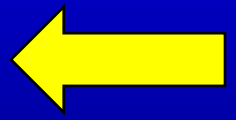
Seismic Attributes - from Interactive Interpretation to Machine Learning

Kurt J. Marfurt (The University of Oklahoma)

Geometric Attributes

GLCM Amplitude Textures

Geometric Attributes that map continuity, amplitude changes and textures

1. Coherence
2. Amplitude gradients
3. GLCM textures 

Gray Level Co-occurrence Matrix (GLCM) Textures

After this section you will be able to:

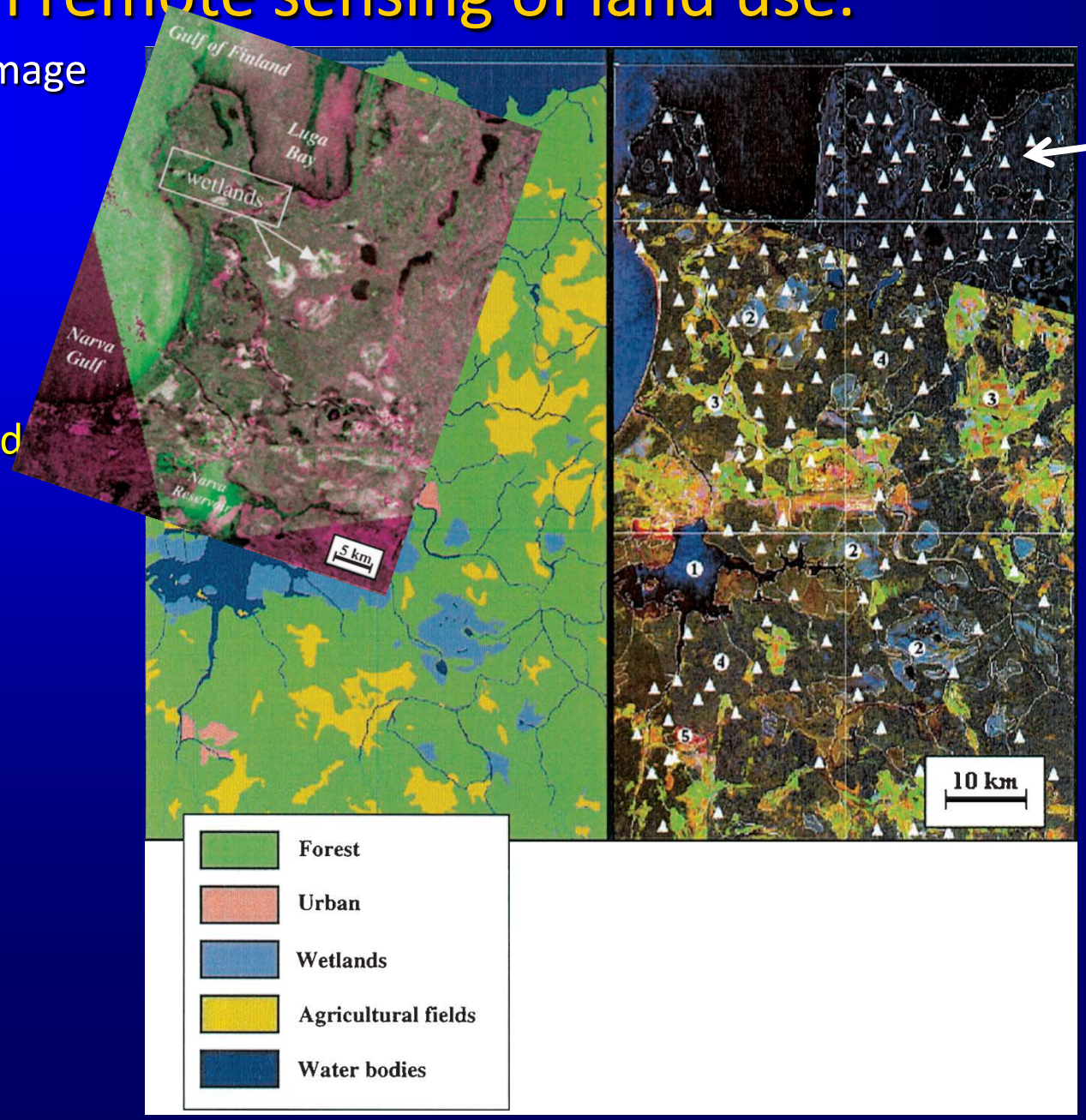
- Use GLCM textures to quantify patterns that the interpreter sees and uses, but finds difficult to describe, and
- Use these textures in subsequent facies identification using machine learning.

Everyday Textures

(Marfurt, 2018)

GLCM used in remote sensing of land use.

ERS-1 SAR image



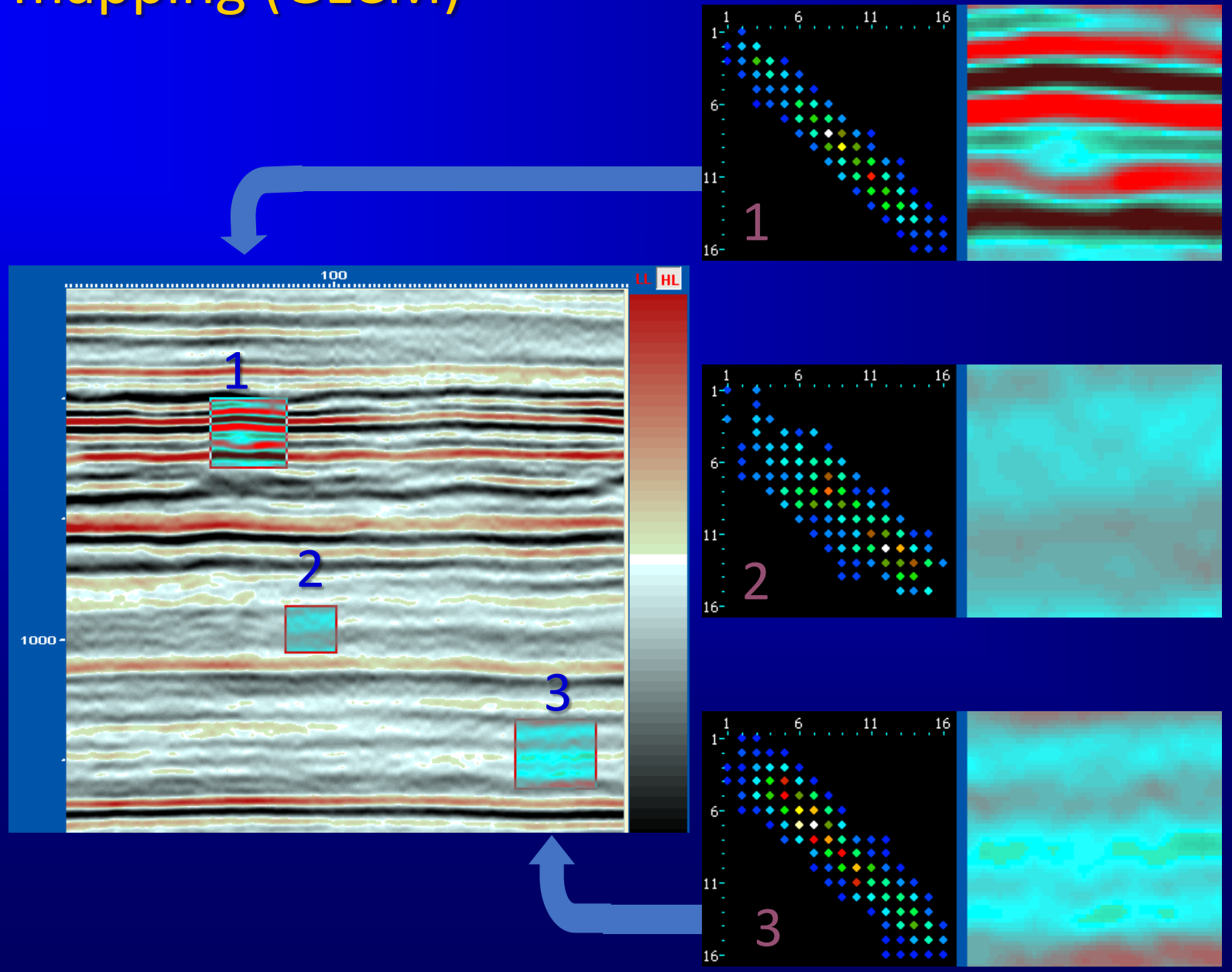
Ground

In-situ control

From satellite data and GLCM clustering

(Miles et al., 2003)

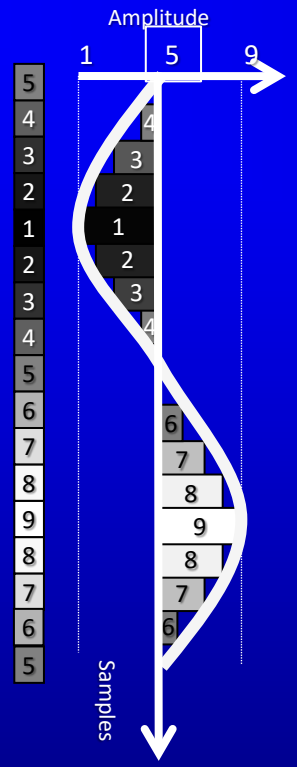
3D texture mapping (GLCM)



Matrix size 16

(Chopra and Marfurt, 2007)

How GLCM is evaluated



	4	6	4	6	4
	4	6	4	6	4
	4	6	4	6	4
	4	6	4	6	4
	4	6	4	6	4

0°

To pixel / From pixel

	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	10	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	10	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0

Contrast: 4
Correlation: -1
Energy: 0.86
Homogeneity: 0.2

90°

To pixel / From pixel

	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	12	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	8	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0

Contrast: 0
Correlation: +1.0
Energy : 0.72
Homogeneity: 1

45°

To pixel / From pixel

	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	8	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	8	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0

Contrast: 4
Correlation: -1
Energy: 0.86
Homogeneity: 0.2

135°

To pixel / From pixel

	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	8	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	8	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0

Contrast: 4
Correlation: -1
Energy: 0.86
Homogeneity: 0.2

(Angelo et al., 2009)

GLCM (texture) attributes

$$C = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{ij}(i-j)^2$$

Contrast
L2 norm of similarity

Returns a measure of the intensity contrast between a pixel and its neighbor over the whole image. Contrast is 0 for a constant image.

$$D = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{ij}|i-j|$$

Dissimilarity
L1 norm of similarity

$$H = \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{P_{ij}}{1+(i-j)^2}$$

Homogeneity
Inverse norm of similarity

Returns a value that measures the closeness of the distribution of elements in the GLCM to the GLCM diagonal. Homogeneity is 1 for a diagonal GLCM.

$$E = \sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N} P_{ij}^{\,2}}$$

Energy
A measure of smoothness

Returns the sum of squared elements in the GLCM. Energy is 1 for a linear amplitude gradient

$$\mu_i = \sum_{j=0}^{N} j(P_{i,j})$$

Mean

$$R = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{ij}\left[\frac{(i-\mu_i)(j-\mu_j)}{V_i^{1/2}V_j^{1/2}}\right] = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{ij}\left[\frac{(i-\mu)(j-\mu)}{V}\right]$$

Correlation

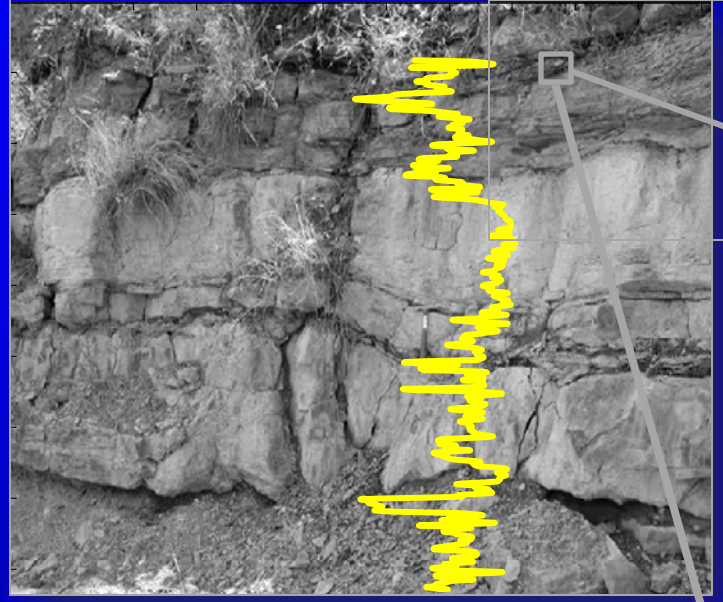
Returns a measure of how correlated a pixel is to its neighbor over the whole image. Correlation is 1 or -1 for a perfectly positively or negatively correlated image. Correlation is NaN for a constant image.

$$S = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{ij}(\ln P_{ij})$$

Entropy
A measure of disorderliness (or roughness)

(Angelo et al., 2009)

Example : GLCM Matrices and attributes from a photo



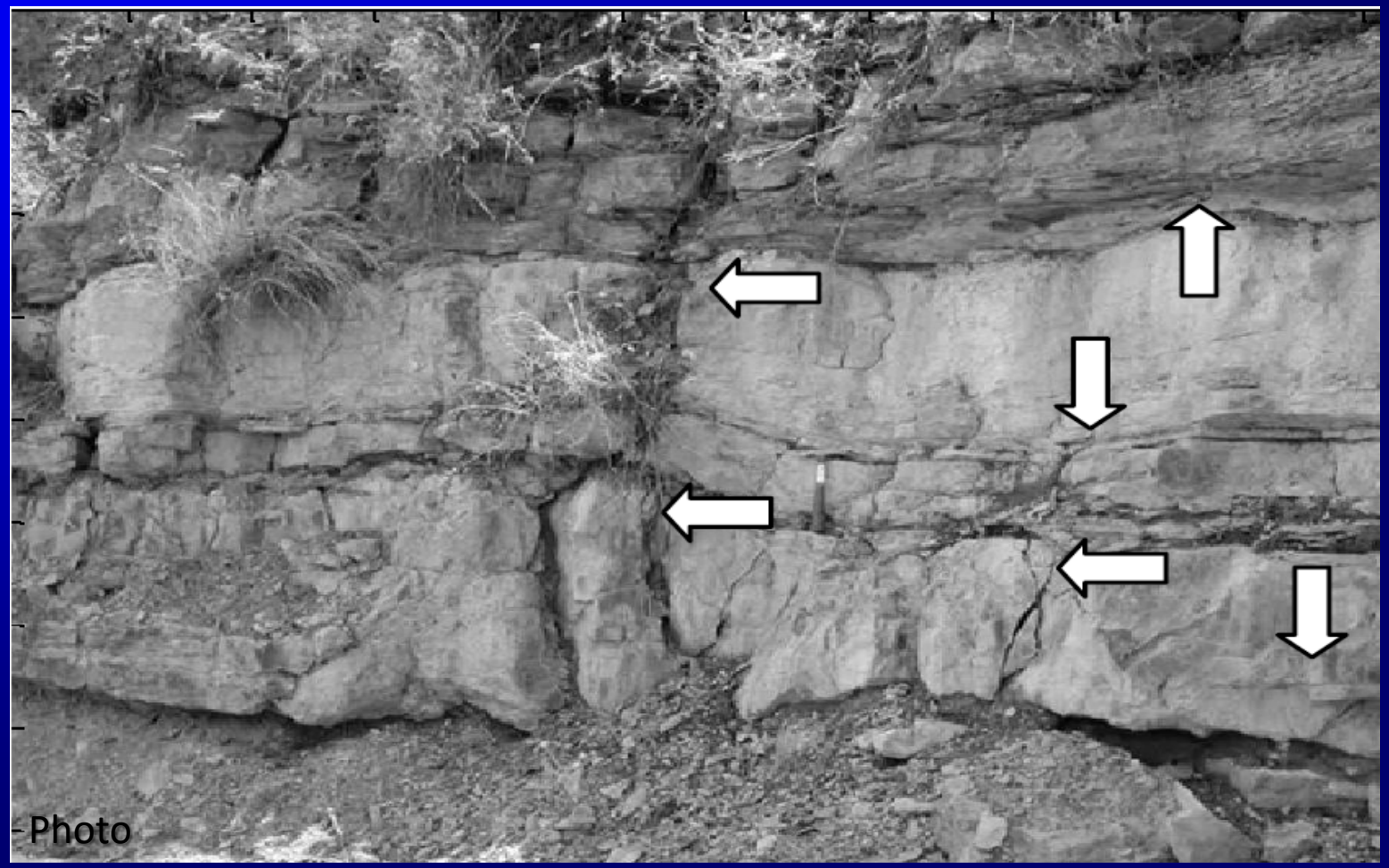
Outcrop image of Monongahela Group, Pittsburgh Formation
(www.geology.pitt.edu)

114	111	108	113	133	115	79	85	83	80	81	74	83	87	81	80	49	72	71	53	62	68
110	102	113	112	117	135	128	80	72	92	85	68	78	80	67	86	78	82	75	70	67	66
124	107	110	99	87	128	137	90	104	118	95	75	83	82	62	84	95	91	76	66	74	73
115	108	129	113	91	110	93	84	100	91	90	86	87	84	58	60	70	89	74	43	43	35
120	119	125	106	86	78	71	77	67	54	72	80	85	78	51	44	41	80	76	53	30	14
95	86	78	55	63	54	45	32	43	46	67	75	88	92	46	65	54	63	83	45	43	69
80	57	54	45	66	52	28	19	59	84	90	70	85	87	27	56	49	47	86	55	54	75
66	49	41	42	69	43	11	41	105	102	99	92	107	103	38	41	40	47	79	71	63	57
42	45	28	30	59	22	5	55	123	101	113	114	99	115	96	78	69	77	71	78	69	47
38	22	17	23	32	10	12	46	68	62	68	95	92	111	112	113	78	63	54	62	66	22
70	3	20	37	20	23	49	41	57	58	61	103	115	92	50	92	94	76	84	62	44	15
77	20	35	17	13	47	89	76	93	101	102	109	98	89	31	80	137	126	96	75	77	64
95	52	50	27	42	61	95	105	103	113	117	100	97	113	40	66	118	120	77	85	103	68
87	85	84	53	53	50	61	73	83	110	97	74	78	103	48	74	91	97	66	73	91	76
84	95	94	67	45	38	58	70	81	81	65	56	65	118	78	84	82	84	77	66	90	115
57	53	45	47	57	70	94	103	94	77	72	65	67	105	78	79	60	71	98	98	111	120
64	57	28	38	65	94	107	96	77	73	68	53	64	107	107	82	78	95	109	111	108	107
34	44	47	69	81	82	84	83	78	67	72	66	71	104	123	91	98	116	108	93	98	105
33	47	56	70	92	89	86	81	99	94	85	87	91	117	133	114	118	120	111	96	100	108
67	82	74	79	87	104	102	89	89	97	98	116	105	107	123	101	123	106	102	110	108	111
86	103	95	87	74	90	93	93	94	114	99	98	94	101	136	132	123	77	61	113	122	117
93	114	121	112	75	75	80	92	82	84	105	109	100	113	139	129	101	89	87	110	116	126

5x5 pixels
256 gray levels and 4 attributes

Contrast	0.986
Correlation	0.7395
Energy	0.0844
Homogeneity	0.5

GLCM attributes and clustering

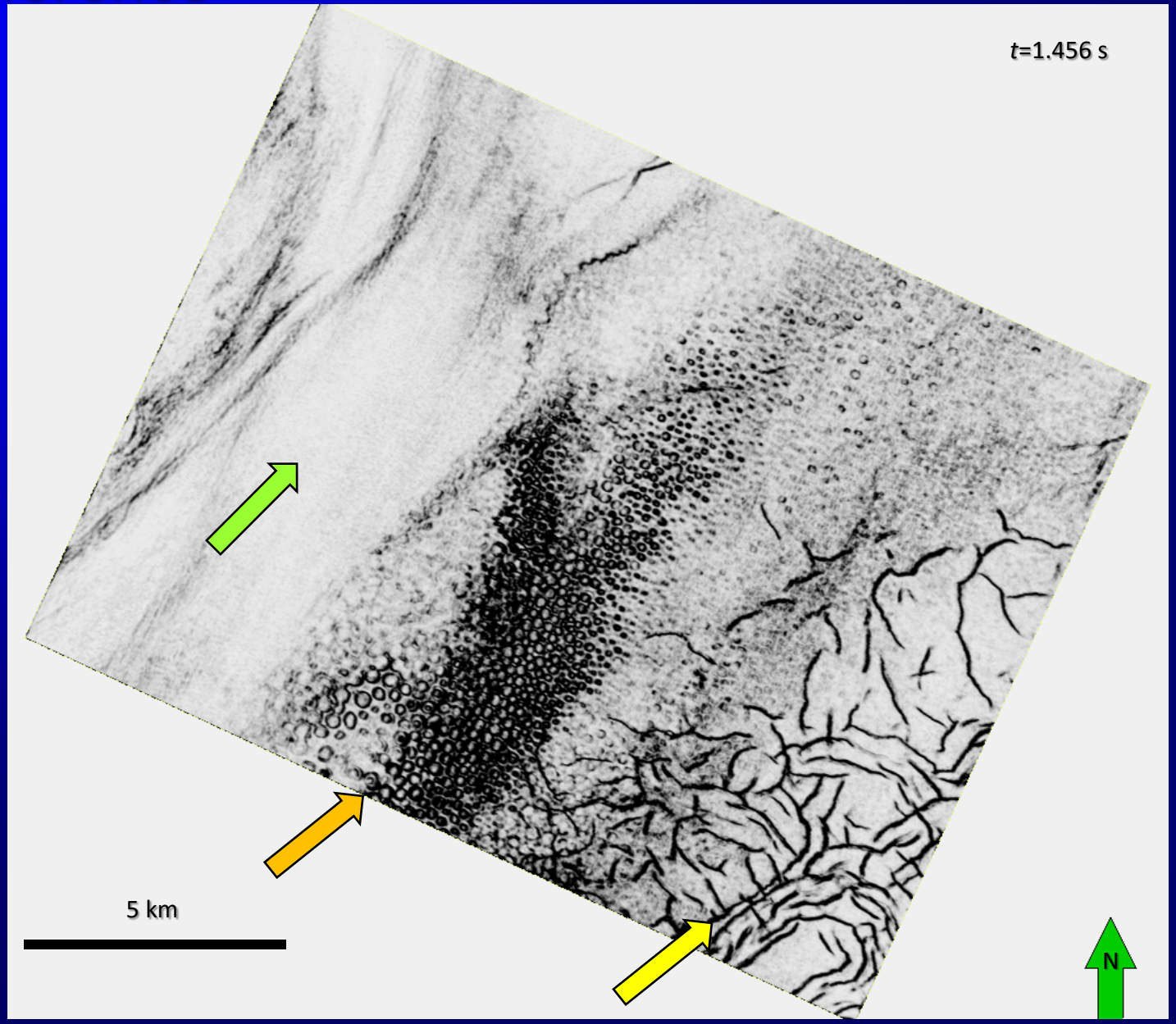


Application to an outcrop photo

(Angelo et al., 2009)

Energy ratio coherence

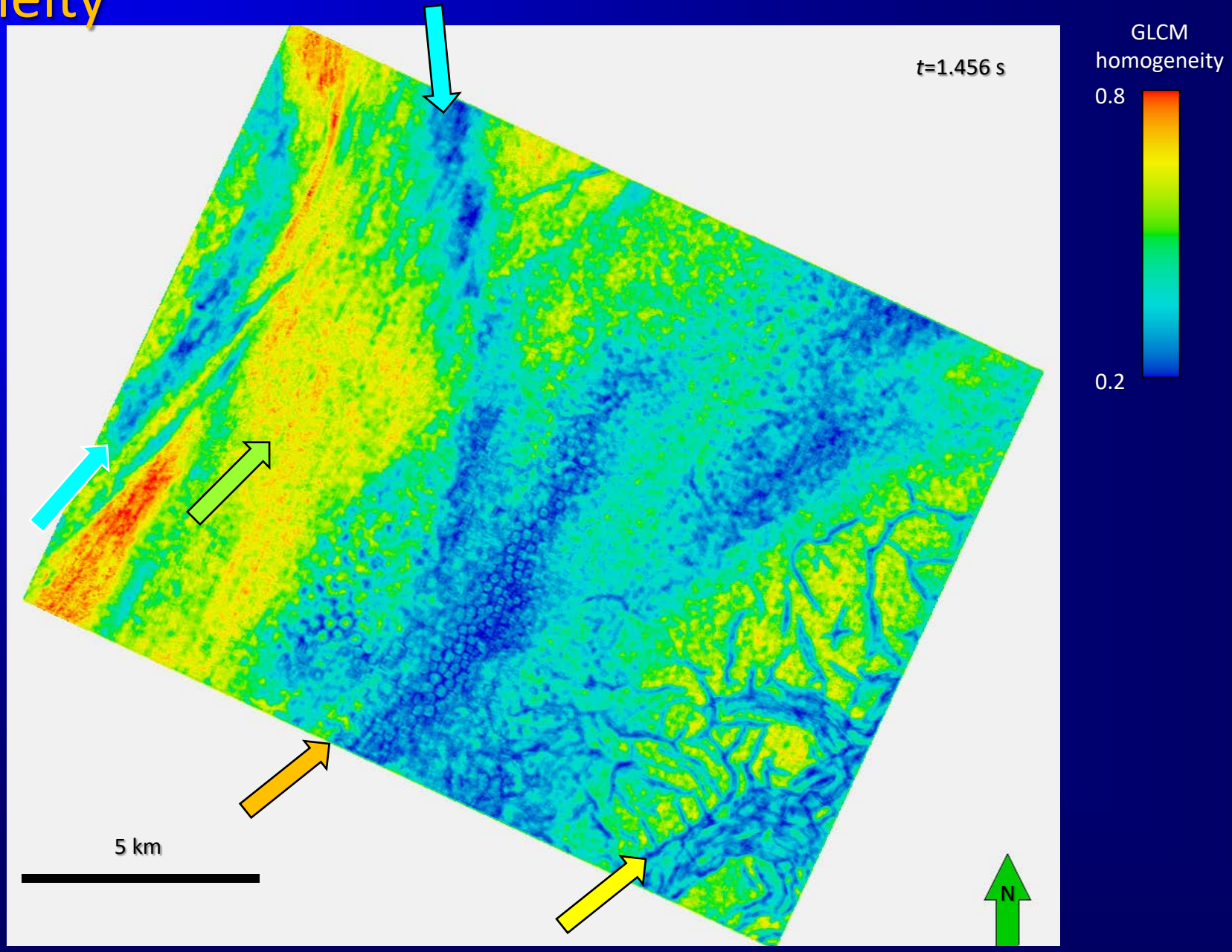
Great South Basin, NZ



(Marfurt, 2018)

GLCM homogeneity

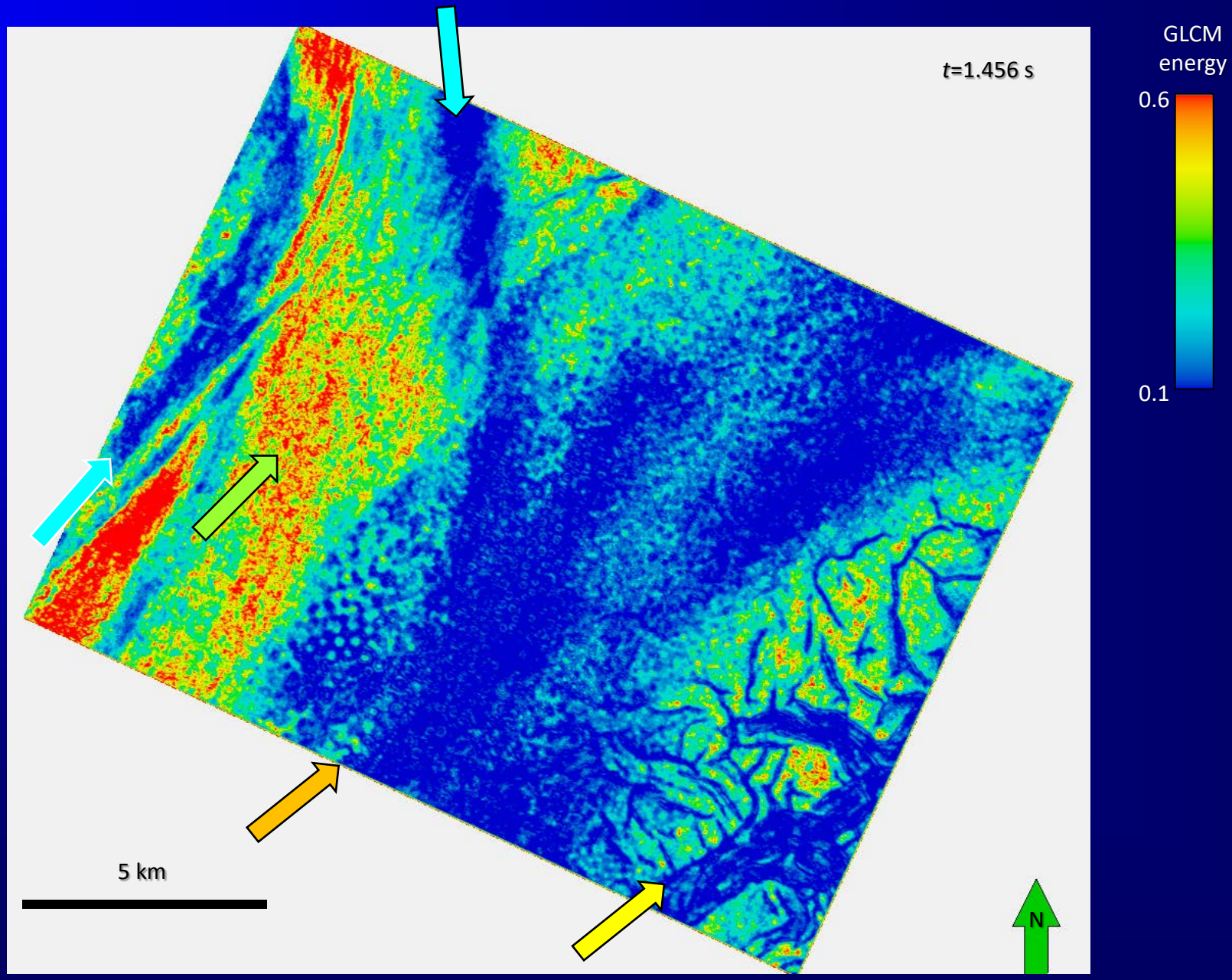
Great South Basin, NZ



(Marfurt, 2018)

GLCM energy

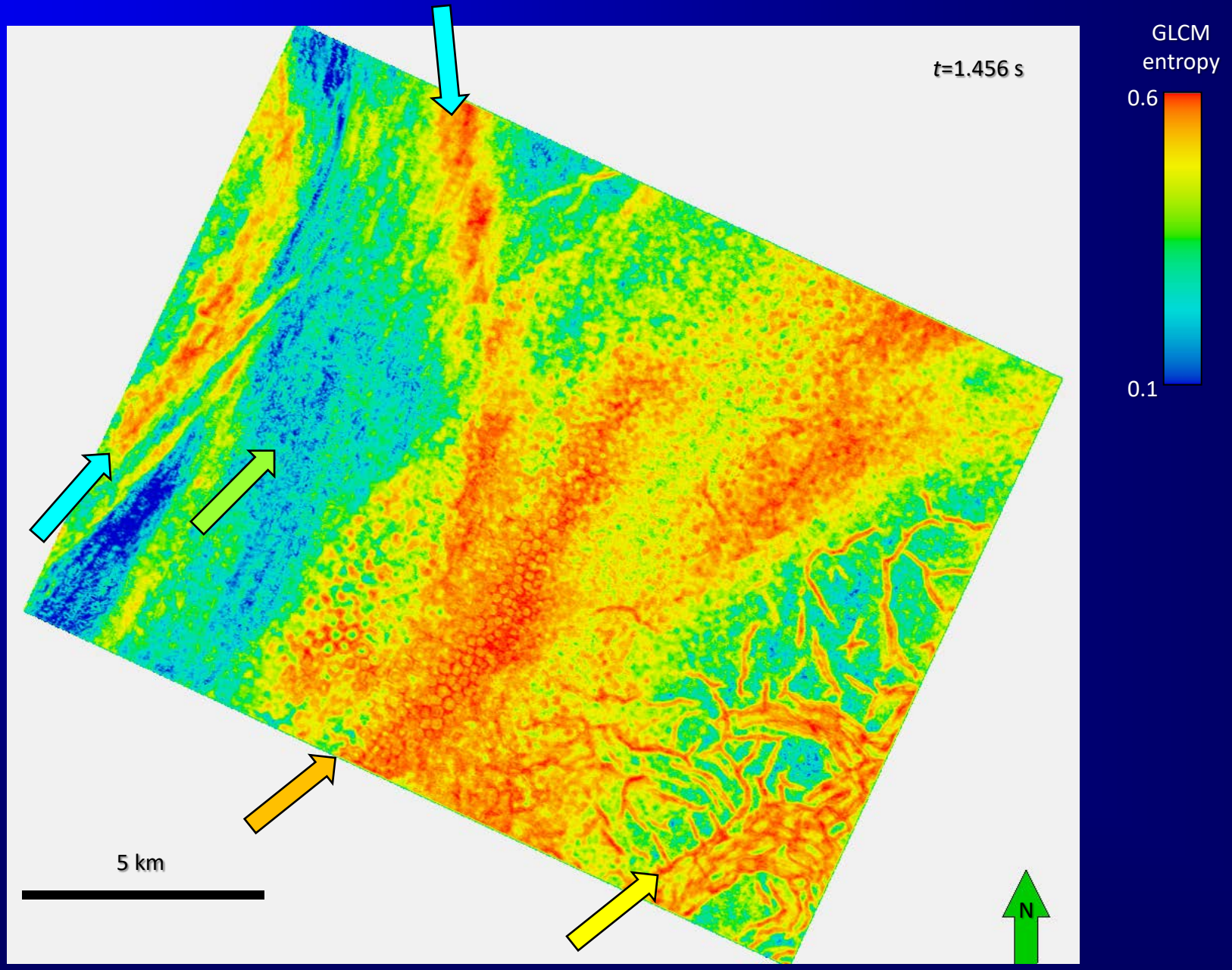
Great South Basin, NZ



(Marfurt, 2018)

GLCM entropy

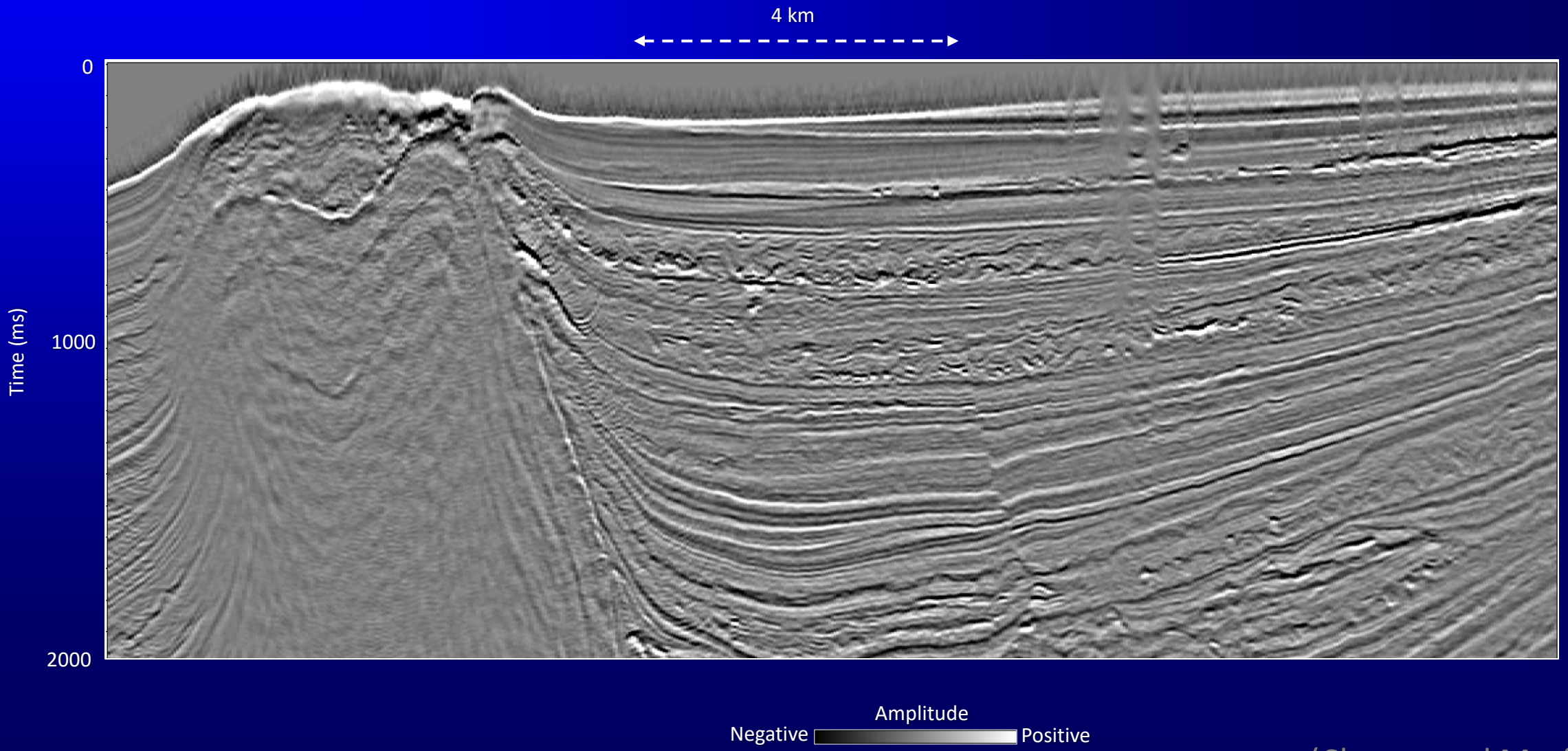
Great South Basin, NZ



(Marfurt, 2018)

Seismic amplitude

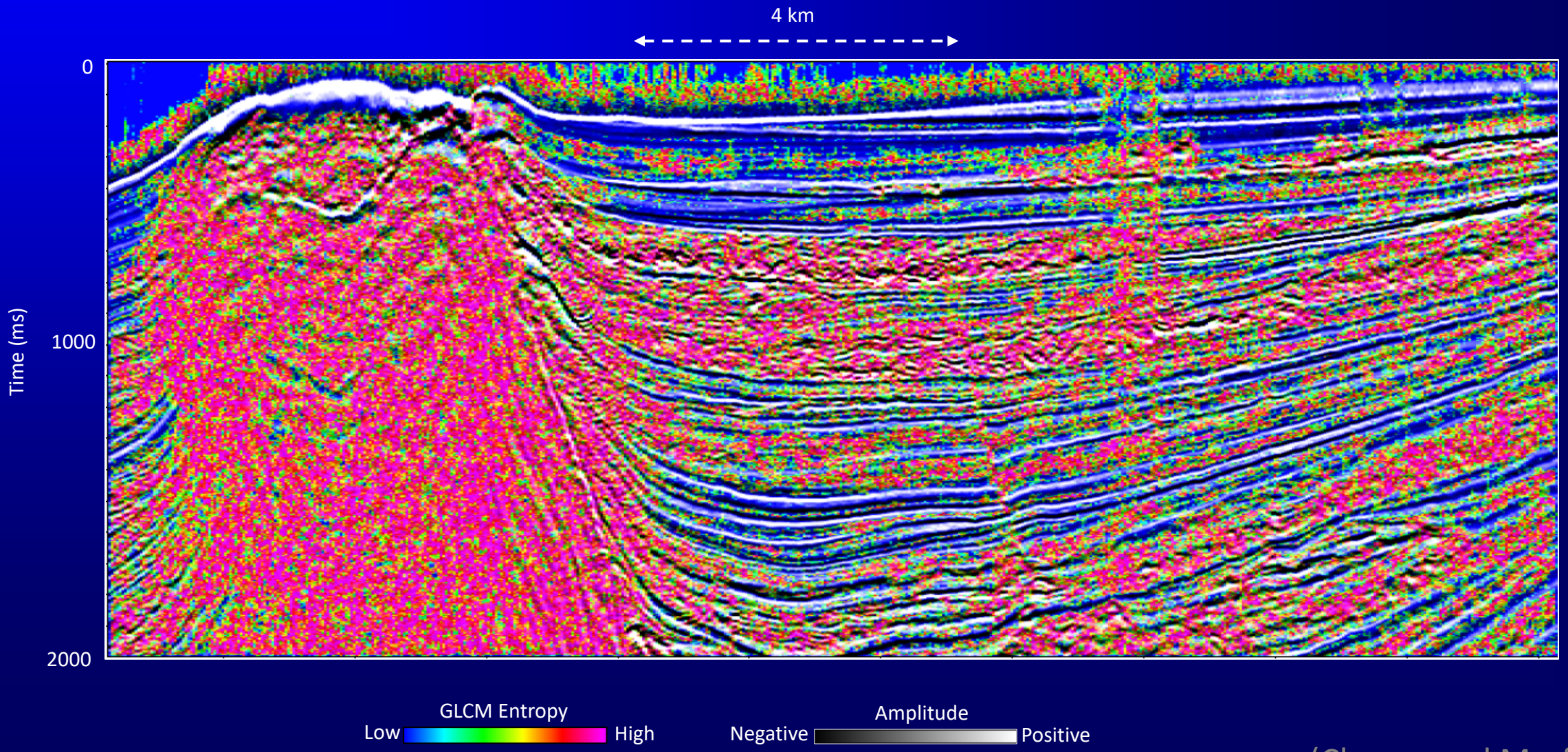
Eugene Island, Offshore Louisiana



(Chopra and Marfurt, 2021)

GLCM entropy corendered with seismic amplitude

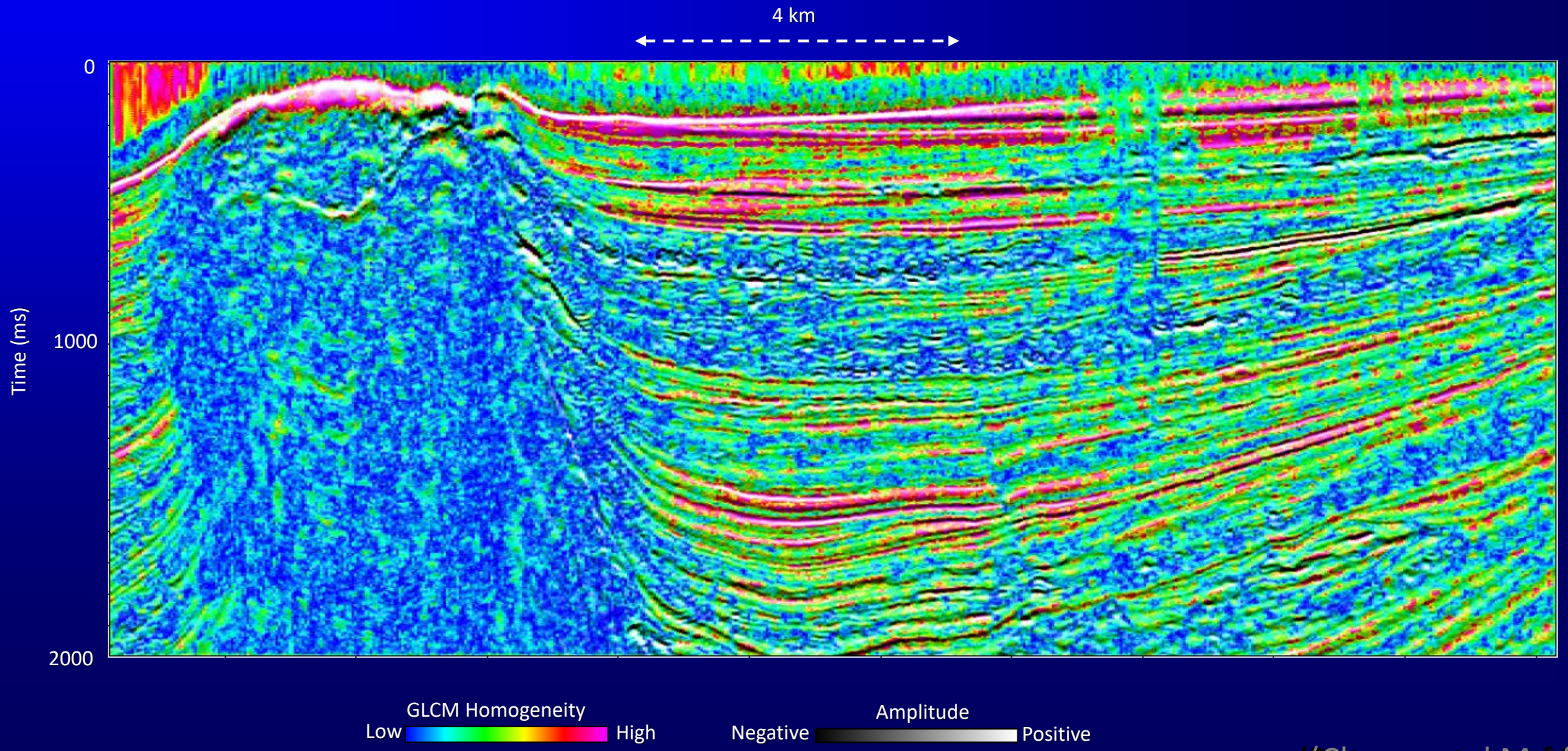
Eugene Island, Offshore Louisiana



(Chopra and Marfurt, 2021)

GLCM homogeneity corendered with seismic amplitude

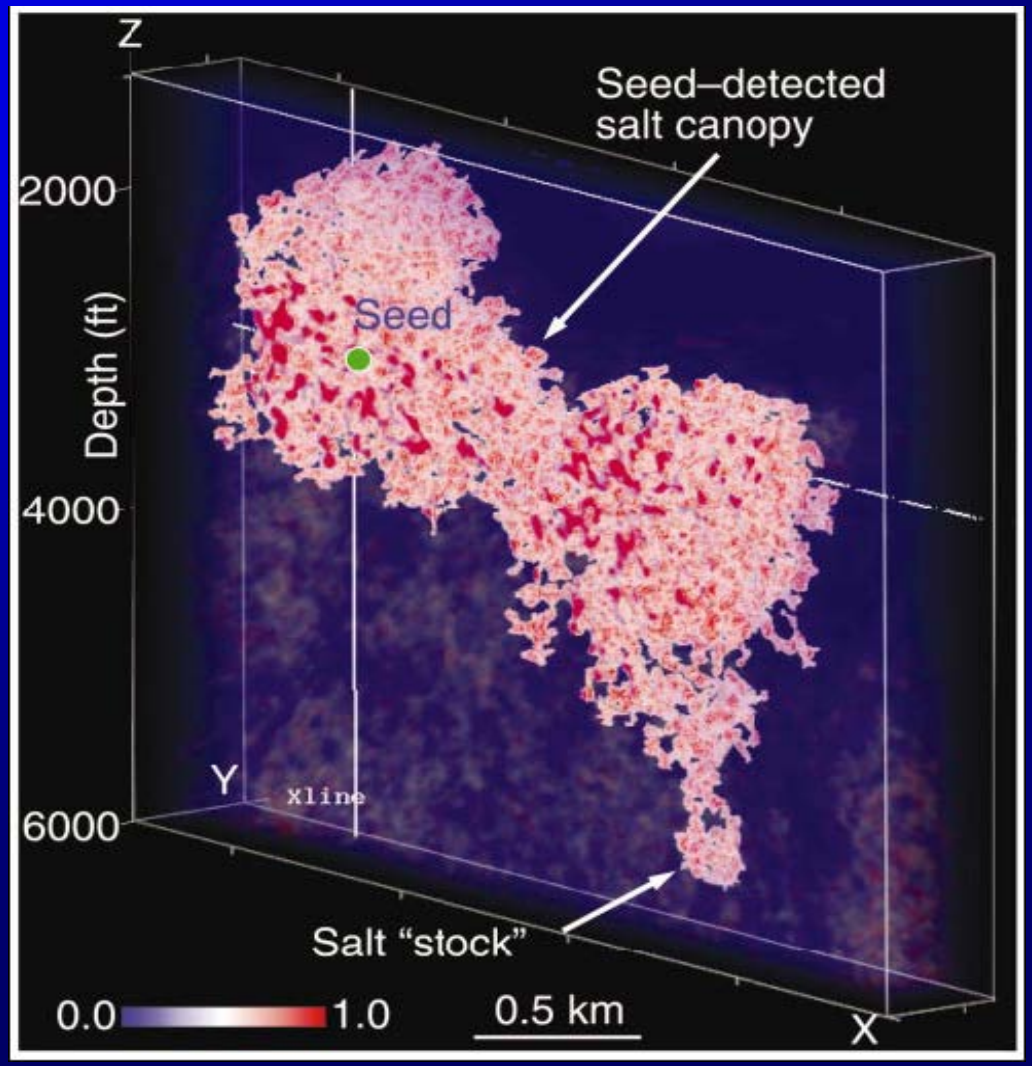
Eugene Island, Offshore Louisiana



((Chopra and Marfurt, 2021)

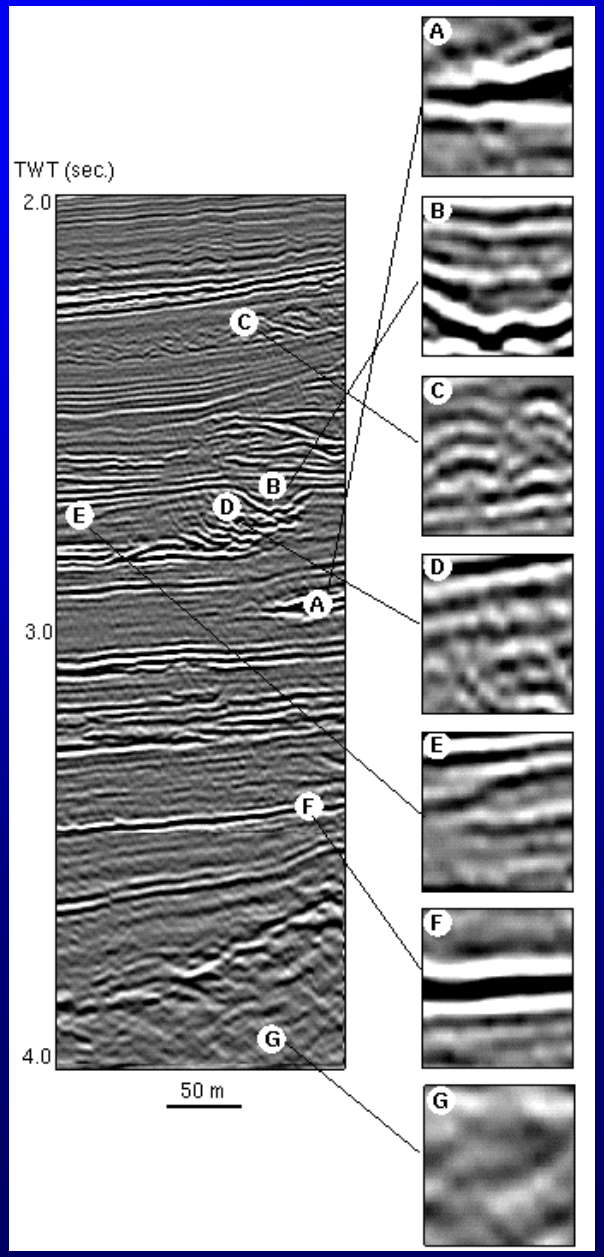
Interactive use of GLCM textures

Salt picked from a seeded GLCM ‘energy’ volume



(Gao, 2003)

Seismic textures



Isolated amplitude anomaly

Low-moderate amplitude, low continuity

Chaotic, hummocky, moderate amplitude, low continuity

Low amplitude, low-moderate continuity

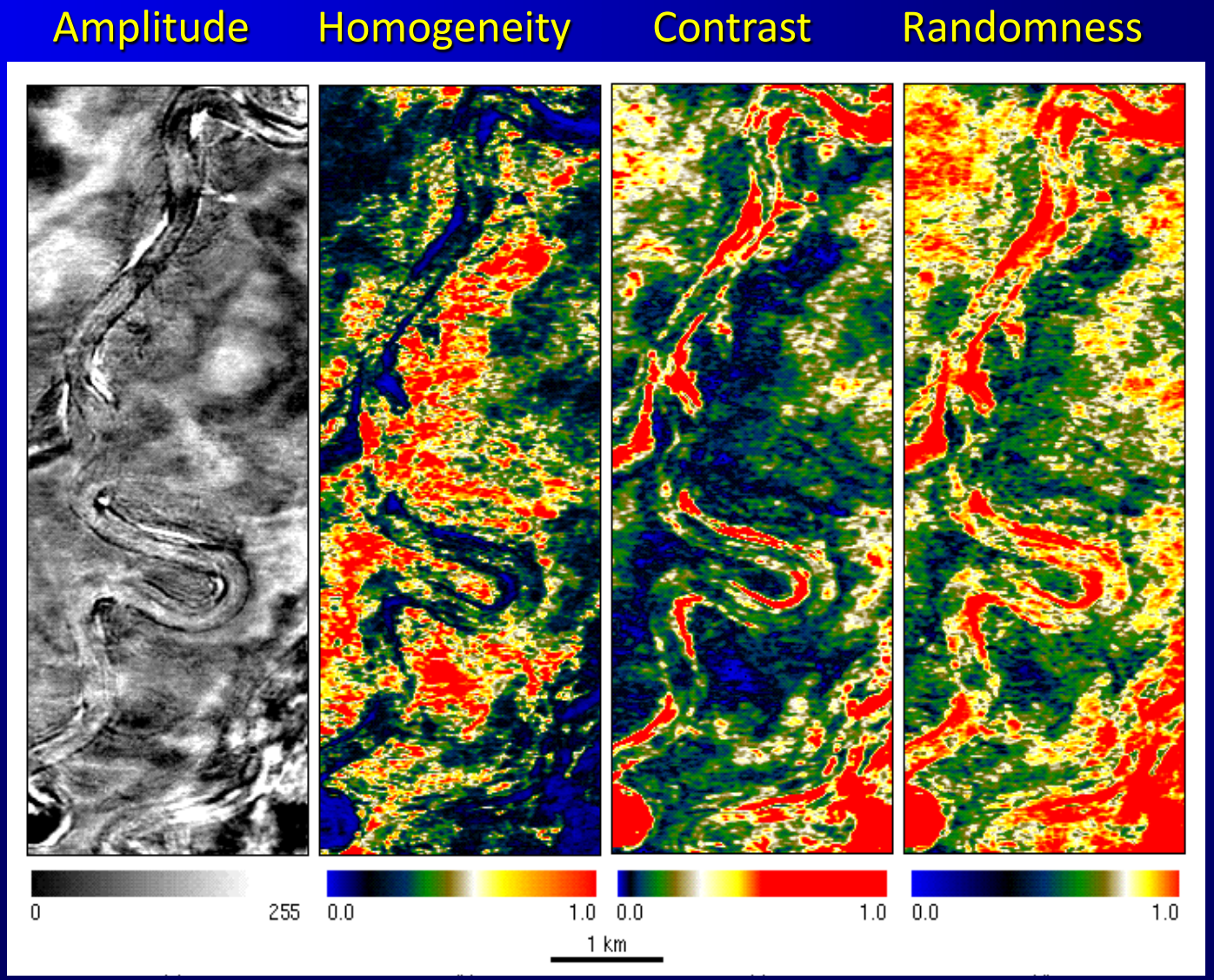
Low-moderate amplitude, moderate continuity

High amplitude, high continuity

Low amplitude, low continuity, massive

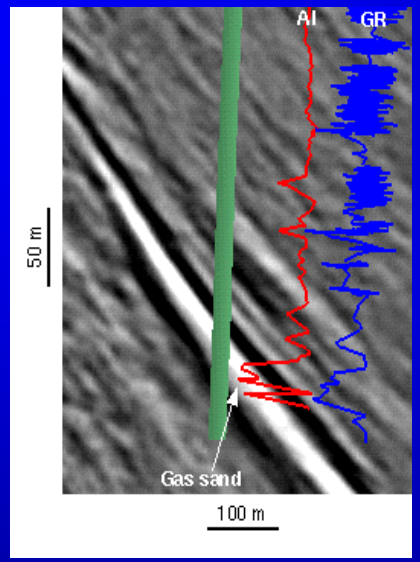
(Gao, 2005)

Textural attribute sensitivity to depositional facies.

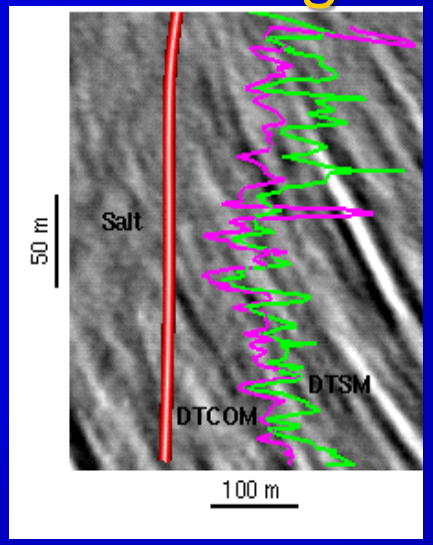


(Gao, 2005)

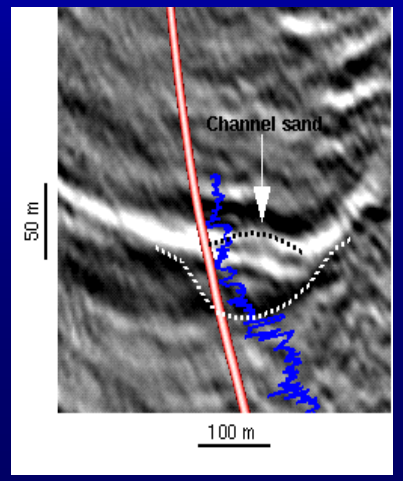
Calibration of textures to facies using well control and geologic models



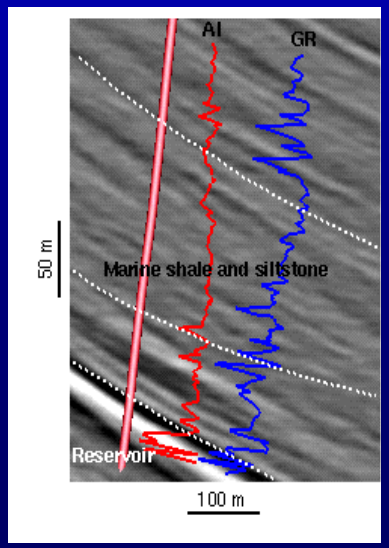
Gas Sand



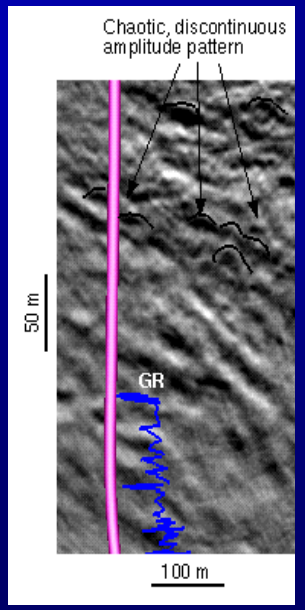
Salt



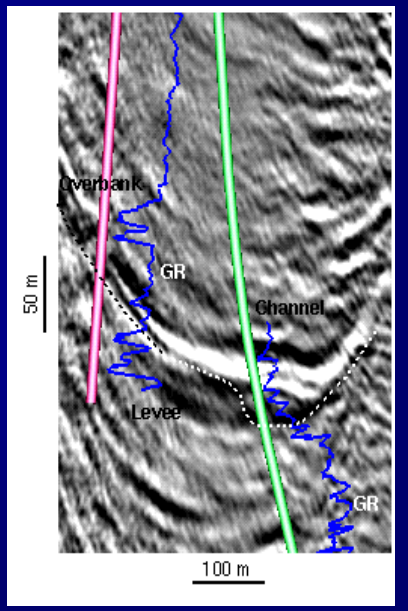
Channel Sand



Marine shale and siltstone



Chaotic Slump

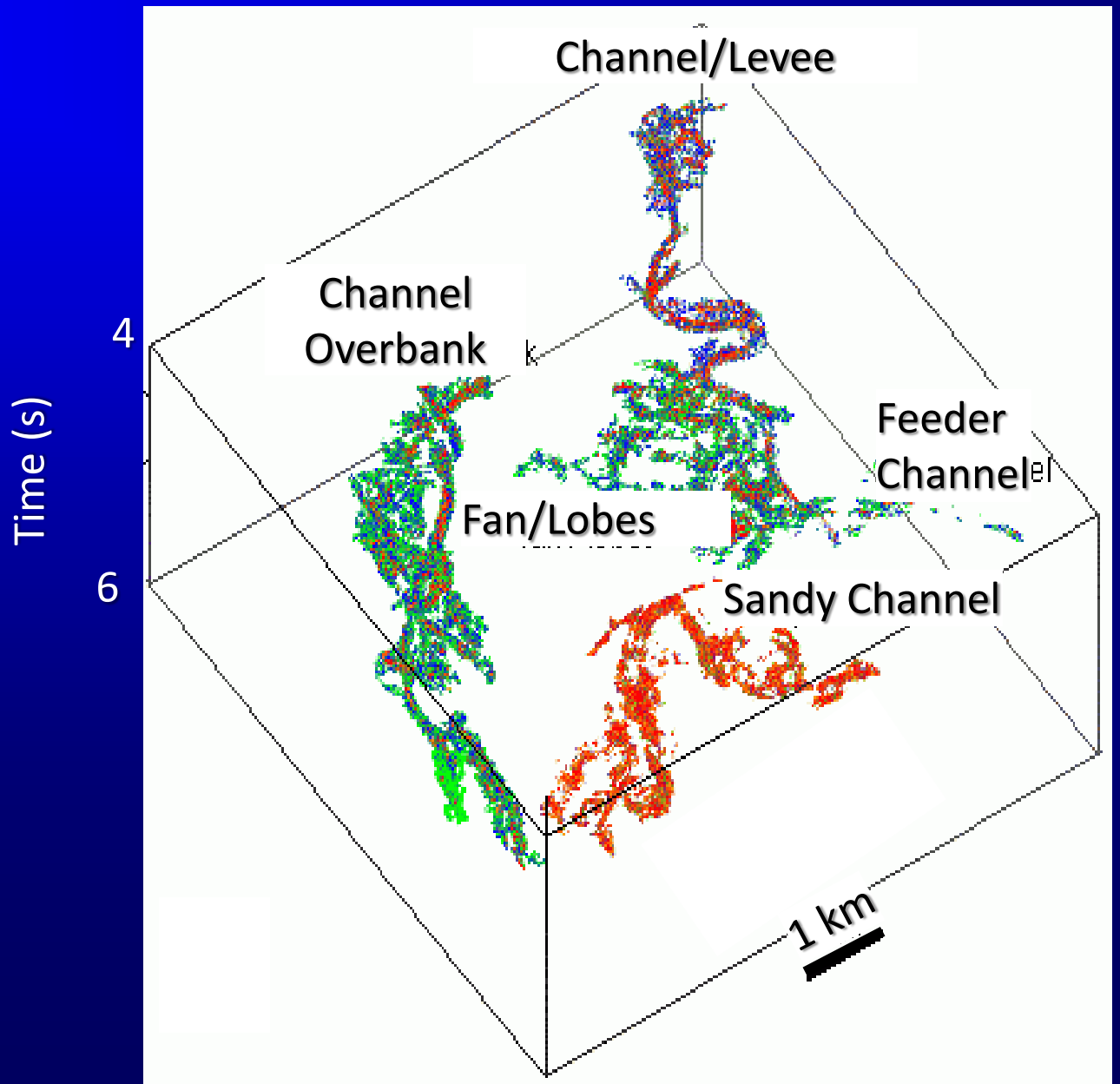


Overbank Deposit

(Gao, 2005)

Interactive use of GLCM textures

Architectural elements mapped using GLCM textures and well control



(Gao, 2005)

Common pitfalls

- Several of the GLCM attributes (correlation, variance) are inferior in resolution to conventional coherence attributes

- GLCM homogeneity and GLCM entropy are be inversely correlated in areas with good signal-to-noise ratios; however, if they have different sensitivity to noise using both can aid in machine learning classification.

Lateral Changes in Amplitude and Texture Analysis

In Summary:

Texture attributes quantify lateral patterns in the data that are hard to describe, but can be used in

- Interactive interpretation when correlated with well control in the construction of geobodies, and

- Machine-learning supervised and unsupervised facies classification.

Pattern-recognition math

if

$$\lim_{x \to 8} \frac{1}{x - 8} = \infty$$

then

$$\lim_{x \to 5} \frac{1}{x - 5} = ?$$