

# Geo Technologies Applied to Manufacturing

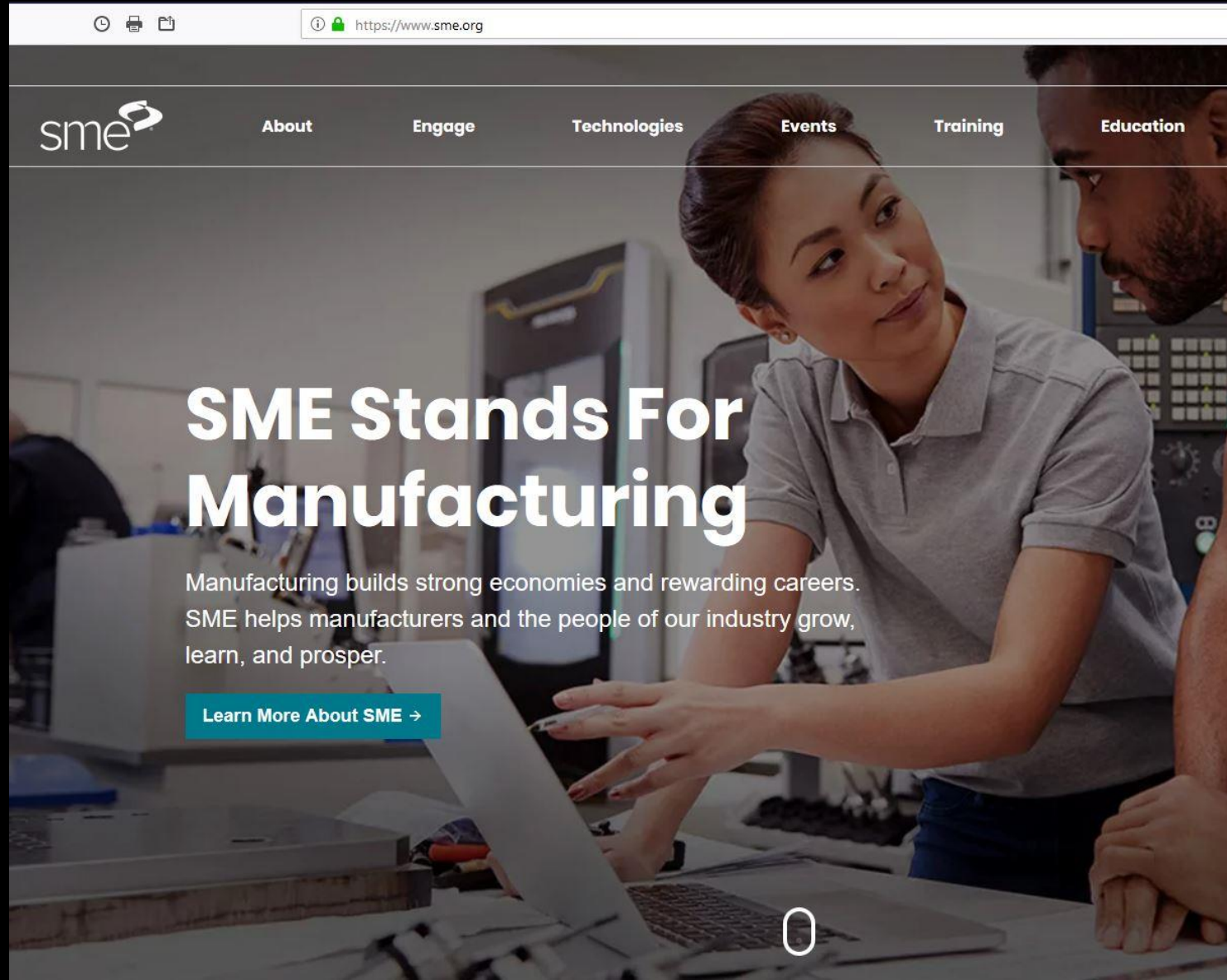
John K. Schueller\*, Won-Suk Lee, Pei-Ying Wu, Oscar Castillo



David Dornfeld Manufacturing Vision Award and Blue Sky Competition

\*[schuajk@ufl.edu](mailto:schuajk@ufl.edu)

Manufacturing enables our modern society and is something to be proud of



The image shows a screenshot of the SME website homepage. The background is a photograph of a woman and a man in a factory setting, looking at a laptop. The website has a dark header with the SME logo and navigation links: About, Engage, Technologies, Events, Training, and Education. The main content area features the headline "SME Stands For Manufacturing" and a sub-headline: "Manufacturing builds strong economies and rewarding careers. SME helps manufacturers and the people of our industry grow, learn, and prosper." Below this is a teal button that says "Learn More About SME →". At the bottom center of the page, there is a white circle containing the number "0".

https://www.sme.org

sme

About Engage Technologies Events Training Education

# SME Stands For Manufacturing

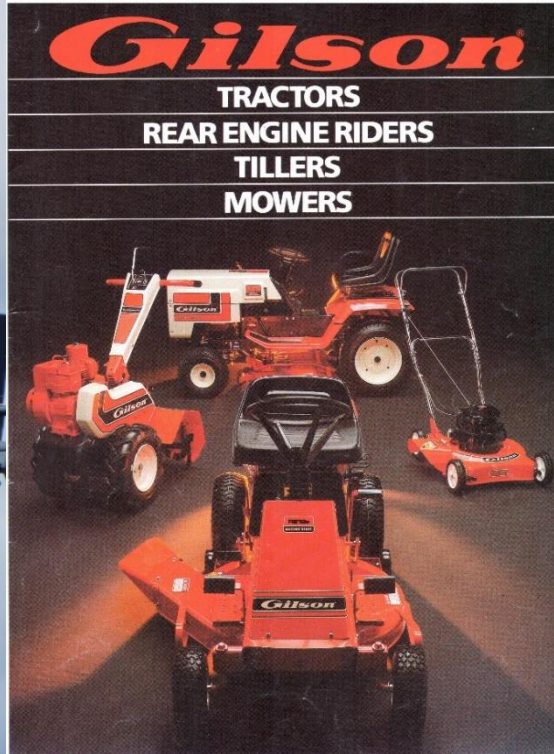
Manufacturing builds strong economies and rewarding careers. SME helps manufacturers and the people of our industry grow, learn, and prosper.

[Learn More About SME →](#)

0

Those of us who have worked in manufacturing are proud of the products we helped produce

We have built our modern society



For example, we build very large and sophisticated machines

But just two weeks ago I went to Utah and was again reminded that our “manufacturing” is overshadowed

**5230**  
Hydraulic Shovel/  
Backhoe

**CAT**<sup>®</sup>



Available in Front Shovel and Backhoe Configuration, the new Cat<sup>®</sup> 5230 is primarily matched to the Cat 785B truck, but can also effectively load the 789B truck. These matches provide efficient loading and hauling systems for mining.

Operating weights (approximate)		
Front Shovel	314 900 kg	693,800 lb
Backhoe (ME)	314 200 kg	692,320 lb
Bucket capacities		
Front Shovel	14.0 to 17.0 m <sup>3</sup>	18.3 to 22.2 yd <sup>3</sup>
Backhoe (ME)	15.5 to 24.0 m <sup>3</sup>	20.3 to 31.2 yd <sup>3</sup>
Cat 3516 Engine (Gross)	1175 kW	1575 HP
(Flywheel power)	1095 kW	1470 HP



In comparison ...  
what we make is not  
so awe-inspiring

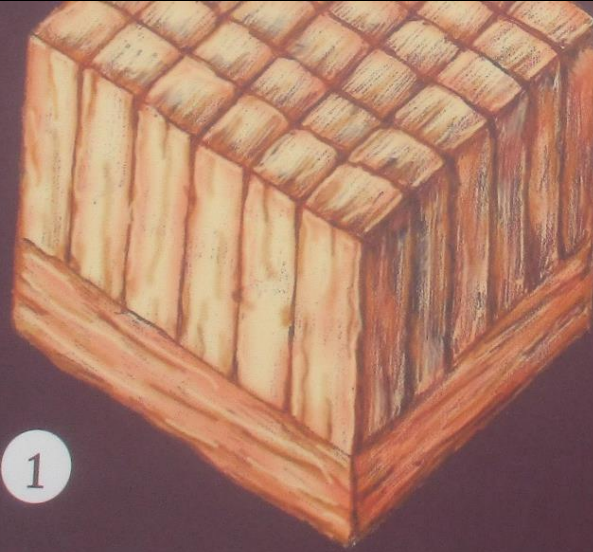
Perhaps we can  
learn from those  
“manufacturing”  
processes which  
have been occurring  
for billions of years



# Natural Processes Create Greatly Varied Structures and Surfaces

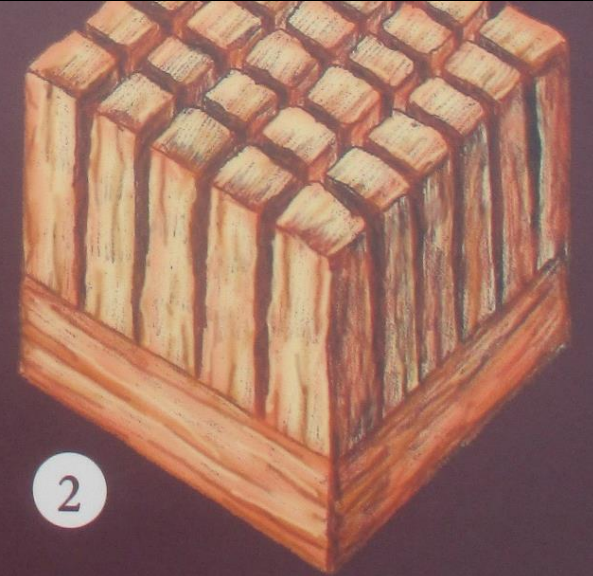


**Amazing examples  
throughout the world  
which can provide  
ideas to us in  
manufacturing**



1

The Needles were formed by sandstone gradually sliding over an underground layer of salt toward the Colorado River.



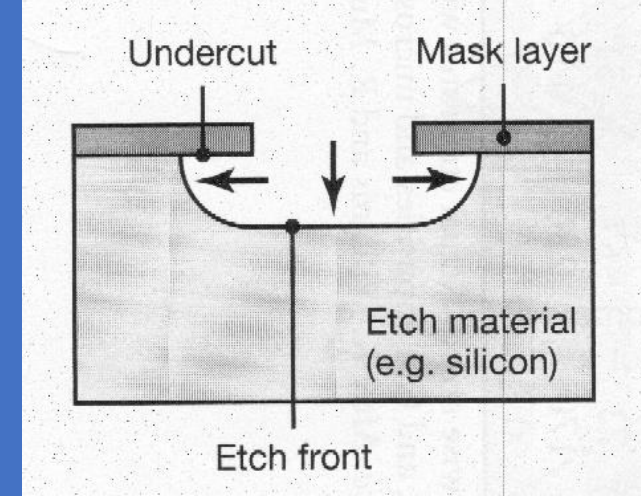
2

This caused the sandstone to fracture into parallel cracks.



e.g., Kalpakjian and Schmid

Perhaps the most significant advances in manufacturing at the end of the 20<sup>th</sup> century were in planar electronics manufacturing



Some processes have Geo analogs





# Additive Manufacturing/3D Printing/Rapid Prototyping is (and has long been) the biggest change in contemporary manufacturing

Even the latest issue of *Manufacturing Engineering*  
still concentrates on it...

- Design freedom
- Low-quantity economy
- Material efficiency
- Predictable production
- Reduced assembly

Peter Zelinski  
[www.mmsonline.com](http://www.mmsonline.com)

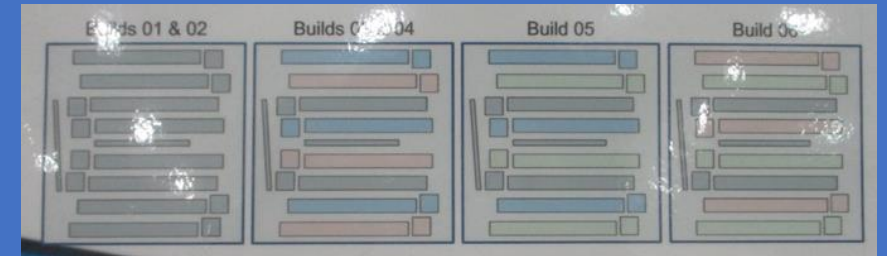


# Additive Manufacturing/3D Printing/Rapid Prototyping is (and has been) the biggest change in contemporary manufacturing

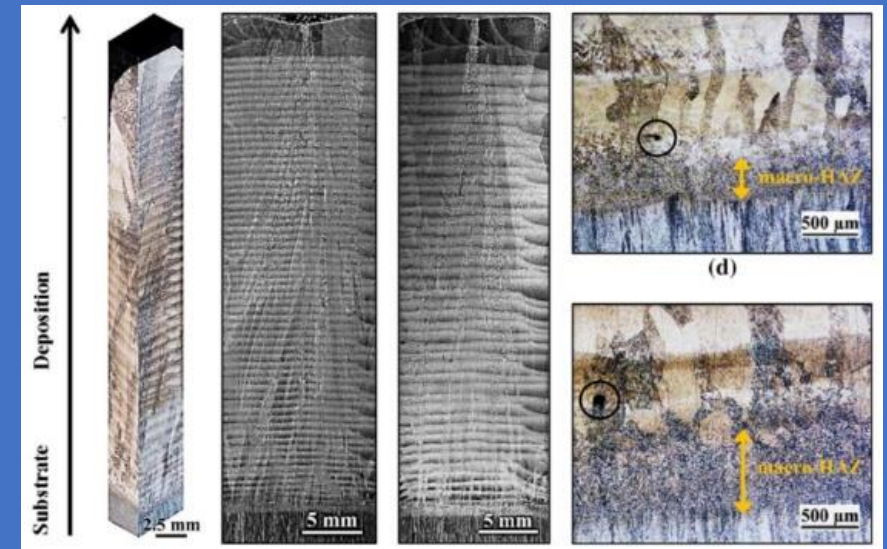
Many processes result in layered materials

Although we in manufacturing have experience with anisotropic and nonuniform materials (such as composites and functionally-graded materials), geological scientists have dealt with such structures in both simplified and sophisticated ways for many years

As manufacturing engineers, we should realize and take advantage of this



Moylan, et al., MSEC 2019



Ti-6Al-4V in Zhai, et al., JOM 66(5):808-816

**Might we not learn  
from similar layering  
processes in nature?**



Similarly, perhaps we can learn more from comparing manufacturing subtractive and cutting processes to similar processes in nature

**ADVANCED MANUFACTURING NOW**  
INNOVATION IN MANUFACTURING PROCESSES

**Rise of Makers Will Bring a Waterjet to Every Garage**

*Manufacturing Engineering, May 2019*

NRCS erosion photo provided by Dennis Flannigan USDA-ARS  
(see Water Erosion Prediction Project)

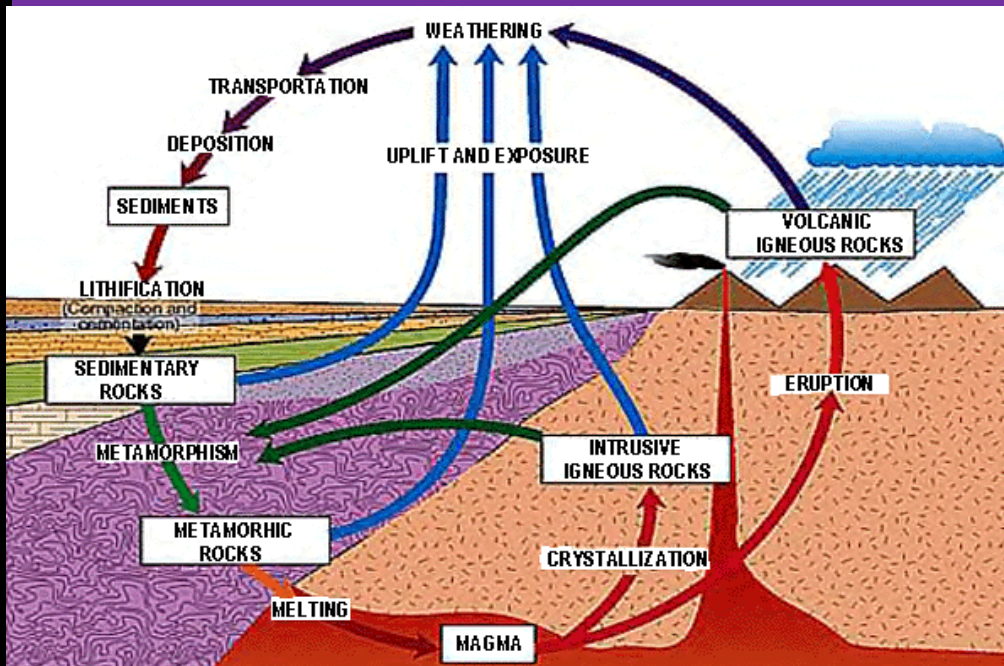


# Hybrid Additive/Subtractive Manufacturing a Current Fad

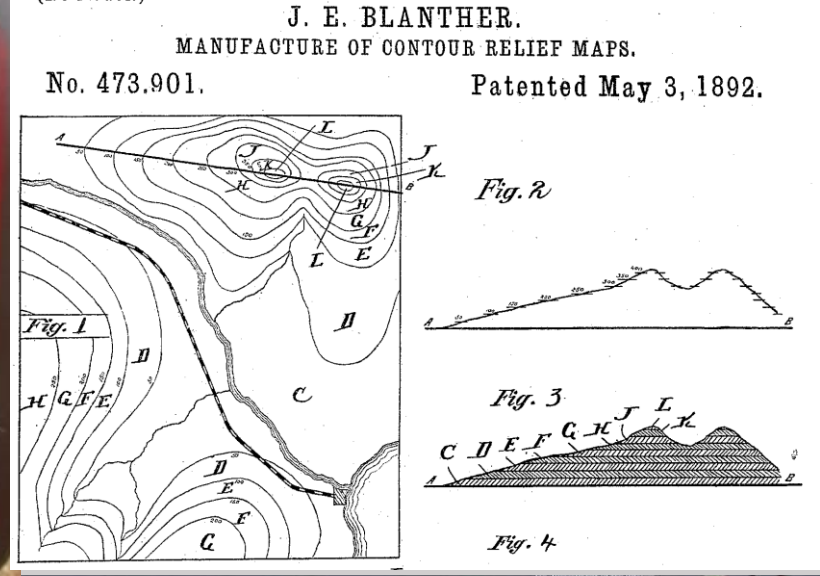
But Additive/Subtractive Combinations Have Long Been Occurring

[us.dmgmori.com](http://us.dmgmori.com)

[academic.brooklyn.cuny.edu](http://academic.brooklyn.cuny.edu)



Besides those in Geo technologies helping us, perhaps those of us in manufacturing can help those in geological sciences solve their mysteries



### A Mystery

Upheaval Dome is a mystery. The rock layers below you are fractured and tilted, forming a circular depression more than two miles wide. How did it form? Scientists propose two potential causes: a salt dome that cracked and tilted the rock over time, or a violent meteorite impact that instantly fractured the rock. Recent findings support the meteorite hypothesis, but questions remain. With more research, we may solve the mystery of this crater and others on our planet.

*This aerial photo shows the pattern of rock layers visible at Upheaval Dome today.*

#### A slow-moving salt dome?

About 300 million years ago, a salty inland sea covered the area.

A large basin trapped the sea, which then evaporated, leaving behind thousands of feet of salt.

Wind and water deposited more sediment, pushing down on the softer salt layer and causing it to dome upwards.

Over time the salt rose, fracturing and distorting the rock layers in its path.

Water eroded the salt and overlying sediment, exposing the distorted crater visible today.

#### An instantaneous meteorite impact?

About 200 million years ago, a meteorite hurtled toward earth.

The meteorite hit the ground with so much force, it vaporized on impact.

The force of the impact fractured the rock, creating a large crater.

Rock layers rebounded inward and upward to fill the void.

Erosion exposed the tilted, broken core of the impact site.

We tend to be proud of not only our process understandings, but our analysis techniques

But Geo fields have similarly developed sophisticated and useful techniques which may help us

Random examples ...

$$\hat{\chi}_k = A^{-1} \int d\mathbf{X}_{soft} f_s(\mathbf{X}_{soft}) B_{k|hs} \mathbf{X}_{hs} \phi(\mathbf{X}_{soft}; B_{s|h} \mathbf{X}_{hard}, c_{s|h}) \quad (11.16)$$

and the variance

$$\sigma_k^2 = c_{k|hs} + A^{-1} \int d\mathbf{X}_{soft} f_s(\mathbf{X}_{soft}) (B_{k|hs} \mathbf{X}_{data} - \hat{\chi}_k)^2 \phi(\mathbf{X}_{soft}; B_{s|h} \mathbf{X}_{hard}, c_{s|h}) \quad (11.17)$$

where  $B_{k|hs} = c_{k,hs} c_{hs,hs}^{-1}$ ,  $c_{k|hs} = c_{k,k} - B_{k|hs} c_{hs,k}$ ,  $B_{s|h} = c_{s,h} c_{h,h}^{-1}$ , and  $c_{s|h} = c_{s,s} - B_{s|h} c_{h,s}$ , and the  $A$  is defined as in Proposition 11.4.

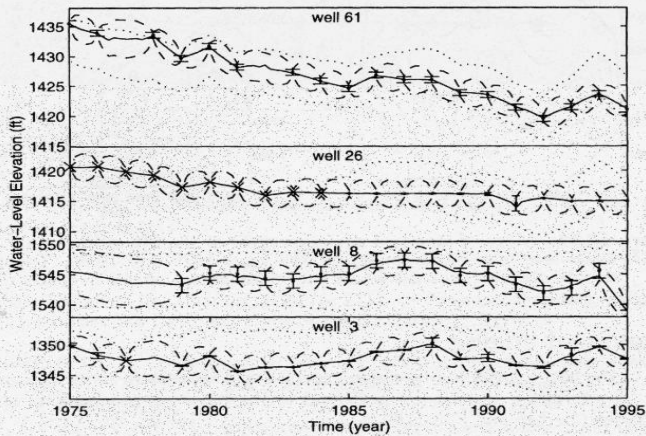
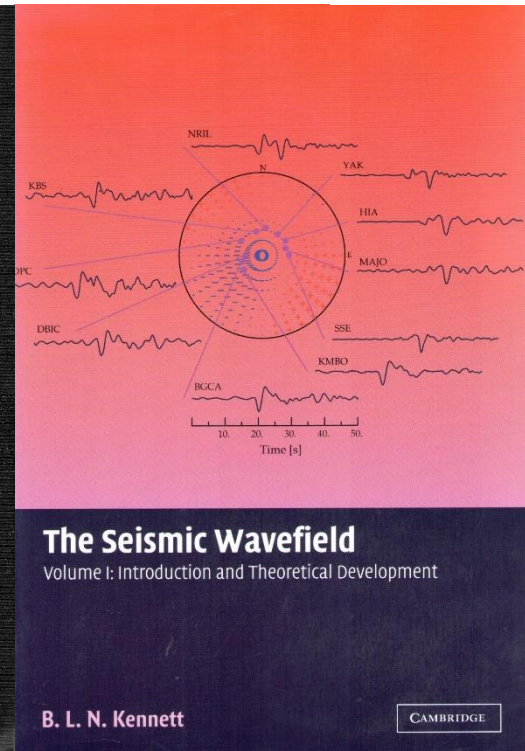
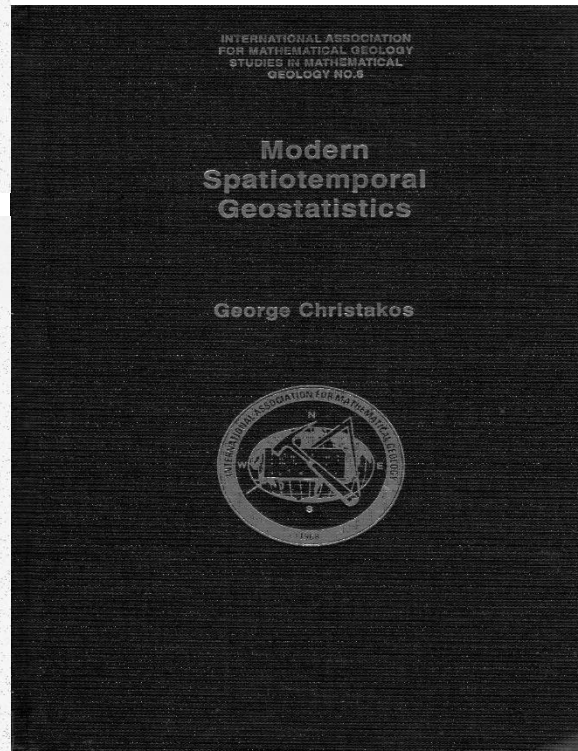


Figure 12.10. BME mode estimates of water-level elevation at a number of selected wells (shown as solid line) and 90% confidence intervals obtained by BME (dashed line) and SK (dotted line). Hard data are shown by x; soft (interval) data are depicted as error bars.



$$\Theta(\mathbf{x}) u_k(\mathbf{x}, \omega) = \int_V d^3 \xi G_{kq}(\mathbf{x}, \xi, \omega) f_q(\xi, \omega) + \int_{\partial V} d^2 \xi [G_{kq}(\mathbf{x}, \xi, \omega) t_q(\xi, \omega) - u_q(\xi, \omega) h_{kq}(\mathbf{x}, \xi, \omega)],$$

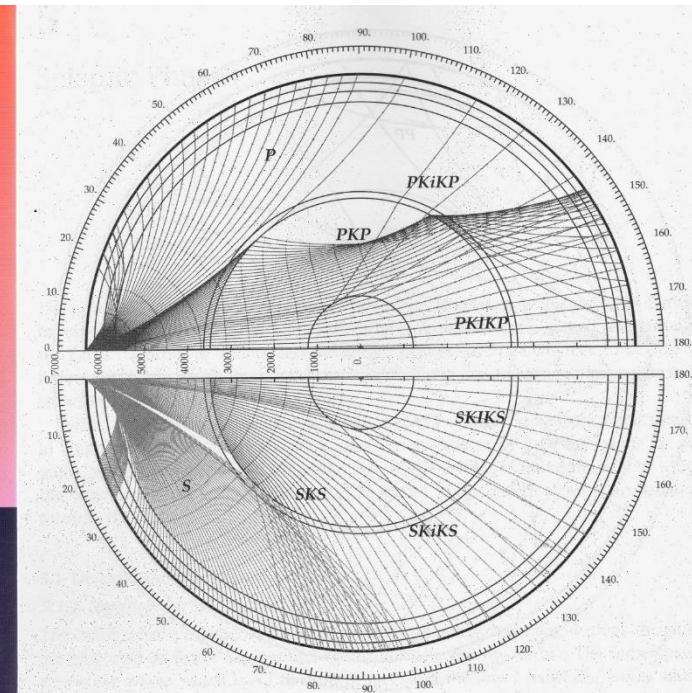
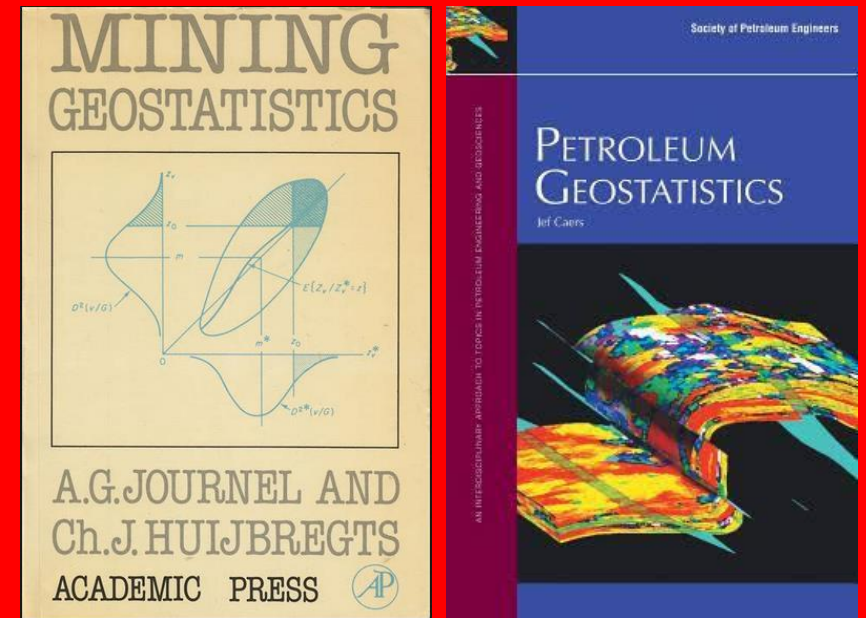


Figure 5.2. Ray paths for major P and S phases for the AK135 model of seismic wavespeeds.

We tend to be proud of not only our process understandings,  
but also our analysis techniques

But Geo fields have similarly developed sophisticated and useful techniques  
which may help us

The one I'm most familiar with is **Geostatistics**



Now standard practice for Geo activities, such as mining and oil and gas



# Those of us who work in agriculture have applied Geostatistics techniques in precision agriculture

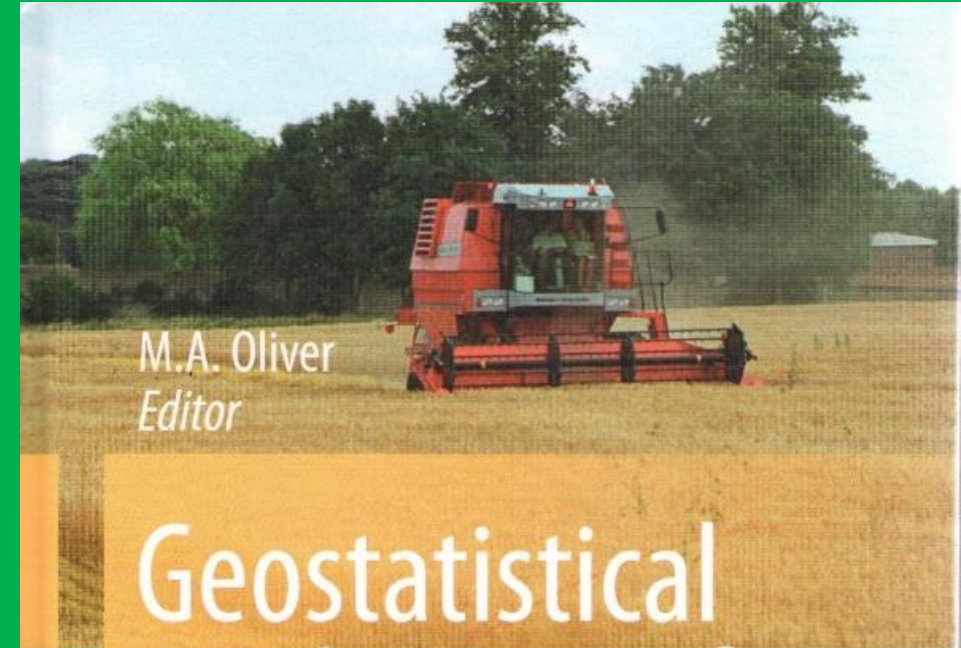
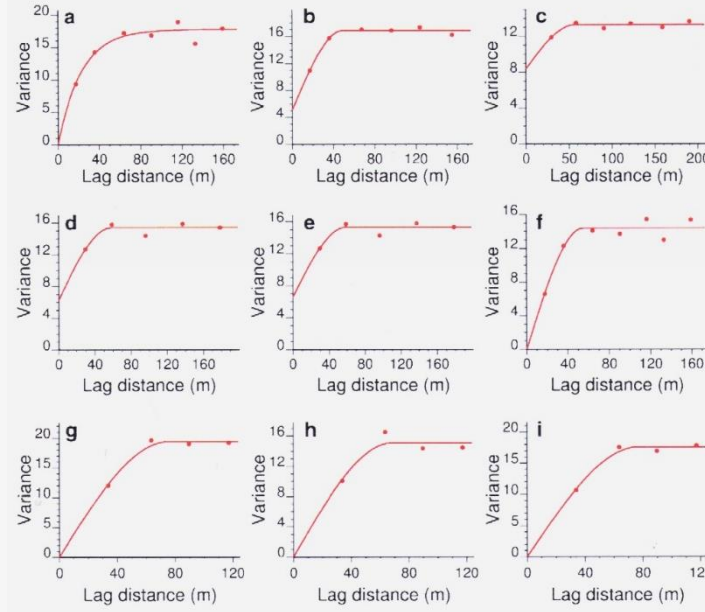
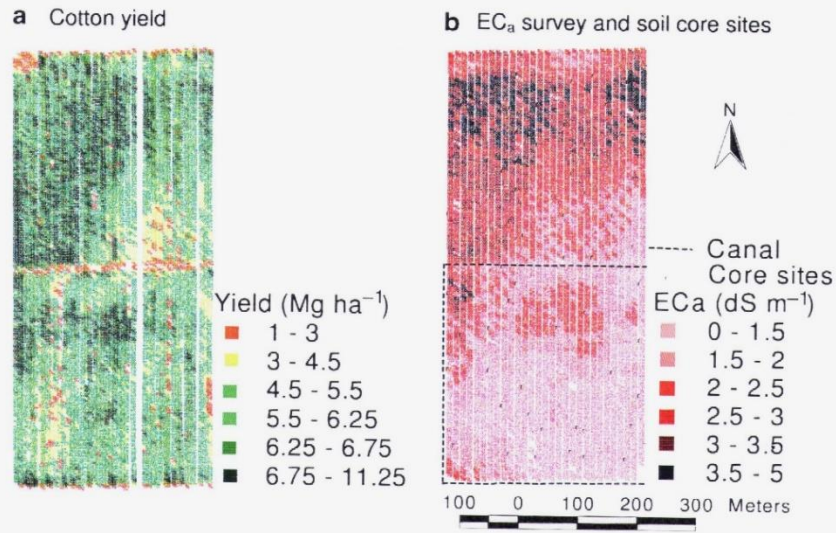
Topography, soil properties, crop properties, and yield are treated spatially or (rarely) spatiotemporally

Provides useful information for researchers and farmers

“We’ve certainly discussed the concepts related to geostatistics with farmers. I’ve not gotten into the mathematics with them, but the general idea of how data closer together are more related than data spaced further apart is useful in discussing spatial variability with farmers.” – Dr. Ken Sudduth, USDA-ARS, the 2019 John Deere Medal recipient

Corwin and Lesch in Oliver, ed.

Goovaerts, et al., in Oliver, ed.



M.A. Oliver  
Editor

# Geostatistical Applications for Precision Agriculture

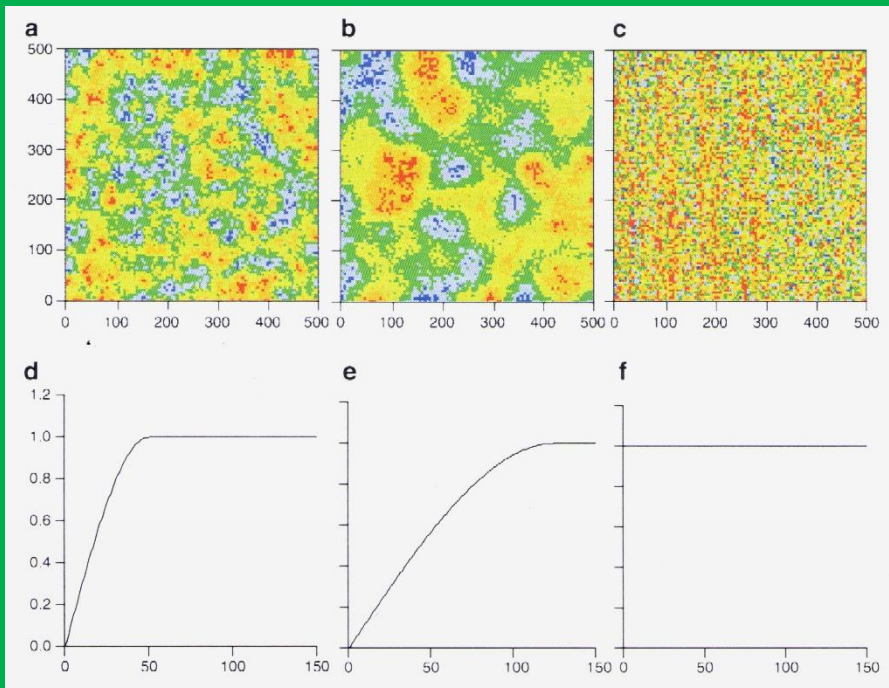
Fig. 7.3 Variograms for 30-m soil data: (a) sand (raw data), (b) soil series residuals, (c) aerial<sup>91</sup>, EC<sub>a</sub> and elevation rr. (d) EC<sub>a</sub> rr. (e) EC<sub>a</sub> and elevation rr. (f) aerial<sup>91</sup> and elevation rr. Variograms for the subset of 30-m soil data with 50 samples: (g) soil series residuals (50), (h) aerial<sup>91</sup>, EC<sub>a</sub> and elevation rr (50) and (i) aerial<sup>91</sup> and EC<sub>a</sub> rr (50)

Fig. 6.1 Maps of: (a) cotton yield and (b) EC<sub>a</sub> measurements including 60 soil sampling sites (Modified from Corwin and Lesch (2003) with permission)

There has been some excellent research on manufacturing surface metrology  
Jiang and Whitehouse *CIRP Annals* 61:815-836  
Leach et al. *CIRP Annals* 64:797-813  
etc.

But in practice we still mainly use  $R_a$ ,  $R_q$ ,  $R_z$ ,  $S_a$ ,  $S_q$ ,  $S_z$

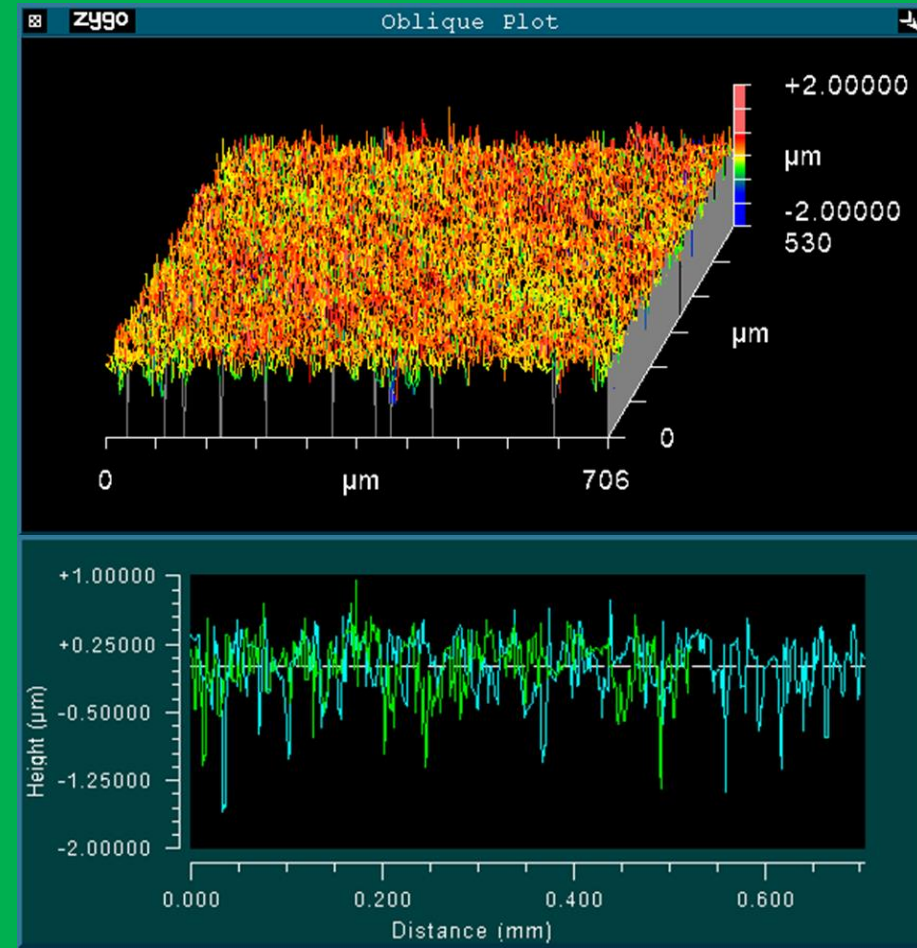
### Simulated Isotropic Agricultural Fields



Similar =====>

Kelly, et al.,  
in Oliver, ed.

### Typical Manufactured Surface



## In our very preliminary investigation...

- Fowler Surface Roughness Standards
- Zygo Newview 7200 Optical Profilometer
  - 5X objective, 1X or 2X zoom tube
- Perpendicular line scans
- R software environment
  - gstat

## Example Results:

Sample	Model	Nugget	Sill	Range	kappa*
HM-16_H1	Gaussian	0.010591	0.073695	109.8784	
HM-16_H2	Matern	14211.3	16295.18	46.07017	0.3
HM-32-2_H1	Matern	0.018627	0.485554	439.0375	0.81
HM-32-2_H2	Matern	4091.756	44889.15	197.1398	0.41
HM-63_H1	Matern	0.098954	1.49077	14.94842	3.68
HM-63_H2	Matern	0.020339	2.01007	89.94012	4.83
HM-63-2_H1	Matern	0	0.878124	45.82599	0.52
HM-63-2_H2	Matern	4164.775	53190.6	158.7643	1.16

\*kappa: smoothness parameter for the Matern class

**Electro-Formed Surface Roughness COMPARISON STANDARDS  
FOWLER COMPOSITE POCKET SET No. 52-720-000**

This Set contains Surface Roughness Standards of the six most important machining methods in the prevalent AA Values, as standardised in ANSI B46.1

The machining data for the production of the Master Specimens were selected in co-operation with many industrial concerns, research establishments etc., as well as the British Standard Institution. These Electro-Formed Standards are identical with those used for the production of our Surface Roughness Scales Nos. 115 to 135. The latter are mainly for workshop and machine shop use, whilst this set (No. 52-720-000) is primarily recommended for Drawing, Planning and Research Offices, Works Managers, Quality Engineers, Inspectors, Foremen etc.

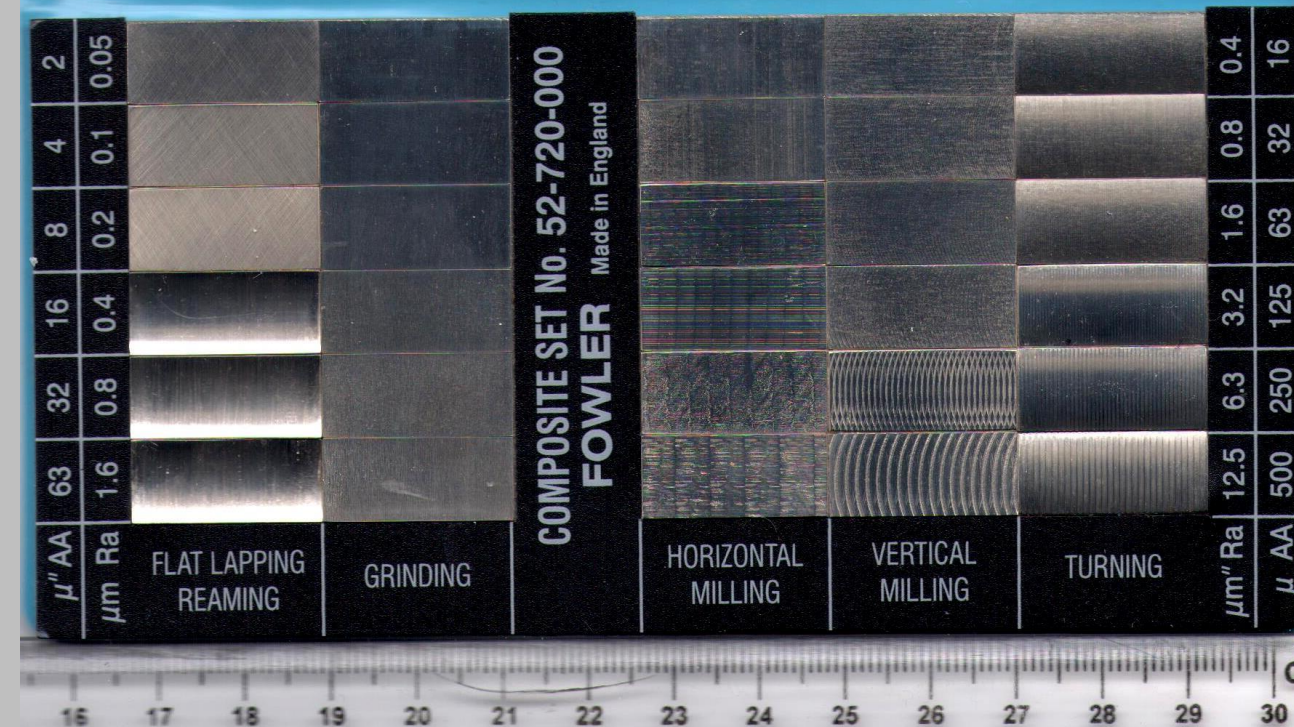
The 30 Specimens are calibrated in  $\mu''$  AA (Arithmetical Average) and in the metric equivalents  $\mu\text{m Ra}$ . They are accurate to within  $\pm 12\%$  of the nominal values indicated, excluding instrumentation errors

For many purposes it is of importance to know also the total peak to valley depth of roughness (referred to in Europe as Rt), which varies from 4 to 12 times the AA values.

In the table below the Rt values are given in  $\mu''$  and  $\mu\text{m}$ . Since during the last few years it has proved impossible to measure Rt to a high degree of accuracy it is of little use to quote respective Rt for every Specimen. The Rt equivalents quoted are therefore only rounded-up figures with may deviate by  $\pm 30\%$  from the actual values.

	$\mu''$ AA	500	250	125	63	32	16	8	4	2
Horizontal Milling Vertical Milling Turning	$\mu''$ Rt	2000	1250	630	320	160	100			
	$\mu\text{m Rt}$	50	32	16	8,0	4,0	2,5			
Ratio	Rt/AA	4	5	5	5	5	6,25			
Flat Lapping Reaming Grinding	$\mu''$ Rt				400	240	120	63	40	22
	$\mu\text{m Rt}$				10	6,0	3,0	1,6	1,0	0,55
Ratio	Rt/AA				6,4	7,5	7,5	7,9	10	11

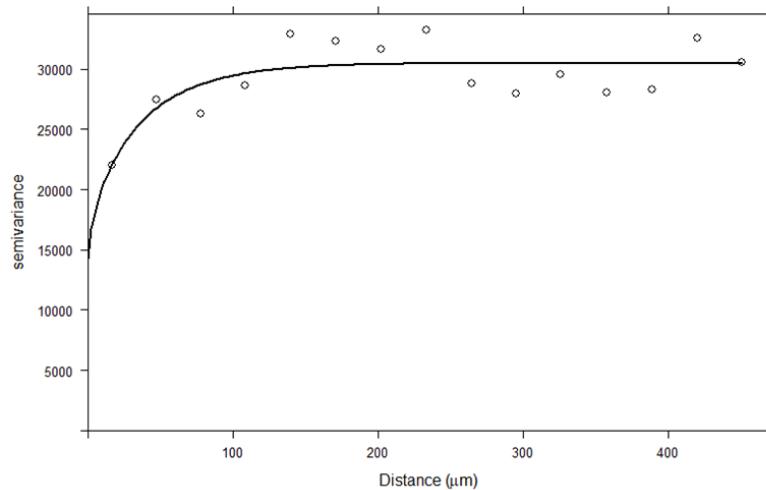
FRED V. FOWLER CO., INV., 66 ROWE ST., NEWTON, MASS. 02466 TEL.: (617) 332 7004 www.fvfowler.com



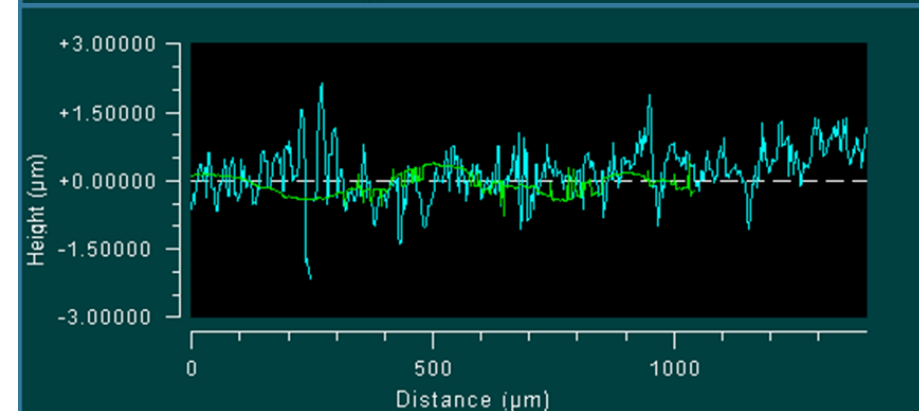
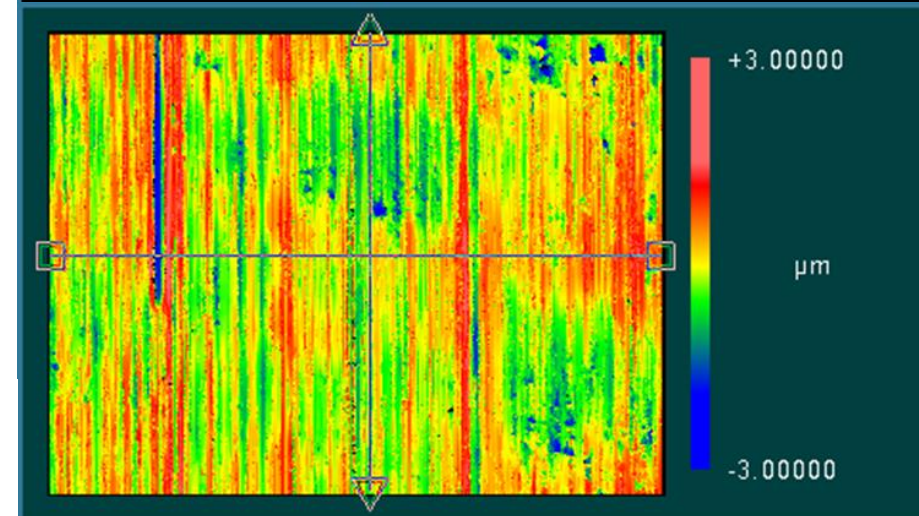
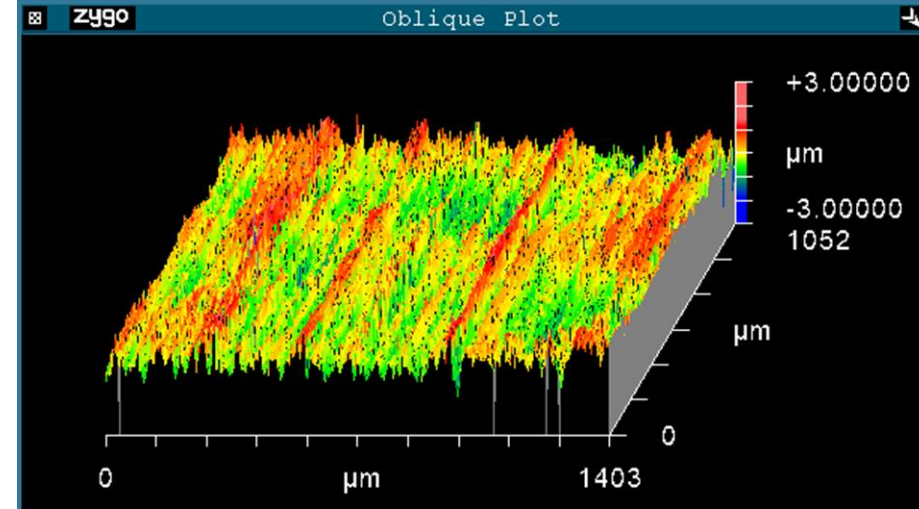
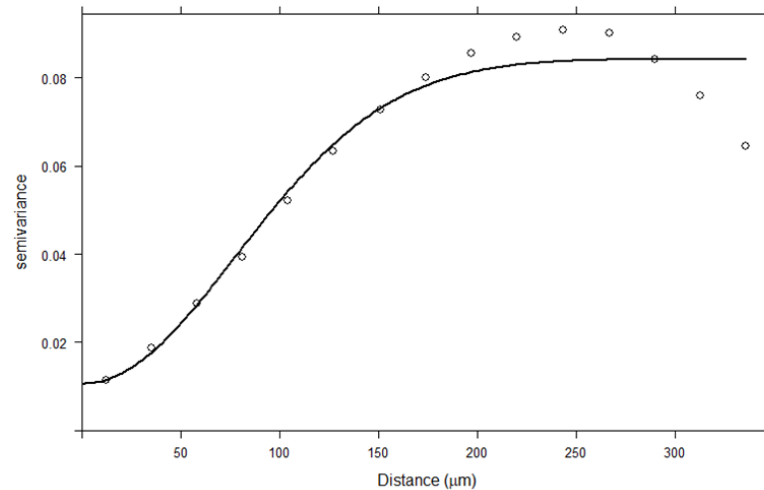
## Results, of course, vary with

- Direction of measurement
- Process (lapping, grinding, milling, turning)
- Roughness (including feeds)

Variogram for H Milling 16 (Horizontal profile)



Variogram for H Milling 16 (Vertical profile)

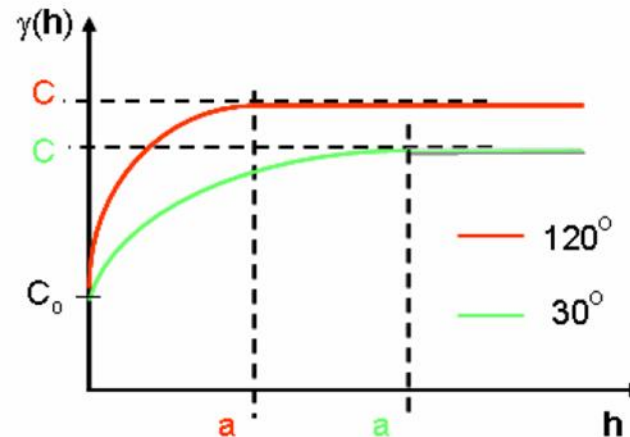
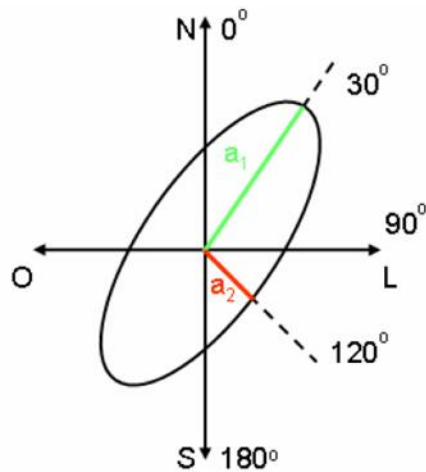


Of course,

further research and development is needed to achieve full potential

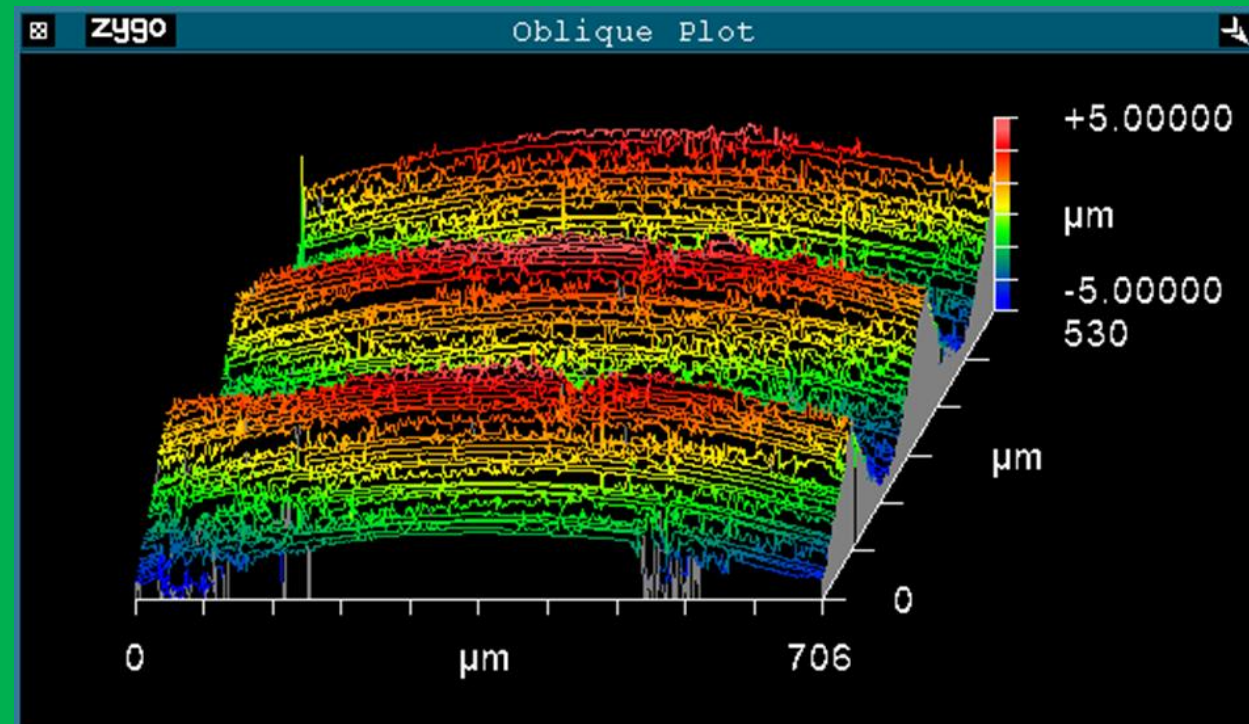
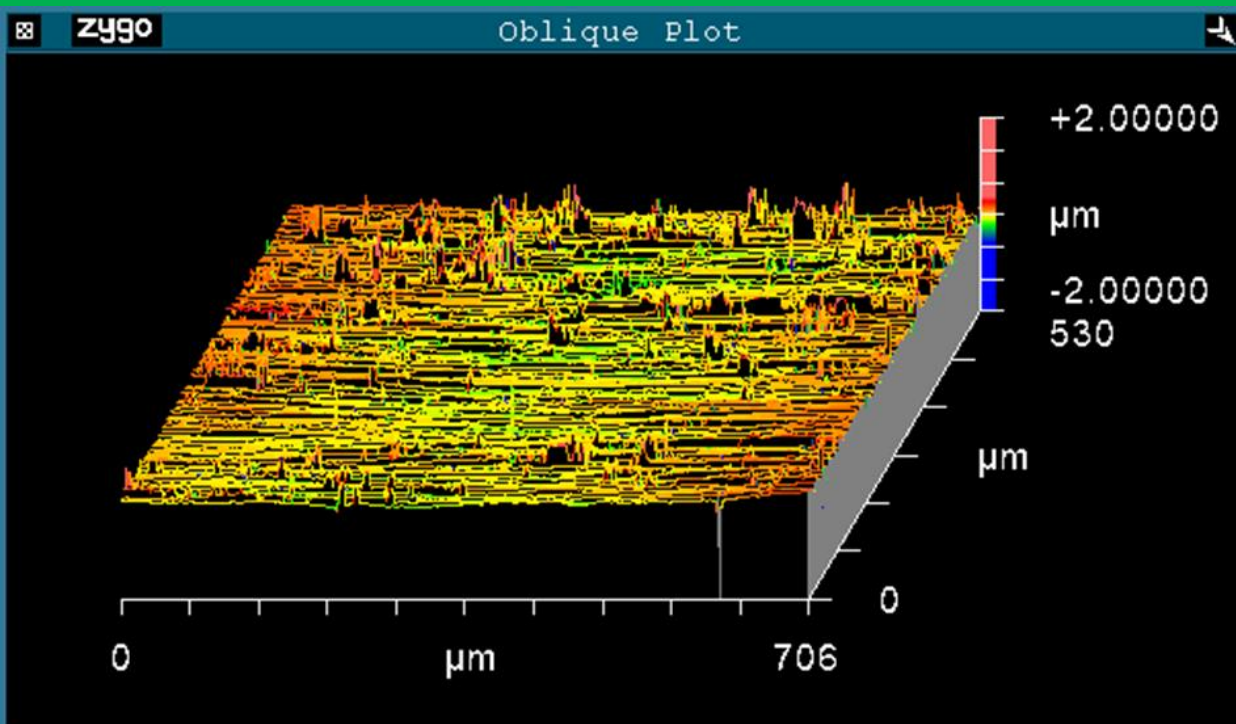
- **Combined (Geometric + Zonal) Anisotropy**

- 2 semivariograms with same model function, different sills and ranges
- it can also have different nugget effects, but is not common



## Variograms may:

- Allow an understanding of spatial variability of manufactured surfaces
- Allow easy identification of surface generation performance and problems
  - e.g., chatter will be blatantly obvious
- Allow easy communication of spatial variability between individuals
  - e.g., can have control-chart-like guidelines



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But this is just ONE EXAMPLE of geostatistics...

... which is just ONE EXAMPLE of geo analysis techniques

**We in manufacturing often talk about learning from nature**

**In fact, the first Dornfeld Award was for biomimetic manufacturing**

**But nature is more than biology. And the manufacturing we do is more like the non-biological “manufacturing” of nature.**



- **Geo Technologies have been “manufacturing” the world for billions of years**
- **Scientists have developed many techniques over many years to study Geo Technologies**
- **Manufacturing researchers should take advantage of those facts**



# Geo Technologies Applied to Manufacturing

John K. Schueller\*, Won-Suk Lee, Pei-Ying Wu, Oscar Castillo



David Dornfeld Manufacturing Vision Award and Blue Sky Competition

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