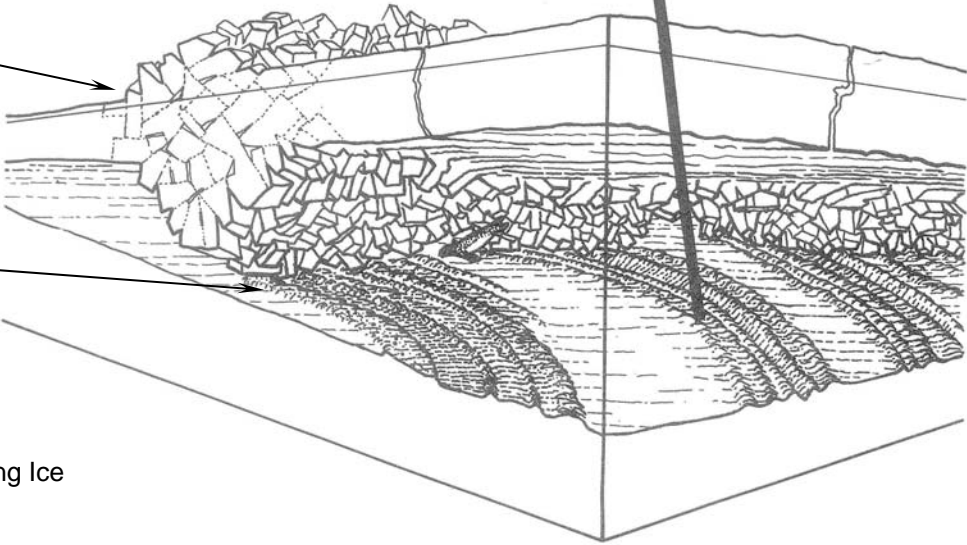
- What Are Ice Gouges?
- Ice Zones
- Who Cares?
- Previous Gouge Work
- Multibeam Sonar Technology
- Traditional Gouge Analysis
- New Engineering Analysis Technique
 - Almost Real time
 - Site Specific
 - No Fancy Software
 - Flexible Statistical Analysis

What Are Ice Gouges?



Pressure Ridge in Ice Sheet

Pressure Ridge Keel Engages Seafloor

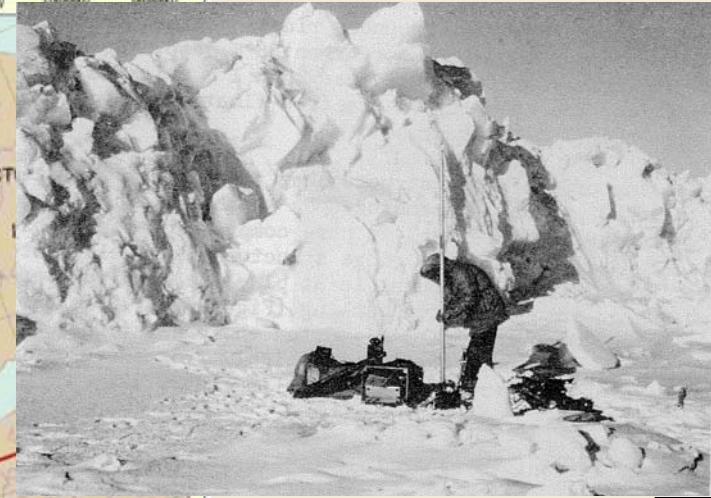
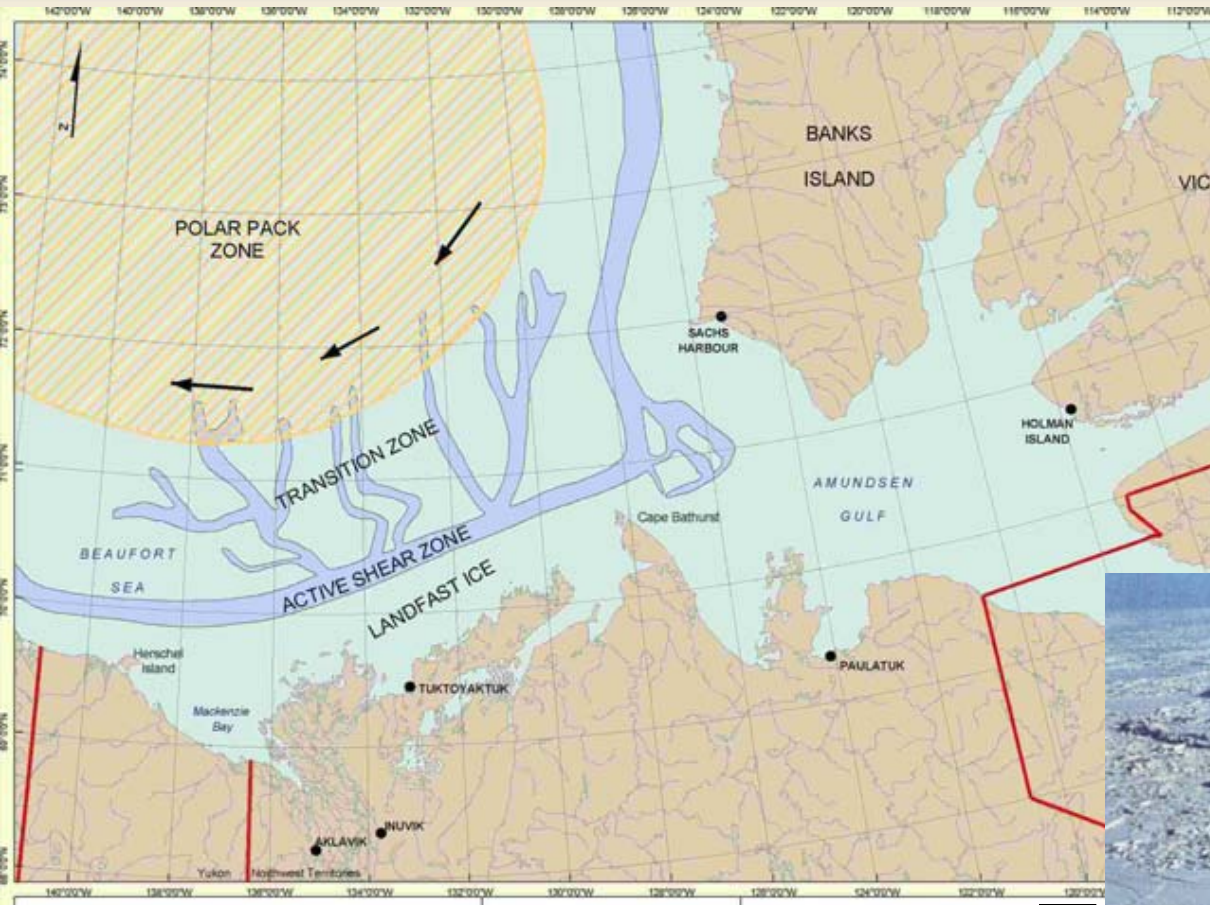


Bottom Features and Processes Related to Drifting Ice
Arctic Shelf, Alaska
USGS Map MF-532, 1973



Ice Gouge Photo



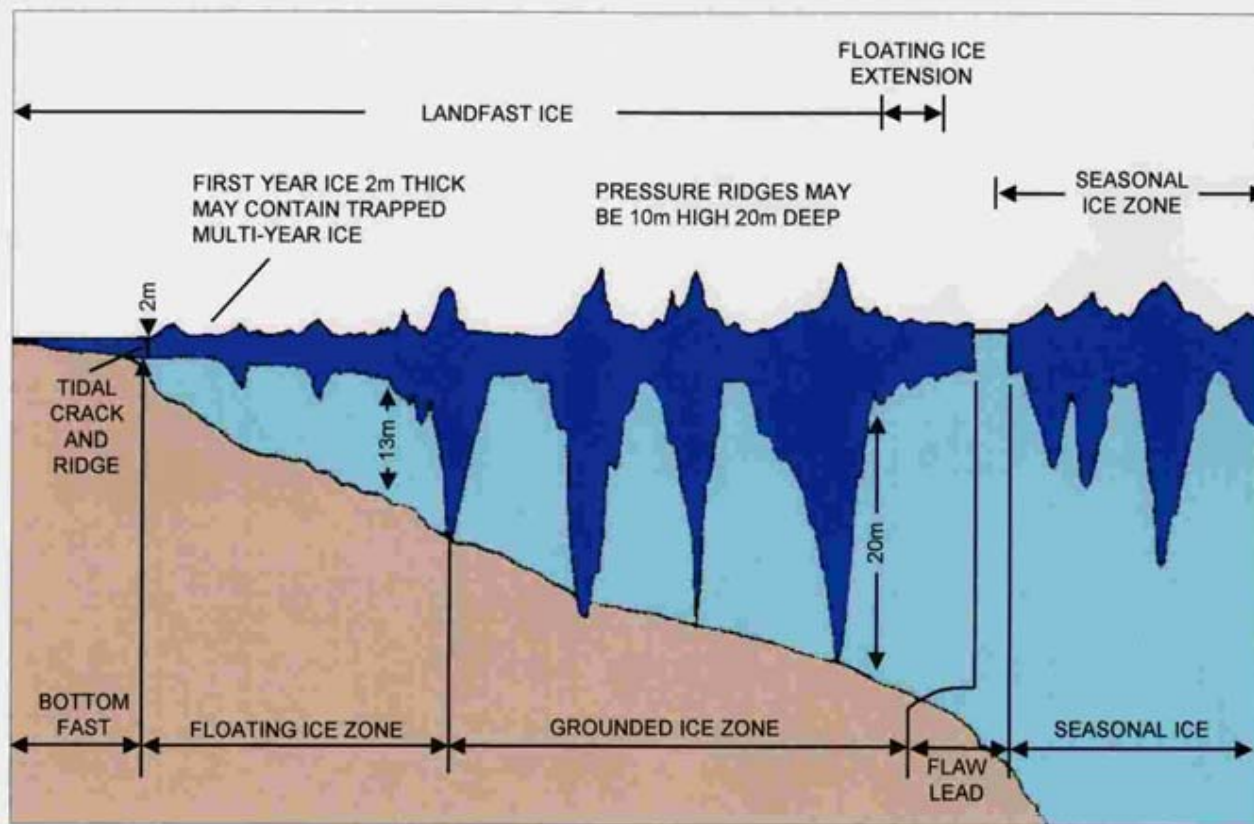


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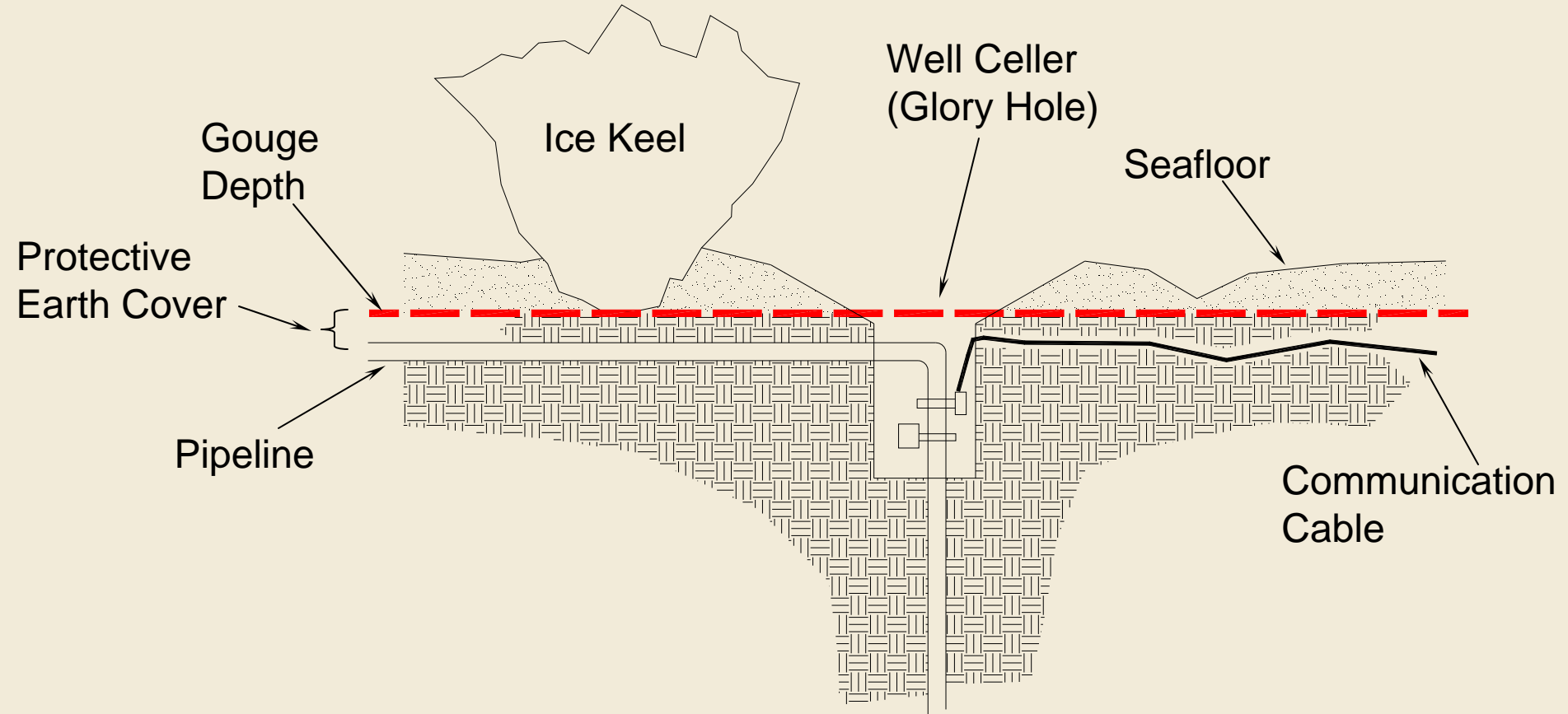


2

1. "Sea Ice Morphology" in The Coast and Shelf of the Beaufort Sea, 1974
2. Natural Resources Canada PERD/CHC Report 35-60, 2005



- Bottom Structures
- Pipelines and Lines of Communication



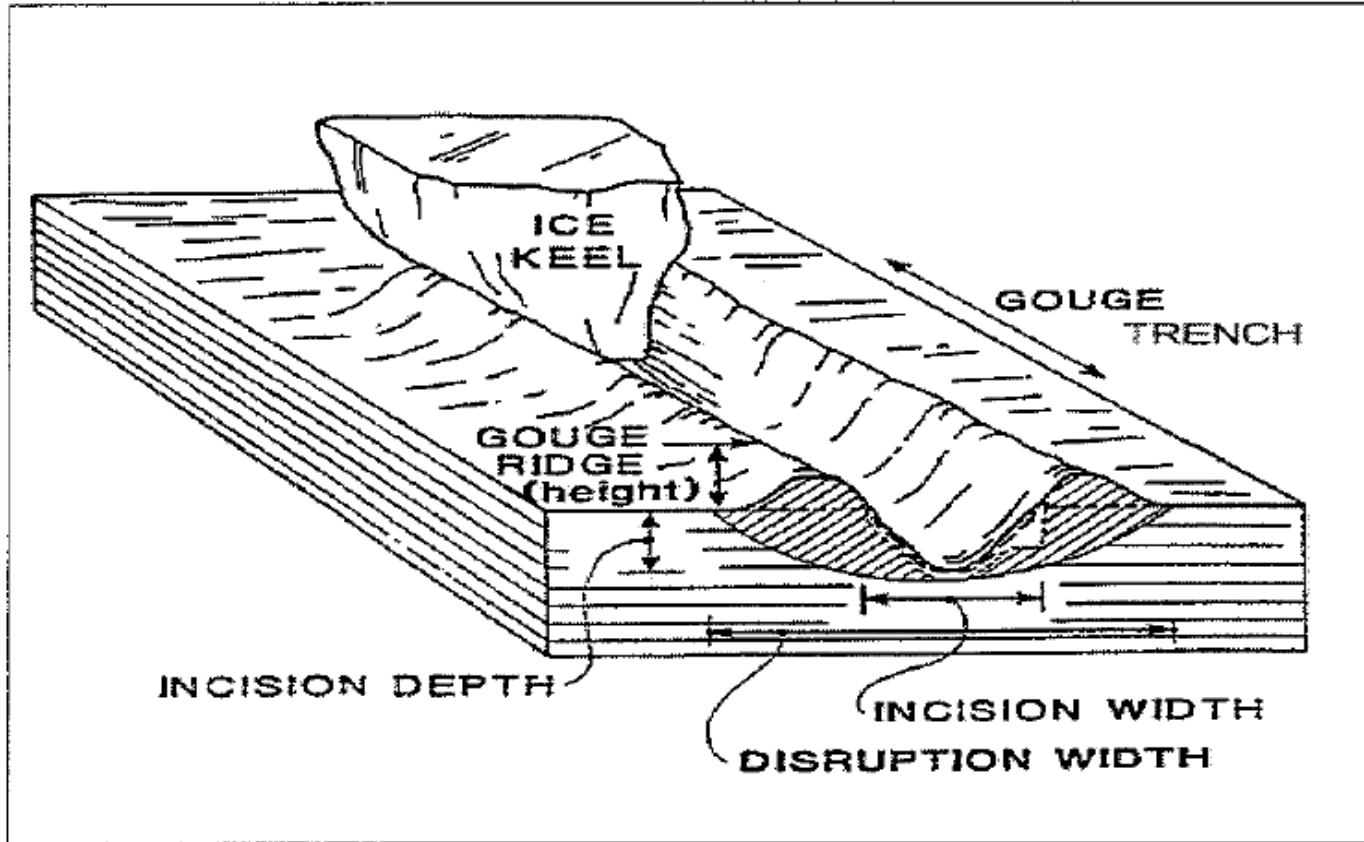


Figure 4- Ice gouge/scour terminology



- Carsola 1954, Rex 1955
- Barnes, Kovacs, Reimnitz, Sater, Walsh Mid 70s, numerous reports. (The 5.5 meter gouge)
- Ice Scour and Arctic Marine Pipelines Workshops
 - BP Amoco
 - Chevron
 - Geological Survey of Canada
 - Minerals Management Service
 - US Office of Naval Research
- Methods of Investigation
 - Sidescan Sonar
 - Single Beam Fathometer
 - Divers (Reimnitz – 40 Dives)
 - Multibeam Fathometer (awesome data)

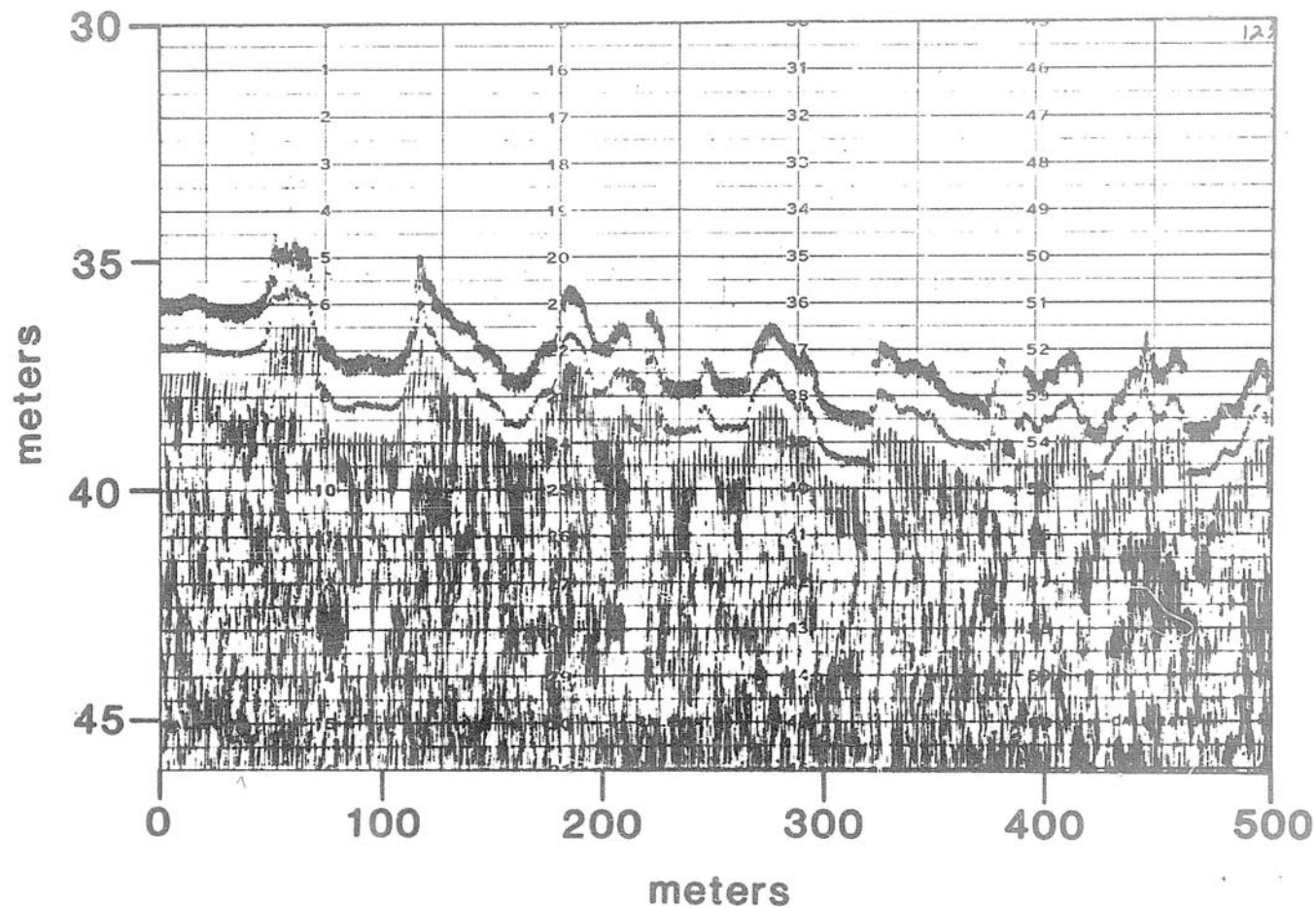


Figure 3. Fathogram of an ice gouged seafloor from which the measurements of gouge depth, ridge height, water depth, and subbottom depth were made. Water depth is 36 meters.



Brief Historical Question

The maximum gouge depth plotted from 1972 surveys (Figure 13) shows a rather patchy distribution. There is no good correlation between gouge density and gouge depth, except in the lagoon and river mouth areas where both have low values. The maximum gouge depth measured is 5.5 m, in the area north of Cape Simpson. These depths, because they were measured with

1

DISTANCE FROM COAST: A = 63 KM; P = 76 KM

ICE GOUGE DATA RECORD

1972

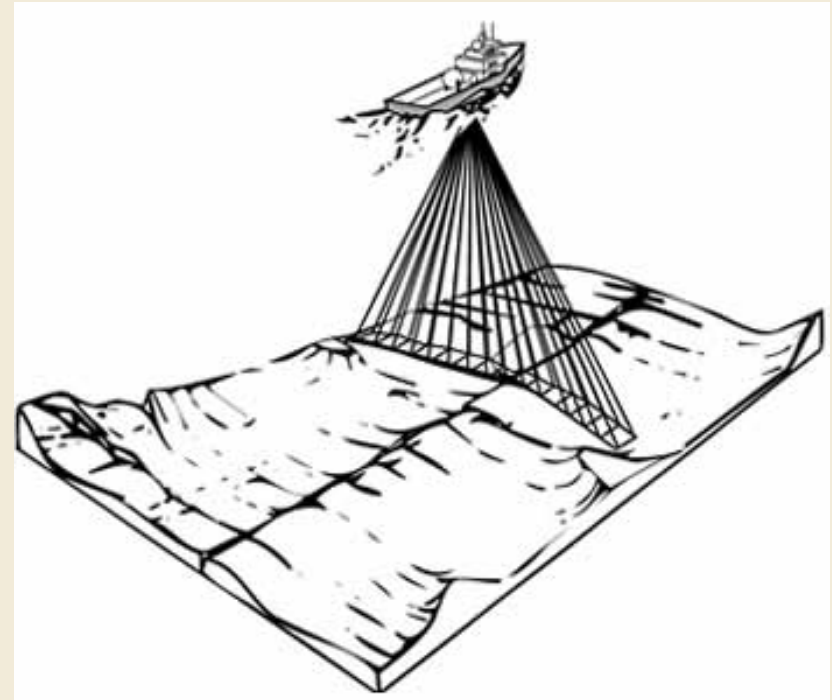
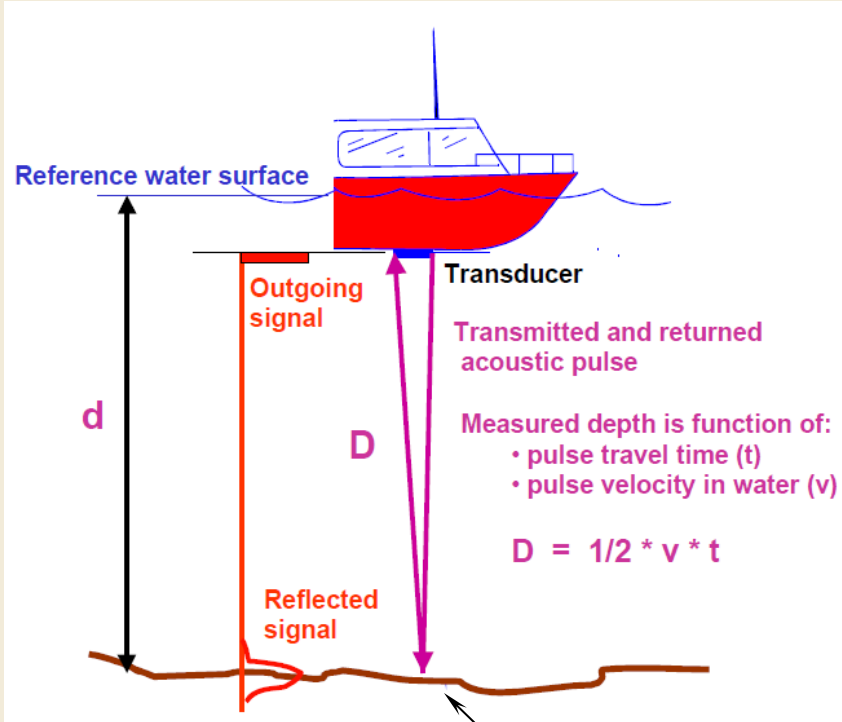
SEGMENT SCALE 1:1117

VESSEL	GLACIER
TEMPLATE SIZE	2.5" x 10"

TRACELINE	ICE GOUGE DATA RECORD																				VESSEL		TEMPLATE SIZE								
	DATE	START TIME	START DEPTH	DRIFTS	SHIP'S COURSE	DRIFT	ADJUSTED OBSERVATION	ORIENTATION	VARIABLE	NUMBER OF OBS.	DEFLECTION FACTOR	GOUGE DENSITY	INCISION DEPTH DISTRIBUTION METERS					MAXIMUM WIDTH	MAXIMUM RIGID HEIGHT	MAXIMUM DENSITY	MULTI-METER GOUGES			DEPTH TO FIRST REFLECTOR	SONAR RANGE	REMARKS					
68	253												N	2-4	4-6	6-8	8-10	10-12	MAX	M	M	NUMBER	MAXIMUM INCISION	MAXIMUM DISSECTION	MAXIMUM WIDTH	DEPTH TO FIRST REFLECTOR	M	M			
AB 1	16040	29.0	042	75/105	117	147	L	89	.96	.4	85	48	0	13	10	9	9	1.8	8	1.9	6	7	45	067	150		12 KHZ FATHOMGRAM AND SONAR AND SEISMIC - SONAR VERY POOR THIS SEGMENT. HIGHLY GOUGED SEA FLOOR.				
BC 2	1617.5	29.0		70/35	112	097	L	190	.96	.4	148	0	7	7	10	18	2.8	8	2.1	3	5	36	097							NUMEROUS SMALL GOUGES (NARROW AND SHALLOW).	
CD 3	1630.7	30.4		75/50	117	092	L	139	.96	.4	95	0	18	8	7	11	1.5	7	2.0	0	-	-	-								
DE 4	1644.0	30.6		75/-	117	-	L	160	.96	.6	153	0	21	8	6	11	2.4	6	2.1	2	5	40	062								
EF 5	1657.0	30.0		80/110	122	152	L	184	.96	.6	176	0	19	8	3	6	2.8	15	2.7	4	7	35	097								
FG 6	1710.0	36.2		75/50	117	092	L	141	.96	.4	135	0	13	3	6	12	4.0	29	2.0	3	2	26	092								GOUGING IS MORE SUBSIDED - GOUGES AND RIDGES SEEM NOT AS FRESH - SEDIMENT TAKING PLACE? DEEPEST GOUGE
GH 7	1723.2	38.1		75/50	117	092	L	106	.96	.8	101	0	11	5	4	18	3.0	10	1.8	2	2	28	092								FOUND ON SHELF (4.0 M DEEP - SMALL LATERAL EMBANKMENTS - WATER DEPTH = 35 M).
HI 8	1737.0	41.0		-	-	-	-	-	-	-	-	0	-	-	-	-	3.6	-	2.1	-	-	-	-								NO SONAR THIS SEGMENT
IJ				-	-	-	-	-	-	-	-																				NO SONAR THIS SEGMENT

2

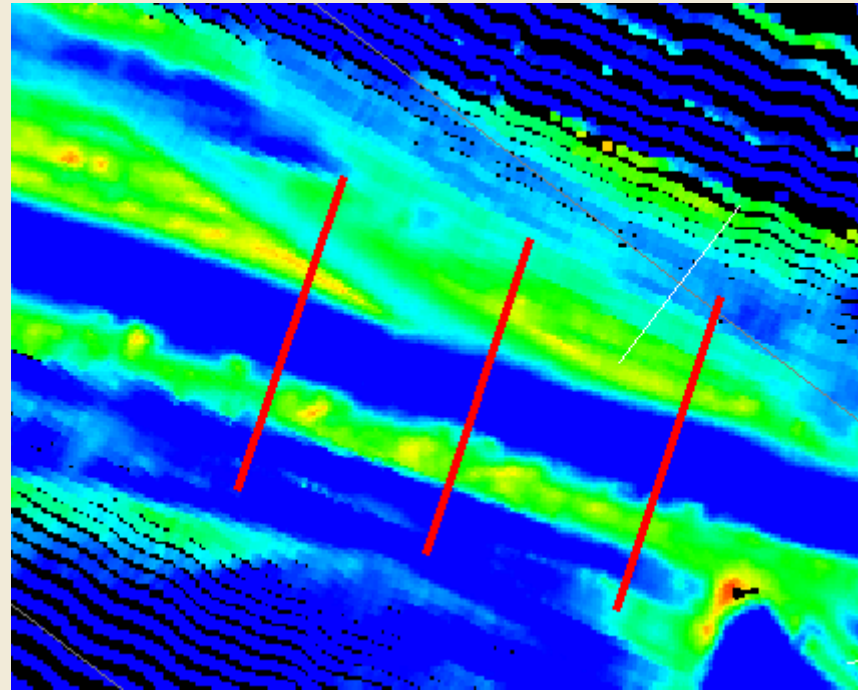
1. "Sea Ice as a Geologic Agent" in The Coast and Shelf of the Beaufort Sea, 1974
2. "Ice Gouge Data, Beaufort Sea, Alaska, 1972-1980" USGS Open-File Report 81-950



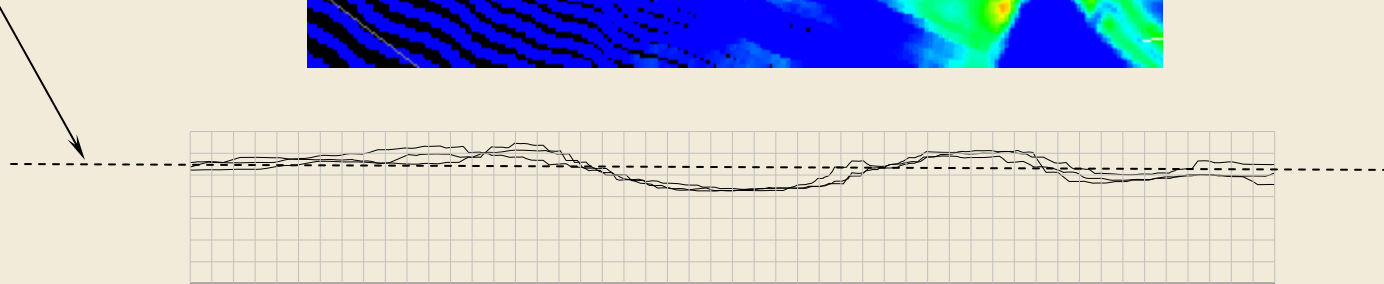
Vertical Resolution: A Few Centimeters

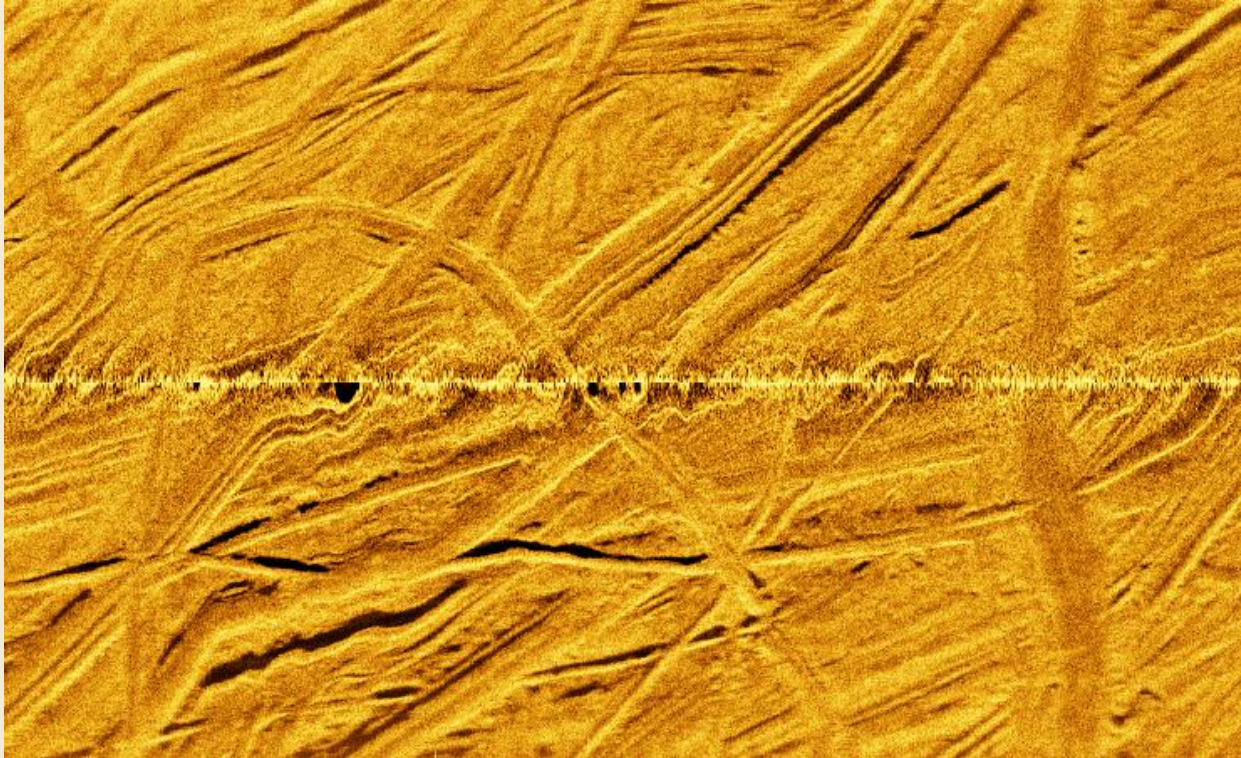


Multibeam Data: Measuring Gouges

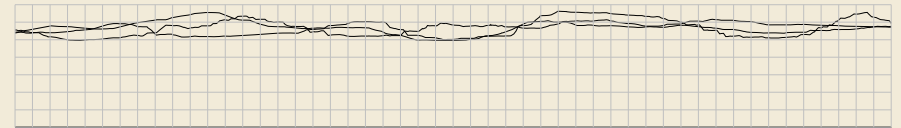
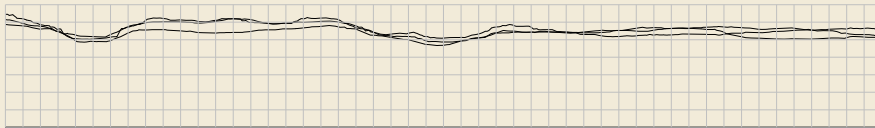
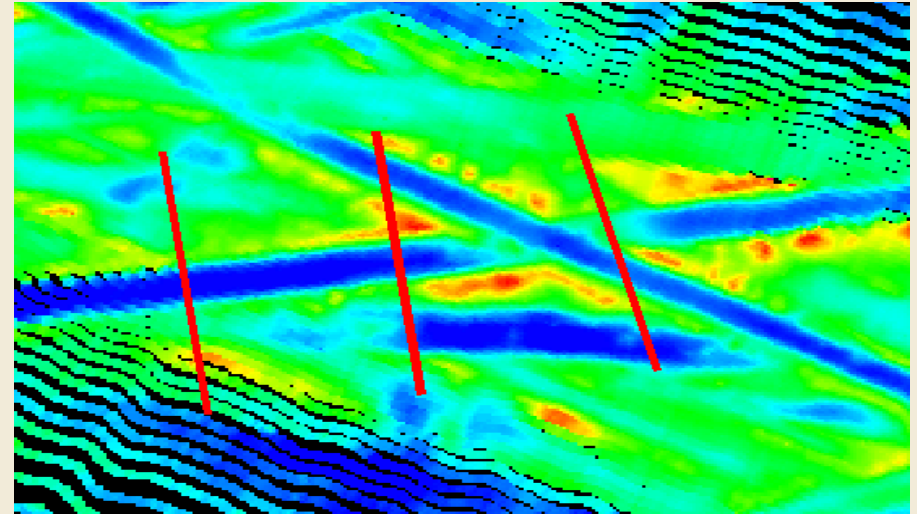
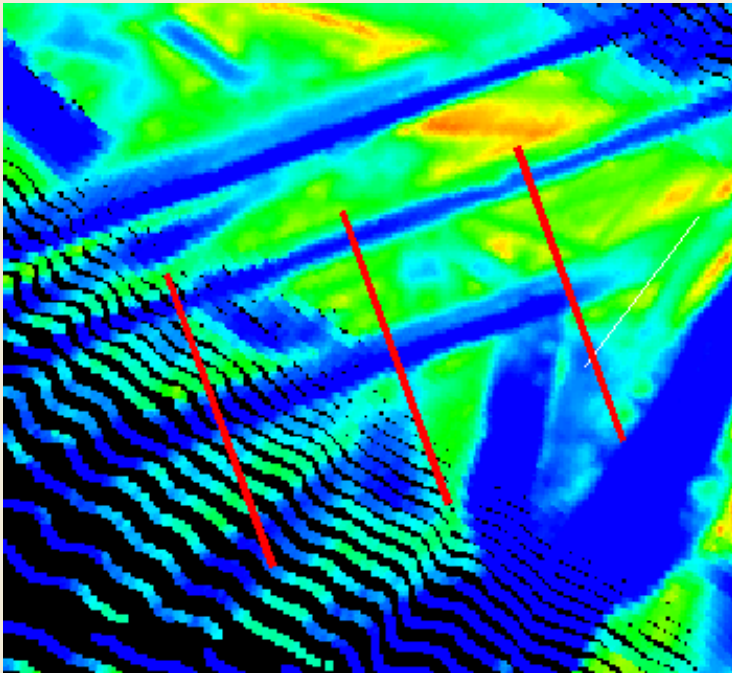


Undisturbed seafloor

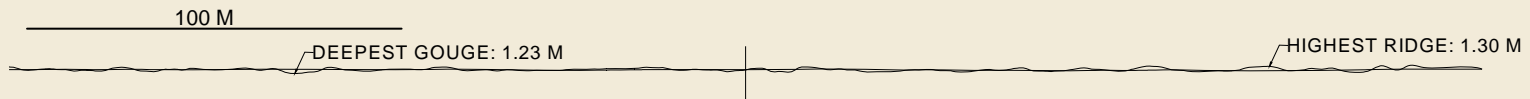
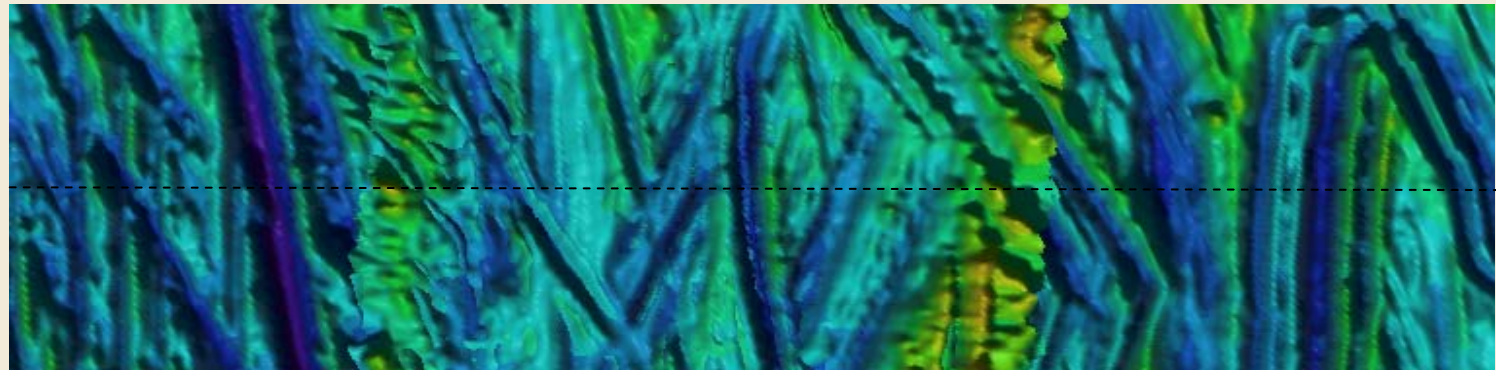
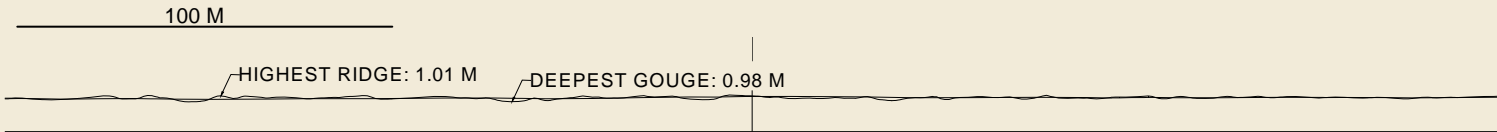
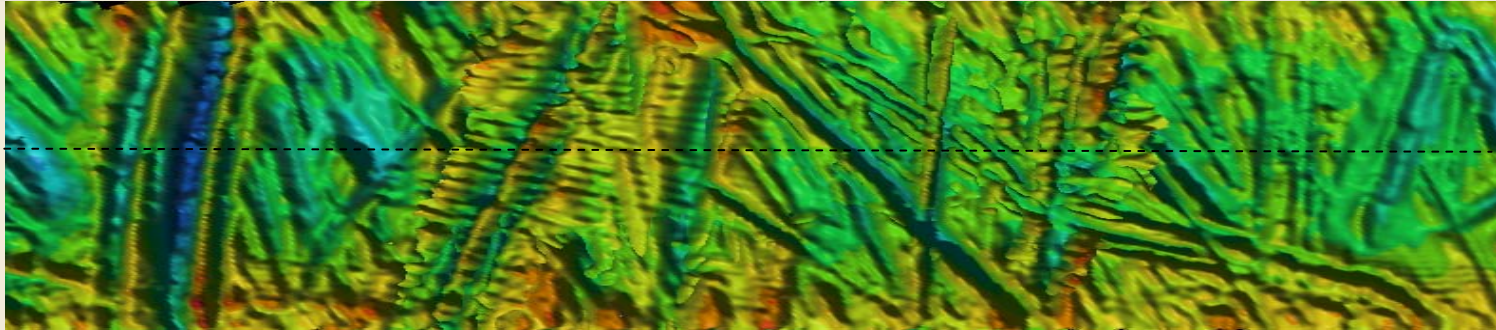




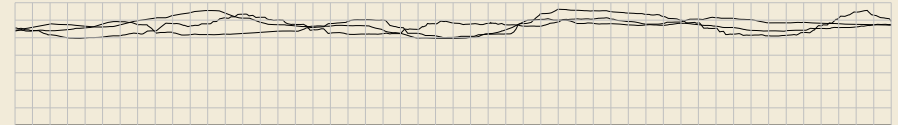
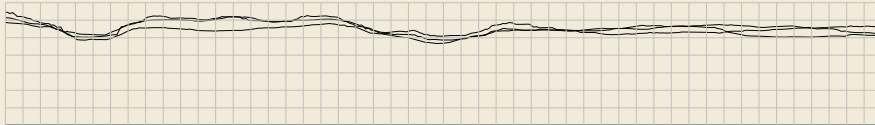
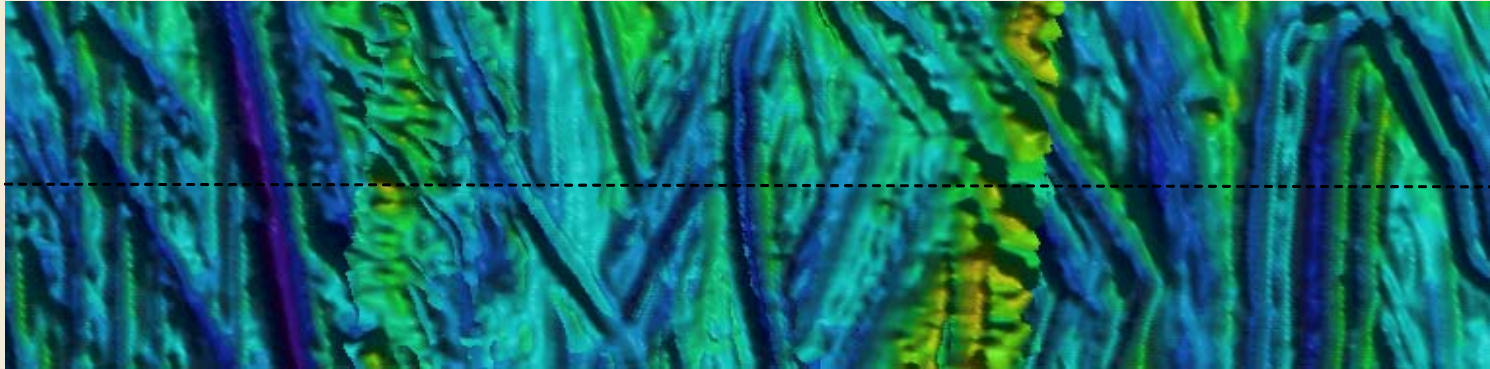
Extensively gouged surface typical



in figure 2. In order to minimize the admittedly subjective factor in the observation and measurement of gouge characteristics, the analysis was performed by one individual (D. R.). Observations and counts from early in



Graphic enhancements make visual appearance of gouges more impressive, but do not necessarily help with scientific interpretation.



- Graphic enhancements make visual appearance of gouges more impressive
- Vertical placement of undisturbed seafloor difficult
- Extracting cross section vertical information is tedious
- Trench and ridge picks vulnerable to subjective bias

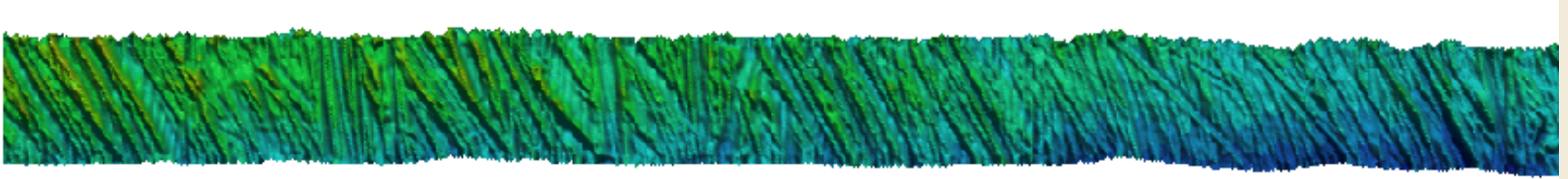


Objective Computer Technique

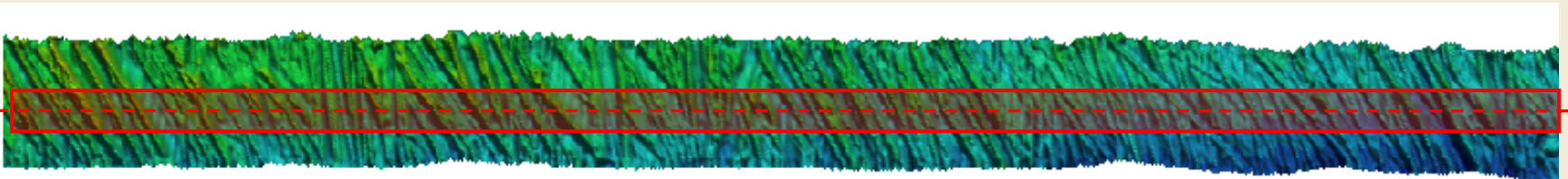
- Fast
- Objective
- Every vertical deviation identified
- Vertical deviations subject to menu of analyses in ubiquitous office software



Objective Computer Technique Steps



Swath of multibeam data: typically 1 meter horizontal resolution, typical 80 meters wide, approximately 80,000 points of XYZ data per kilometer



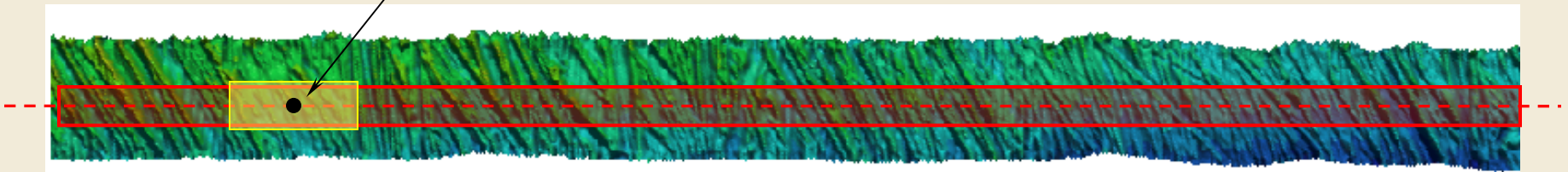
Define an alignment and associated “smoothing corridor”, typically 4-5 meters offset from alignment.



Seafloor Multibeam Data Points Smoothing

Extract two swaths of data within alignment corridor: original multibeam surface and a smoothed surface.

Each data point averaged with neighboring local points



The smoothed surface is mass neutral (mass balanced). Like a road grader.

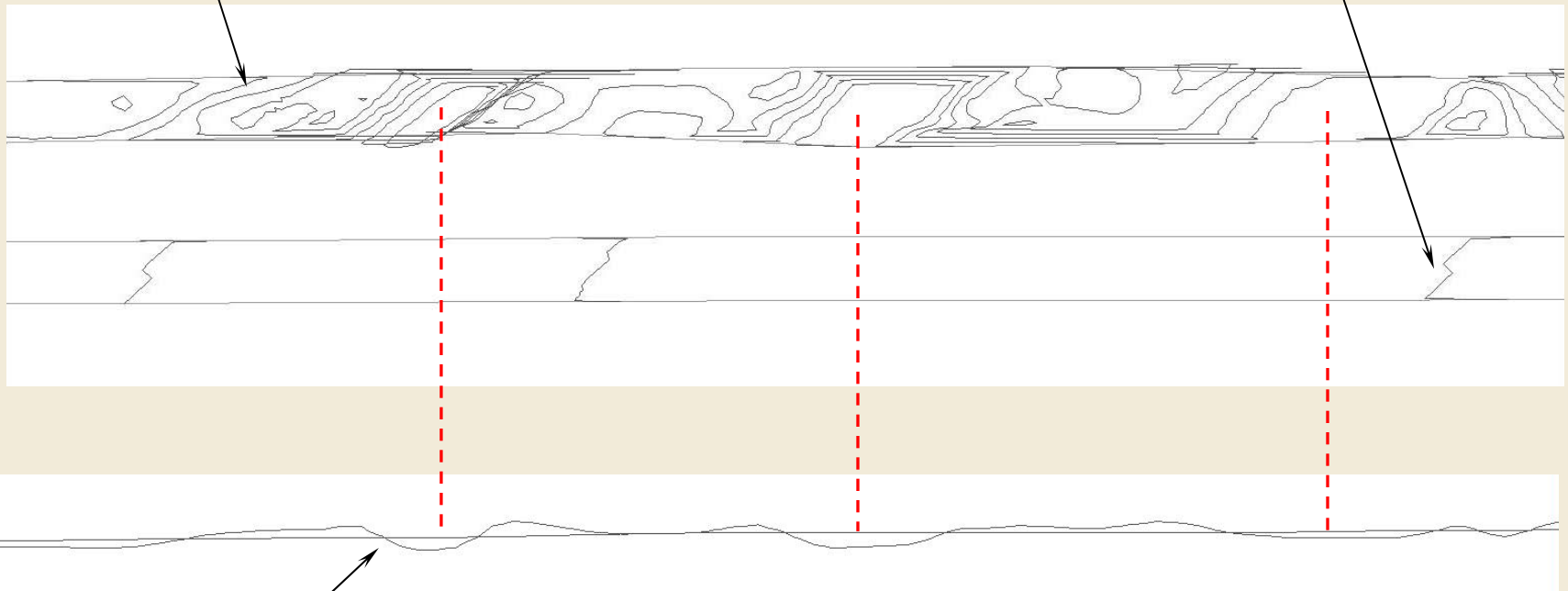


Smooth Surface Versus Original Surface

Both surfaces imported to CAD:

Contours from multibeam 1 meter XYZ data

Smoothed surface contours



Profile of multibeam surface and smoothed surface



- Vertical deviations (ridges/trenches) identified by in-house computer program.
- Profile trench/ridge results imported to Excel for analysis.

Results: The characteristics of *all* vertical deviations

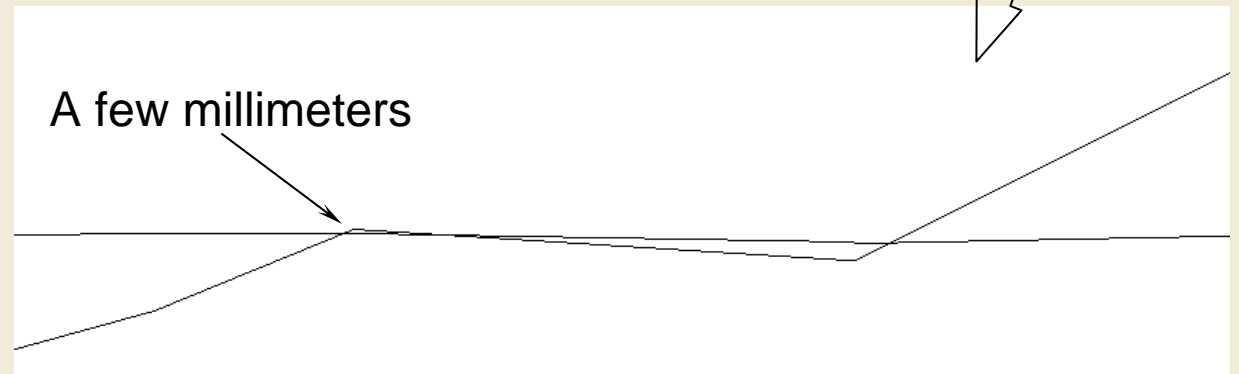
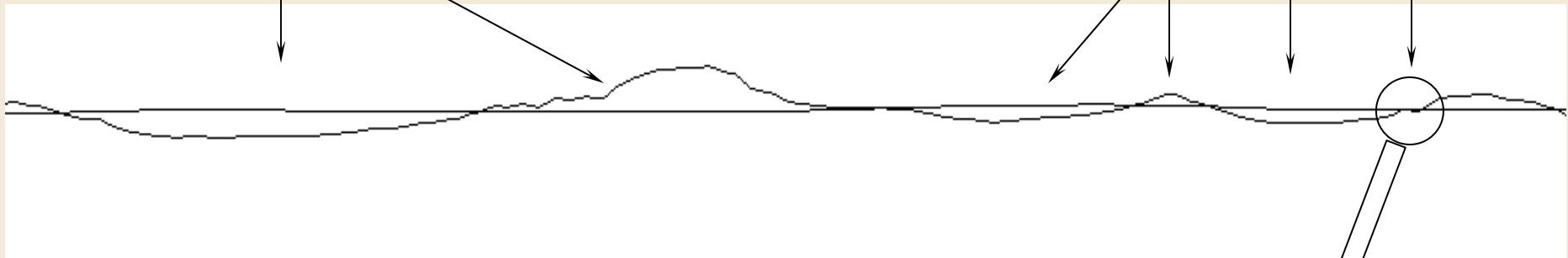


DISTANCE (m)	VERTICAL DEV (m)	DEV SEGMENT LENGTH (m)	CUT / FILL (m ³)
7.61	-0.23	7.61	-1.26
18.78	0.13	11.16	1.04
24.47	-0.12	5.70	-0.39
26.54	0.02	2.06	0.04
38.61	-0.25	12.08	-1.46
46.61	0.24	8.00	0.98
54.77	-0.08	8.16	-0.41
70.92	0.34	16.15	3.33
))))
9450.94	0.62	14.65	3.32
9458.75	-0.42	7.81	-1.68
9460.27	0.07	1.52	0.07
9464.52	-0.44	4.25	-1.03
9485.13	0.56	20.61	4.67
9498.67	-0.73	13.54	-7.68
9514.83	0.96	16.15	11.20
9536.37	-0.59	21.54	-9.18
9547.04	0.97	10.68	6.04
9560.14	-0.68	13.09	-6.31
9585.21	0.66	25.08	7.65
9594.30	-0.76	9.08	-5.30



Analysis and Extracted Profile Example

DISTANCE (m)	VERTICAL DEV (m)	DEV SEGMENT LENGTH (m)	CUT / FILL (m ³)
1323.36	-1.06	20.07	-13.75
1341.74	1.68	18.39	13.31
1353.75	-0.62	12.00	-4.38
1357.51	0.42	3.77	0.74
1366.43	-0.55	8.92	-3.40
1366.96	0.00	0.53	0.00
1367.74	-0.04	0.78	-0.03
1374.05	0.57	6.31	2.40

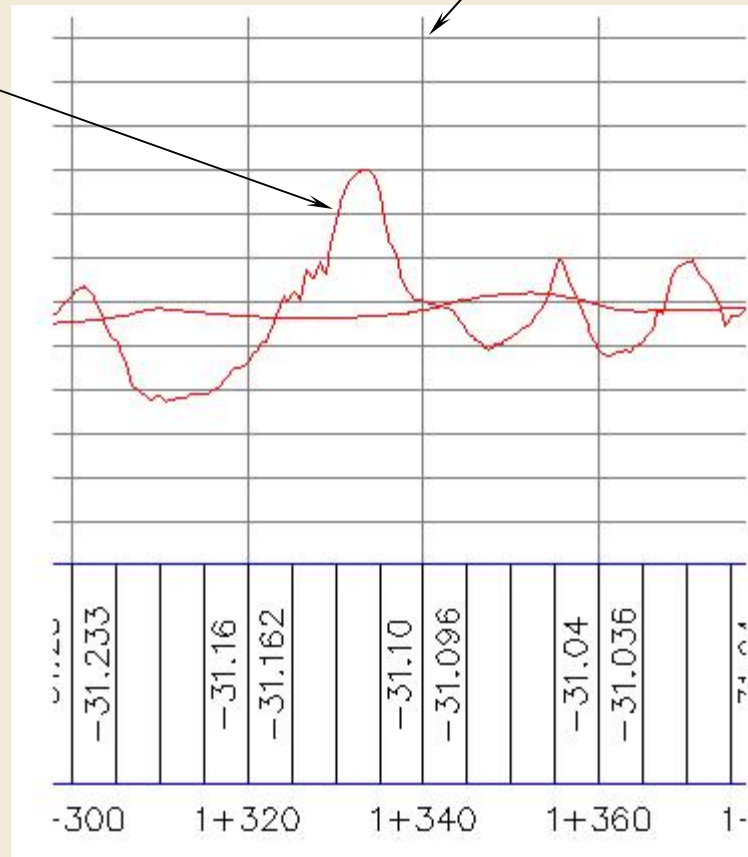




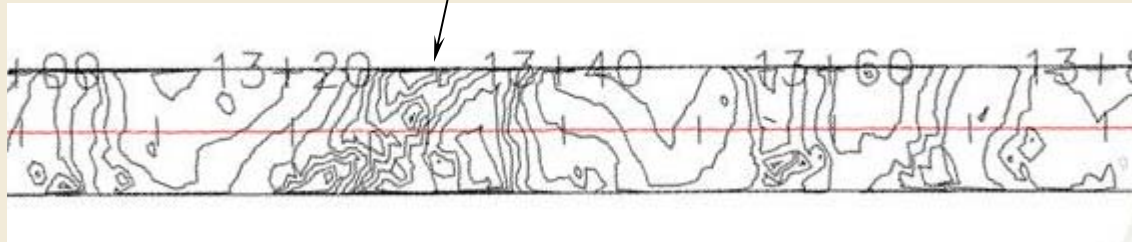
Vertical Deviation Picks in CAD

DISTANCE (m)	VERTICAL DEV (m)	DEV SEGMENT LENGTH (m)	CUT / FILL (m ³)
1323.36	-1.06	20.07	-13.75
1341.74	1.68	18.39	13.31
1353.75	-0.62	12.00	-4.38
1357.51	0.42	3.77	0.74
1366.43	-0.55	8.92	-3.40
1366.96	0.00	0.53	0.00
1367.74	-0.04	0.78	-0.03
1374.05	0.57	6.31	2.40

Typical CAD Profile
(vertical 10 X horizontal)



Typical CAD Contours





Utility of All Deviations in Excel

When all vertical deviations in Excel, analysis tools and filters can be used as desired.

Filter: Ridges greater than 1.2 m

Filter: Trenches deeper than 1.0 m

DISTANCE (▼)	VERTICAL DEV (▼)	DEV SEGMENT LENGTH (▼)	CUT / FILL (r▼)
1341.74	1.68	18.39	13.31
1960.76	1.27	13.63	5.66
4549.94	1.30	13.00	9.23
6392.75	1.39	18.40	17.03

DISTANCE (▼)	VERTICAL DEV (▼)	DEV SEGMENT LENGTH (▼)	CUT / FILL (r▼)
534.12	-1.21	11.68	-11.40
1323.36	-1.06	20.07	-13.75
2016.21	-1.12	3.14	-2.48
2922.25	-1.21	18.95	-13.19
3334.15	-1.06	13.92	-4.97
4327.85	-1.02	13.00	-9.13
6414.96	-1.07	22.21	-15.61
6658.96	-1.21	17.07	-12.26
7419.82	-1.38	19.37	-10.13
8145.17	-1.05	11.34	-7.20

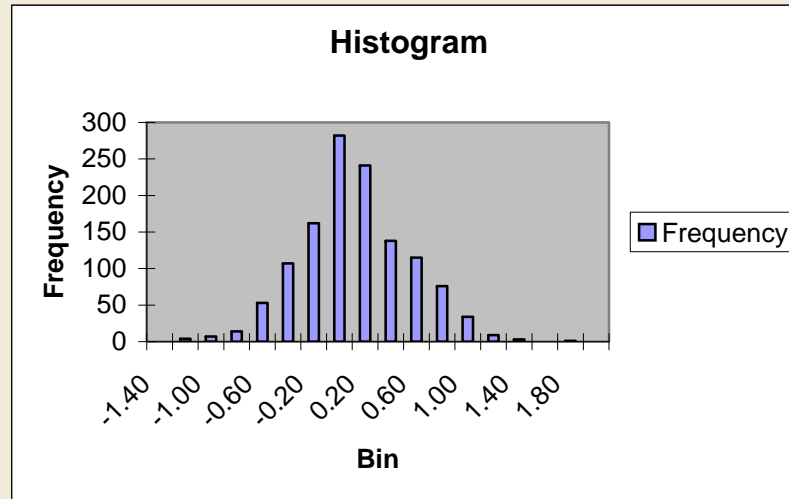
DISTANCE (▼)	VERTICAL DEV (▼)	DEV SEGMENT LENGTH (▼)	CUT / FILL (r▼)
1272.48	-0.82	16.74	-9.39
1323.36	-1.06	20.07	-13.75
2922.25	-1.21	18.95	-13.19
3334.15	-1.06	13.92	-4.97
4190.46	-0.99	14.53	-8.51
4327.85	-1.02	13.00	-9.13
4571.47	-1.00	21.54	-13.84
4794.71	-0.85	28.01	-15.31
5186.71	-0.86	21.54	-6.59
5415.87	-0.87	14.46	-9.01
5953.11	-0.96	13.92	-7.19
6414.96	-1.07	22.21	-15.61
6564.65	-0.95	15.23	-9.57
6658.96	-1.21	17.07	-12.26
7419.82	-1.38	19.37	-10.13
9077.76	-0.80	21.16	-9.83

Filter: Trenches deeper than 0.8 m and wider than 12 m



Utility of All Deviations in Excel

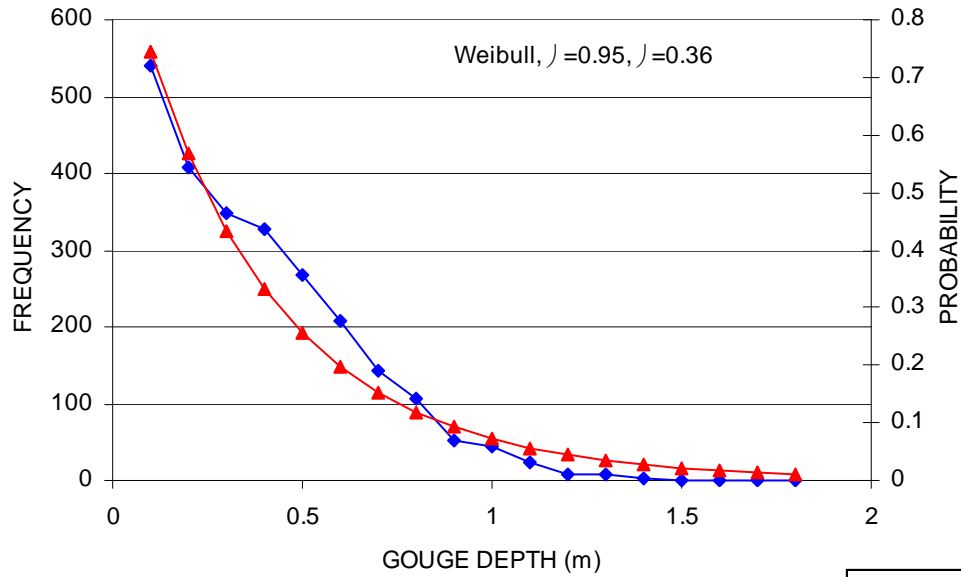
Bin	Frequency
-1.40	0
-1.20	4
-1.00	7
-0.80	14
-0.60	53
-0.40	107
-0.20	162
0.00	282
0.20	241
0.40	138
0.60	115
0.80	76
1.00	34
1.20	9
1.40	3
1.60	0
1.80	1
More	0



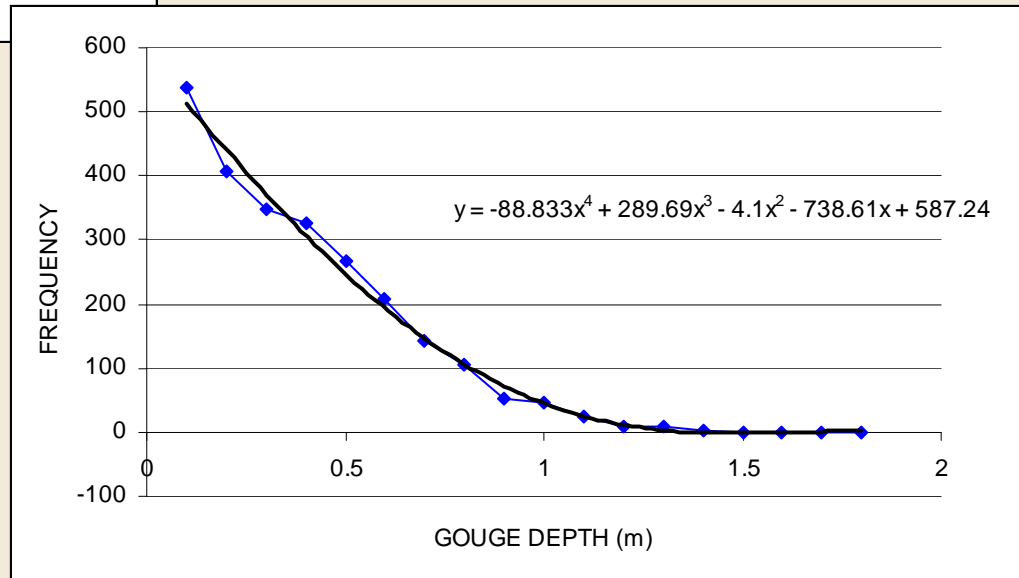
<i>Gouge Stats 1</i>	
Mean	0.0213
Standard Error	0.0119
Median	-0.0005
Mode	0
Standard Deviation	0.4194
Sample Variance	0.1759
Kurtosis	0.2186
Skewness	0.1355
Range	3.06
Minimum	-1.38
Maximum	1.68
Sum	26.56
Count	1246



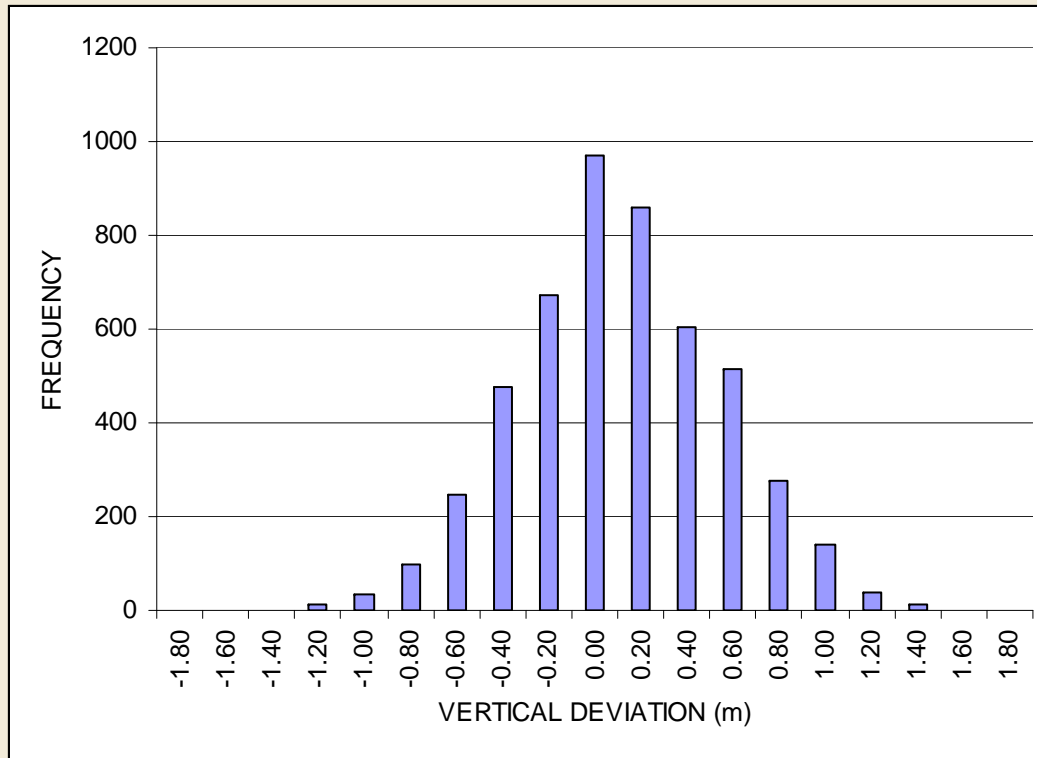
Utility of All Deviations in Excel



Curve fitting



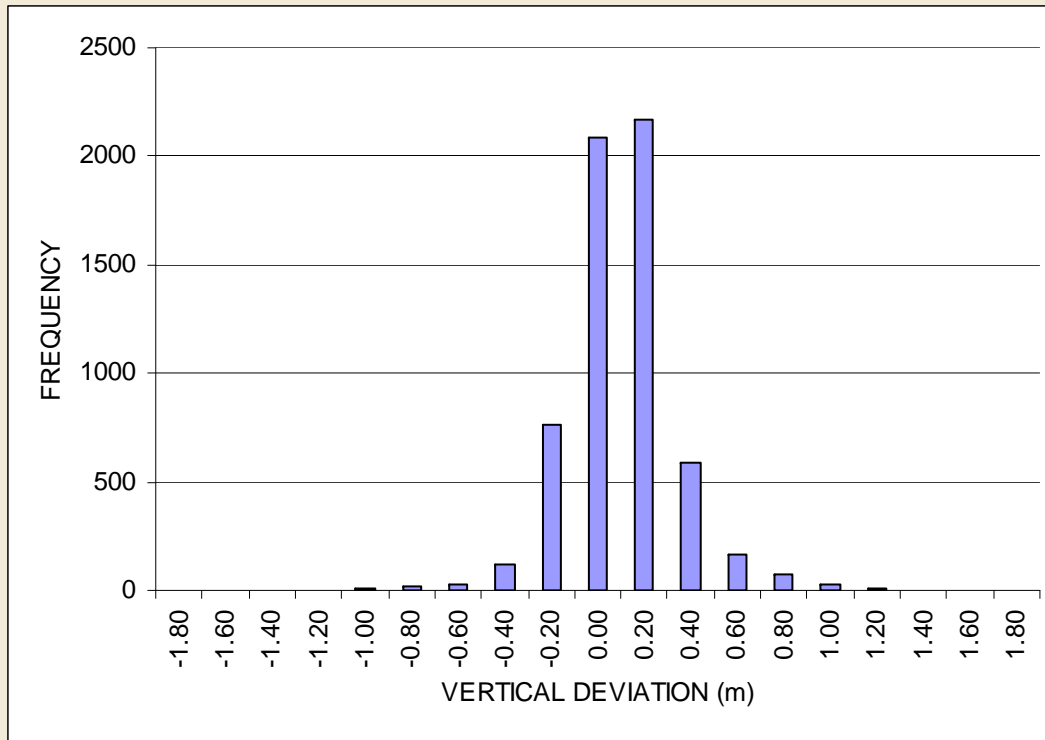
30 meter water depth, 48 line km of data



Mean	0.01
Median	0.00
Standard Deviation	0.44
Sample Variance	0.19
Skewness	0.08
Range	3.06
Minimum	-1.38
Maximum	1.68
Sum	65.92
Count	4966



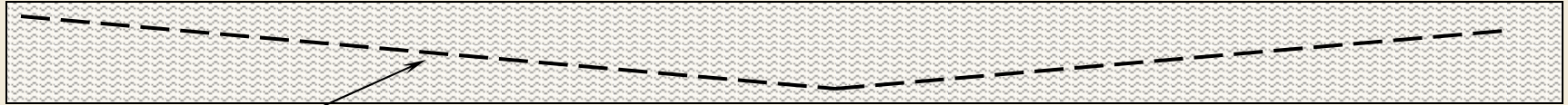
40 meter water depth, 54 line km of data



Mean	0.00
Median	0.00
Standard Deviation	0.24
Sample Variance	0.06
Skewness	-0.01
Range	3.05
Minimum	-1.72
Maximum	1.33
Sum	-13.14
Count	6065



Flexible Configuration of Analysis Lines

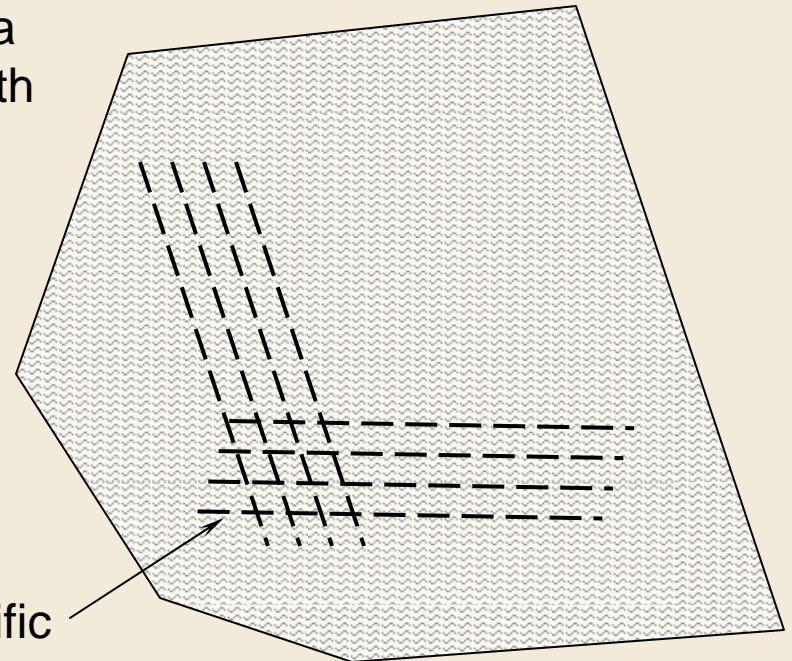
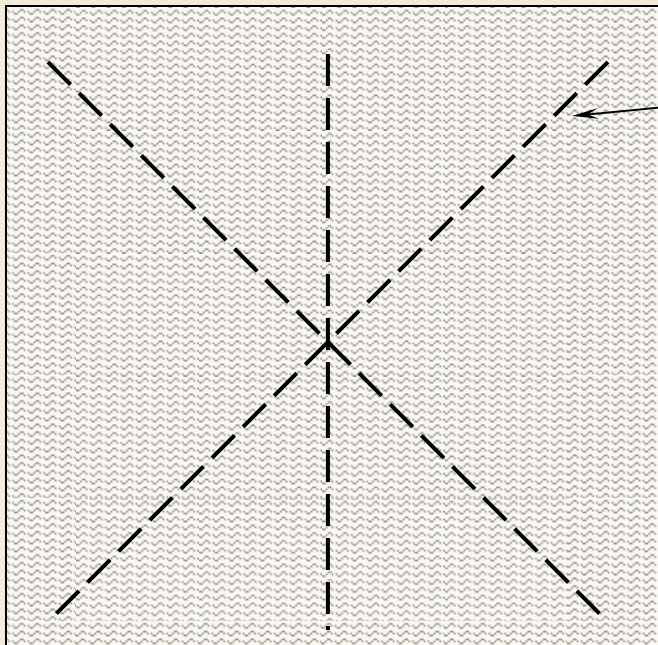


Horizontal alignment with angular changes



Offset alignments

Combined
multibeam area
multiple-azimuth
lines



Site specific



Computer Gouge Analysis

- Multibeam data very powerful basic data
- Fast
- Objective
- Every vertical deviation identified
- Vertical deviations subject to wide range of analysis in ubiquitous office software
- Side benefit: plan and profile in CAD