2. Geological Complexity

Geotechnical and Geological Engineering with Melanges, Fault Rocks and Other Bimrocks

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BIG CONCLUSION 1: Remember this picture!!!

Actual Distribution of Blocks

Scale: 1:??????

Matrix

Blocks, inclusions, lenses, etc

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BIG CONCLUSION 2: Remember this picture as well!!!
GEOTECHNICAL ENGINEERING = FROM ROCK TO SOIL

<table>
<thead>
<tr>
<th>EFFECTS OF SATURATION ON ROCKS AND ROCK-LIKE MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terzaghi's Guides for Distinguishing Rock, Weathered Rock, and Soil*</td>
</tr>
</tbody>
</table>

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

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

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“Rock”: simple word, complex concept!

“simple” geology but challenging rock engineering

“complex” geology and REALLY challenging rock engineering

Laznicka, 1988
An early (1986) Geotechnical Classification of Complexity

**Figure 4.1** Italian geological classification scheme showing types of Structural Complexity, after Manfredini and others (1985), DiElia and others (1986)

From Medley, 1994
..and > 1000 geological words/terms for fragmented rocks and complex mixtures

| 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; laterite rudrocks, 324-5; latite flow sole bx, 491; latite intrusive bx, 585F; lava autobrecia, 459, 481; lava channel collapse bx, 417, 424F; lava cooling joints crackle bx, 422F; lava contraction bx, 416; lava crackle bx, 416; lava flow autobrecia, 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, 648; limestone/sulphur bioepigenetic bx, 405; lithic fragments supported inclusion bx, 478; lithic lag bx, 113; lithic tuff bx, 482; local fragments in granoblastic matrix bx, 596; lodgement till, 208, 240, 300; lunar bx, 64; lunar bx, 715, 716F, 717F, 719-21F, 722F; lunar fragmentites, 715-722; lunar soil bx, 71*.

M Macrobrecia, 9; mafic bx dikes, 603; mafic block tectonite bx, 9, 80*; marble matrix bx, 625; marl-flaser bx, 559F; martite-magnete stockwork bx, 491; massive sulphide bx, 594, 7599F; matrix-free bx, 362; matrix-supported bx, 5; matrix-supported chaotic bx, 338; magnetite-supported polymeric (lunar), 716, 717F; megabrecia, 9, 41*, 119*-124F, T, 279, 339, 446, 479, 597, 604, 667, 675, 692, 696, 673, 700; melange, 18, 21.

Laznicka, 1988
So: the main reason for the word bimrocks

Term “bimrocks” created intended to focus engineer/geopractitioner on working with geological complexity regardless of countless geological terms and variety of geological causes

i.e.: reduce the complexity of geologic WORDS and geologic origins to a simple word/simple concept suitable for engineers
Bimrocks (and bimsoils)

Think of Rock/Soil mixtures

Term “bimrocks” intended to focus engineer/geopractitioner on working with geological complexity regardless of countless geological terms and variety of geological causes

Bimrocks definition (Medley, 1994): 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 with little or no bond between blocks and matrix (debris flow deposits, glacial tills, colluvium, etc.) - depends on scale of interest
A bimsoil: coarse alluvium (BUT: scale matters!)

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

Road cut Hwy 1 near Carmel, CA
E. Medley, 1990
Glacial till: rock/soil mixture

Corestones, block, boulder

Glacial till in Michigan

Virginia Tech Univ website

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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)
Decomposed Granite

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

photograph by Dana Willis, RG
Volcanic rock masses can be complex too

Pahoe’hoe lava  Volcanoes National Park, Hawaii
Background: Basalt Lava Flows
Background: Detail of Basalt Lava

Clinker forms at cooling surfaces

Website of Dan Stora, France
Formation of clinker

- Molten flow core
- A’a rock core
- A’a clinker
- Top a’a clinker
- Bottom clinker

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Pa’hoe’hoe (ropey lava)
a’a lava
a’a lava

a’a
clinker
Successive flows are irregular
Sequences of rock/clinker/cavities

Volcanoes National Park, Hawaii

Blocks of massive a’a basalt within irregular non-uniform sequences of massive a’a, a’a clinker, paho’hoe flows and pahoe’hoe lava tubes and cavities

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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
Classification

Engineering Geological Classification of Fault Rocks
(Riedmuller 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)

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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.
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.
Block orientation in bimrocks

Cowan, 1985
Mapping of slopes (Bolu Tunnel, Turkey)

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

Area of photo
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)
Sheared Serpentinite, Franciscan Complex, Oakland, California; 2015 photo: E. Medley
Fault Structures

Blocks (phacoids) of quartzite embedded in graphite phyllite

Tunnel Steinhaus, Austria, Tunnel Face

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Faulted and Sheared Rock

Mixture of sheared rock and intact blocks at a Quarry within San Andreas Fault zone – not your typical soil slope.
Formation of Melange in an Foreland Basin Overthrust Setting, Main Tunnel, Mae Kuang Irrigation Project, N – Thailand

Foliated soft matrix showing ductile and brittle compressional deformation features

Lenticular stiff block showing extension fractures

Quartzitic Sandstone, Devonian

Graphitic Shale, Carboniferous

Fault Structures
Melanges

Franciscan Complex melange, Mendocino California  photo: Ed Medley
Melanges and Similar Bimrocks

• **Bimrocks**: block-in-matrix rocks
  “mixtures of rocks composed of geotechnically significant blocks within a bonded matrix of finer texture”

• **Melanges**: (French *mélange*): UNCHILE* mixtures of competent blocks composed of sedimentary/metamorphic blocks in weaker matrix of sheared shale or serpentinite

• Melanges are the most difficult bimrocks..

• **Similar Bimrocks**: Saprolites, Breccias, Fault Zones, Lahars, Tillites, etc.

*CHILE*: CONTINUOUS HOMOGENEOUS ISOTROPIC LINEARLY ELASTIC
Melanges (mélanges) - the most intractable of bimrocks

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

*photo: Dr. E. Medley, 1992*

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

*photo: E. Medley*

Franciscan Complex melange, Caspar Headland, near Mendocino, California
Melanges are common (and ignored!)
Global distribution of melanges (> 70 countries)

Medley, 1994
Franciscan Complex near San Francisco, California

From Medley, 1994; after Ellen and Wentworth, 1995
Alcatraz Terrane: crustal block of “broken formation” (like mélange) graywacke sandstones and shales

Ft Point-Hunters Point Shear Zone: a melange of sheared shale and serpentinite, with sandstones and exotic blocks

Source: GDR, Transbay Transit Center, Arup
Graywacke outcrops at Baker Beach, Presidio, San Francisco

http://www.nps.gov/goga/forteachers/images/graywacke-outcrop1.jpg

Graywacke hand sample

http://www.nps.gov/goga/forteachers/images/graywacke2-copy.jpg
Marin Headlands: E Medley 2005
Baker Beach landslides in Serpentinite

https://encrypted-tbn1.gstatic.com/images?q=tbn:ANd9GcSLlad8a3K1pA7zGk2gjaaZrYhh_bkJBFk4A7wQUwxFCfAcr
big block of strong graywacke

Weaker sheared matrix

But: weaker “sheared matrix” is actually a mix of hard blocks in sheared shale

Mendocino; E Medley ~1992

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Read the mixture: Medley, mélange, Wales, Berkeley, etc..
http://edmedley.com/blog/2009/02/07/on-first-encountering-melange/
tortuous shear
Typical Melange Showing Diverse Elongate Blocks and Irregular Foliated Matrix (S-M-C-Cataclasites)

Slope debris

Sandstone

Marble / Shale

Tectonic Melange

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

Melanges look like fault rocks

Bolu Tunnel, Turkey
weak block/matrix contacts

Gwna Melange
Lleyn Peninsula,
N. Wales
photo: E. Medley
Matrix and blocks in core

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

Intercept of block and core (not the "diameter!")

Scott Dam melange  (California)

photos: Prof. R Goodman
Simple model for origin of melanges

[Diagram showing structural infolding, forearc basin, bedrock framework, oceanic crust, and offscraped ocean deposits.]
BUT: melanges are even more complex: there are many different kinds, and many geology arguments.

Laznicka, 1988
Cowan, 1985
Definition of melange (from Geological Dictionary)

“A body of rock mappable at a scale of 1:24,000 or smaller and characterized both by lack of internal continuity of contacts or strata and by the inclusion of fragments and blocks of all sizes, both exotic and native, embedded in a fragmentated matrix or finer-grained material”

In engineering sense and considering the scale of most engineering works (larger than 1:24,000) → This definition is not satisfactory

Prof. Dr. Reşat Ulusay, Turkey, 2004
Melanges in Turkey

Modified from Terrane Map of Turkey (Göncüoğlu et al., 1996)

Prof. Dr. Reşat Ulusay, Turkey, 2004

• Melanges have been recognized by geologists as significant components of orogenic belts for decades, yet the engineering community has been slow to appreciate their importance.

• In many engineering projects, melanges are still treated as stratified units, or occasionally mistaken for soil with boulders.

• Whether a melange is of tectonic or sedimentary origin is unimportant for engineering purposes.

• In contrast, the grade of metamorphism of the matrix can be important, because significant recrystallization of the matrix strengthens it and reduces block-matrix strength contrast.

• Serious errors have been by engineers made because of mischaracterization of melanges.
Summarizing: bimrocks have strong blocks, weak matrix

- Melange
- Sheared serpentinite
- Weathered rocks
- Major fault zones
Summarizing: block-in-matrix fabric is common

*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!

**SO WHAT?** Mischaracterizations of bimrocks **co$t** - so important to Contractors, Owners and Lawyers

Geopractioners **must** consider blocks (lithology, shape, SIZE etc..)
Start by looking at blocks (look at matrix later!)
Some elements of CHARACTERIZATION
(much more in another Lecture)

- Block/matrix discrimination
- Matrix lithology
  - block size
  - block shape
  - block lithology
  - block orientation
  - block size distribution
  - block discontinuities
  - Etc…

Photo: Julien Waeber, 2006
Q: Z kdw#v#e× fn#v{l} hB#D #UdHo #kh$glp hwhu’
Drilling through a block: chords and diameters


Only rarely will a drilled chord be the same as the diameter: so when drilling bimrocks be very careful when you use the words: “block diameter”
the importance of **scale independence** in our work with bimrocks
Scale independence

Cowan, 1985
a Franciscan Complex melange: **blocks at many scales**

Huge blocks, big blocks, small blocks, tiny blocks – all depends on your scale of interest
Measuring block sizes (and size distributions) in 2-dimensions

Outcrop scale of interest

\[ A < 1 \text{ m}^2 \]

“size” = \( d_{\text{mod}} \)

Medley, 1994
Histogram of block sizes

Medley, 1994
Log Histogram of block sizes

Area = 7.9 m²
Number blocks = 173
max. block size = 1.98 m

D = 1.2

“fractal dimension” in 2D:
(add 1 to get fractal dimension in 3D)

Medley, 1994
Block measurements at many scales

Medley, 1994
Histograms at several scales

Distributions look similar….

“Censoring” of data due to undercounting—blocks too small to see at this scale but will be counted when scale zooms in smaller

Medley, 1994
Log Histograms at several scales

Compilation of all block size data measured from cliff face at Caspar Headlands, Mendocino, CA

Medley, 1994
Normalization by $\sqrt{A}$

$\text{RF}_{\text{peak}} = 50\%$

$D = 1.25$

$d_{\text{peak}} = 0.04A^{1/2}$

$d_{\text{max\Approx}} = A^{1/2}$

$A^{1/2} = \text{square root of the area of that portion of the photo image containing all the blocks measured (m)}$

$d_{/A^{1/2}} = \text{max. measured dimension of blocks (m),}$
Add Franciscan Complex blocks in Marin County

Regional map scale of interest
A~1000 km²

From Medley, 1994; after Ellen and Wentworth, 1995

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Log Histogram at km scale

Block size distribution for Franciscan Complex blocks of Marin County, California
Compare Log histograms at different scales

(a) slope = Fractal Dimension, D

- peak
- ascent limb
- descent limb

Number of blocks:
- D = 1.4
- Area = 7.9 m²
- No. blocks = 173
- max. block = 1.98 m

(b) D = 1.61

Number of blocks:
- Area = 920 km²
- No. blocks = 314
- max. block = 18 km
Scale-independent block size distributions of Franciscan melanges

Plotted as a Log-Histogram

Block/matrix threshold: 0.05√A

$d_{\text{max}} = \text{size of largest block}: 0.75\sqrt{A}$

Low frequency because too small to count accurately (“censored data”)

Kalendar et al, 2014, after Medley, 1994

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Another reason to select the 5% block/matrix threshold

95% of number of blocks are smaller than $0.05d_{\text{max}}$ but represent < 1% of total volume of blocks.
Blocks in Franciscan Complex melange (and many other bimrocks)

- Blocks range in size between mountains and sand and will always be present, even if you cannot see them.
- Block size distributions are scale independent and fractal (power law) - they look much the same.
- Regardless of scale – one or two large blocks, and increasing numbers of smaller blocks.
- Largest reasonable block is: \(0.75\sqrt{A}\) aka \(d_{\text{max}}\).
- Block/matrix threshold is \(0.05\sqrt{A}\).
- Blocks will always be found: Characterization must take blocks into account.
AND: findings from studies of “model” bimrocks at outcrop and laboratory scale **ARE** relevant for in-situ bimrock masses!!!
SO: if blocks will be found at all scales:

What is Block and What is matrix?

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, thickness of expected failure zone, $\sqrt{A}$, etc.
Use these guidelines at *any scale of interest*

- **smallest blocks are:**
  
  \[ 0.05L_c \text{ or } 0.05 \sqrt{A} \text{ or } 0.05d_{\text{max}} \]

- **largest block is:**
  
  \[ 0.75L_c \text{ or } 0.75 \sqrt{A} \text{ or } 0.75d_{\text{max}} \]

(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
\[ L_c \sim 2 \ m \ (trench \ width) \]
Smallest block = 0.1 m
Largest block = 1.5 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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From the chaos of geological complexity and geological words we can focus on a few simple ORDERLY concepts
So: the block-in-matrix fabric is common

Summarizing so far:

Lessons learned from studying engineering problems in melanges applies to geotechnical problems for all geologically complex mixtures

*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!

**SO WHAT?** Mischaracterizations of bimrocks **co$t** - so important to Contractors, Owners and Attorneys

**Geopractitioners must consider blocks (lithology, shape, SIZE etc..)**
BIG CONCLUSION 1: Remember this picture!!!

Actual Distribution of Blocks

Matrix

Blocks, inclusions, lenses, etc

Scale: 1:??????

Matrix
BIG CONCLUSION 2: Remember this picture as well!!!
Weathered Rocks

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

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

University of Florida website

Soil Layers

- O Horizon (humus)
- A Horizon (topsoil)
- E Horizon (eluviation layer)
- B Horizon (subsoil)
- C Horizon (regolith)
- R Horizon (bedrock)

Enchanted Learning website

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bimrocks are “miserable materials”

<table>
<thead>
<tr>
<th>GEOLICAL STRENGTH INDEX FOR JOINTED ROCKS (Hoek and Marinos, 2000)</th>
<th>SURFACE CONDITIONS</th>
<th>STRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>From the lithology, structure and surface conditions of the discontinuities, estimate the average value of GSI. Do not try to be too precise. Quoting a range from 30 to 37 is more realistic than stating that GSI = 35. Note that the table does not apply to structurally controlled failures. Where weak planar structural planes are present in an unfavourable orientation with respect to the excavation face, these will dominate the rock mass behaviour. The shear strength of surfaces in rocks that are prone to deterioration as a result of changes in moisture content will be reduced if water is present. When working with rocks in the fair to very poor categories, a shift to the right may be made for wet conditions. Water pressure is dealt with by effective stress analysis.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VERY GOOD - very rough, fresh unweathered surfaces</td>
<td>INTACT OR MASSIVE - intact rock specimens or massive in situ rock with few widely spaced discontinuities</td>
<td></td>
</tr>
<tr>
<td>GOOD - rough, slightly weathered, iron stained surfaces</td>
<td>BLOCKY - well interlocked un-disturbed rock mass consisting of cubical blocks formed by three intersecting discontinuity sets</td>
<td></td>
</tr>
<tr>
<td>FAIR - smooth, moderately weathered and altered surfaces</td>
<td>VERY BLOCKY - interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets</td>
<td></td>
</tr>
<tr>
<td>POOR - slicked, highly weathered surfaces with compact coatings of fillings or angular fragments</td>
<td>BLOCKY/DISTURBED/SEAMY - folded with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity</td>
<td></td>
</tr>
<tr>
<td>VERY POOR - slicked, highly weathered surfaces with soft clay</td>
<td>DIGINTEGRATED - poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LAMINATED/SHEARED - Lack of brittleness due to close spacing of weak schistosity or shear planes</td>
<td></td>
</tr>
</tbody>
</table>


Courtesy: www.Rocscience.com
“At the scale of engineering interest, a chaotic rock mass composed of competent blocks of various size and lithology, embedded within a weaker, usually argillaceous matrix” (Medley, 1994)
Scale-independent block size distributions of Franciscan melanges

Plotted as a Log-Histogram

Medley, 1994
Formation of Clay Minerals

<table>
<thead>
<tr>
<th>Sample</th>
<th>Smectite</th>
<th>Illite</th>
<th>Kaolinite</th>
<th>Mixed Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1</td>
<td>92%</td>
<td>8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample 1a</td>
<td>87%</td>
<td>13%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample 2a</td>
<td>77%</td>
<td></td>
<td>17%</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Illite 3%</td>
<td></td>
</tr>
<tr>
<td>Sample 2b</td>
<td>40%</td>
<td></td>
<td>50%</td>
<td>10%</td>
</tr>
</tbody>
</table>

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

Copyright © All rights reserved - Dr. Edmund Medley, Sept. 2017
Formation of Melange in an Foreland Basin Overthrust Setting, Main Tunnel, Mae Kuang Irrigation Project, N – Thailand

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

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

**Quartzitic Sandstone, Devonian**

**Graphitic Shale, Carboniferous**

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Fault Structures

- Extension fractures
- Blocks of serpentinite
- Extensional shears

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

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Fault Structures

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

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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

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Fault Classification (Classical References)


- Zhang Xian-Gong, Han Wen-Feng & Nie De-Yin (1986):