

# Lecture 1

## Characterization and Classification of Fault rocks and Melanges

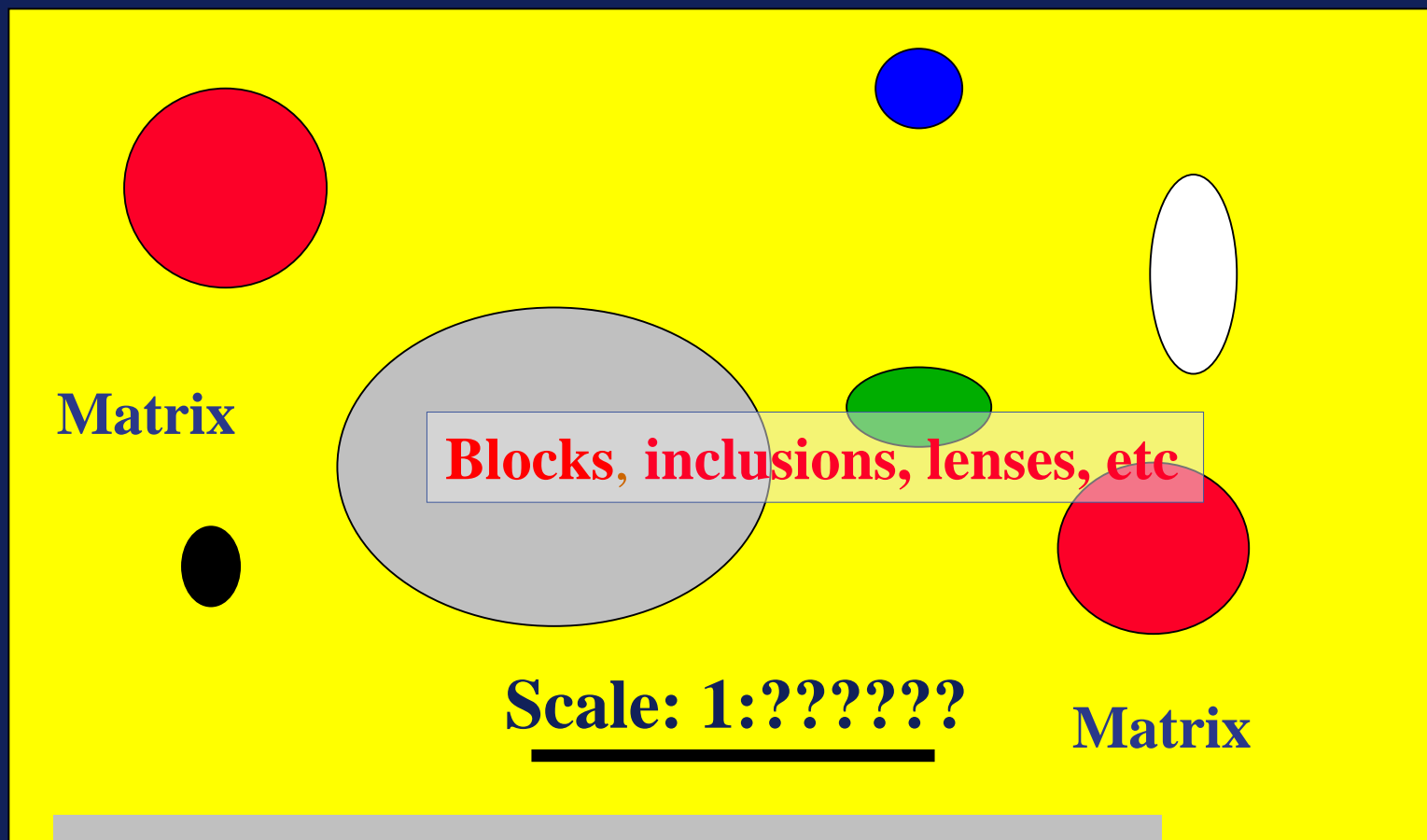
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[emedley@bimrocks.com](mailto:emedley@bimrocks.com)

**Bimrocks Short Course, Hacettepe Univ, Ankara,  
June 21, 2004**



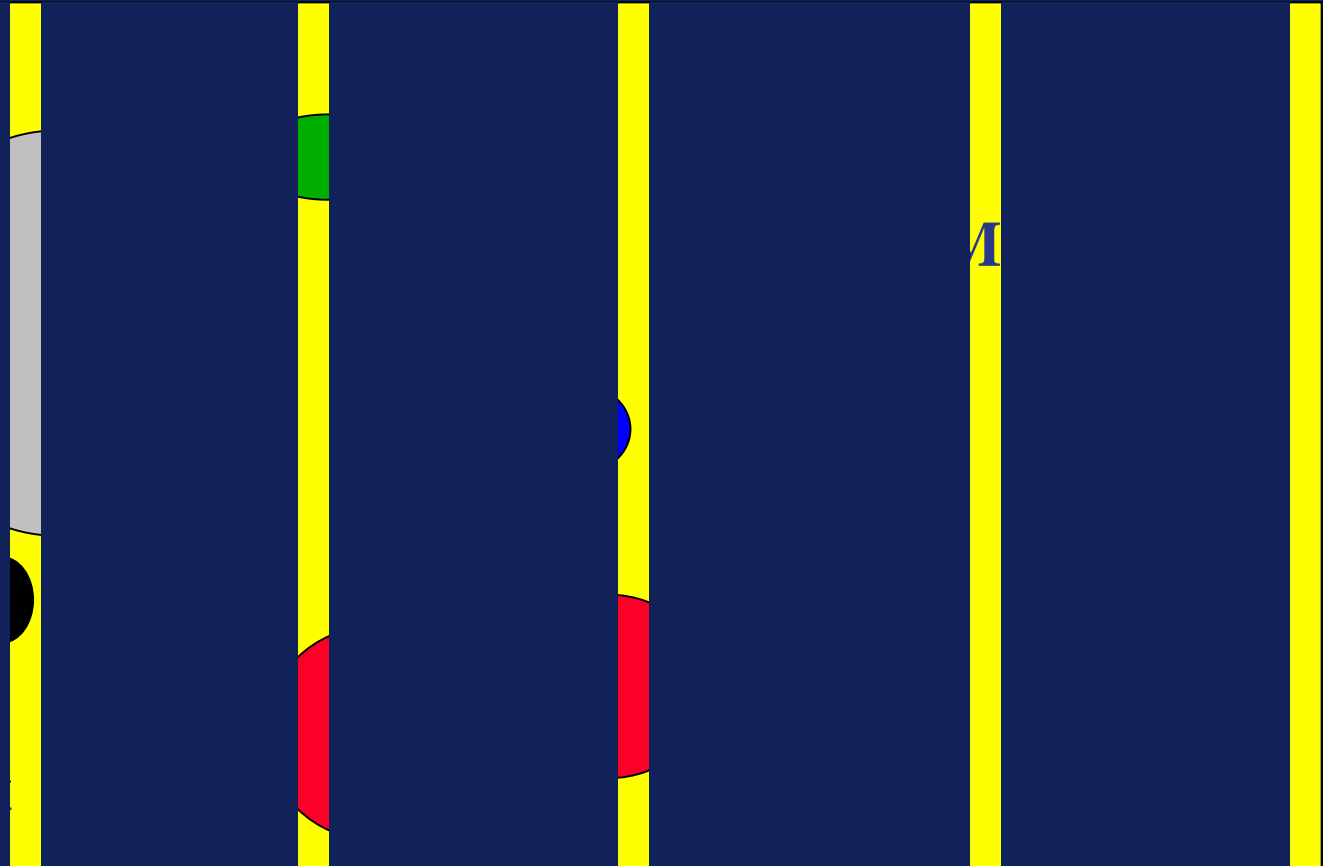
# BIG CONCLUSION 1: Remember this picture!!!



**Actual Distribution of Blocks**

Medley, 2000

# BIG CONCLUSION 2: Remember this picture as well!!!



**Apparent Distribution of Blocks**

**Dana Willis**

# Geotechnical Engineering = Rock to Soil (and everything in between.....)

**EFFECTS OF SATURATION ON ROCKS AND ROCK-LIKE MATERIALS**  
 Terzaghi's Guides for Distinguishing Rock, Weathered Rock, and Soil\*

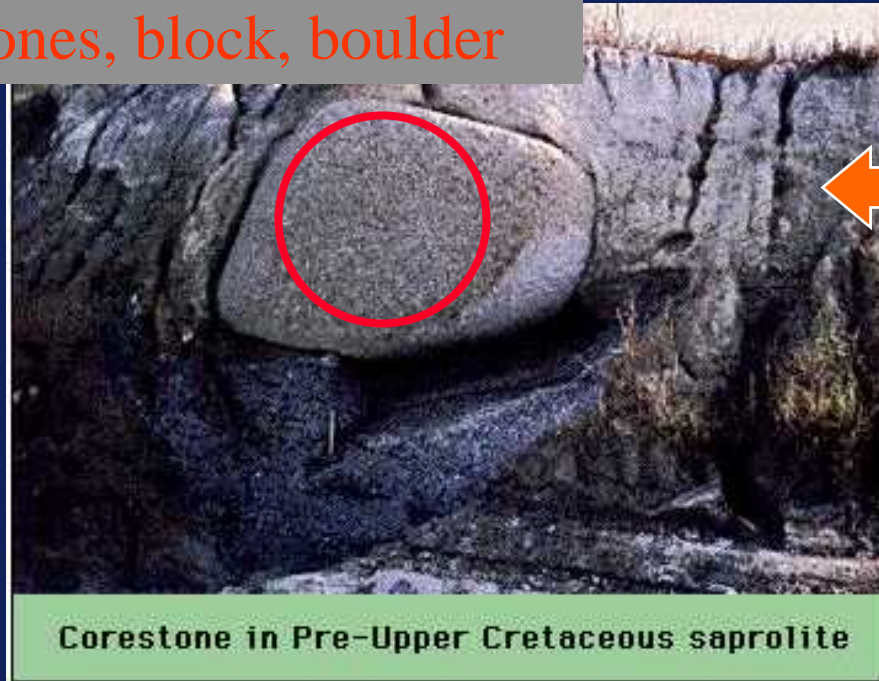
In original state	After repeated drying, immersing, and shaking, or upon prolonged exposure to the atmosphere	Volume change produced by saturating dried fragments with water	Group
Solid with ringing sound when struck with a hammer	unchanged	imperceptible	a) solid rock
	breaks up into small hard pieces with clean surfaces		b) finely fissured or crushed unaltered rock
	breaks up into small fragments with "greasy" surfaces owing to the presence of fine-grained weathering products		c) slightly decomposed fissured rock
	breaks up into individual sand or silt particles		d) sandstone or mudstone with unstable cement
Solid with dull sound when struck with a hammer	breaks up into small angular fragments without any indication of chemical alteration	measurable	e) intermediate between rock and clay, rock characteristics dominant
	gradually transformed into a suspension of soil particles		f) intermediate between rock and clay, clay characteristics dominant
	gradually transformed into a suspension of clay particles and a sediment consisting of angular rock fragments	imperceptible to important	g) thoroughly decomposed rock
	completely transformed into a suspension and/or a loose sediment		h) clay, silt, and very fine sand in dry or a very compacted condition

\* From Professor Karl Terzaghi's course notes for Engineering Geology at Harvard University; included with kind permission of Dr. Ruth Terzaghi (with minor editorial changes) and including revisions made by Karl Terzaghi shortly before his death.

Courtesy of Prof. R.E. Goodman

# Example of Rock and Soil Mixture

Corestones, block, boulder



soil

Glacial till in  
Michigan

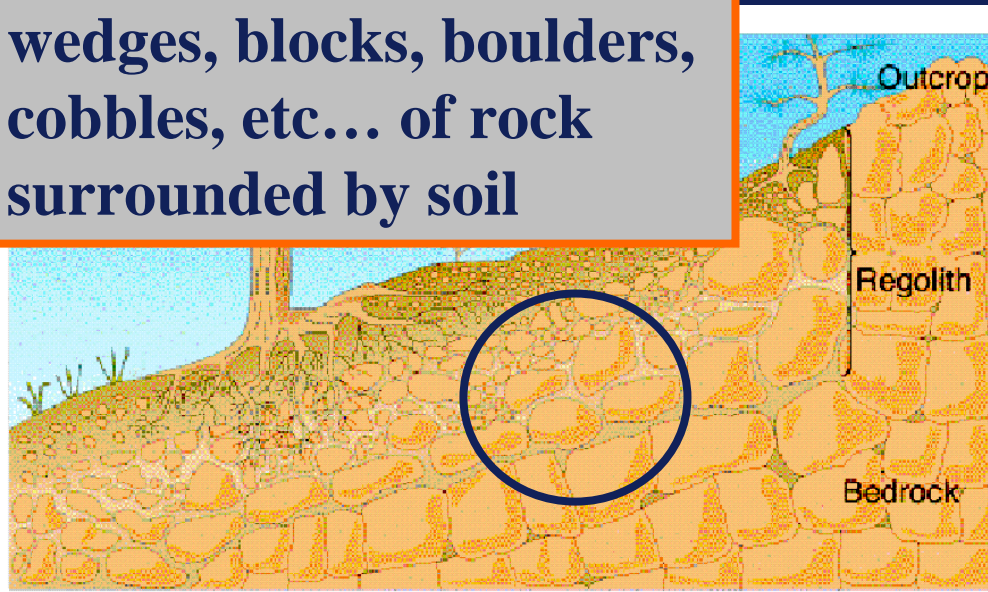
Corestone in Pre-Upper Cretaceous saprolite

Virginia Tech Univ website

# Weathered Rocks

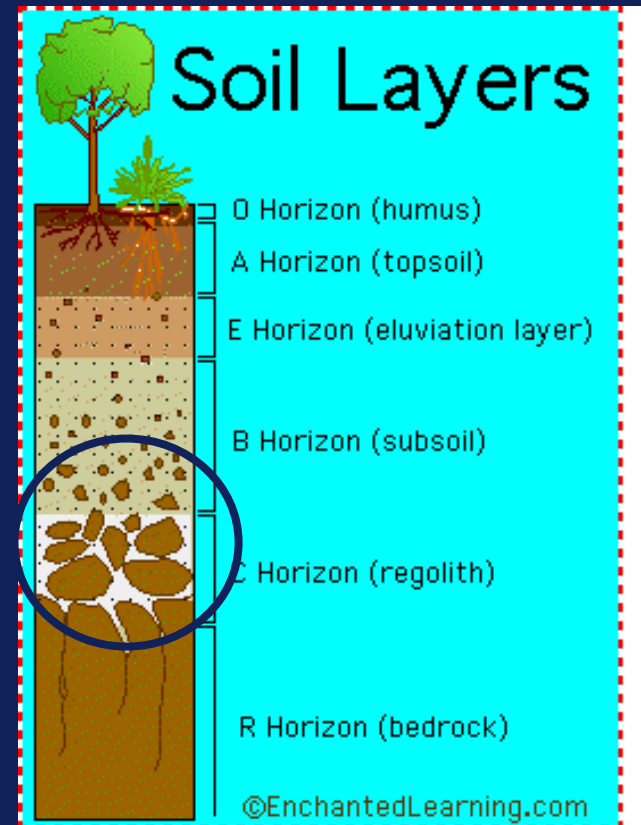
- Rock weathers into soil, saprolite and corestones above intact bedrock

Corestones, ledges, wedges, blocks, boulders, cobbles, etc... of rock surrounded by soil



(a)

University of Florida website



©EnchantedLearning.com

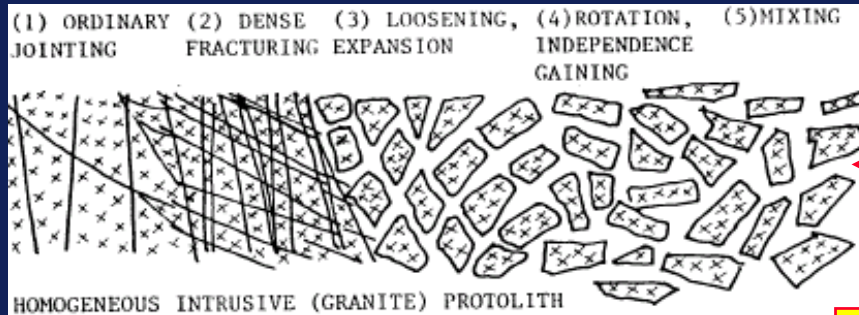
Enchanted Learning website

# Example of weathered rock



**Mixture with weaker soil and strong blocks  
(decomposed granite at Hwy 50, California)**

# “Rock”: simple word, complex concept!



MIXED BRECCIA:  
one-fragment

Intact

fragmented



BEDDED BUT COMPOSITIONALLY HOMOGENEOUS LIMESTONE.

MIXED BRECCIA:  
one-fragment



BEDDED, COMPOSITIONALLY HETEROGENEOUS UNIT (BASALT, SANDSTONE, CONGLOMERATE, THIN SHALE INTERBEDS)

“simple” geology but  
challenging rock engineering

“complex” geology and  
REALLY challenging rock  
engineering

# The complexity of a “simple” rock/soil mixture



**turbidite sequence - interbedded sandstones and shales**

**(Devil's Slide, Pacifica, California)** photo: Ed Medley

# Complex poly-lithologic geologic mixture

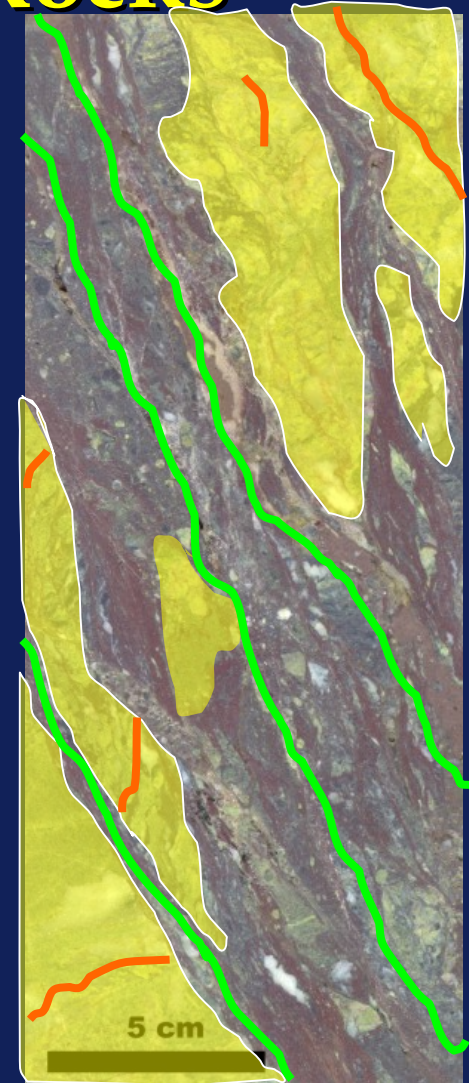
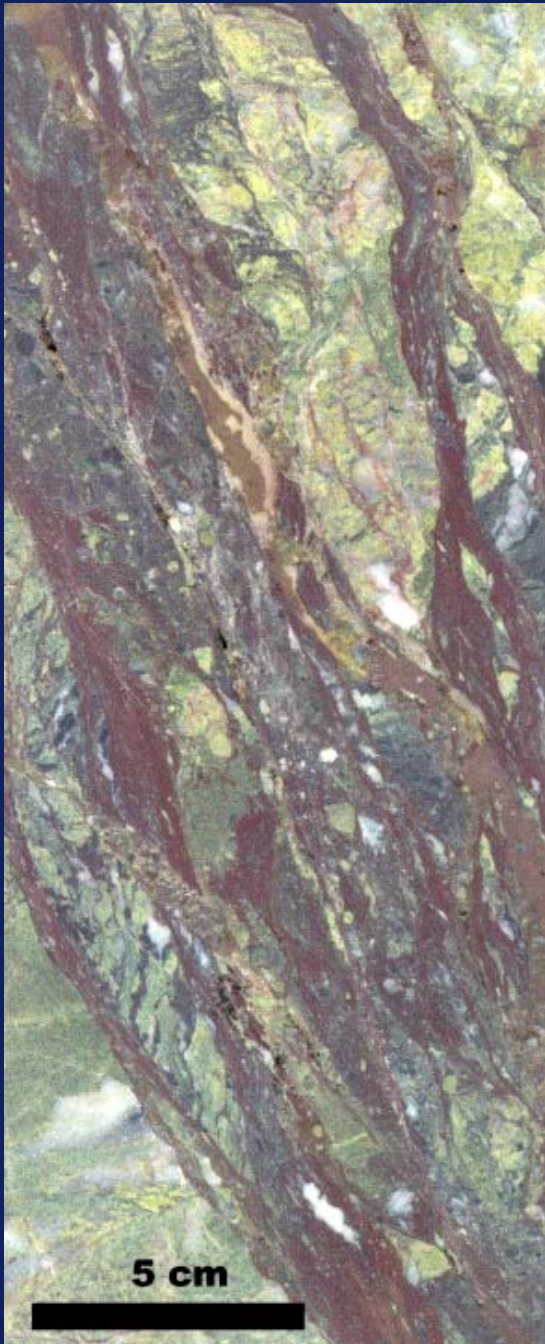


**mega-breccia, Death Valley, California**

# Fault Rocks and Shear Rocks

Fault zones and  
Shear zones  
may have blocks  
millimeters to  
100s of meters  
wide:

**BLOCK SIZE  
DISTRIBUTIONS  
TEND TO BE  
SCALE  
INDEPENDENT**

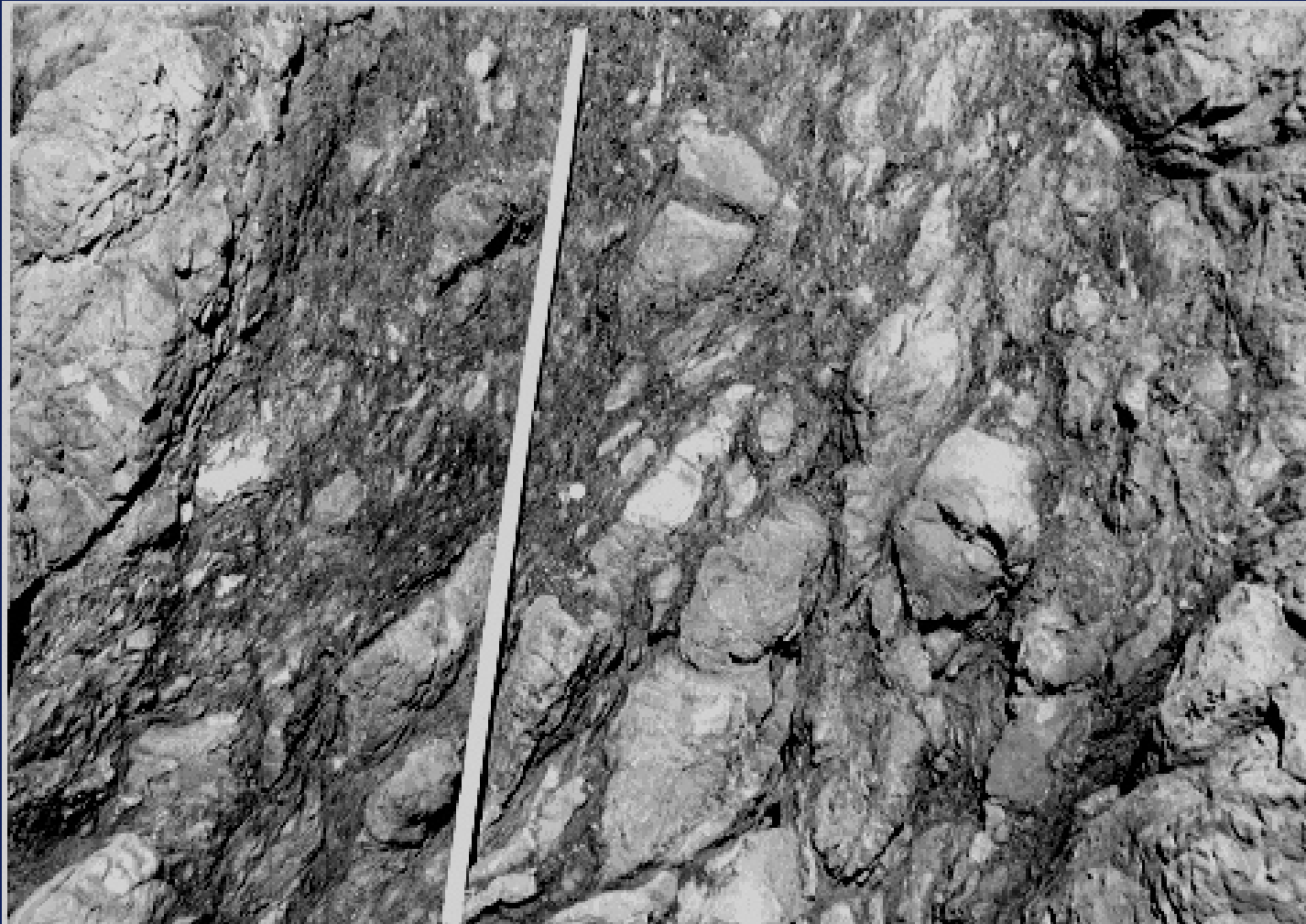


**A geological mixture with polyolithologic blocks ranging in size from sand to mountains:**



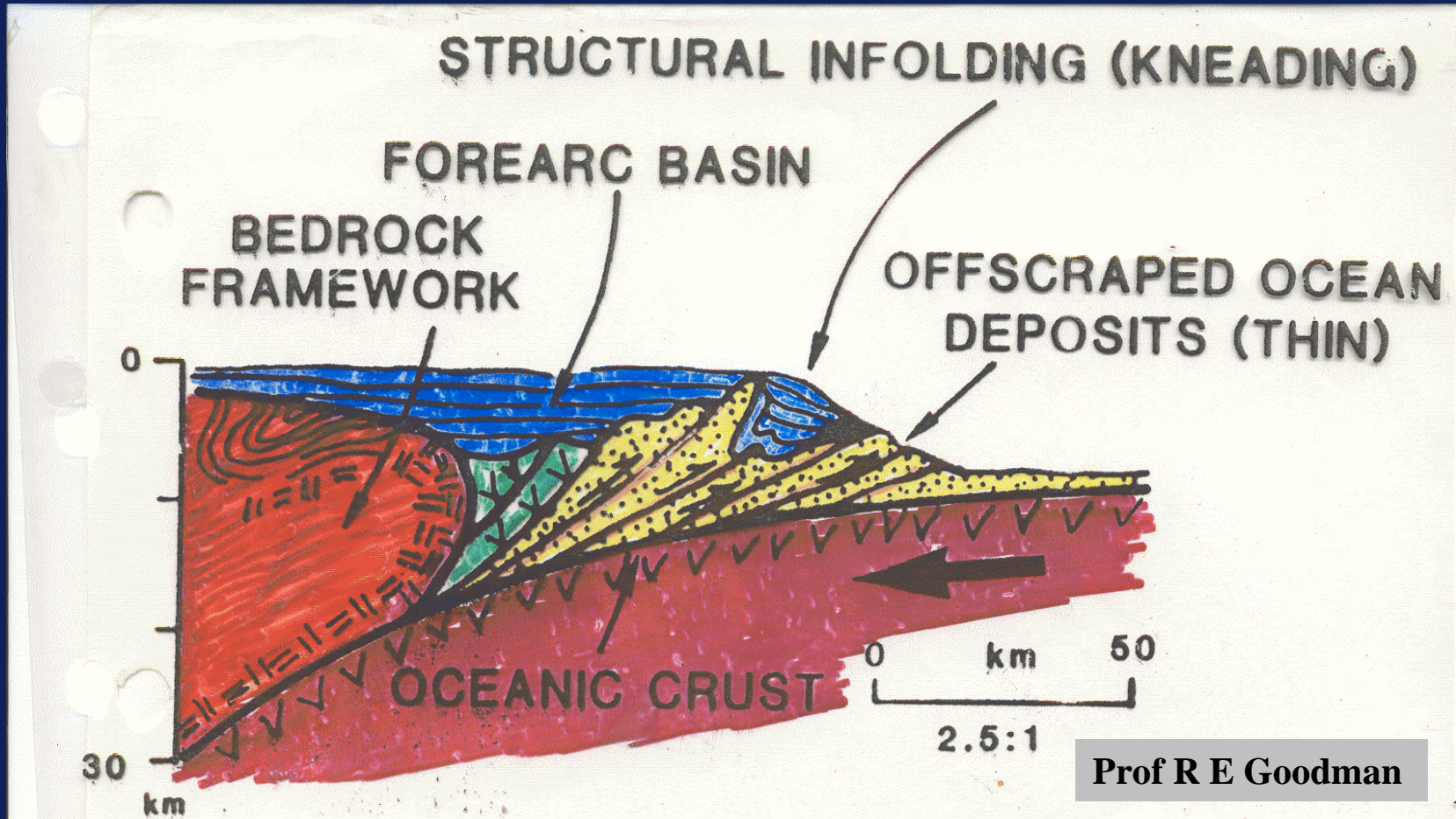
**Blocks in the Gwna melange, Anglesey, North Wales photo Ed Medley**

# Melanges

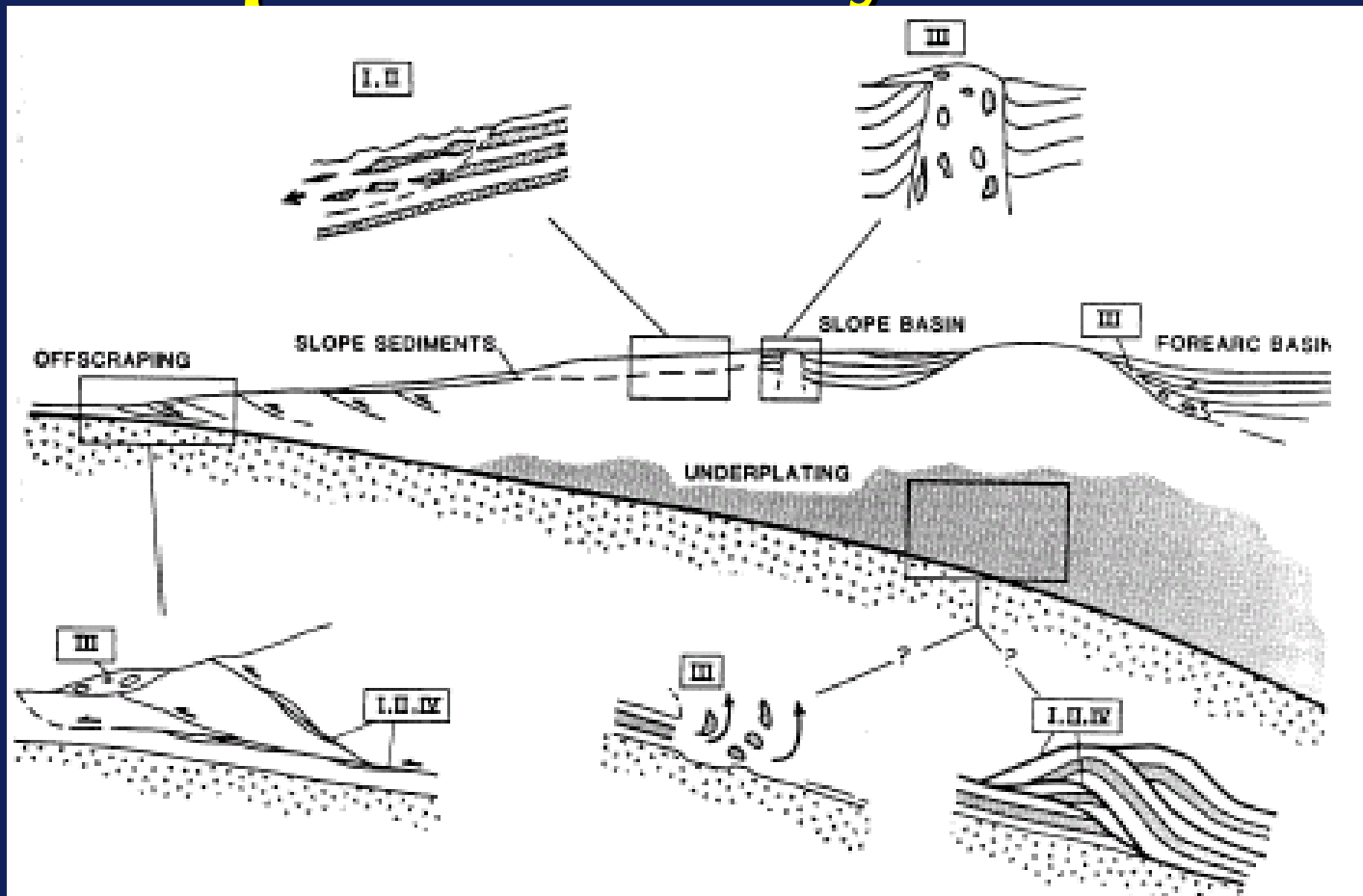


**Franciscan Complex melange, Mendocino California photo: Ed Medley**

# Simple model for origin of melanges



# Even melanges are more complex than they seem...

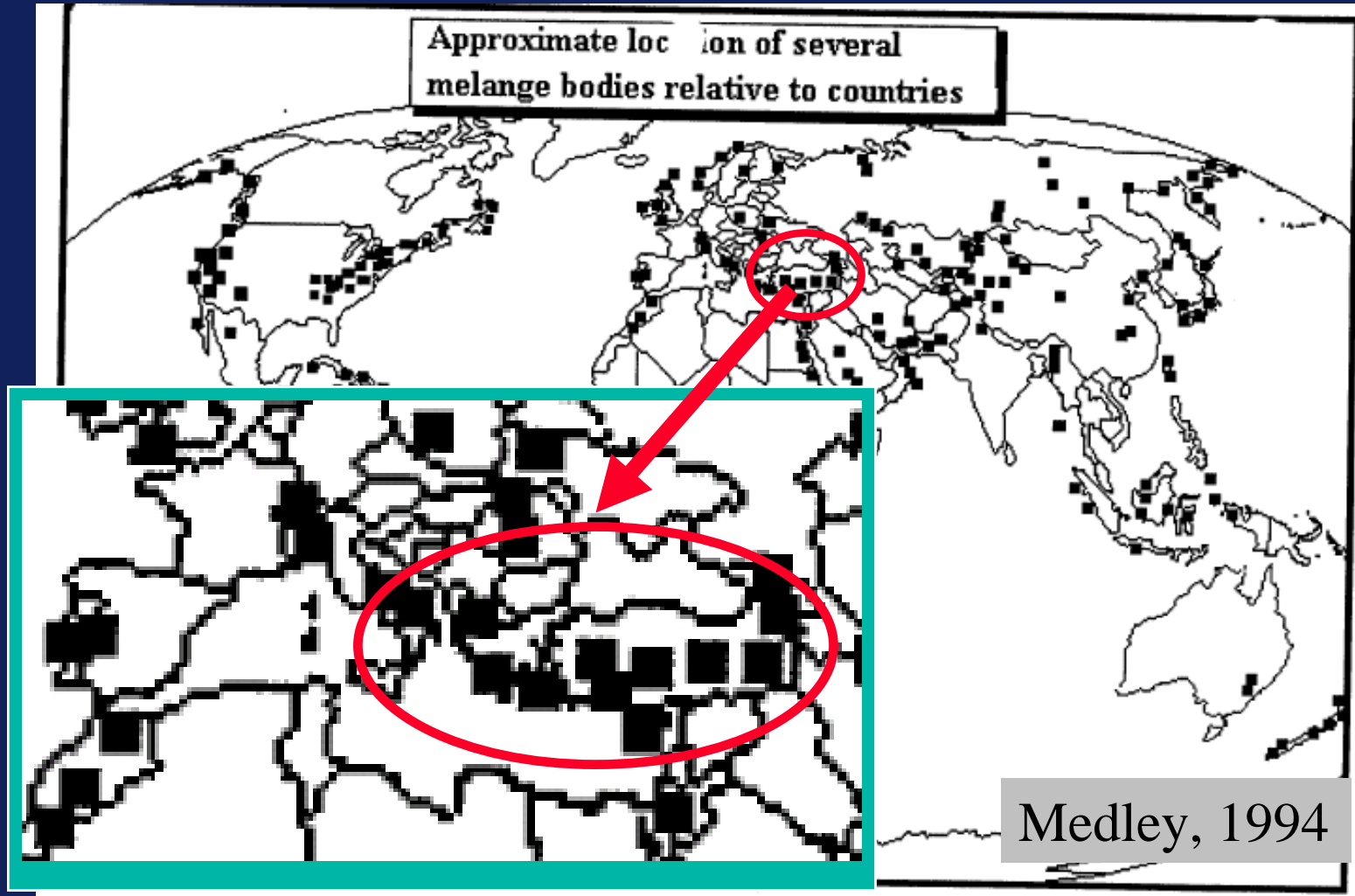


an anastomosing network of parallel faults, tectonic slices. Often superimposed on an earlier mélangé. Includes Type IV mélangé of Cowan (1985).

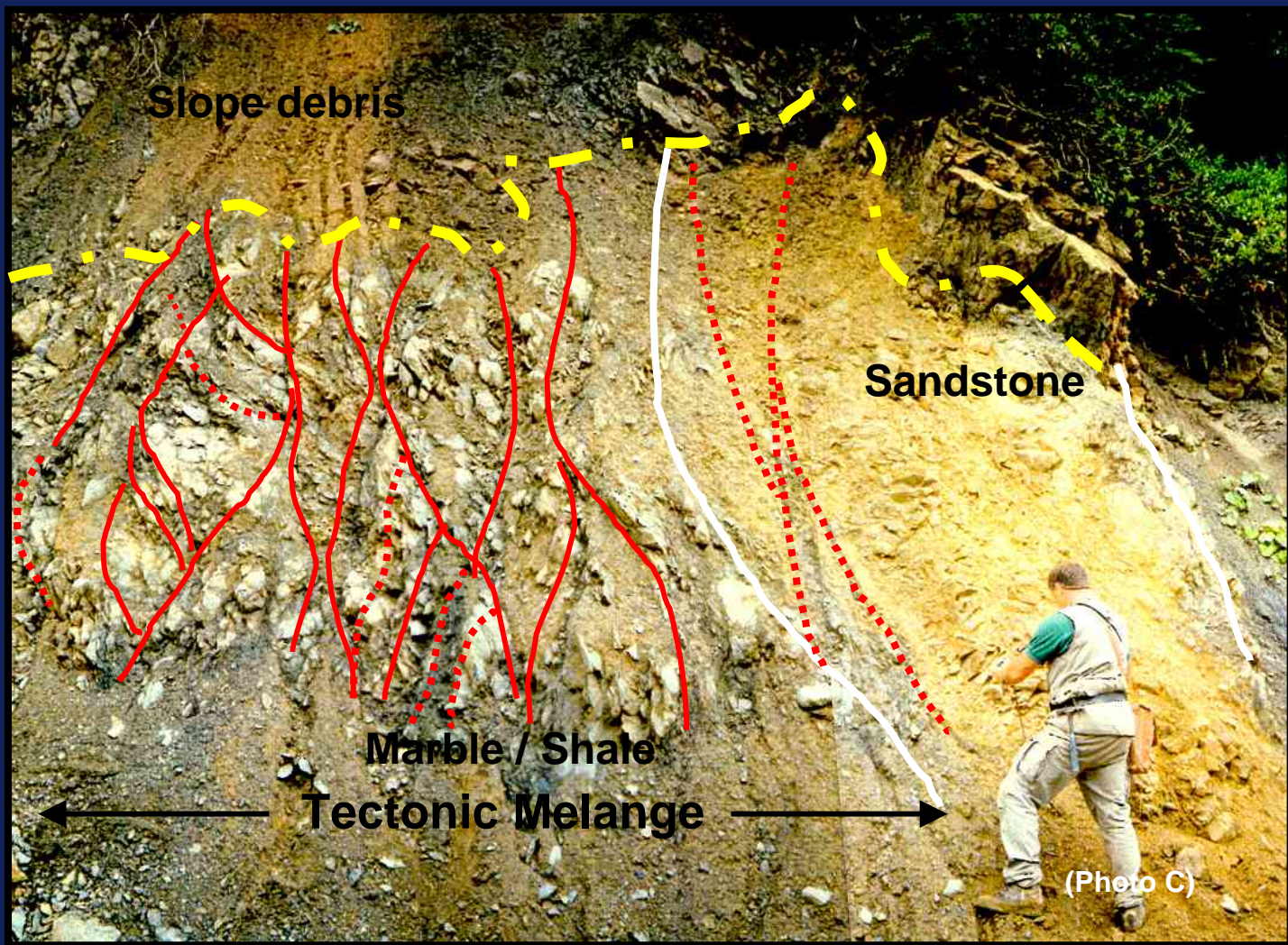
Laznicka, 1988

Cowan, 1985

# Melanges are in >70 countries

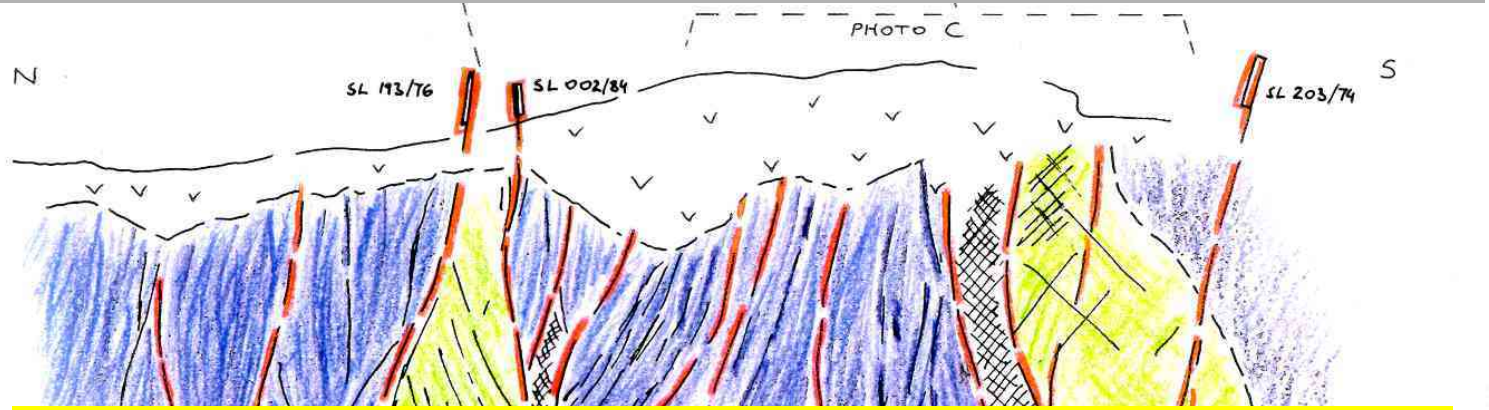


*Typical Melange Showing Diverse Elongate Blocks and Irregular Foliated Matrix (S-M-C-Cataclasites)*



# Typical Melange Showing Diverse Elongate Blocks and Irregular Foliated Matrix (S-M-C-Cataclasites)

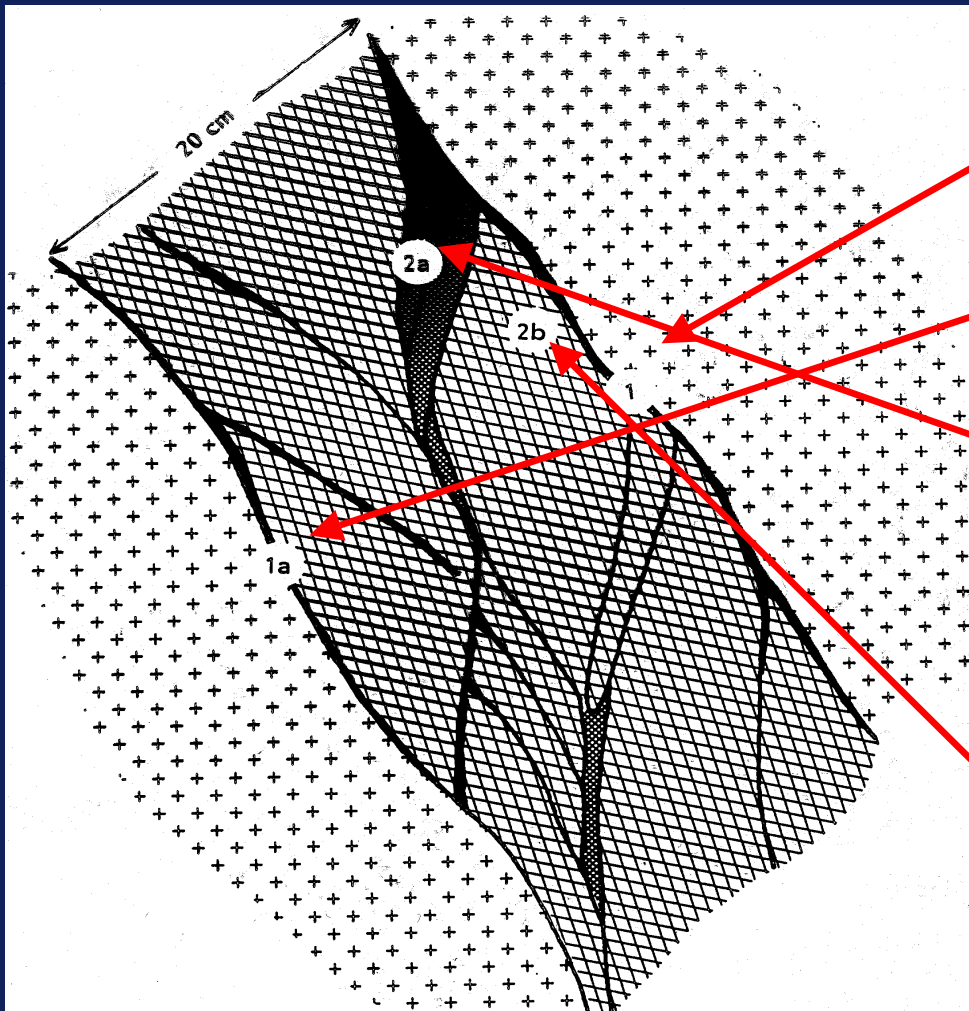
Bolu Tunnel, Turkey



**Melanges look like fault rocks**



# Formation of Clay Minerals



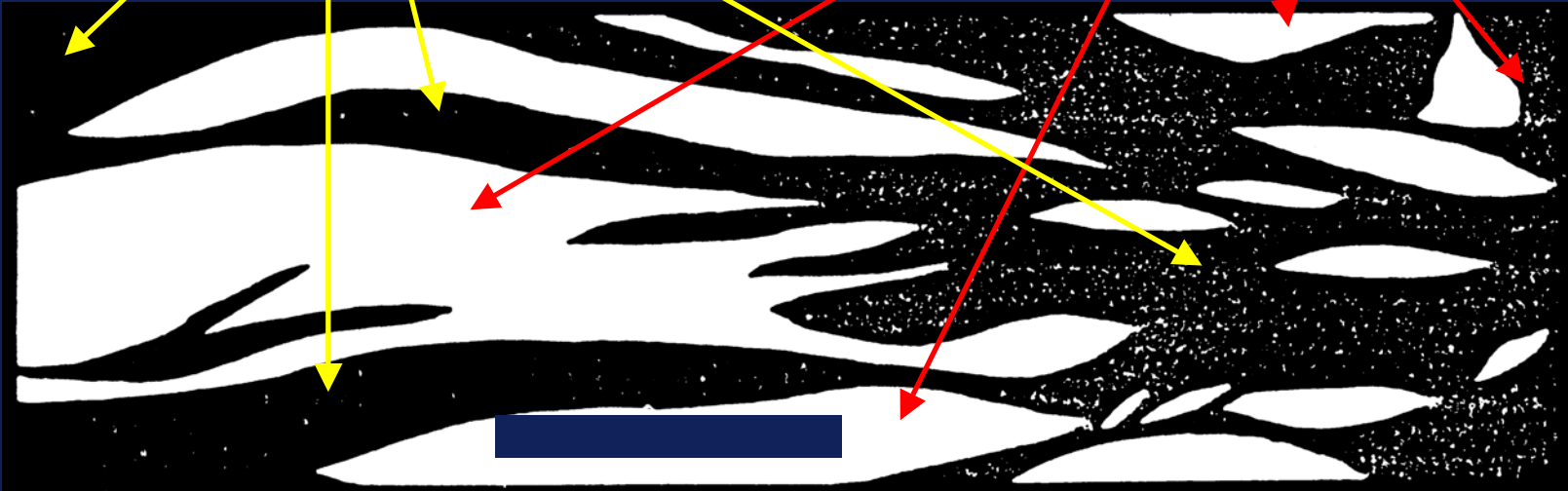
Sample 1:	Smectite 92% Illite 8%
Sample 1a:	Smectite 87% Illite 13%
Sample 2a:	Smectite 77% Mixed Layer 3% Kaolinite 17% Illite 3%
Sample 2b:	Sample 40% Kaolinite 50% Illite 10%

Fault Zone in Gneiss („Zentralgneis“)  
HPP MALTA – Göß Tunnel, Km 4,615

# Fault Structures

**FINE - GRAINED  
INTENSELY SHEARED  
GOUGE**

**LOZENGE - SHAPED  
BLOCKS OF NO  
DEFORMATION**



Fault Zone Model, Blocks Show Fractal Dimensions,  
from the Micro – to the Megascale (SCALE INDEPENDENCE)

# Significance of Fault Zones

## *Geotechnical Relevant Characterization of Brittle Faults*

- **Faults** are elongated complex zones of deformation, ranging from decimeters to kilometers in magnitude
- A significant **internal structure** of shear and extensional fractures has developed, reflecting the geometry of the strain field and, consequently, the orientation of the principal stresses
- The **brittle deformation**, such as particle size reduction by crushing of grains and reorientation of grains by shearing, generates the characteristic fine-grained gouge
- Low-temperature solution transfer contributes substantially to the **alteration of fault rocks**, in particular **gouge**, through transformation and neoformation of clay minerals

# Significance of Fault Zones

## ***Geotechnical Relevant Characterization of Brittle Faults***

- The significant geotechnical feature is a substantial **heterogeneity**, reflected by the occurrence of more or less undeformed **competent blocks** which are typically **surrounded by a fine-grained matrix** consisting of gouge and highly fractured rocks. The **matrix** appears to be **flowing around the blocks in an anastomosing pattern**
- The mainly lozenge shaped blocks exhibit a **fractal distribution of dimensions**, ranging from the microscale to hundreds of meters in length. **Fault structures are scale independent**
- A considerable **heterogeneity of the stress field** may exist. Variations in the stress field might be an important cause of segmentary fault zone formation
- **Groundwater conditions are also highly variable**. Water pressures and flow directions may change dramatically across fault zones. **A fault zone acts as aquifer, aquitard and aquiclude**

# Fault Structures

Extension fractures

Blocks of serpentinite

Extensional shears



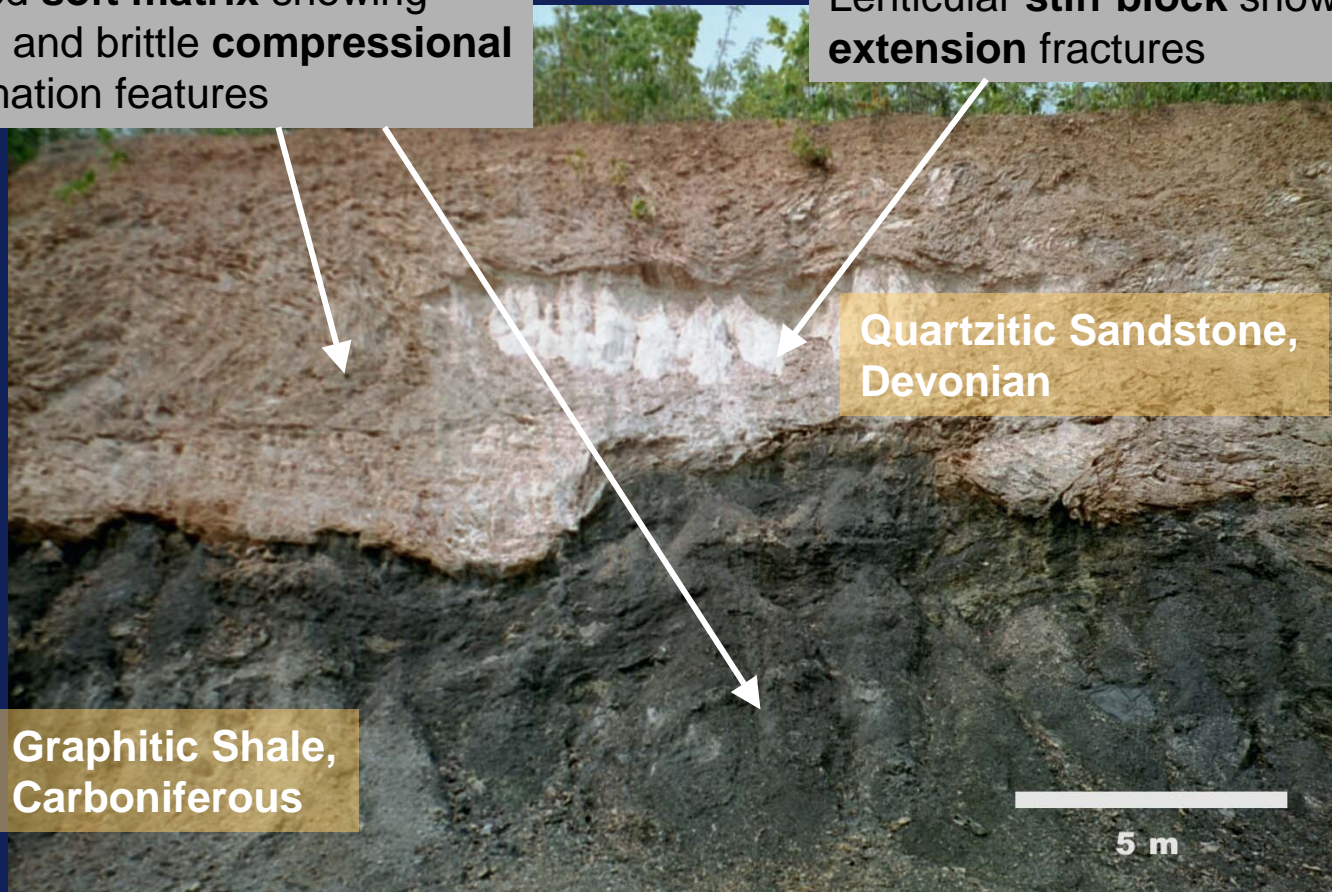
4 cm base

Typical Structure of Ophiolitic Melange in Mesoscale  
Egnatia Motorway, N-Greece

# Fault Structures

Foliated **soft matrix** showing ductile and brittle **compressional** deformation features

Lenticular **stiff block** showing **extension** fractures



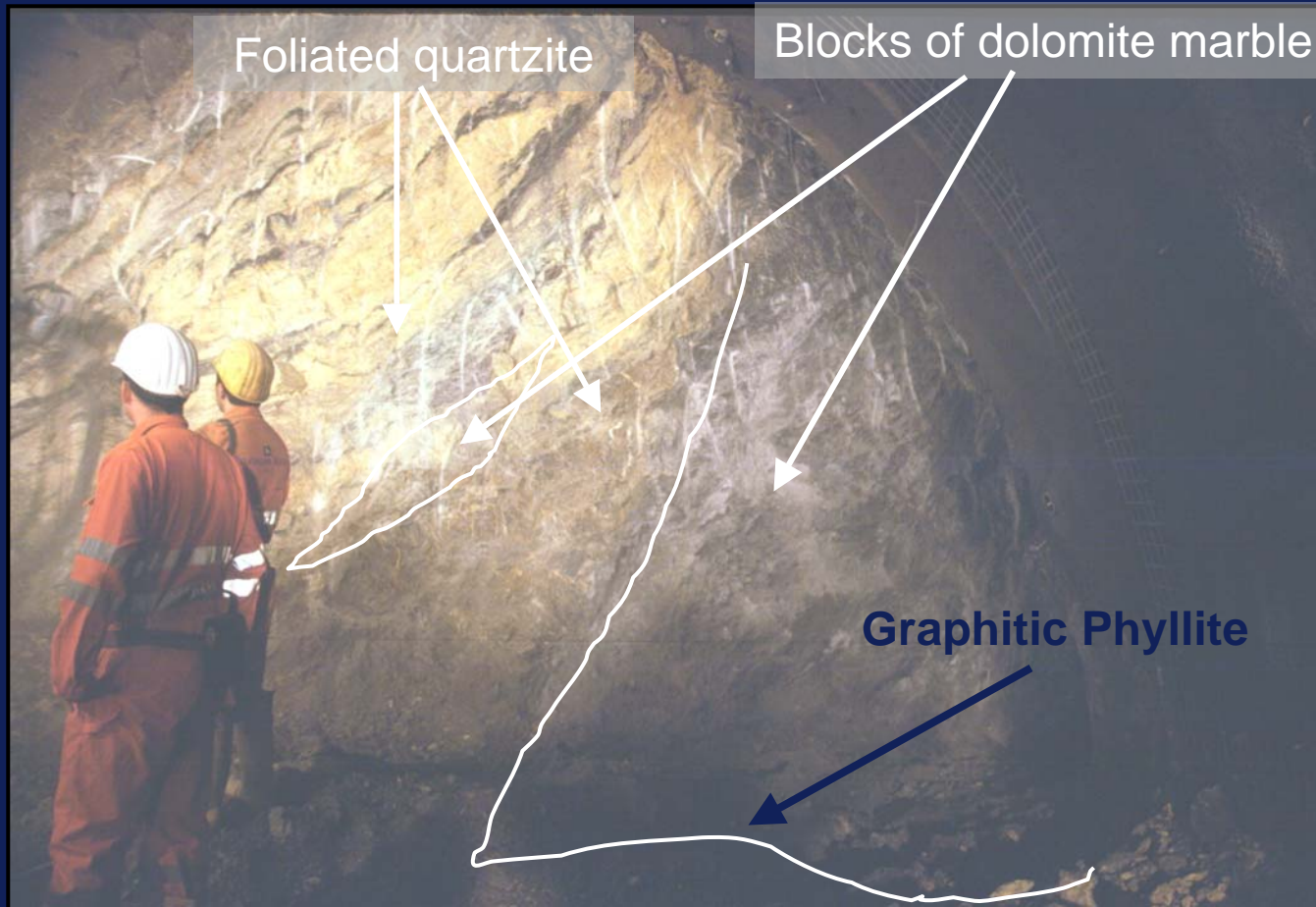
Formation of Melange in an Foreland Basin Overthrust Setting, Main Tunnel, Mae Kuang Irrigation Project, N – Thailand

# Fault Structures



Blocks of Serpentinite in an Ophiolitic Tectonic Melange  
Egnatia Motorway, N- Greece

# Fault Structures



Tectonic Melange in an Alpine Thrust Setting  
Semmering Motorway, Tunnel Steinhaus, Austria

# Fault Structures

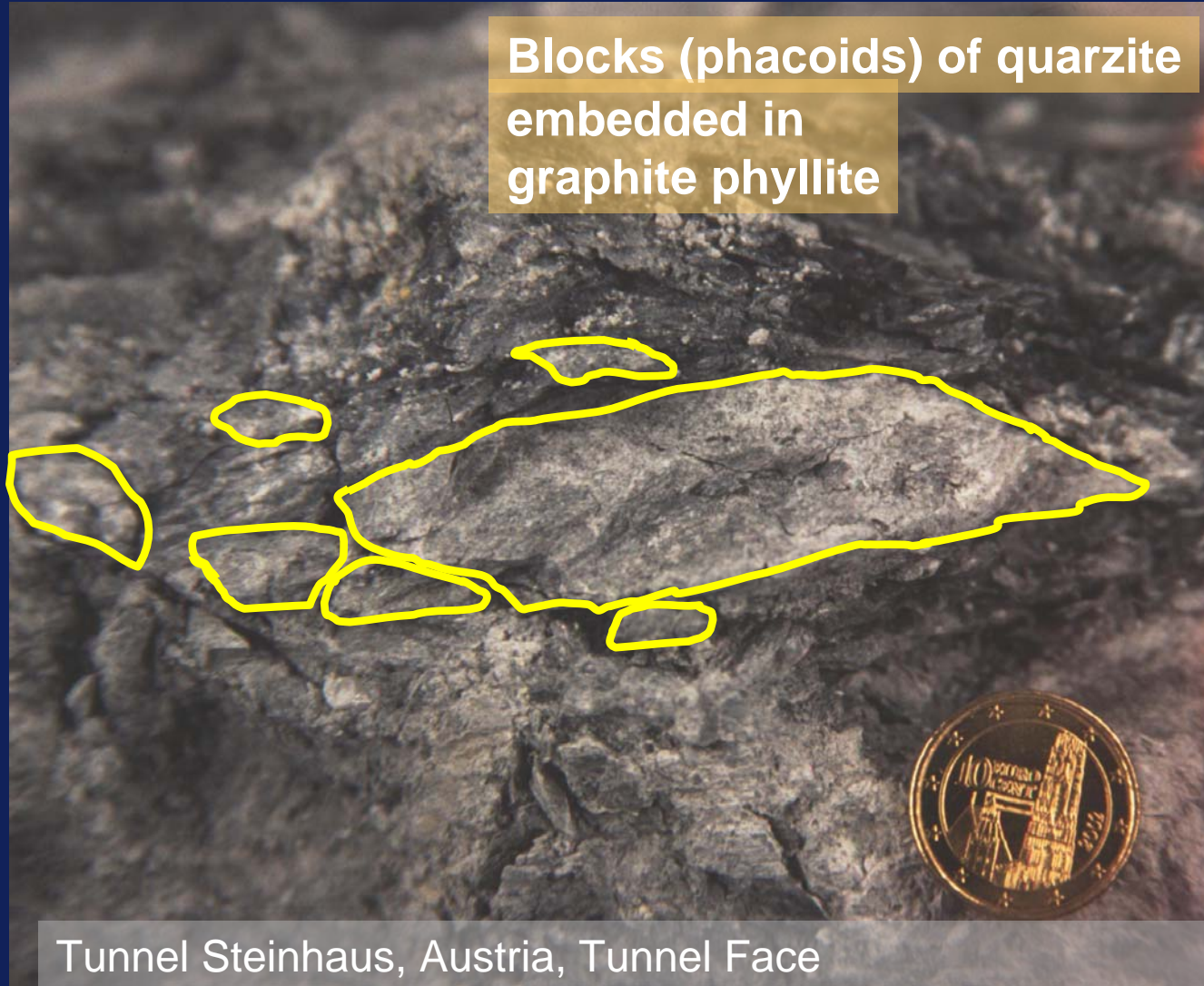
Marble block  
with calcite filled  
extension  
fractures  
embedded in  
graphitic phyllite  
and foliated  
quartzite



Tectonic Melange in an Alpine Thrust Setting  
Semmering Motorway, Tunnel Steinhaus, Austria

# Fault Structures

Blocks (phacoids) of quartzite  
embedded in  
graphite phyllite

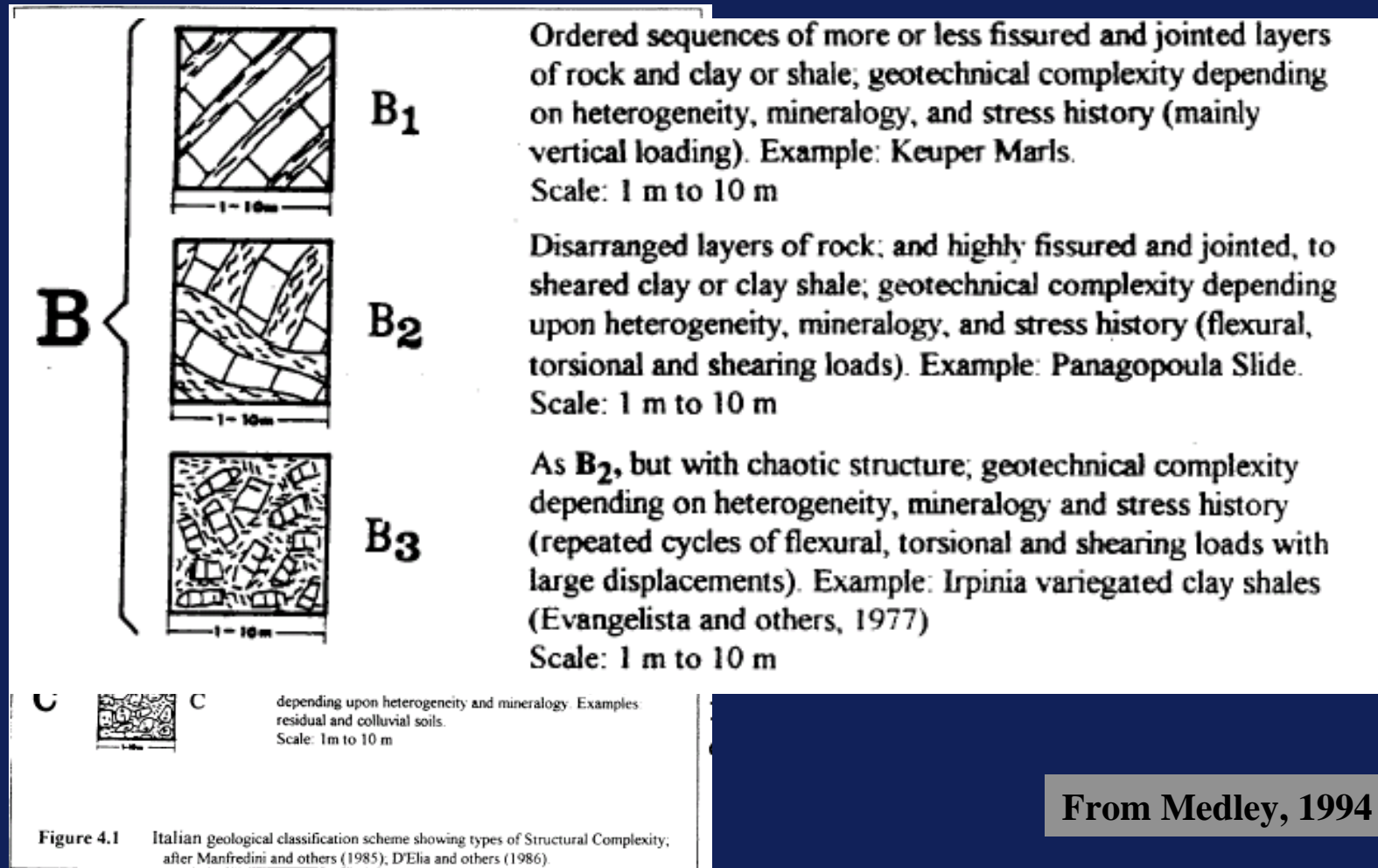


Tunnel Steinhaus, Austria, Tunnel Face

# Fault Classification (Classical References)

- Brekke T.L & T. R. Howard (1973):  
**Functional classification of gouge material from seams and faults in relation to stability problems in underground openings. *U.S.Bureau of Mines Contr. H0220022, pp.195.***
- Zhang Xian-Gong, Han Wen-Feng & Nie De-Yin (1986):  
**Engineering geological classification of fault rocks. *5th Intern. IAEG Congr. Buenos Aires, 479 - 486.***

# An early Geotechnical Classification of Complexity



From Medley, 1994

# ..and > 1000 geological words/terms for fragmented rocks and complex mixtures

intrusion rocks, 558F; intrusive bx, 81, 156, 216\*, 546\*, 547, 576, 580, 581F, 582F, 595, 700, 701F; intrusive bx (mafic dike), 599; lambricate bx, 76\*; impact bx, 65, 698; impact-fused polymict bx, 719F; impact ignimbrite, 721; impact melt bx, 694; iron mixture, 306; isolated fragment bx, 68; isolated fragment rocks, 555; isolated fragments rocks, 707; isolated inclusion granite, 558F; isolated pillow bx, 68, 303, 506\*

J Jaeger bx, 264, 321, 327; Jaegeroid bx, 371, 3; Jigsaw bx, 136\*, 665; Jigsaw puzzle bx, 537; joint, 506\*; Jökulhlaup rubble, 425F; jointed bx, 76\*; joint

K Kankrite, 653\*, 654-5F, 659F; karnite, 695\*; karat flowstone bx, 350; karat rubble bx, 345; karat lambricate bx, 619; knotted bx, 140\*; koptoclastic bx

L Lag breccia, 214, 286; lag boulders, 291; lag c; bx, 416, 419; lag debris bx, 291F; lag gravel, 2; 214; lag rocks, 214; Laminar bx, 23, 40, 91, 498-500, 501F, 502-3F; lake beds bx, 441; landslides, 279, 311, 494; landslide bx from caldera walls, debris, 271; landslide, basaltic, 336; landslide

lapilli pumice bx, 459; lapilli suevite, 695; lapilli lapilli tuff bx, 485, 522; laterite/calcrete bx, relic bx, 418; lateritic rocks, 324-5; laterite f; latite intrusive bx, 585F; lava autobreccia, 459, 481 collapse bx, 417, 424F; lava cooling joints crackle concretion bx, 416; lava crackle bx, 418; lava f; 457; lava flow bx, 485; lava flow front rubble, 421 bx, 481; lava friction bx, 416, 422F; lava inclusion 483; lava lake crust collapse bx, 417; pseudoconglomerate, 418; lava rubble, 232; lava t 426, 507\*; layered bx, 112; lime mylonite limestone/sulphur bioepigenetic bx, 405; lithic frag inclusion bx, 477; lithic lag bx, 113; lithic tuff fragments in granoblastic matrix bx, 596; lodgement 300; lunar bx, 64; lunar bx, 715, 716F, 717F, 719-2 fragmentites, 715-722; lunar soil bx, 71\*

M Macrobreccia, 9; mafic bx dikes, 603; mafic blo 9, 80\*; marble matrix bx, 625; marl-flaser 599F; matrix-free bx, 362; matrix-supported chaotic bx, 338; magmatic-supported (lunar), 716, 717F; megabreccia, 9, 41\*, 119\*-124F, 469, 479, 596, 604, 667, 675, 692, 696, 673, 700; 82, 217, 678\*; melt-cemented impact bx, 695; n bx, 694; melt-matrix bx, 703; melt-veined bx, 5 debris, 291; mesobreccia, 26, 479, 512, 678; metamorphic cement-filled net-veined bx, 651; me 616; metasomatized tectonite bx, 710; meteorite bx impact wall slide bx, 194; microbreccia, 9, 41, 232, 244, 716; microbreccia, tectonic, 671; mica 248, 249F; milled agglomerate, 619; milled bx, fault bx, 642F; millrock bx, 310-11F; mineralize bx, 80\*, 104\*; mixed bx (impact), 693; mixed debris mixed expanded bx, 137F; Mn-cemented lithic tuff b cemented rhyolitic bx, 475; monobreccia, 80\*; monolithologic bx, 9, 80\*, 165, 245; monocyclic 10, 136\*, 139F, 570F; mosaic microbreccia, 268-3F; mottled 161F\*, 163, 607; mudstone bx, 229; mud-supported carbonate bx, 3 mud volcano flow bx, 382; multistage bx, 108, 664-5F; mylonite 64.

N Nappe bx, 371; nappe sole bx, 674; nebulous bx, 162F\*, 11 nebulous rocks, 558; negative bx, 53\*, 54, 36F, 57, 3; net-veined bx, 10, 61, 136\*, 151\*, 622, 648, 678, 688; net-veiled carbonate bx, 617, 621; net-veined fanitic bx, 611; net-veiled intrusion bx, 563F; net-veined mafic bx, 601; net-veined matrix or 667F; net-veined sulphide bx, 603; network-veined bx, 558F.

O Obsidian bx, 466, 469; obsidian flow bx, 472F; obduction mélang

debris, 271; landslide hematitic bx, 326; landslide megabx, 193; lapilli pumice bx, 459; lapilli suevite, 695; lapillistone, 66, 522; lapilli tuff bx, 485, 522; laterite/calcrete bx, 319F; laterite relic bx, 418; lateritic rocks, 324-5; latite flow sole bx, 491; latite intrusive bx, 585F; lava autobreccia, 459, 481; lava channel collapse bx, 417, 424F; lava cooling joints crackle bx, 422F; lava contraction bx, 416; lava crackle bx, 416; lava flow autobreccia, 457; lava flow bx, 485; lava flow front rubble, 422F; lava flowtop bx, 481; lava friction bx, 416, 422F; lava inclusion bx, 459, 481, 485; lava lake crust collapse bx, 417, 422F; lava pseudoconglomerate, 416; lava rubble, 232; lava tube collapse bx, 426, 507\*; layered bx, 112; lime mylonite bx, 647; limestone/sulphur bioepigenetic bx, 405; lithic fragments supported inclusion bx, 477; lithic lag bx, 113; lithic tuff bx, 482; local fragments in granoblastic matrix bx, 596; lodgement till, 203, 290, 300; lunar bx, 64; lunar bx, 715, 716F, 717F, 719-21F, 722F; lunar fragmentites, 715-722; lunar soil bx, 71\*.

M Macrobreccia, 9; mafic bx dikes, 603; mafic block tectonite bx, 9, 80\*; marble matrix bx, 625; marl-flaser bx, 34 martite-magnetite stockwork bx, 491; massive sulphide bx, 594, 599F; matrix-free bx, 362; matrix-supported chaotic bx, 338; magmatic-supported (lunar), 716, 717F; megabreccia, 9, 41\*, 119\*-124F, T, 279, 339, 469, 479, 596, 604, 667, 675, 692, 696, 673, 700; mélange, 18, 21

Laznicka, 1988

# Melanges and Similar Bimrocks

- **Melanges: (French *mélange*) :**  
**UNCHILE** mixtures of competent blocks composed of sedimentary/ metamorphic blocks in weaker matrix of sheared shale or serpentinite
- **Bimrocks: block-in-matrix rocks**
  - mixtures of rocks composed of geotechnically significant blocks within a bonded matrix of finer texture
- **Similar Bimrocks:** Saprolites, Breccias, Fault Zones, Lahars, Tillites, etc.

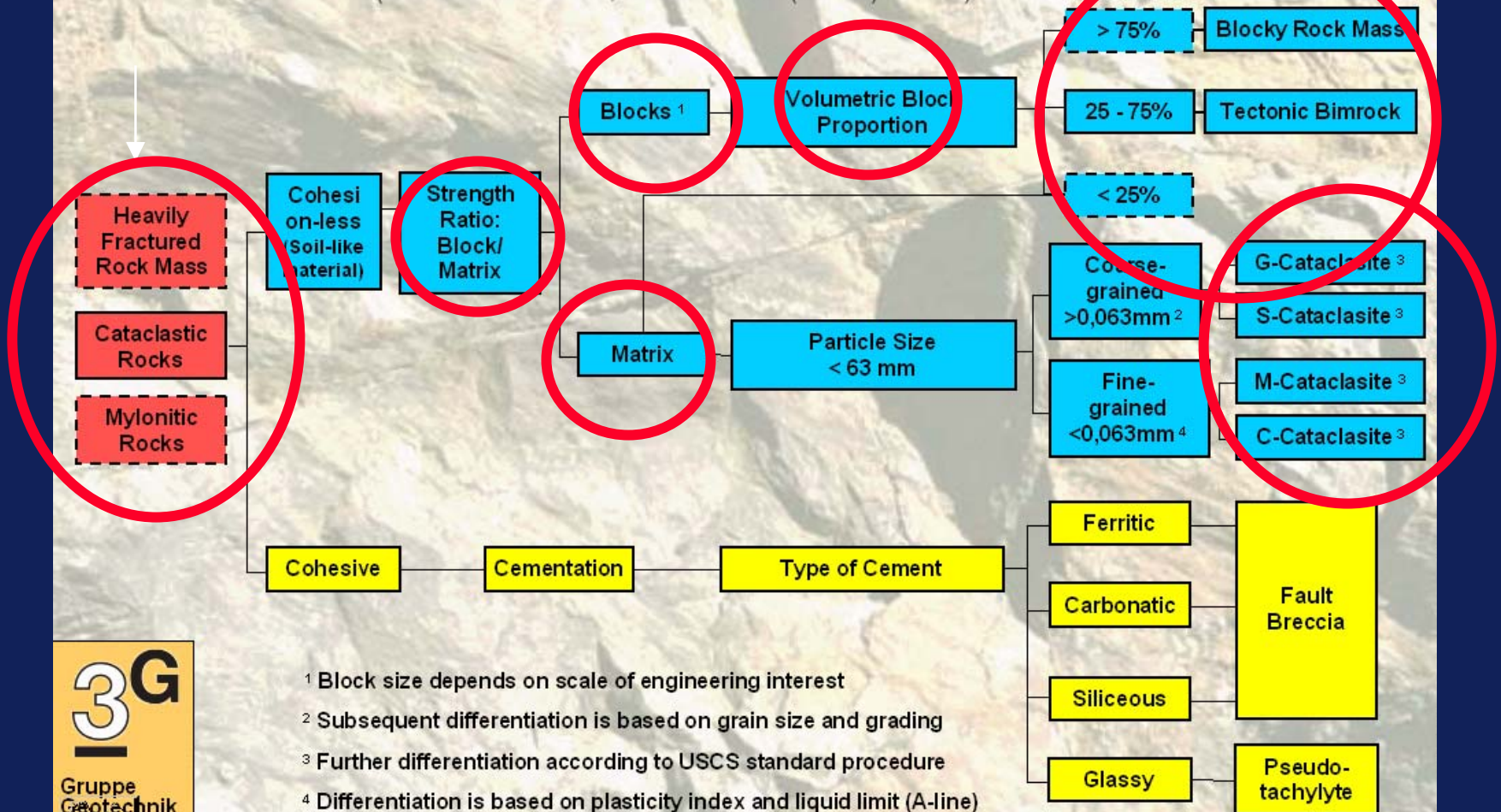
**Trying to organize the complexity....**

# **Classification of Fault rocks and melanges**

**by Riedmueller et al (2001)**

# Classification

## Engineering Geological Classification of Fault Rocks (Riedmüller et al., Felsbau 19 (2001) No. 4)



- 1 Block size depends on scale of engineering interest
- 2 Subsequent differentiation is based on grain size and grading
- 3 Further differentiation according to USCS standard procedure
- 4 Differentiation is based on plasticity index and liquid limit (A-line)

# **Problem\$\$\$\$ with bimrocks**

- **Often severe spatial variability**
- **Heterogeneity in properties**
- **Design and construction shortcomings in characterizations cost someone \$\$\$\$\$, (usually the Owner and/or Contractor)**

**So, YES: bimrocks ARE chaotic...**

**But Practitioners should NOT say:**

**“those rocks are too chaotic, let’s design for the weak matrix...”**

**So What? Who Cares\*?**

**\*Answer: Owners, Contractors and Lawyers**

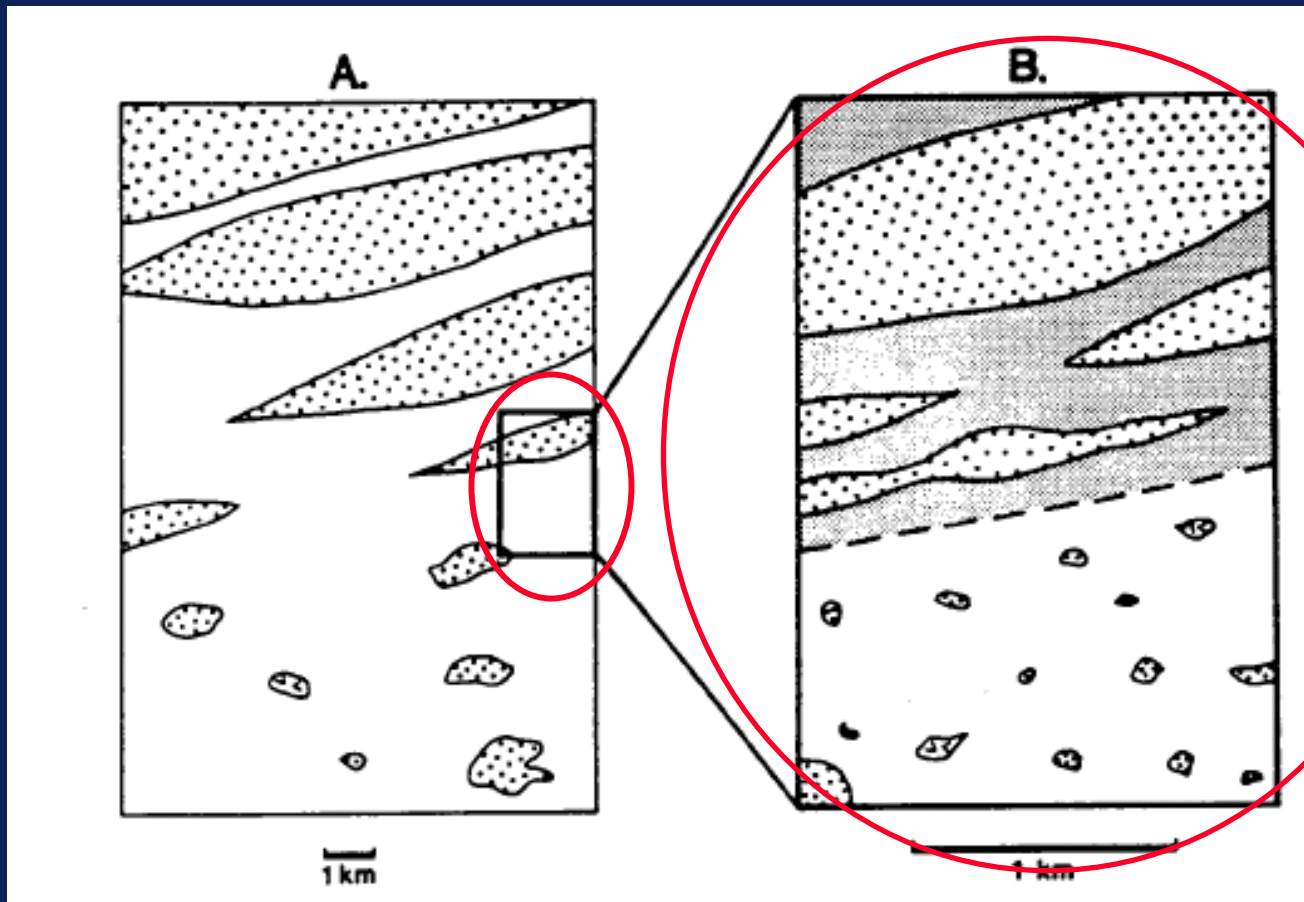
# Some elements of CHARACTERIZATION

- **Block/matrix discrimination** Matrix lithology,
- **block lithology, block size, block shape,**
- **block orientation**
- **Block size distribution**
- **Block discontinuities**
- **Etc...**

**ALL are straight forward geological engineering during field investigation...**

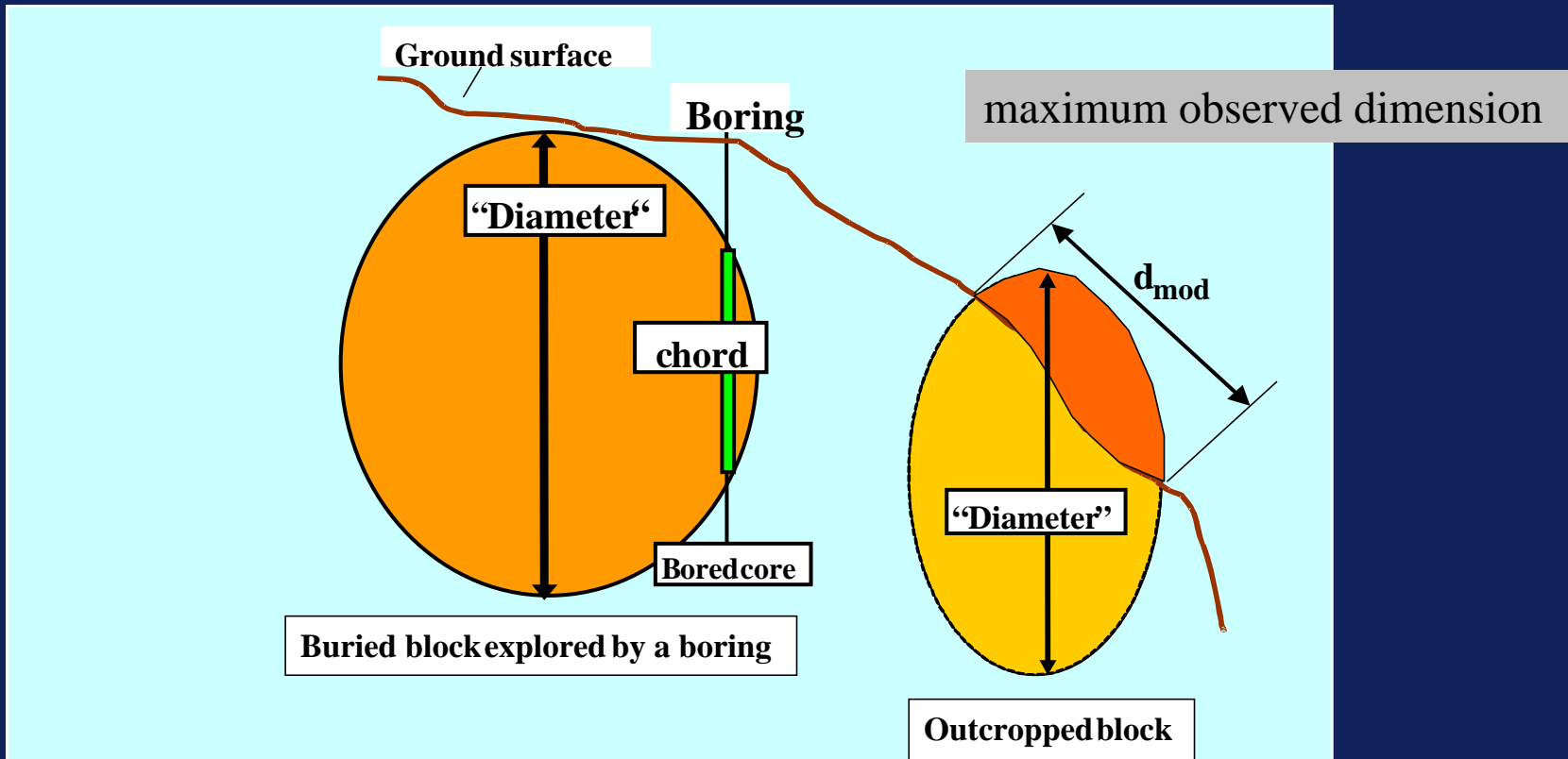
**the importance of scale  
independence in our work  
with bimrocks**

# Scale independence

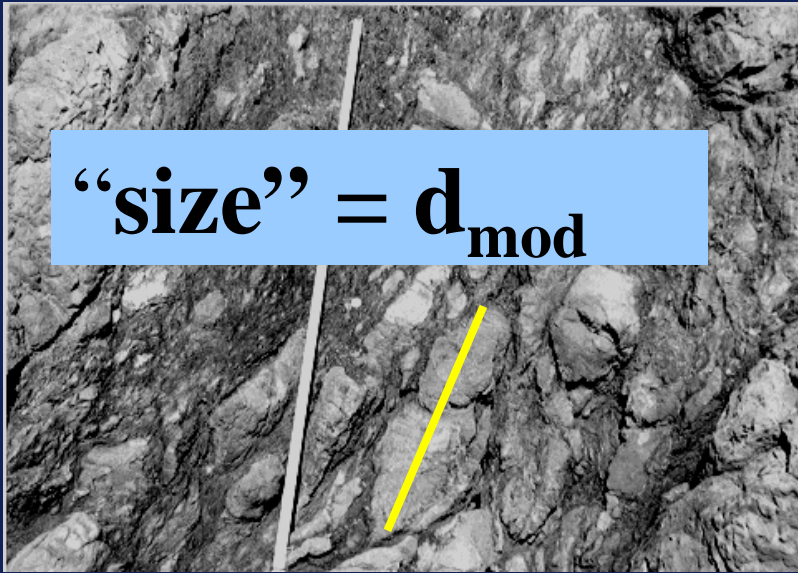


Cowan, 1985

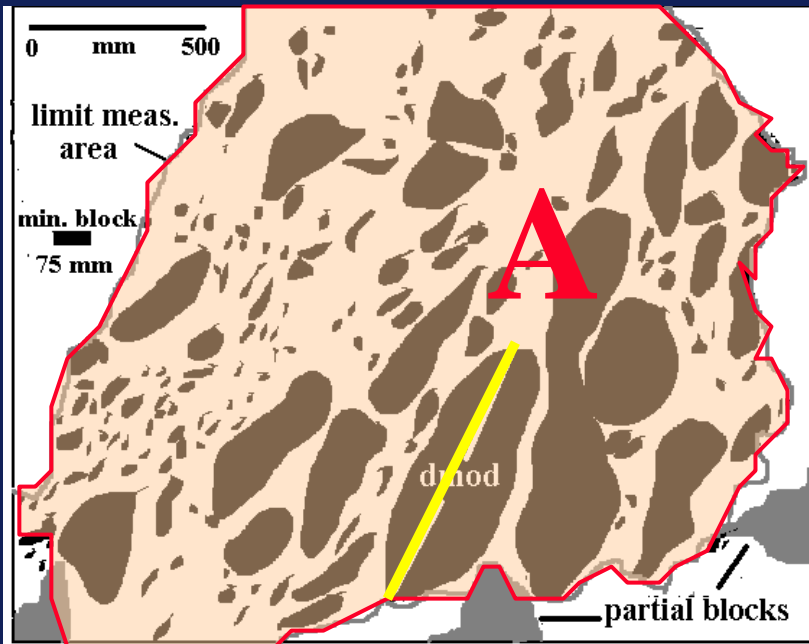
# Q: What is Block Size??



**A: Rarely the "diameter"**



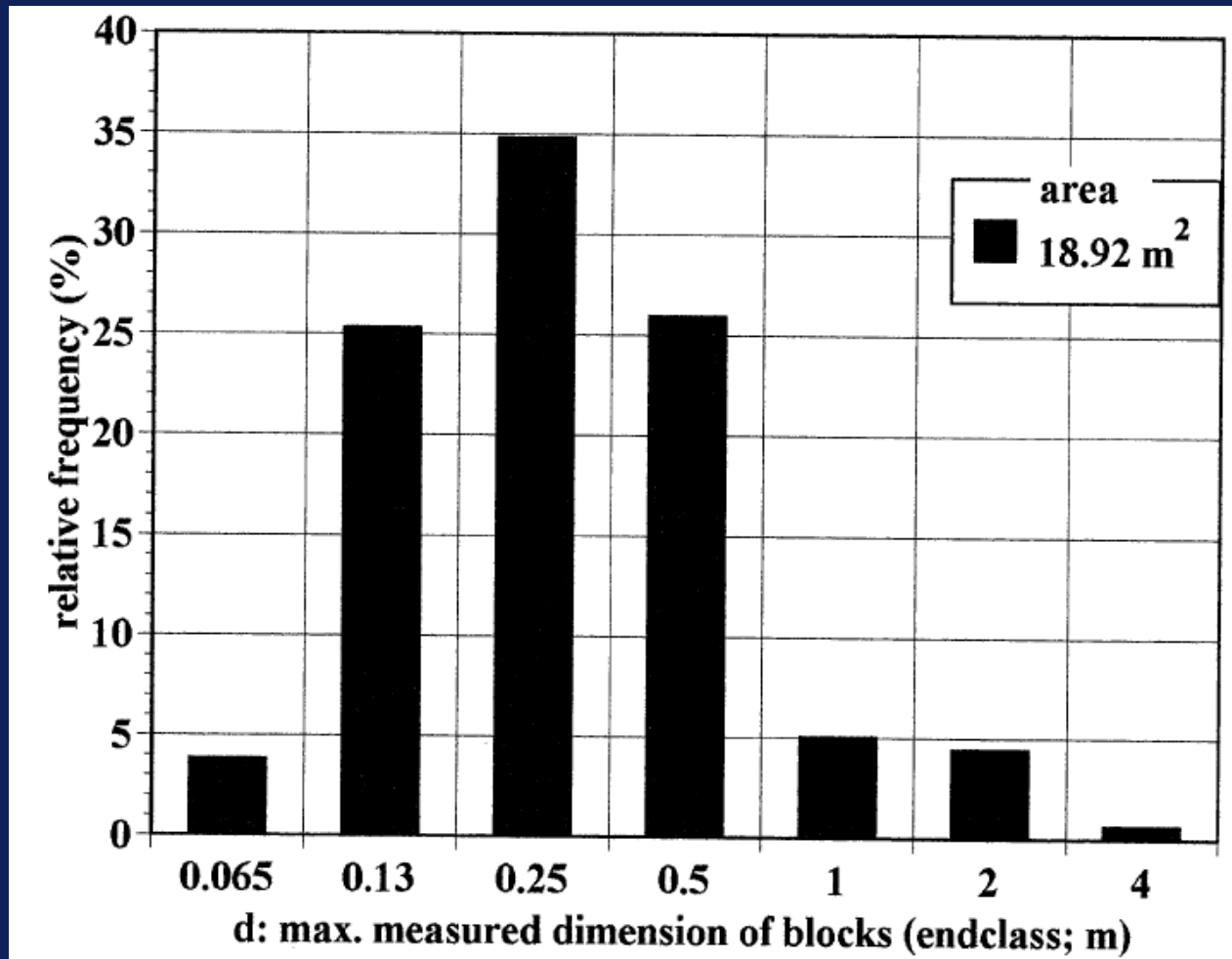
Measuring block sizes  
(and size distributions)  
in 2-dimensions



Outcrop scale of interest

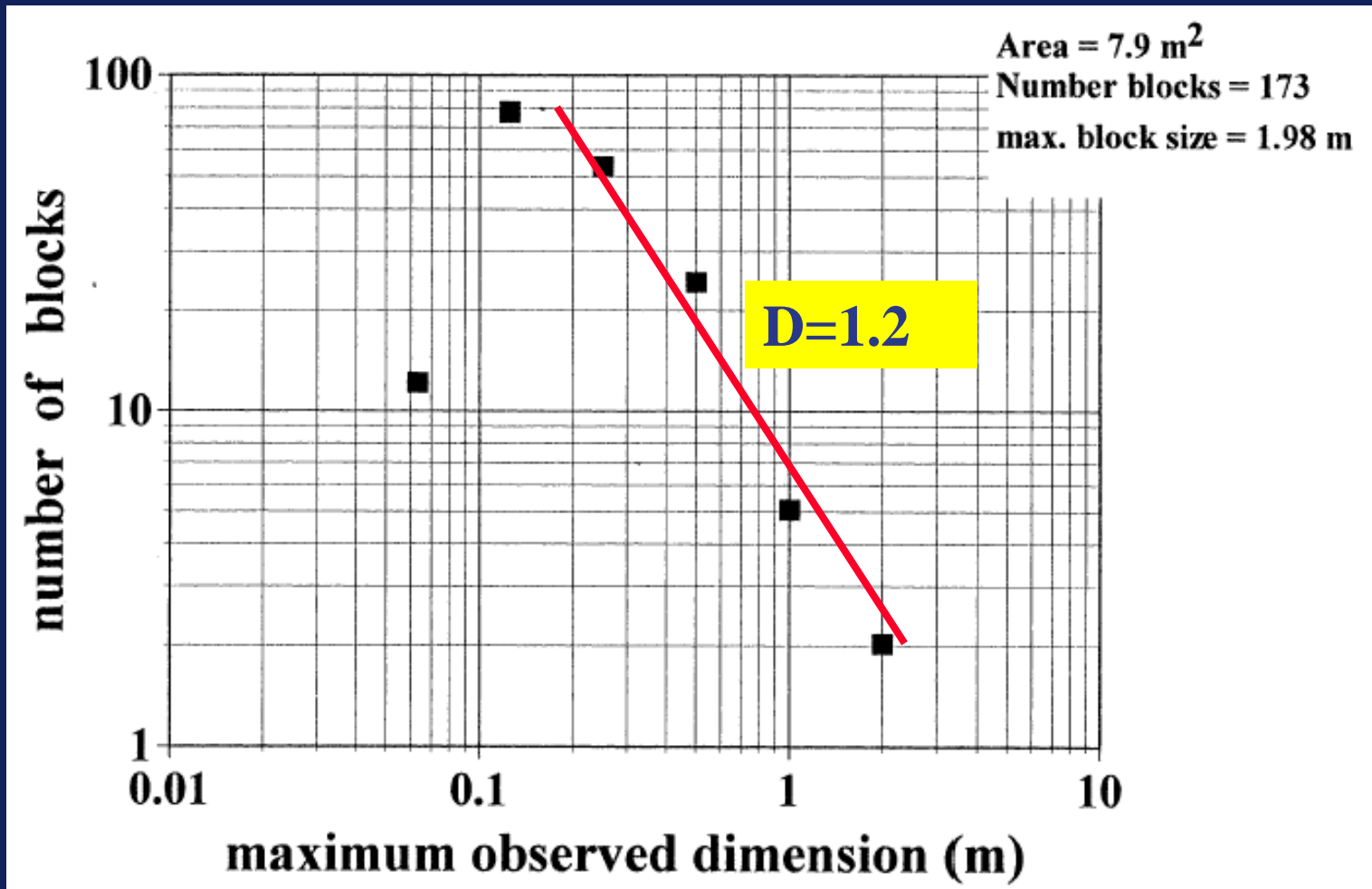
$$A < 1 \text{ m}^2$$

# Histogram of block sizes

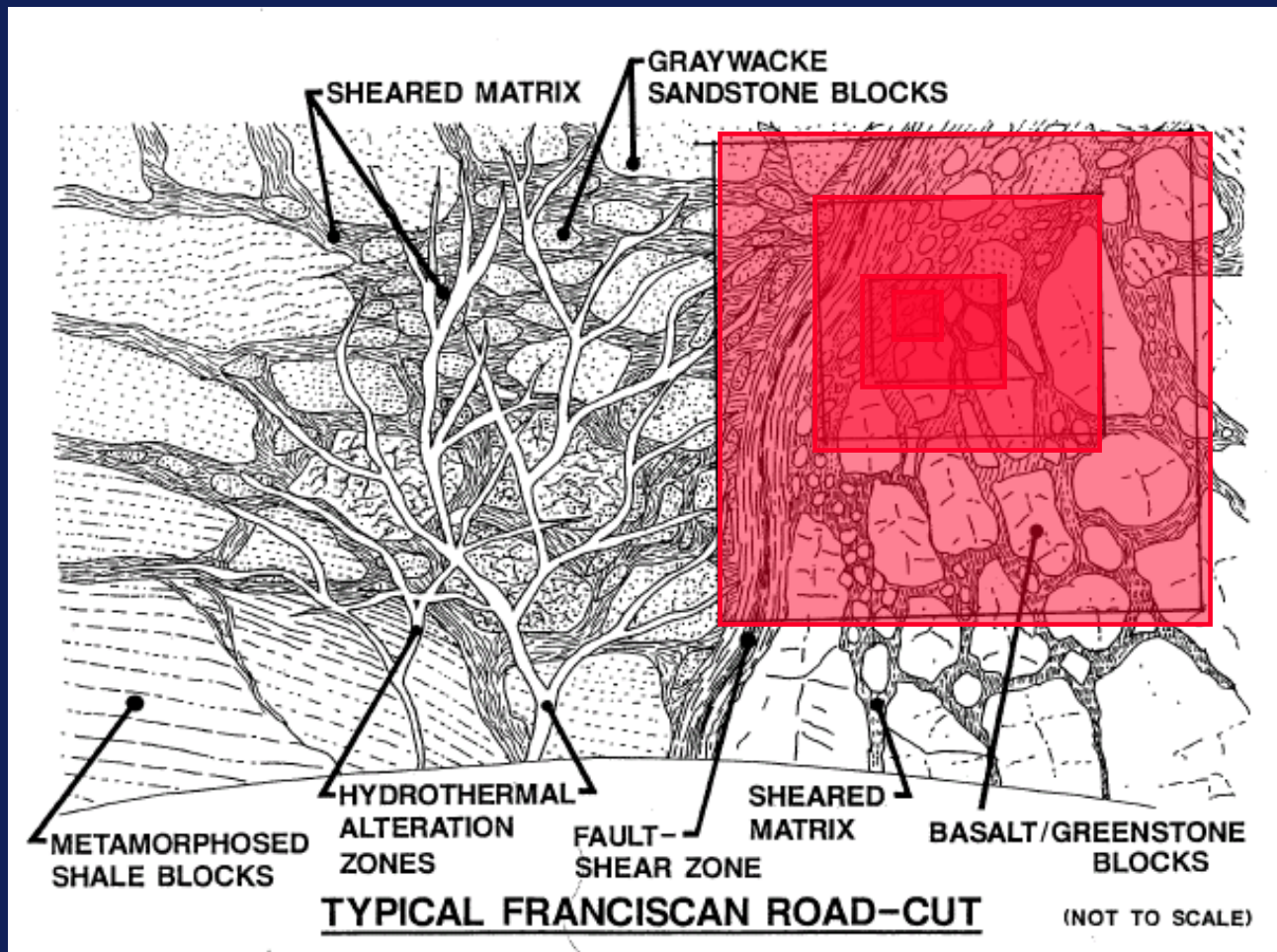


Medley,  
1994

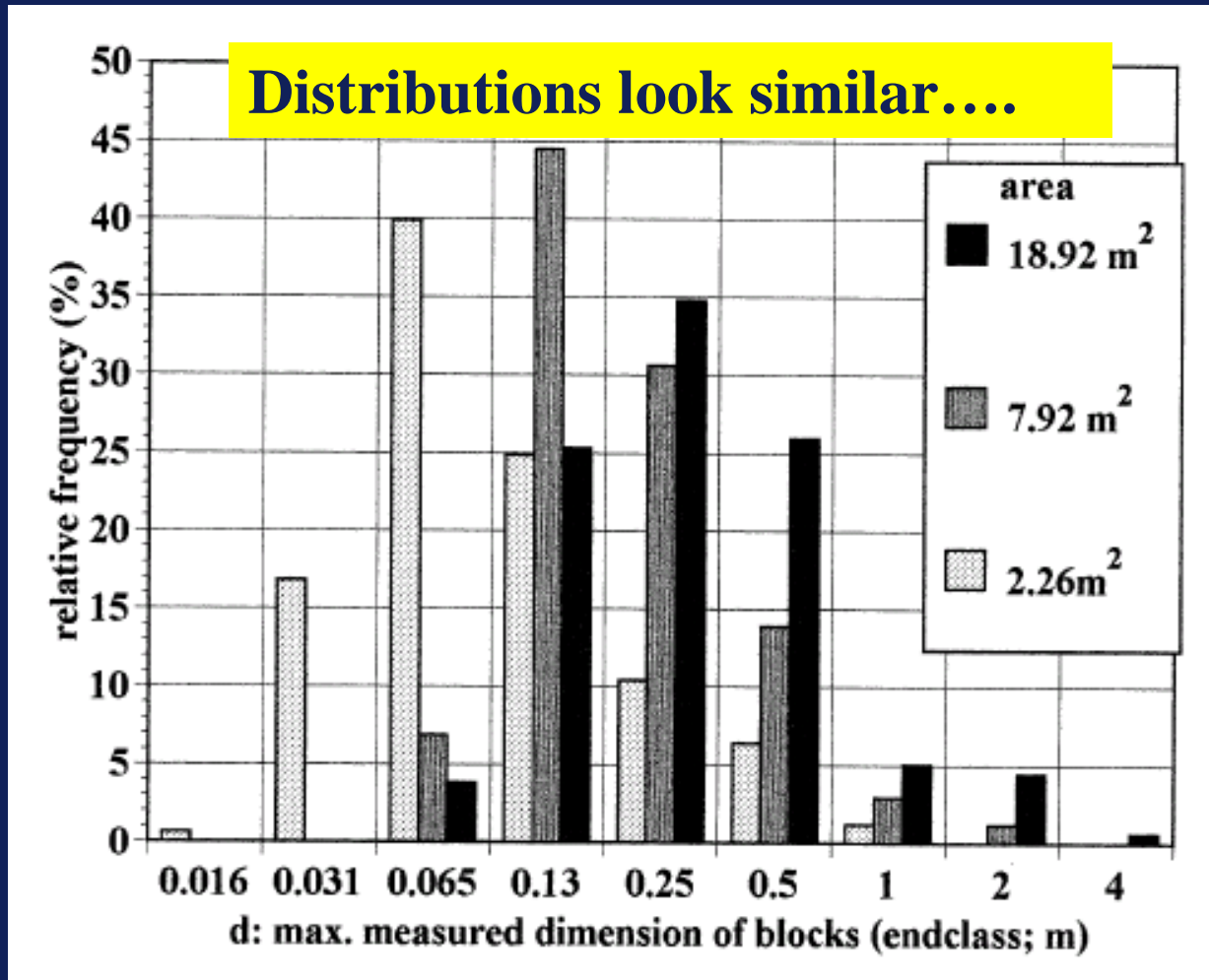
# Log Histogram of block sizes



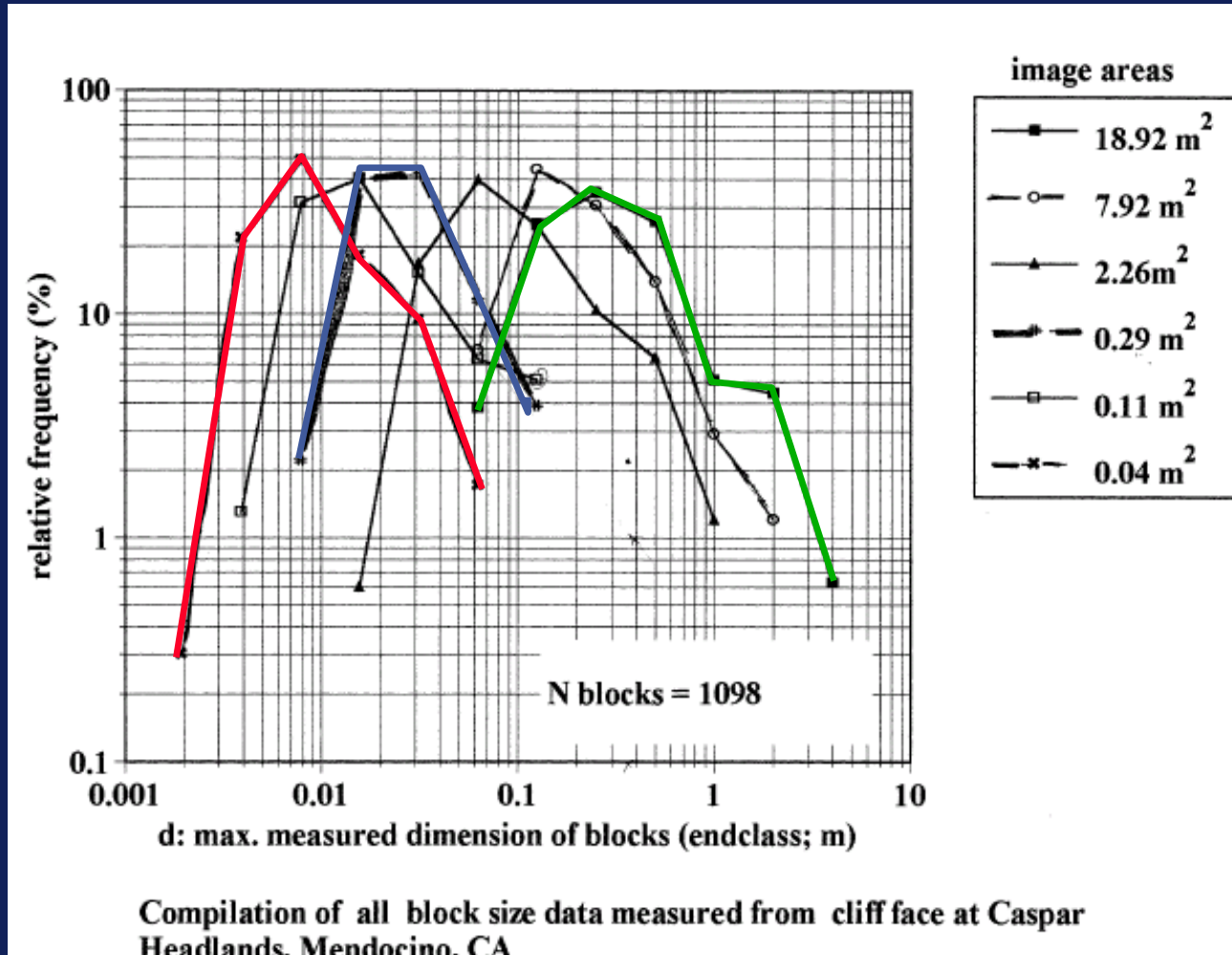
# Block measurements at many scales



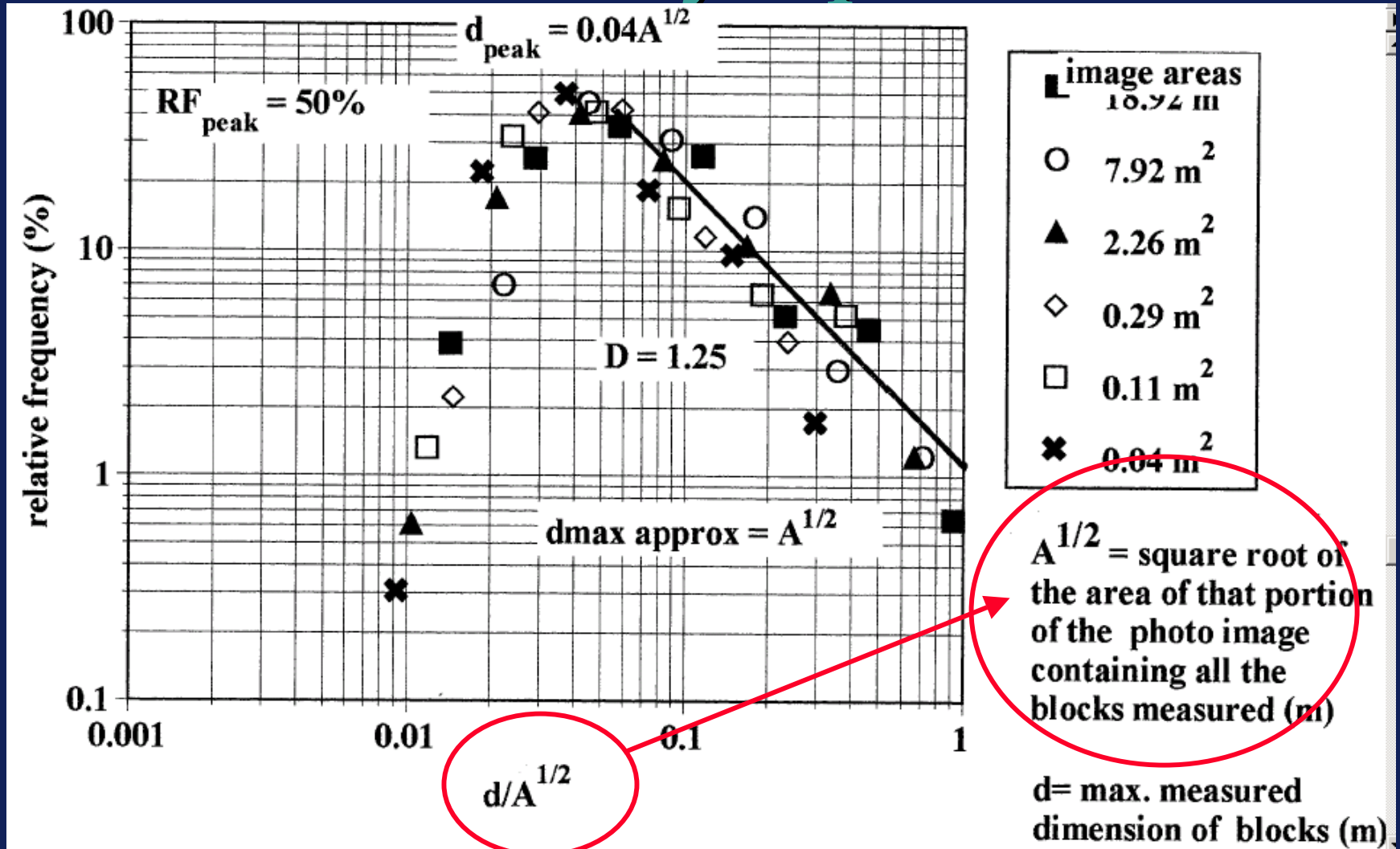
# Histograms at several scales



# Log Histograms at several scales

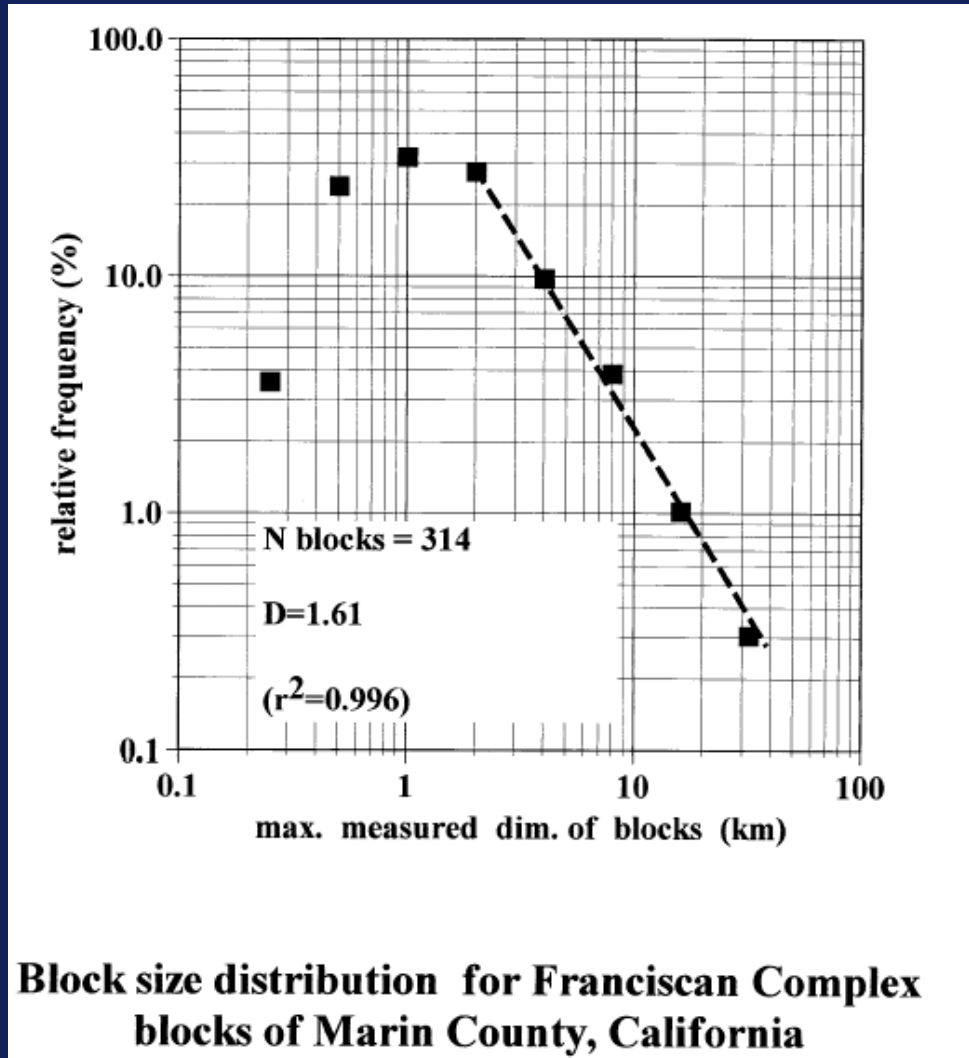


# Normalization by Square Root A

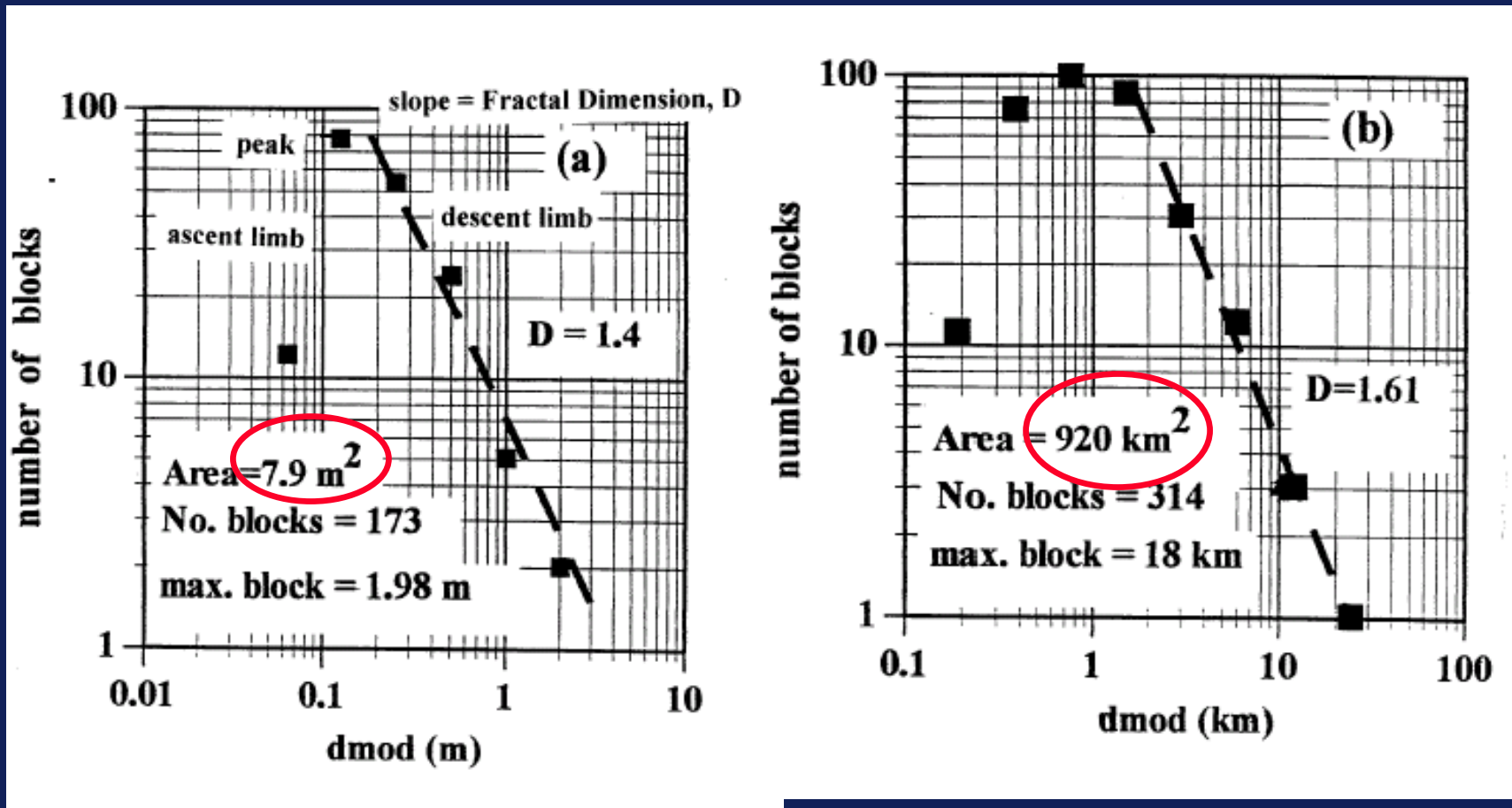




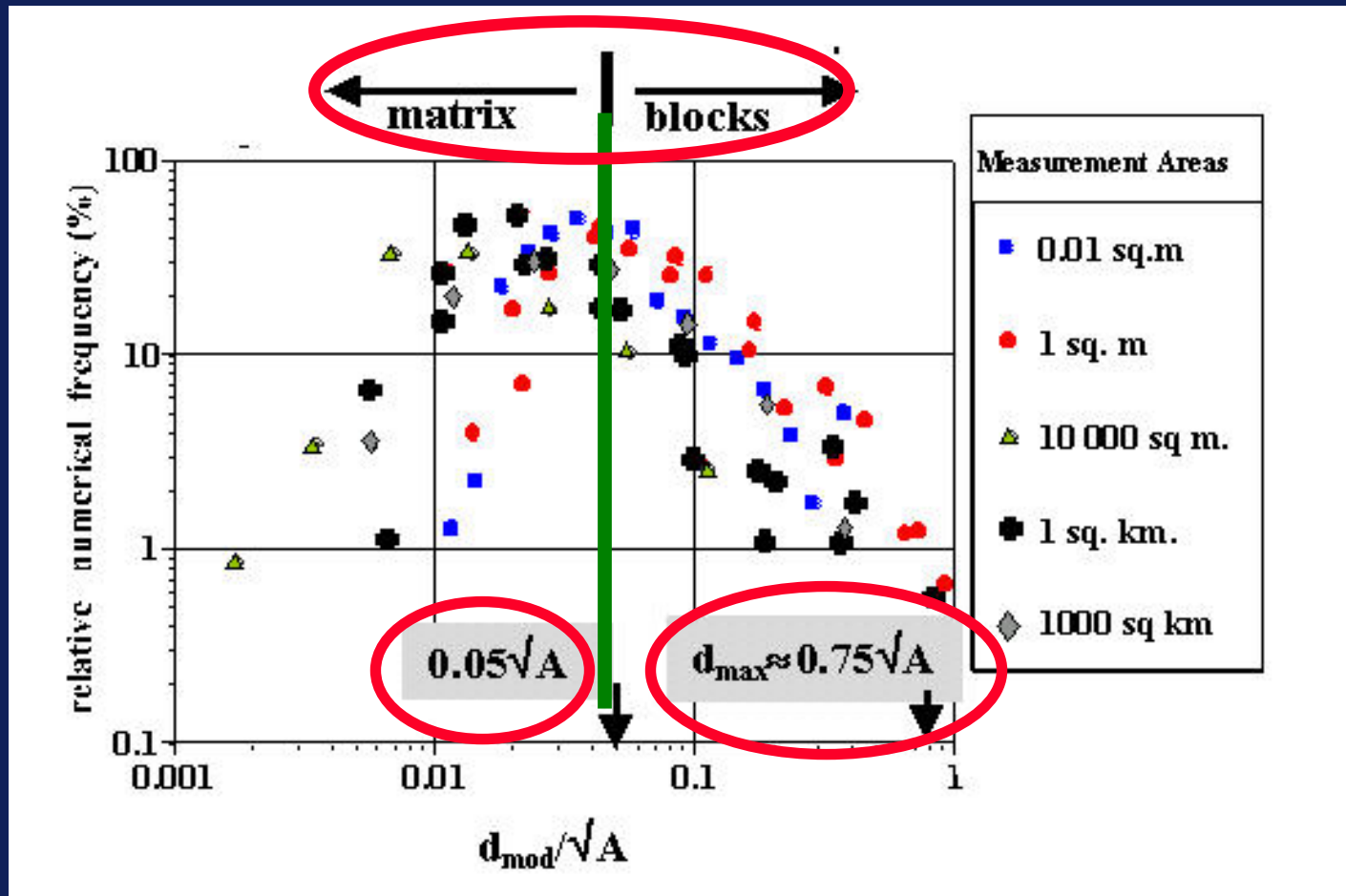
# Log Histogram at km scale



# Compare Log histograms at different scales



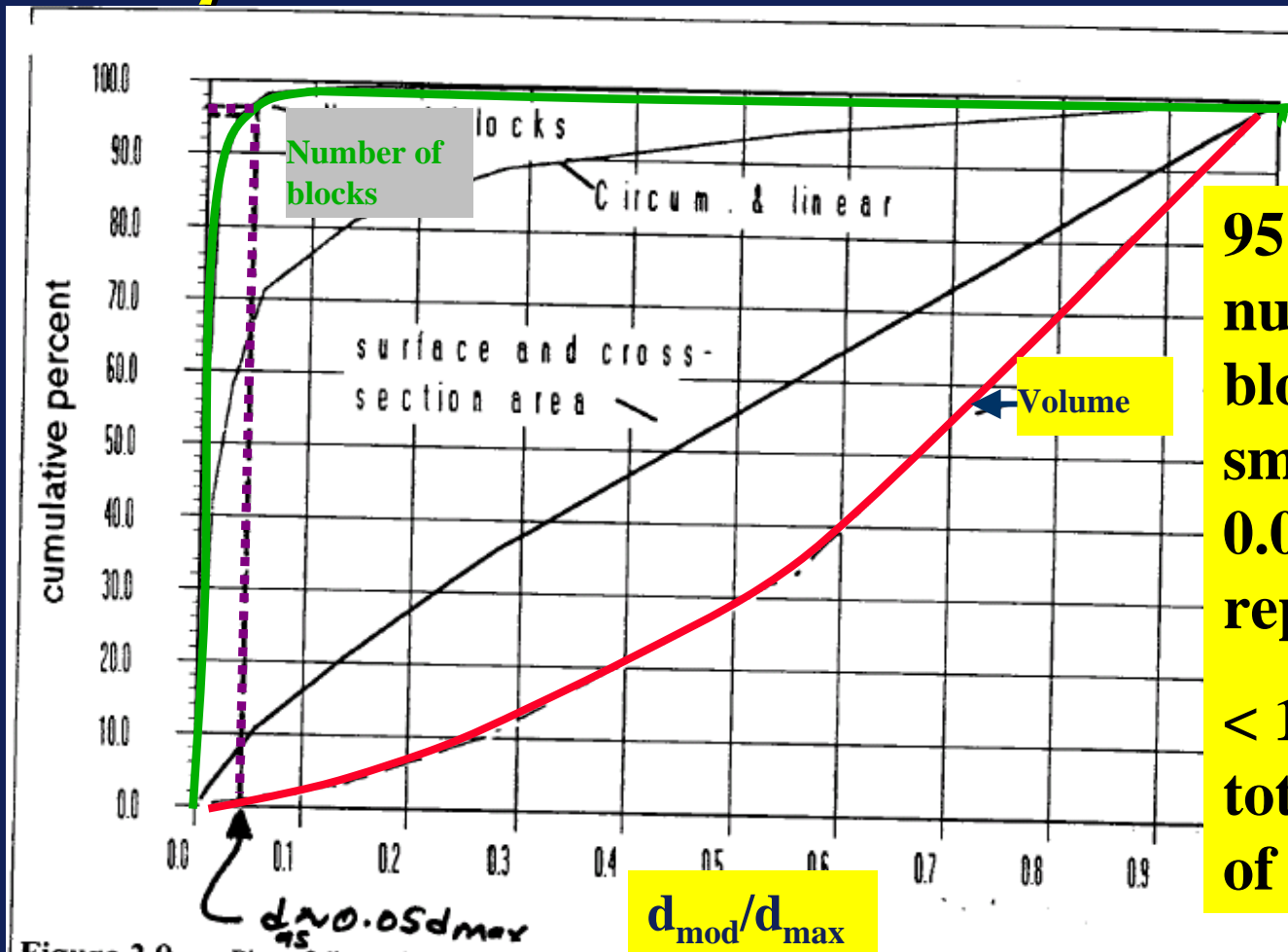
# Scale-independent block size distributions of Franciscan melanges



Plotted as a Log-Histogram

Medley, 1994

# Another reason to select the 5% block/matrix threshold



**95% of number of blocks are smaller than  $0.05d_{max}$  but represent < 1% of total volume of blocks**

# Blocks in Franciscan Melange

- Blocks range in size between mountains and sand and will **always be found**
- Block size distributions are scale independent **and** fractal (**power law**)
- Largest reasonable block is:

$$0.75\sqrt{A} \quad \text{aka} \quad d_{\max}$$

- Block/matrix threshold is  $0.05\sqrt{A}$
- Characterization **must** take blocks into account

**AND: findings from studies of  
many bimrocks at small scale  
ARE  
relevant for large scale bimrock masses!!!**

Use these guidelines at any scale of interest

- **smallest blocks are:**

$$0.05L_c \text{ or } 0.05 \sqrt{A} \text{ or } 0.05d_{\max}$$

- **largest block is:**

$$0.75L_c \text{ or } 0.75 \sqrt{A} \text{ or } 0.75d_{\max}$$

**We look at other aspects of  
Characterization in the other Lectures....**