Simple Concepts Useful for Characterizing Complex Bimrocks Underlying Slopes

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Landslide and Slope Stability Short Course
AEG-IE/ASCE-IE
UC Riverside Extension Center, Riverside, CA
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Medley

Geopractioner for 30+ years
Licensed Geologist/Engineer in US, Canada, UK

Education:
- Geological Engineering (UBC 1978)
- Geotechnical Engineering (UC Berkeley 1991, 1994)

Investigate geo-failures
Specialize in bimrocks
By the End of this Lecture, I Hope:

You will appreciate better that there is an ubiquitous geological fabric of strong blocks surrounded by weak matrix

You will think twice before drawing straight lines between boring contacts on your cross sections

You will not always “design for the weaker soil component” when working with “rock/soil mixtures”

You will test lab specimens with included rock fragments when appropriate

You will be inspired to develop scarier “What If?” scenarios

You will consider that Contractors will have to construct your simple designs in complex geology

You will forever remember the most important Conclusions of this Lecture…
BIG CONCLUSION 1
Remember this picture!

Matrix

Blocks, inclusions, lenses, etc

Scale: 1:??????

Actual Distribution of Blocks

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Medley, 2000
BIG CONCLUSION 2: Remember this picture as well…

Apparent Distribution of Blocks

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Willis, 2000
Bimrocks (and bimsoils)

Think of Rock/Soil mixtures

Nothing to do with BIM (Building Information Modeling)

Term “bimrocks” intended to focus geopractitioner focus on working with geological complexity regardless of geological terms/origins

Bimrocks definition: block-in-matrix rocks - mixtures of rocks composed of geotechnically significant blocks within a bonded matrix of finer texture (melanges, fault rocks, weathered rocks, etc.)

Geotechnical significance means that there is mechanical contrast between blocks and matrix, and the geometry and proportion of the blocks influence the properties of a rock/soil mass underlying a slope, at the scales of engineering interest (centimeters to hundreds of meters) i.e.: scale matters!

Bimsoils are analogous to bimrocks but without bonded matrix (debris flow deposits, glacial tills, colluvium, etc. - depends on scale of interest)

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A bimsoil: coarse alluvium (BUT: scale matters!)

HARD cobbles and boulders: troublesome to work with? Depends on excavation method

Scale matters! This is a bimsoil at lab scale; possibly for a scraper (but not a D-10); possibly for micro-tunnel (and maybe a TBM)

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Weathered rock: Bimsoil?

Residual soil not likely a bimsoil; but highly to moderately rock could be a bimrock/bimsoil (depends on state of matrix)

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Decomposed Granite - a weathered rock bimrock

Mixture of weaker matrix (very strong soil) and strong blocks: decomposed granite at Hwy 50, California blocks **definitely awkward** if unexpected during excavation.

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Fault Rocks and Shear Rocks

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

Riedmueller et al, 2001

Block size distributions tend to be scale-independent
Franciscan Complex blocks in Marin County

scale of interest: Regional area of ~ 1000 km²

From Medley, 1994; after Ellen and Wentworth, 1995
Faulted and Sheared Rock

Mixture of sheared rock and intact blocks at a Quarry within San Andreas Fault zone – not your typical soil slope

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Melanges (mélanges)

*melanges*: geological mixtures with poly-lithologic blocks ranging in size from sand to mountains

Gwna Melange, Tryn-y-moel, Lleyn Peninsula, Wales

Franciscan Complex melange, Caspar Headland, near Mendocino, California

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Global distribution of melanges

Medley, 1994
Obvious(?) Melange: Limestone blocks in sheared shale at proposed Highway cut slope

Egnatia Motorway, Greece  Photo by Prof. Gunter Riedmueller

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Obvious(?) clue to Franciscan melange

This block was once buried, before weak matrix was eroded from around it. It could be shallow rooted.

Imagine this was buried and you drilled 10 feet into “bedrock”.

Could that characterization lead to problems?

Patriotic “knocker”, Marin Co., CA

E. Medley
Subtle geomorphic clues to melanges
a Franciscan Complex melange: blocks at many scales

Huge blocks, big blocks, small blocks, tiny blocks – all depends on your scale of interest
A Franciscan Complex melange: outcrop scale
weak block/matrix contacts
Matrix and blocks in core

matrix-rich core - sheared shale: (aka argille scaglieose)

Intercept of block and core (not the “diameter!”)

Scott Dam melange  (California)  

photos: Prof. R. Goodman

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So: block-in-matrix fabric is common

Summarizing so far:

Bimrocks include: melanges, fault rocks, weathered rocks, etc.

Bimsoils, analogous to bimrocks but without bonded matrix (debris flow deposits, glacial tills, colluvium, etc. - depends on scale of interest

Bimrocks/bimsoils often have severe spatial variability and mechanical/lithological heterogeneity- depends on scale of interest!

Mischaracterizations of bimrocks co$t - so important to Contractors, Owners and Attorneys

Geopractitioners must consider blocks (lithology, shape, SIZE etc..)
Q: What is block size?  
A: Rarely the “diameter”

- Bored core
- Maximum observed dimension
- Ground surface
- Boring
- “Diameter”
- Chord
- Buried block explored by a boring
- Outcropped block

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Some more block characteristics

In Franciscan melanges, blocks range in size between mountains and sand. (In other bimrocks size range will be more limited).

Blocks will always be found in bimrocks - so, characterization must take blocks into account.

In melanges (and many other bimrocks): block size distributions are scale independent – they look much the same regardless of scale – one or two large blocks, and increasing numbers of smaller blocks.

Scale matters! Need a characteristic dimension ($L_c$) to scale the bimrock mass to the scale of engineering interest (like having coin, penknife, Significant Other/Graduate Student in field photos))

$L_c$ is lab specimen diameter, height of slope, width of footing, etc.
Scale-independent block size distributions of Franciscan melanges

Plotted as a Log-Histogram

Medley, 1994
Use these guidelines at *any scale of interest*

smallest blocks (at block/matrix threshold): \(0.05L_c\)

largest block(s) at (block/blocky rock) threshold: \(0.75L_c\)

**Remember:** \(L_c\) is a characteristic dimension to scale the bimrock mass to the scale of engineering interest; such as lab specimen diameter, height of a slope, width of footing, etc.

(Medley and Lindquist, 1995)
When is a block not a block? **Depends on scale of interest**

For a large area, A:
- use $L_c = \sqrt{A}$ (100m)
- Smallest block = 5 m
- Largest block = 75 m

At scale of trench
- $L_c \approx 2$ m (trench width)
- Smallest block = 0.1 m
- Largest block = 1.5 m

At scale of width of Rt. of Way (for day to day progress)
- $L_c = 20$ m (ROW width)
- Smallest block = 1 m
- Largest block = 15 m

For construction estimates of whole trench use $\sqrt{\text{Area of trench}}$ (45 m)
- Smallest block = 2.2 m
- Largest block = 33 m

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Strength and deformation properties of melange bimrocks

Oh dear… not enough time to explore fully….

And: NOT covering the rock mechanics approach (Hoek-Brown Criterion)
Summary of strength and deformation properties of melange bimrocks

Overall strength increase over matrix-only strength is **directly related to volumetric block proportion** (Lindquist, 1994; Lindquist and Goodman, 1994)

Strength and deformation of melanges **are independent** of block strengths

The **presence** of blocks increases frictional strength of the bimrock, stiffens the mixture, reduces/increases cohesion (depends...) and induces tortuous failure surfaces (all at the scale of interest)

Must perform geotech tests with blocks in specimens because bimrocks at lab scales are models of bimrocks at site scales
Failed Tx specimen of physical model melange

150 mm diameter Tx specimens (Lindquist, 1994)

Developed surface of Tx specimen - tracing of blocks on transparent kitchen film

Medley, 2004

failure surfaces tortuously negotiate blocks
Tortuous failure surfaces in sectioned TX Specimens

A. 00°/71%  
B. 60°/55%  
C. 90°/29%

High block proportion: threshold for block-to-block contacts

Lindquist, 1994; Medley, 2004

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Overall strength of a bimrock depends simply on **volumetric block proportion**

![Graph showing the relationship between volumetric block proportion and friction angle](image-url)

- **Scott Dam melange**
- **Physical models**
- **Conservative trend**
  - Irfan and Tang, 1993
  - (Lindquist 1994a)
At high block proportions (> 60-70%) blocks start touching: consider as blocky rock mass with wide joint infilling

Lindquist, 1994
Examples of Increases in Effective Friction Angle with Volumetric Block Proportion (from Triaxial Lab Tests)

Between about 10% and 70% Volumetric Block Proportion - gain up to 20 degrees of added effective friction angle, relative to matrix strength

Data: Prof. R Goodman
Simple Ideas for Characterizing Complex Melanges and Similar Bimrocks
Biggest, Simplest Idea

Know you are working with complex geology
Exploring layer cake geology

exploration borings

Layer 1

Layer 2

Layer 3

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The complexity of a turbidite sequence - interbedded sandstones and shales (2 borings)

Devil’s Slide, Pacifica, CA  E. Medley

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The complexity of a turbidite sequence - (OK to interpret interbedded sandstones and shales on basis of boring contacts)
Reading between the lines (boring data)
Reading between the lines (drawing straight lines between the contacts)
Reading between the lines (interpretation)
The **actual picture** is different....
Wrong way to map melanges

Wakabayashi & Medley, 2004
Right way to map melanges

Outcrops (blocks)

Wakabayashi & Medley, 2004
Systematic investigation of chaos

Some Mappable Melange Characteristics

- Melange matrix
- Block
- Block Proportions
- Block Type Inventory
- Block Preferred Shape and Orientation
- Foliation Orientation
- Mappable subzones with different block types
- Mappable subzones of different block proportions
- Orientation and Nature of Bounding Melange Contacts

Wakabayashi & Medley, 2004

Matrix strength
More wrong way..

Wakabayashi & Medley, 2004
More right way...

NOT “interlayered” shale and sandstone!!
NOT “soils with boulders”
NOT ‘miscellaneous soils’
Mischaracterization means misery- Investigation

“shallow landslide in soil over bedrock”
Mischaracterization means misery – Excavation

"shallow landslide in soil over bedrock”

15 m excavation looking for the “failure plane”
Mischaracterization means misery - Embarrassment

NO “shallow landslide in soil over bedrock”
be deep-seated slide in melange

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For further thoughts...

The Arrogance of Straight Lines

By Edmund W. Medley, Ph.D., P.E., C.E.G.

Figure 1. The red "best fit" line represents data points (red dots) and the blue curve fits all of them.

Investigators may not often consider how we use data to create models and pictures. The process of finding scattered data and transforming them into convincing coherent failure analyses or subsurface characterizations is much like drawing lines to connect dots in performing failure investigations. We connect dots to develop our best estimate of what happened. In performing site characterizations, we connect spatial data and rock units and cross-sections depicting areas of rock and soil, faults, and planes of contamination.

Figure 1. Another way to represent the relationship between the data is to find a "best-fit" trend line. Confidence in the trend line improves as additional data are added to the set.

In a failure investigation, efforts are made to find all available data, but then ignore the data points that are not consistent with the trend line. This is what happened in the true story we’ll be telling in our next phase. Geologists often make terrible misinterpretations of data that can be explained by simple misinterpretations of the data.

But often the investigator has to discover the most likely failure scenario, which is akin to identifying the "best-fit" straight trend line shown in Figure 1. Early in an investigation, it is easy to "jump to conclusions" and release the few resources at

http://bimrocks.com
“Very Nice Plot!!
“So, Strength depends on Volumetric Block Proportion?”

“But how do you get at the latter in Real Life?”
First Steps

- Recognize working with a bimrock
- Select \( H = L_c \)
- Establish block threshold: 0.05\( L_c \)
- Drill cored borings
- Recover Lab specimens (shrink wrap)
Melange matrix/blocks in drill core

Scott Dam melange (California)  
photo Prof. R Goodman

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Blocks in drill core (Scale matters!)

Blocks in core are part of matrix at site scale but ARE blocks at lab specimen scale!

Core specimens are scale models of the in-site rock mass.

Test specimens with different proportions of blocks; measure the volumetric proportions.

USE a testing lab experienced with rock/rocky specimens!

The stronger the matrix that you measure, the better off you will be - even if you design on basis of matrix only.
Next Steps: measure lengths of core/block intercepts and estimate linear block proportions

- Measure chords (core/block intercept lengths)
- Calculate Linear Block Proportion
- Estimate Volumetric Block Proportion and Uncertainty of the estimate
Calculating Block Linear Proportions based on core/block intercepts

B1 (TD 180m)  B2 (TD 105m)  B3 (TD 32m)  B3 (TD 45m)

- 26 m blocks (81%)
- 6 m blocks (6%)
- 85 m blocks (47%)

Total length blocks = 117 m
Total length borings = 362 m
Total linear block proportion = 32%
Next Step: Estimate volumetric block proportion

With calculated linear proportions from drill core:

Apply *stereological principle*:

linear proportion = areal proportion = volumetric proportion

Yay! At last! Something logical and simple!!
Beware Geological Engineers with Accents!

BE CAREFUL!!! Don’t believe everything you hear/read!!

Although stereology => Volumetric% = Areal % = Linear %
This law is TRUE ONLY when:
• have sufficient linear measurements!! (lots of drilling, LOTS of $$$ !)
• lots of blocks to intersect

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Geometrical probability problems…

Vertical blocks
Vertical borings
Low block proportion
So: little data…

boring or scanline

Horizontal blocks
Vertical borings
High block proportion
Lots of data
(but useless for block sizes…)

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But.....

How wrong would we be if we did make the assumption:  
Volumetric % = Linear % ??

Let us perform some simple “coring” experiments with bimrock models with known volumetric proportions
Holiday weekend physical bimmodels

Fabricated 4 models with known block size distributions and known, but different, Volumetric Block Proportions

• Cut and photographed 10 slices per model
• Drew 10 “borings” per slice
• Measured 100 linear proportions per model
How close are Linear% values to actual Volumetric%?

Plan view of bimmodel with 100 linear%s from “drilling” -

actual volumetric proportion = 32%
Evaluating Uncertainty in Estimates When Linear Proportions are Assumed to be Same as Volumetric Block Proportions

Example:
Total drilling = 200 ft
$L_c = \sqrt{A} = 70$ m
Largest block ($d_{max}$) = 0.75$L_c$
Hence $d_{max} \approx 50$ ft
And, $N_{d_{max}} = \frac{200}{50} \approx 4$
Linear proportion = 40%
For $N_{d_{max}} \approx 4$; and, assuming Linear Proportion of 40% is same as Volumetric Proportion, then Uncertainty is $\approx 0.20$
Hence: Uncertainty range is: $\pm (0.2 \times 40\%) = \pm 8\%$

For strength purposes use $32\%$ (40\% - 8\%) Volumetric Proportion;
For earthwork estimates use $48\%$ (40\% + 8\%)

$N_{d_{max}}$ = length of drilling expressed as multiples of size of largest block, $d_{max}$, (length of estimated largest block: often 0.75$L_c$)
Example of Estimation of Strength

Scott Dam, CA
Assumed characteristic dimension ($L_c$) was thickness of a sliding shear below dam: 3m (10 ft.)

Dam height: heel to crest ~ 150 feet or $L_c = 7.5$ feet
Estimating volumetric block proportion

Since characteristic engineering dimension was 10 ft (3m), block/matrix threshold selected at

\[0.05 \times 10 = 0.5\text{ ft (0.15 m)}\]

Reviewed drill core photographs and boring logs

Measured all chords (core/block intercepts) >0.10m and used them to calculate block linear proportion
measured block chords in core

Scott Dam melange (California)  photo Prof. R Goodman

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Example of estimating strength of Franciscan melange below foundation of Scott Dam, CA

Testing showed matrix $\phi = 25$ deg.
Measured linear proportion = 40%
Adjusted vol. block proportion = 31%
Hence Estimated Rockmass $\phi = 39$ deg
Estimating 3D Size distributions from 1D Borings

1D chord length distributions are NOT the same as 3D block size distributions

So: be shy of estimating 3D from 1D
Measurement of chords from bim models

- 10 “borings” per slice
- 100 borings per model
- 400 “borings”
- Block size distributions the same for each model
- 2150 block/boring intercepts (chords)

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“PSD”-style plot of chord lengths for all models (~2150 chords)

Actual block size distribution for all models

Tailing shows 30% to 45% of measured chords were shorter than actual size of smallest block (and smaller than block.matrix threshold)

Despite abundant data, still cannot duplicate original 3D BSD with chords...
Chord length Distributions for Lindquist TX Specimens

- \( d_{\text{max}} \) indicated
- Considerable number small chords- at lengths smaller than smallest actual blocks
- Relative orientation of borings and blocks matter

Smallest blocks at block/matrix threshold \( \sim 0.05d_{\text{max}} \)

Actual block size distribution

Small blocks

Large blocks

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SLOPE STABILITY of bimrocks
Motivation: analysis of slopes in bimrocks
Melange Fabric in a Slope

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

- Shears negotiate around blocks tortuously
- Not smooth rotational “failure surfaces” but chaotic trajectories

Bolu Tunnel, Turkey

Photo: GGG, Graz
Franciscan Complex melange
weak block/matrix contacts
What are the influences on slope stability in bimrocks?

Block/matrix vol. proportion; matrix c, φ?

Block shape, block & shear orientation?

Block size, location, orientation?

Bimrock weak zones: width? variability?

Medley & Sanz, 2004
edmedley@bimrocks.com  www.geopractitioner.com
What are the influences on slope stability in bimrocks?

i.e.: really complex problem – how then should we analyze slope stability in bimrocks??

For now - use a soils engineering approach (although rock engineering methods are more appropriate when working with rocks)

Medley & Sanz, 2004
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Slope stability of Hong Kong Bouldery Colluvium

Plate 29 - Colluvium Layer No. 1, Slope behind Fairmont Gardens

Hong Kong GEO TN 4/92

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Hong Kong bouldery colluvium: Trial tortuous failure surfaces with blocks oriented out-of-slope

After Irfan & Tang, 1992

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Simple analysis of slope stability in a model Franciscan bimrock - start with matrix only

- Critical failure surface for matrix-only case

- H = 10 m
- Slope angle 35 degrees

- $c' = 10$ kPa (200 psf)
- $\phi' = 26$ degrees
- unit wt = 1.92 (120 pcf)
- NO GWT

- FS for matrix only: 1.26

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Simple analysis of slope stability in model bimrock: add blocks to the matrix

- ~ 50% Areal Block Proportion
- typical Franciscan block size distribution
- NO Block strengths

Envelope of tortuous failure surfaces is ~ 0.05L_c to 0.15 L_c wide
Abstract trial failure surfaces, perform slope stability analyses using matrix strength only

- Matrix-only failure surface $FS=1.26$
- Normalized $FS = 1.65/1.26 = 1.31$

Medley and Sanz, 2004

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Combine analyses: presence of blocks increases slope stability FS

Normalized: ratio of FS of tortuous sfc to FS of matrix-only sfc

Block proportion of 30% raises bimrock FS to 1.5 from matrix-only FS of 1.3

Approx. fit line

NOTE: assumed that Areal Proportion = Volumetric Proportion
Some Observations on Bimrocks in Slopes

Blocks add to slope stability by virtue of tortuosity of failure surfaces negotiating blocks (little to do with block strength)

Tortuosity is most influenced by block proportions and block orientations

Increased block proportions means increased tortuosity and increased stability

Actual block distributions in bimrocks are unknowable so we can never predict the actual trajectories of tortuous failure surfaces in slopes

Assume envelope of tortuous trajectories is about 0.05H to 0.15H thick (using slope height as $L_c$)
A Few Construction Considerations

**EXPECT** unexpected surprises when working with bimrocks

Run WHAT IF? Scenarios - Adopt the Geotechnical Observation Method

If you neglect blocks in your analysis, and then forgot them – the Contractor will find them and remind you.

Large HARD blocks happen – estimate conservatively

Adjacent large blocks wide, weak shears are common

During slope excavations, maybe OK to leave well-rooted blocks in hillsides (probe to evaluate size)

Hydraulic augers may not work well for long –drained blocks may initially gush, then eventually dribble
CONCLUSIONS

• Bimrocks ("rock/soil mixtures") can be characterized
• Strength and deformation properties of bimrocks are determinable
• Uncertainties in estimates must be considered
• Ponder before connecting boring "contacts" on your cross-sections
• Bimrocks are NOT:
  – "soil with boulders",
  – "interlayered shale and sandstone"
  – "miscellaneous soils"
• Design for more than the "weak component" matrix
• Do not forget about blocks if you do design only for matrix
• Block volumes, sizes and lithologies are $important$ to Contractors/Owners - effort should be made to determine them
• Block sizes should be estimated conservatively for construction
BIG CONCLUSION 1: Remember this picture!!!

Matrix
Blocks, inclusions, lenses, etc
Scale: 1:???????
Matrix
Actual Distribution of Blocks
BIG CONCLUSION 2: Remember this picture as well!!!
For more background information.....

For more bimrocks info see bimrocks.com or Google “Ed Medley”
Geopractitioner approaches to working with antisocial mélanges

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ABSTRACT

Although mélanges are exciting, puzzling, and controversial to geologists, it is geopractitioners and contractors who must work with them to engineer the constructed works of society. Geopractitioners include geotechnical engineers, geological engineers, engineering geologists, and rock engineers. Mélanges are the most intractable bimrocks (block-in-matrix rocks), complex geological mixtures composed of hard blocks of rocks surrounded by weaker matrix, and are famously exemplified by those within the Franciscan Complex of Northern California. Bimrocks also include olistostromes, weathered rocks, fault rocks, and lahars. The conventional characterization, design, and construction procedures used by geopractitioners for well-behaved stratified rocks and soils are not well suited to mélanges. The considerable engineering and construction difficulties related to mélanges burden society to the extent that they can be considered “antisocial.” Case histories exemplify a recommended systematic...
Some References


Lindquist, E. S., 1994; *The Strength and Deformation Properties of Melanges*, Ph.D. Dissertation, Department of Civil Engineering, University of California at Berkeley (kindly made available by Dr. Eric Lindquist, P.E.)


Medley, E.W., 1994; *The Engineering Characterization of Melanges and Similar Block-in-Matrix Rocks (Bimrocks)*, Ph.D. Dissertation, Department of Civil Engineering, University of California at Berkeley (also: darker reprints of selected pages).


Thank you
Questions?