Geo Technologies Applied to Manufacturing

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ASME SETTING THE STANDARD

David Dornfeld Manufacturing Vision Award and Blue Sky Competition

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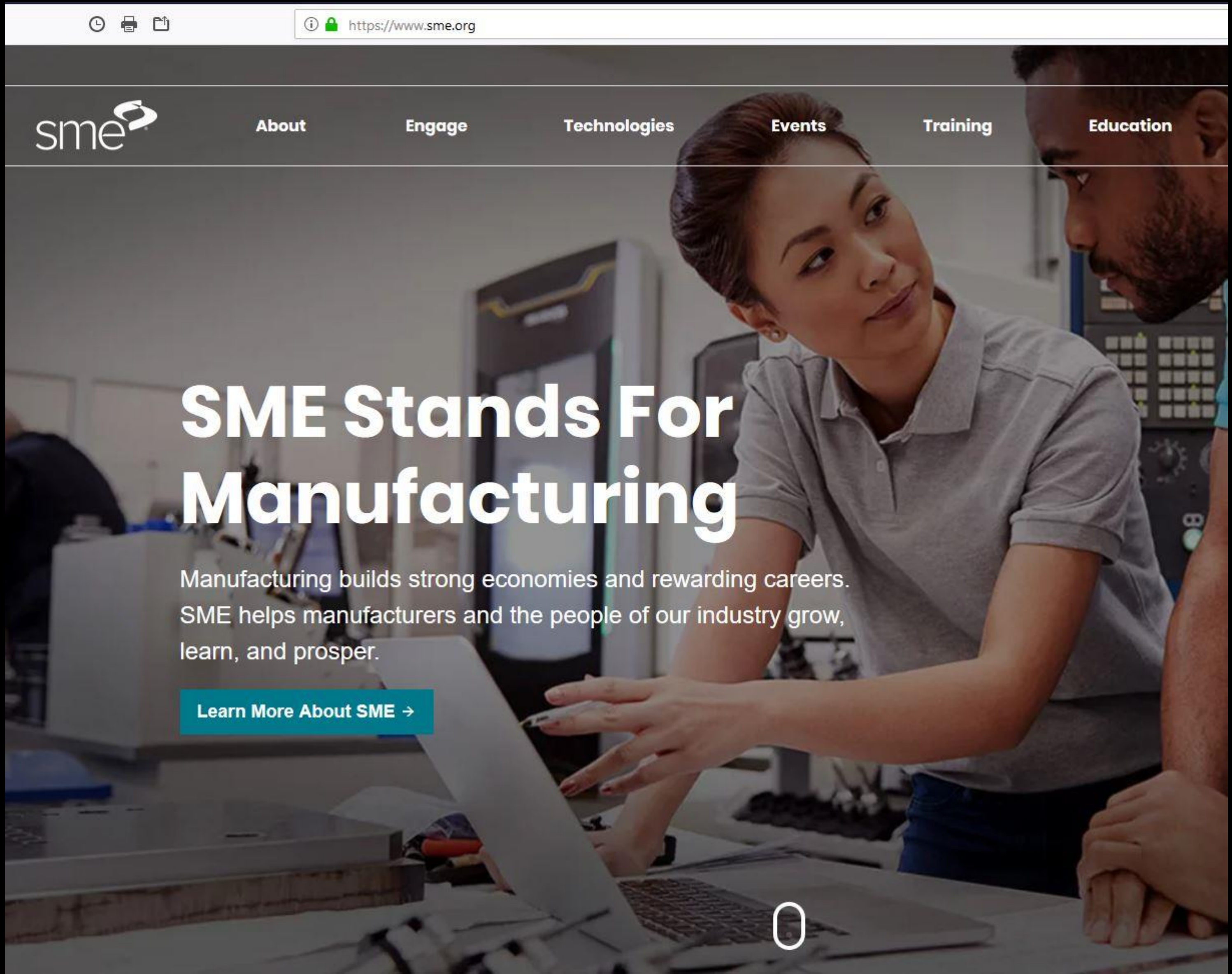
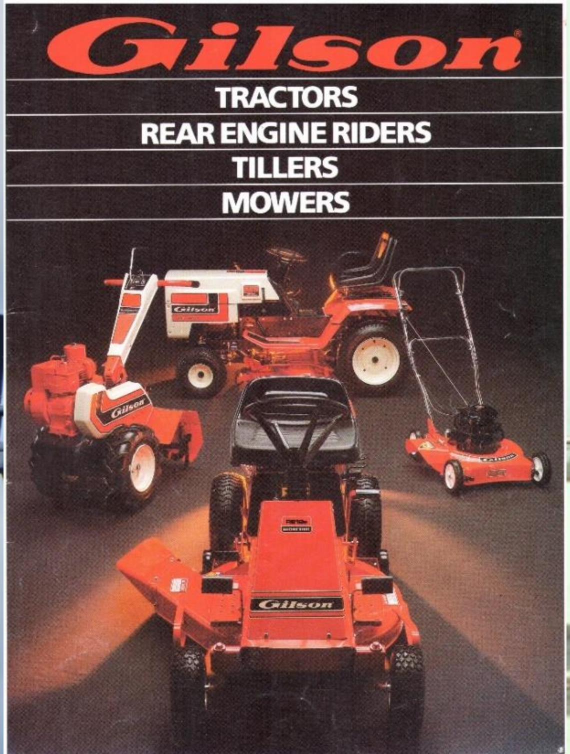
Manufacturing enables our modern society and is something to be proud of



www.sme.org

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

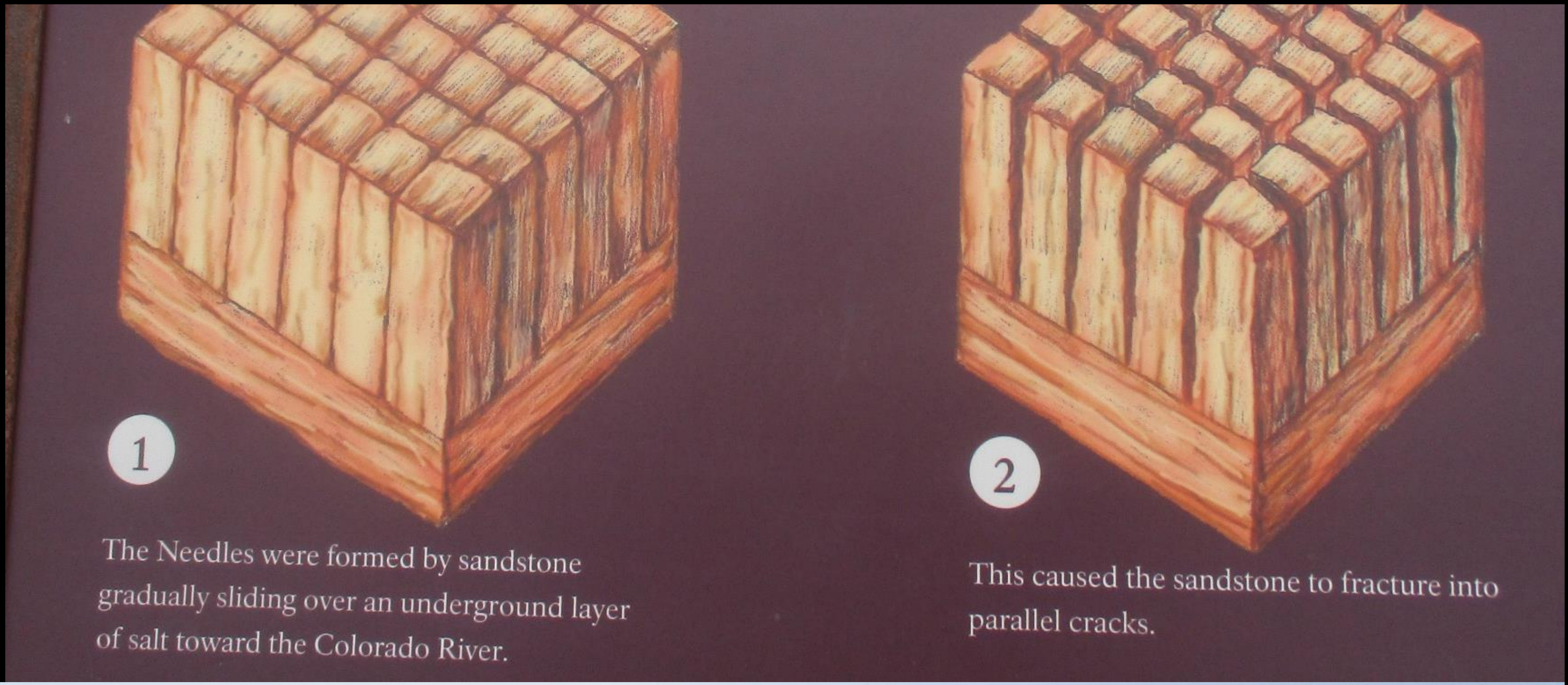
But just two weeks ago I went to Utah and was again reminded that our "manufacturing" is overshadowed

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

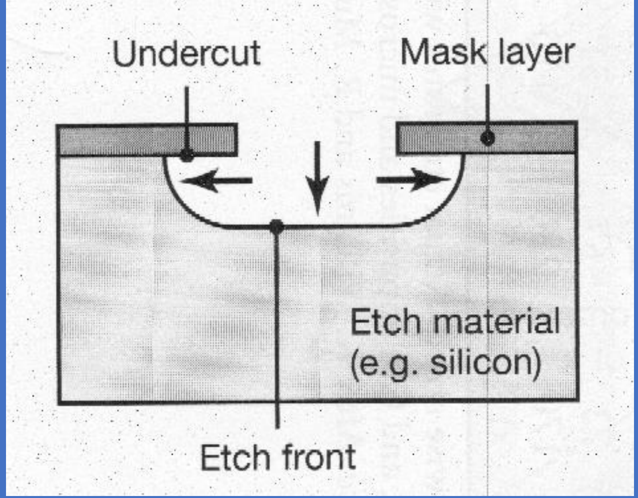
Perhaps we can
learn from those
"manufacturing"
processes which
have been occurring
for <u>billions</u> of years

Natural Processes Create Greatly Varied Structures and Surfaces

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



e.g., Kalpakjian and Schmid



Perhaps the most significant advances in manufacturing at the end of the 20th 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

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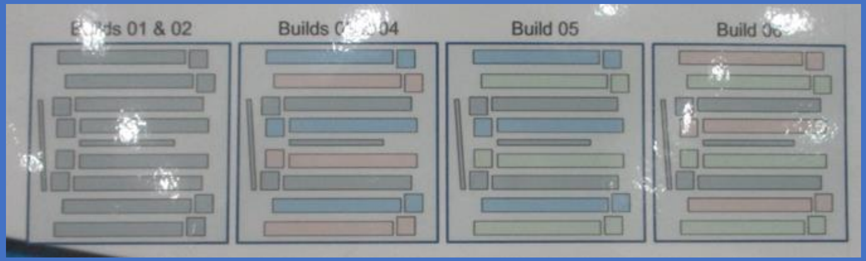
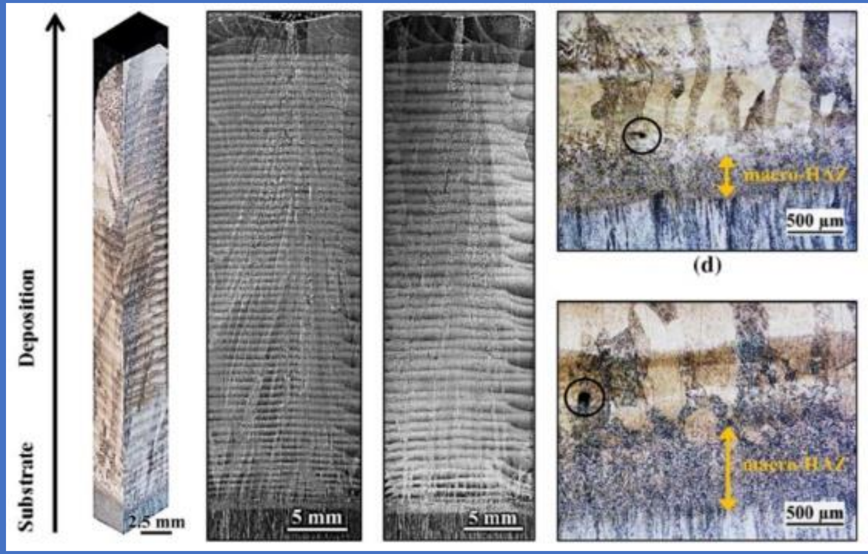


Moylan, et al., MSEC 2019

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



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

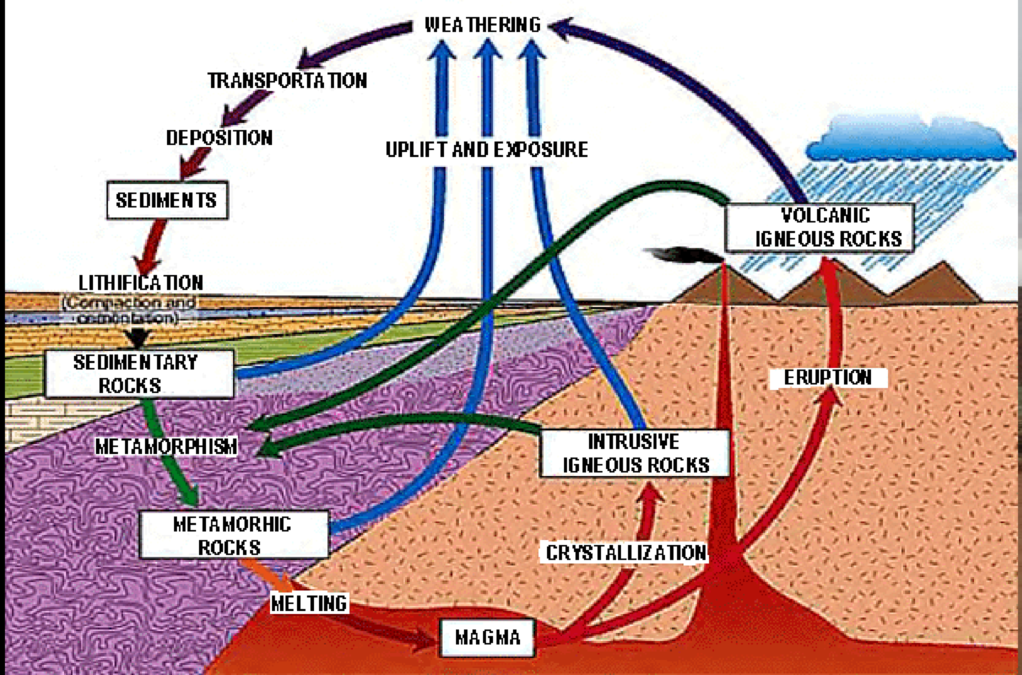
(see Water Erosion Prediction Project)

Hybrid Additive/Subtractive Manufacturing a Current Fad

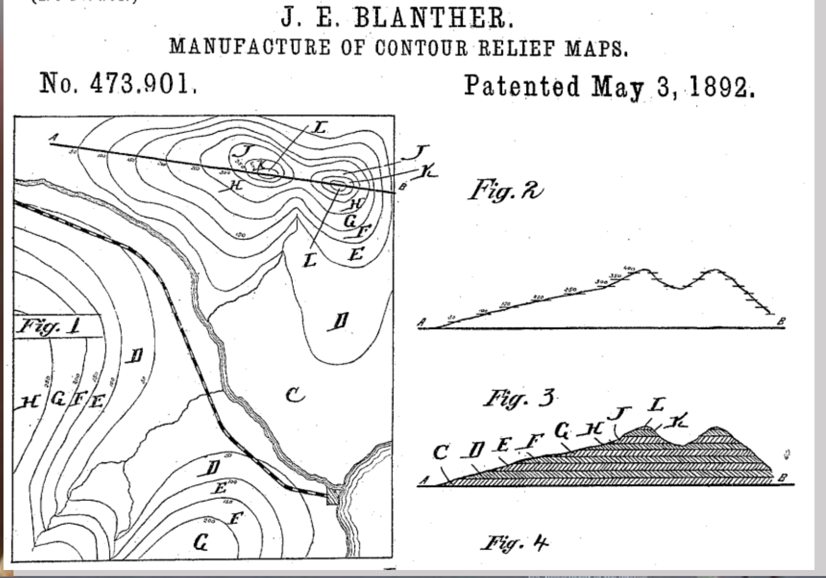
But Additive/Subtractive Combinations Have Long Been Occurring

us.dmgmori.com

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



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 …

$$\hat{\chi}_k = A^{-1} \int d\boldsymbol{\chi}_{soft}\, f_S(\boldsymbol{\chi}_{soft})\, \boldsymbol{B}_{k|hs} \boldsymbol{\chi}_{hs}\, \phi(\boldsymbol{\chi}_{soft};\, \boldsymbol{B}_{s|h} \boldsymbol{\chi}_{hard},\, \boldsymbol{c}_{s|h}) \quad (11.16)$$

and the variance

$$\sigma_k^2 = c_{k|hs} + A^{-1} \int d\boldsymbol{\chi}_{soft}\, f_S(\boldsymbol{\chi}_{soft}) \left(\boldsymbol{B}_{k|hs} \boldsymbol{\chi}_{data} - \hat{\chi}_k \right)^2 \phi(\boldsymbol{\chi}_{soft};\, \boldsymbol{B}_{s|h} \boldsymbol{\chi}_{hard},\, \boldsymbol{c}_{s|h}) \quad (11.17)$$

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

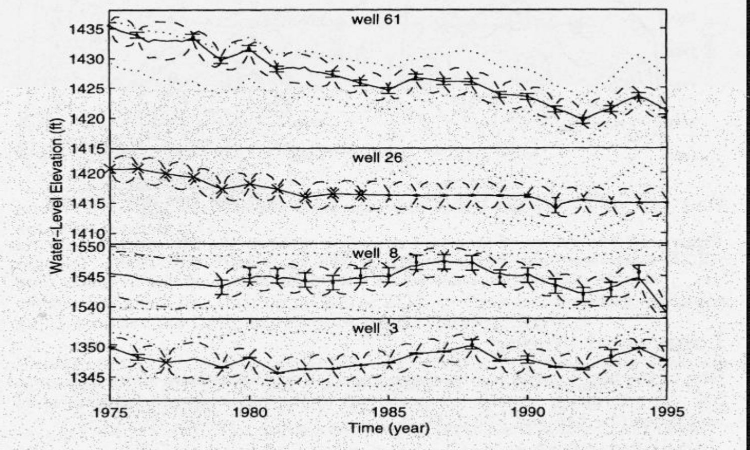
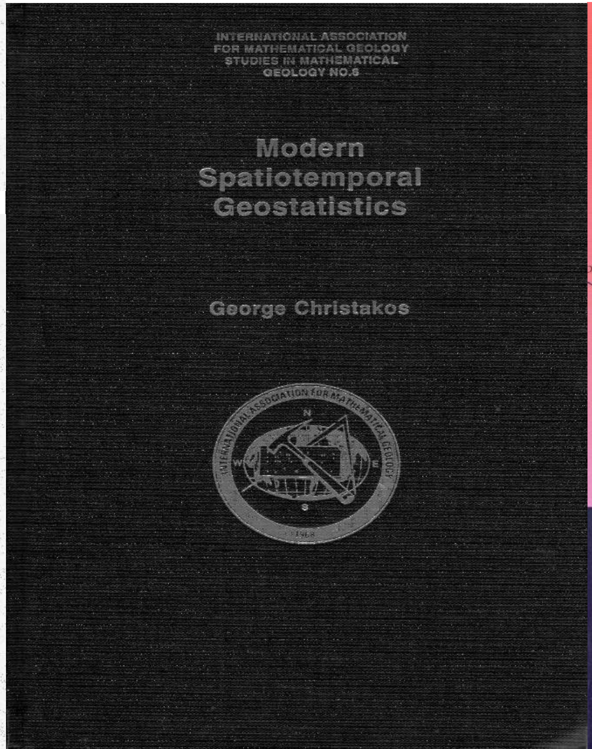
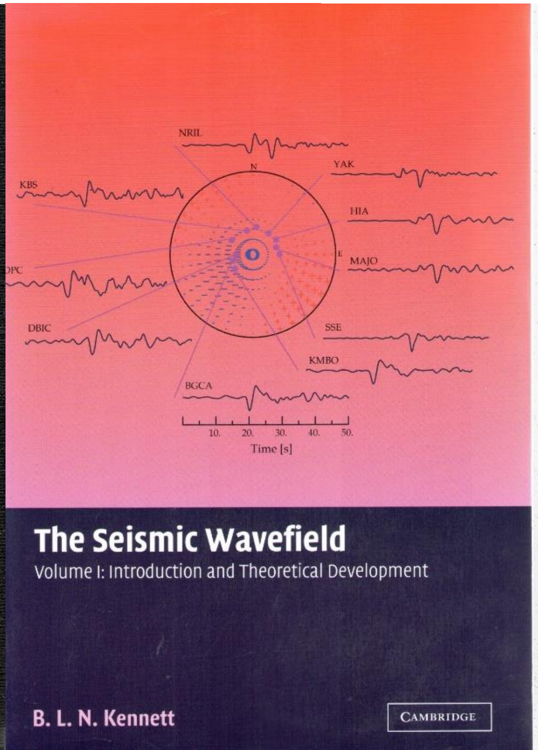


Figure 12.10. BMEmode estimates of water-level elevation at a number of selected wells (shown as solid line) and 90% confidence intervals obtained by BME (dashed line) and SK (dotted line). Hard data are shown by ×; soft (interval) data are depicted as error bars.





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

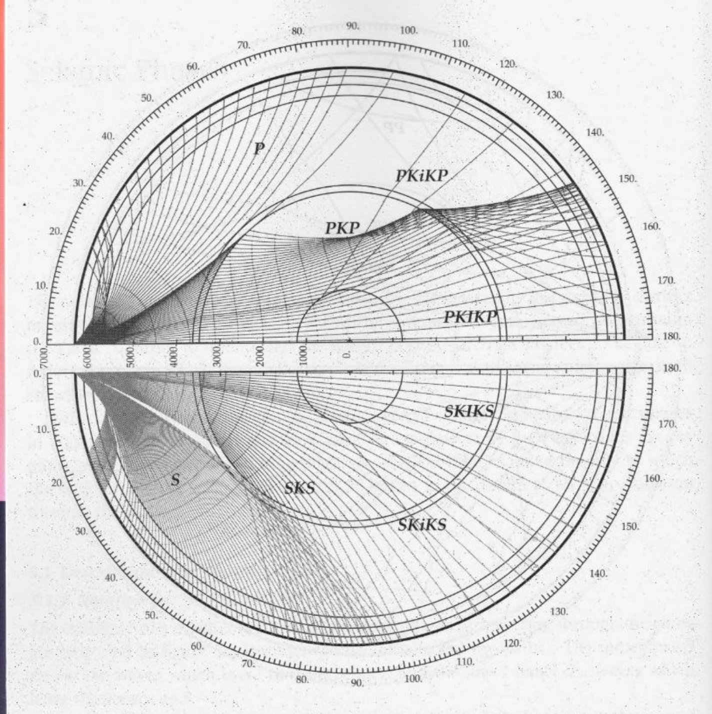


Figure 5.2. Ray paths for major P and S phases for the AK135 model of seismic wavespeeds.

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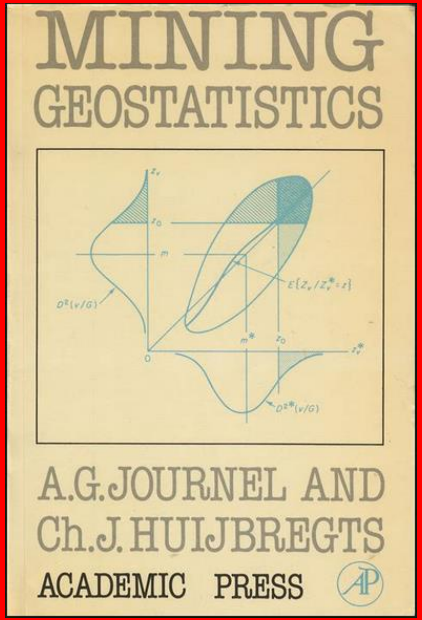
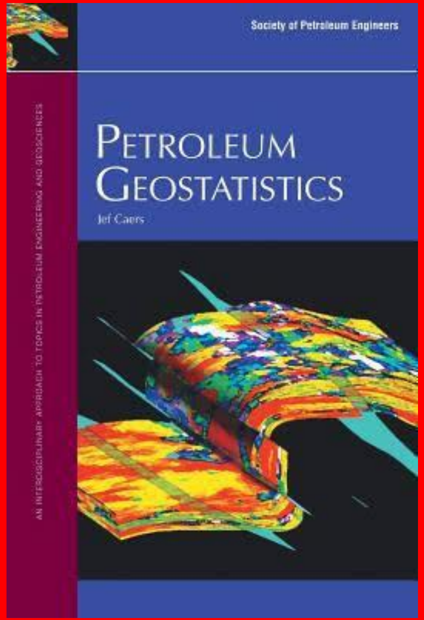




The one I’m most familiar with is Geostatistics

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.

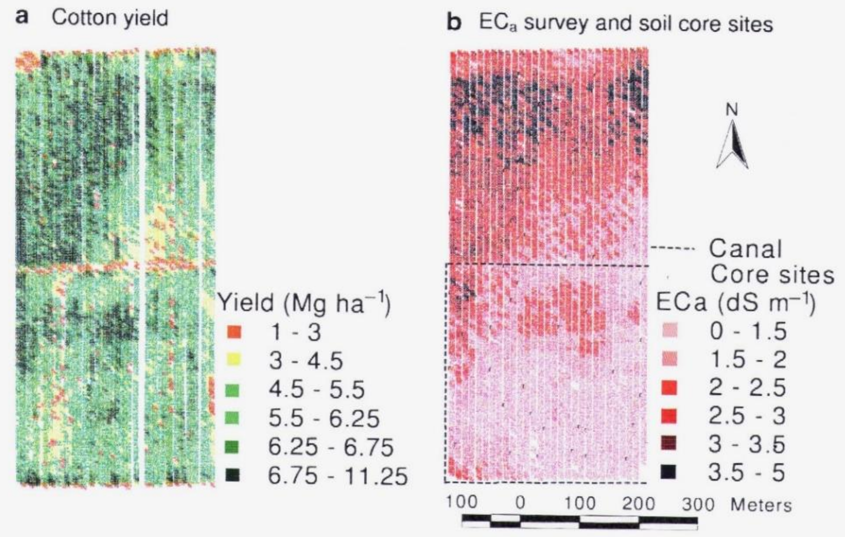


Fig. 6.1 Maps of: (a) cotton yield and (b) EC_a measurements including 60 soil sampling sites (Modified from Corwin and Lesch (2003) with permission)

Goovaerts, et al., in Oliver, ed.

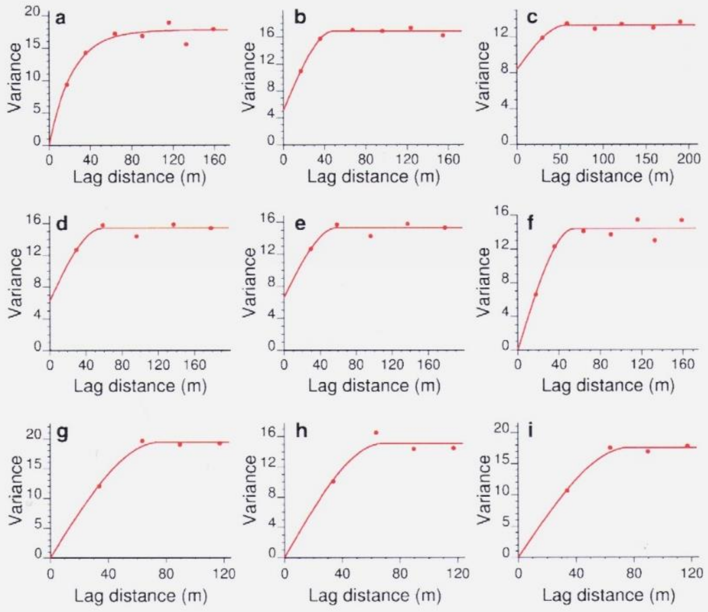
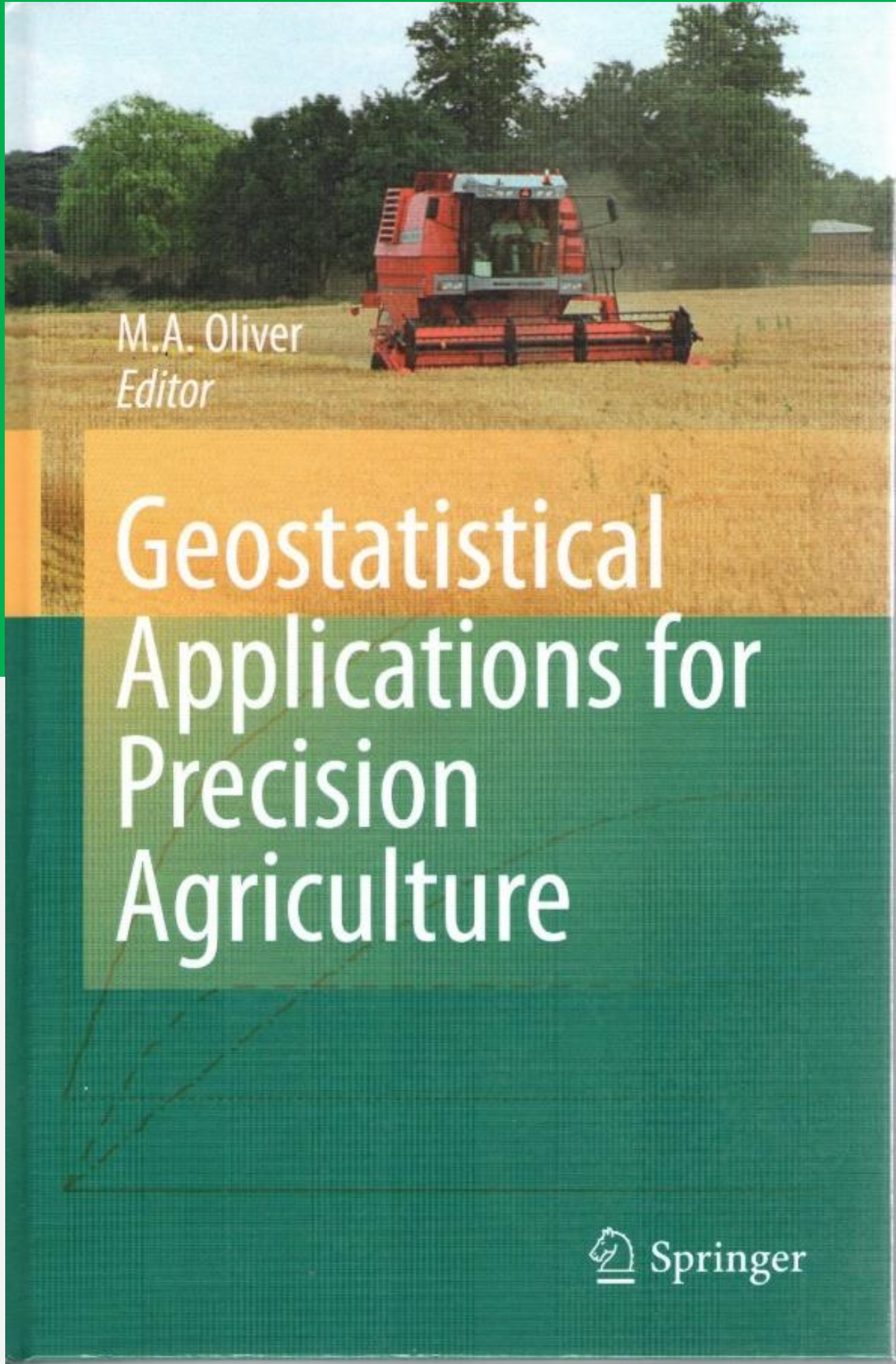


Fig. 7.3 Variograms for 30-m soil data: (a) sand (raw data), (b) soil series residuals, (c) aerial[91], EC_a and elevation rr, (d) EC_a rr, (e) EC_a and elevation rr, (f) aerial[91] and elevation rr. Variograms for the subset of 30-m soil data with 50 samples: (g) soil series residuals (50), (h) aerial[91],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



There has been some excellent research on manufacturing surface metrology

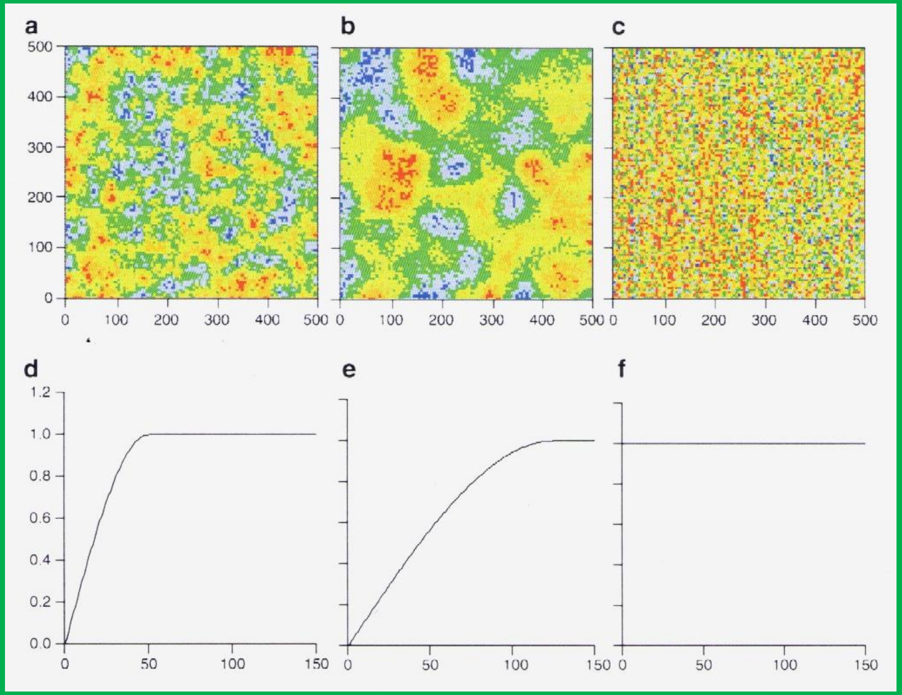
Jiang and Whitehouse *CIRP Annals* 61:815-836

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

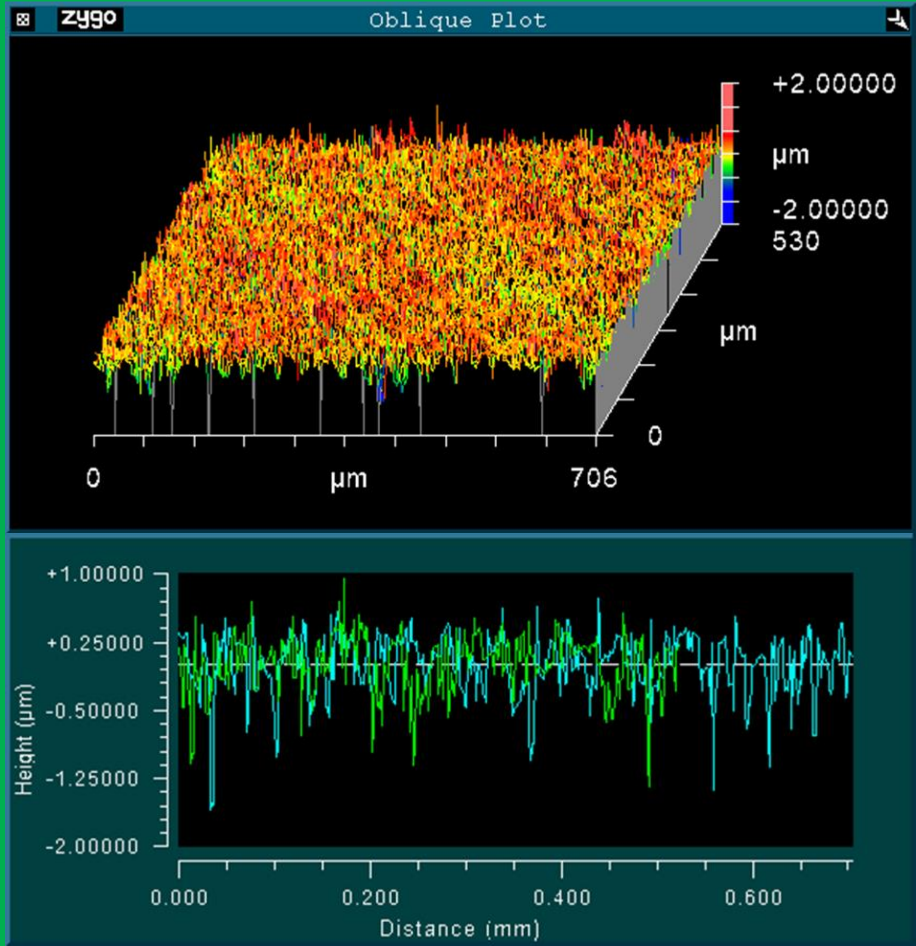
Simulated Isotropic Agricultural Fields



Similar ==================➔

Kelly, et al.,
in Oliver, ed.

Typical Manufactured Surface



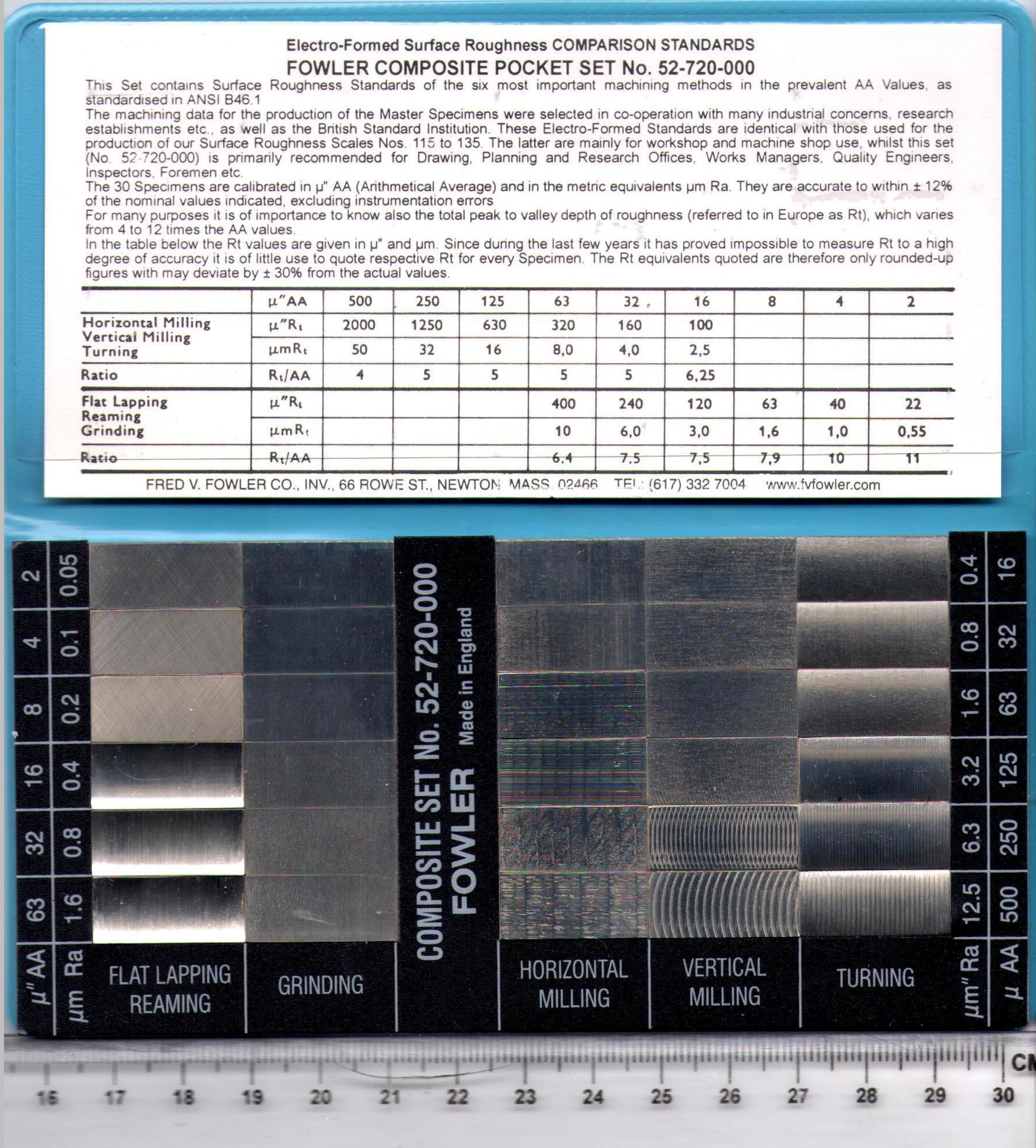
In our <u>very</u> preliminary investigation…

- **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:

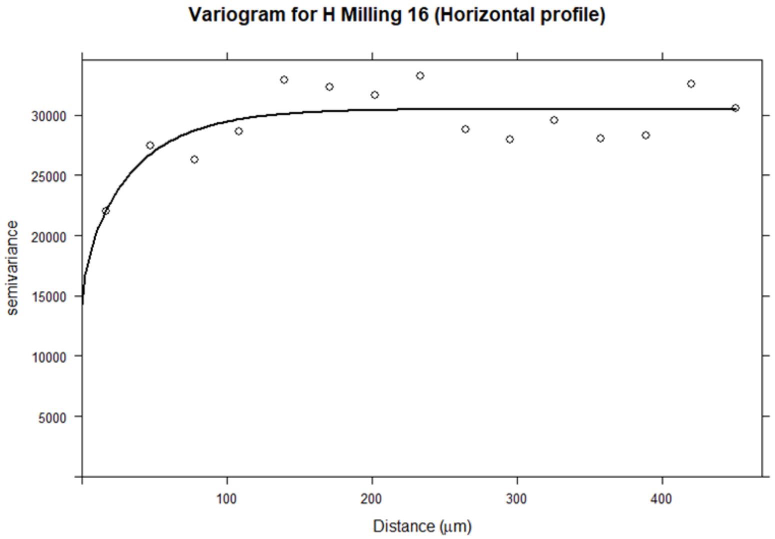
Sample	*Model*	*Nugget*	*Sill*	*Range*	*kappa**
HM-16_H1	Gaussian	0.010591	0.073695	109.8784	
HM-16_H2	Matern	14211.3	16295.18	46.07017	0.3
HM-32-2_H1	Matern	0.018627	0.485554	439.0375	0.81
HM-32-2_H2	Matern	4091.756	44889.15	197.1398	0.41
HM-63_H1	Matern	0.098954	1.49077	14.94842	3.68
HM-63_H2	Matern	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

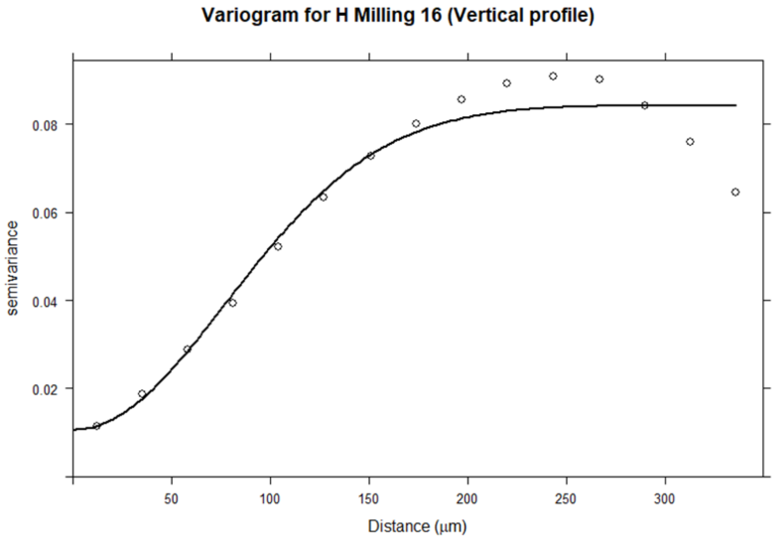
*kappa: smoothness parameter for the Matern class

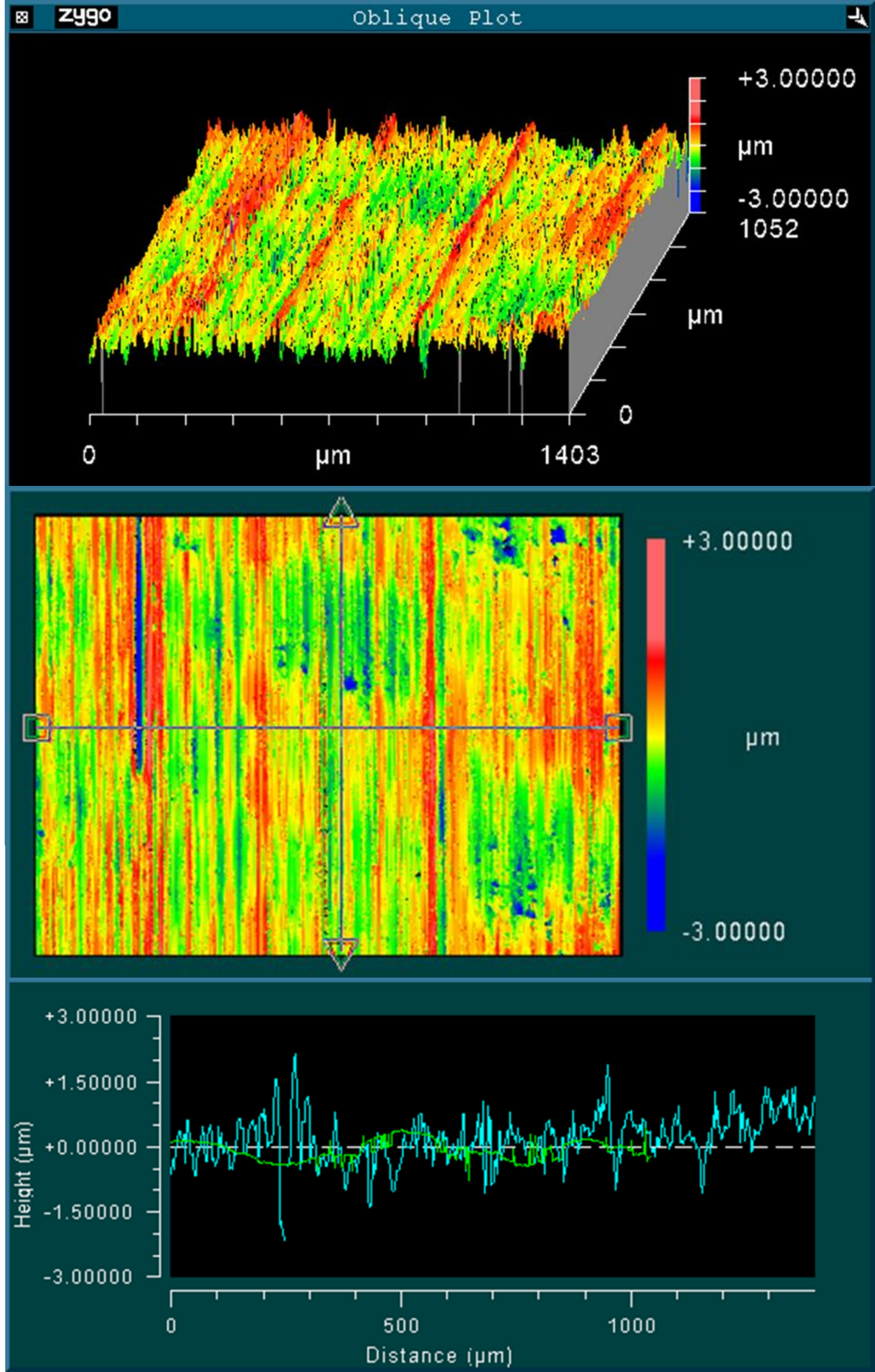


Results, of course, vary with

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



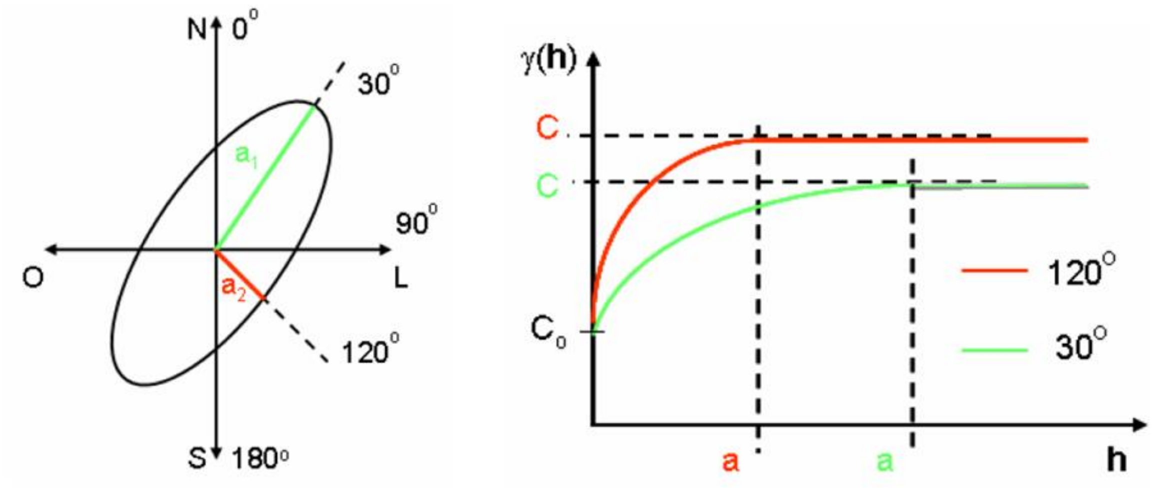




Of course,

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



Geostatistics
Predictions with
Anisotropy and Simulations

Carlos Alberto Felgueiras
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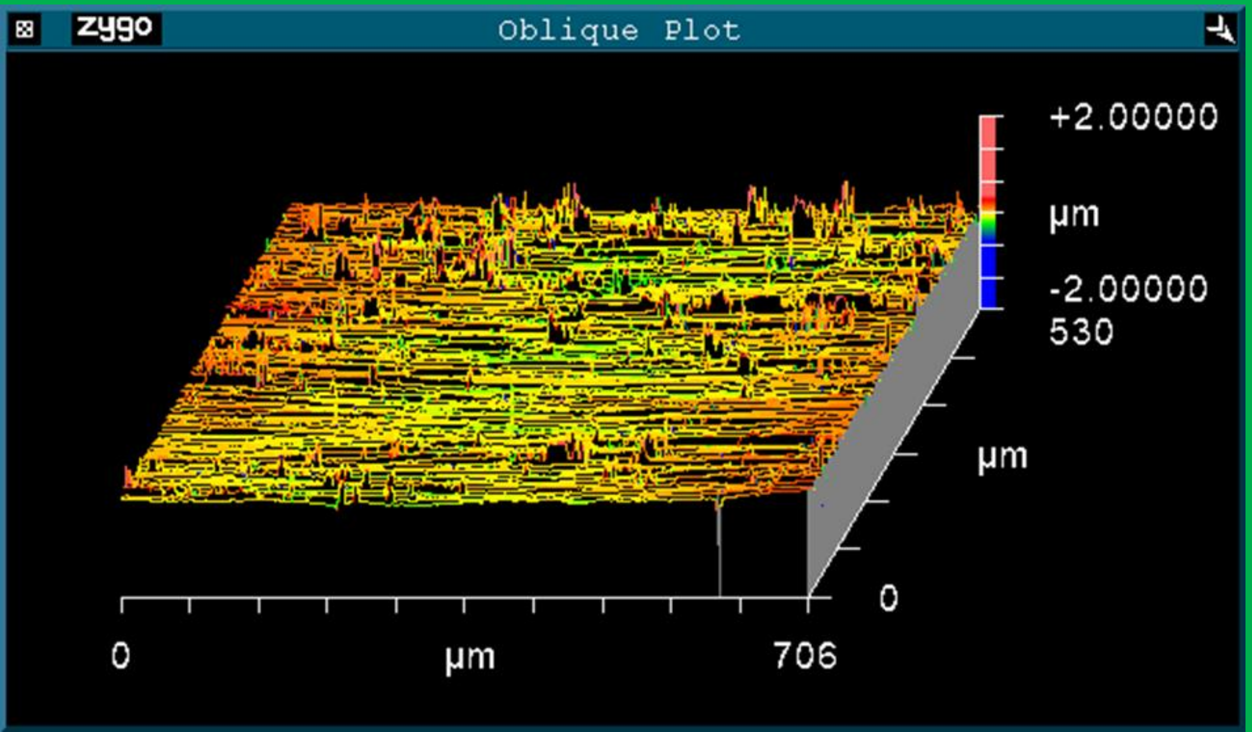
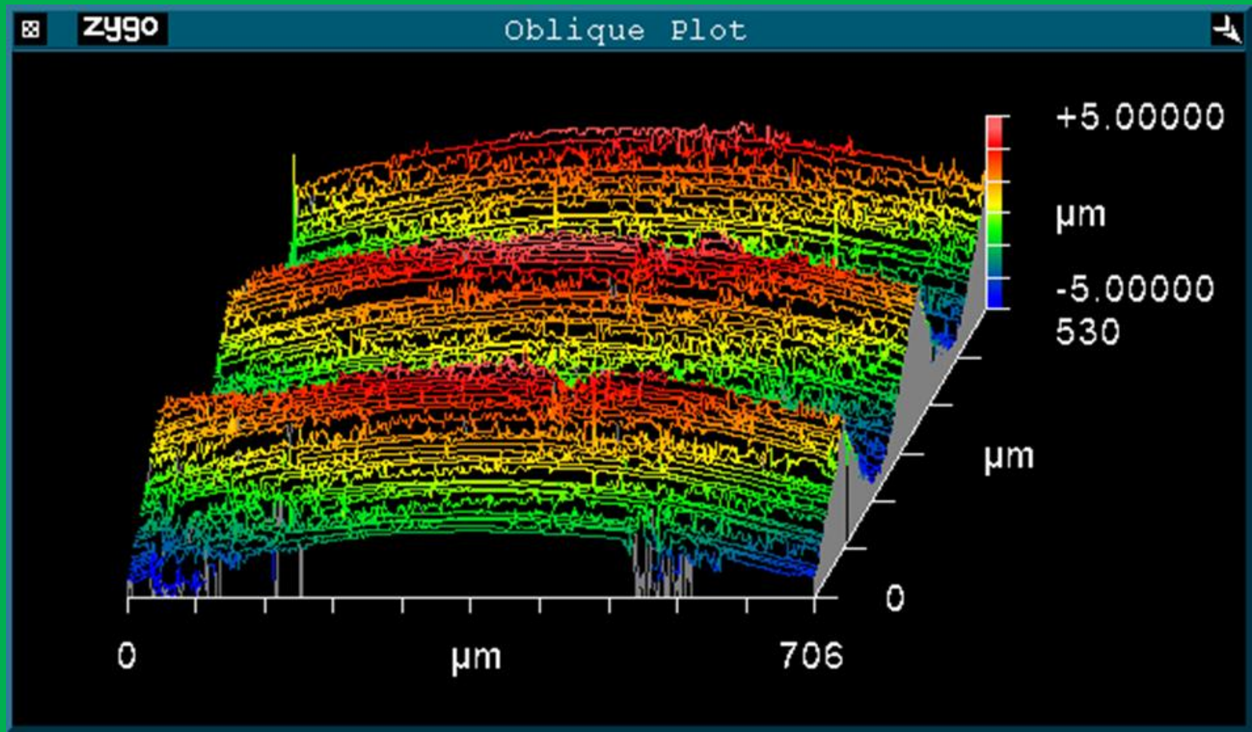
Variograms may:

- 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 <u>ONE EXAMPLE</u> of geostatistics…

… which is just <u>ONE EXAMPLE</u> 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

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