ENGINEERING GEOLOGY

10.03.2014

Syllabus of Engineering Geology INS1122, Spring Semester, 2014

Lecturer: Assistant Prof. Dr. Ömer Ündül – İstanbul University (İ.Ü.) Geological Engineering Dept.

Lecture: Monday, 13:00 – 15:50

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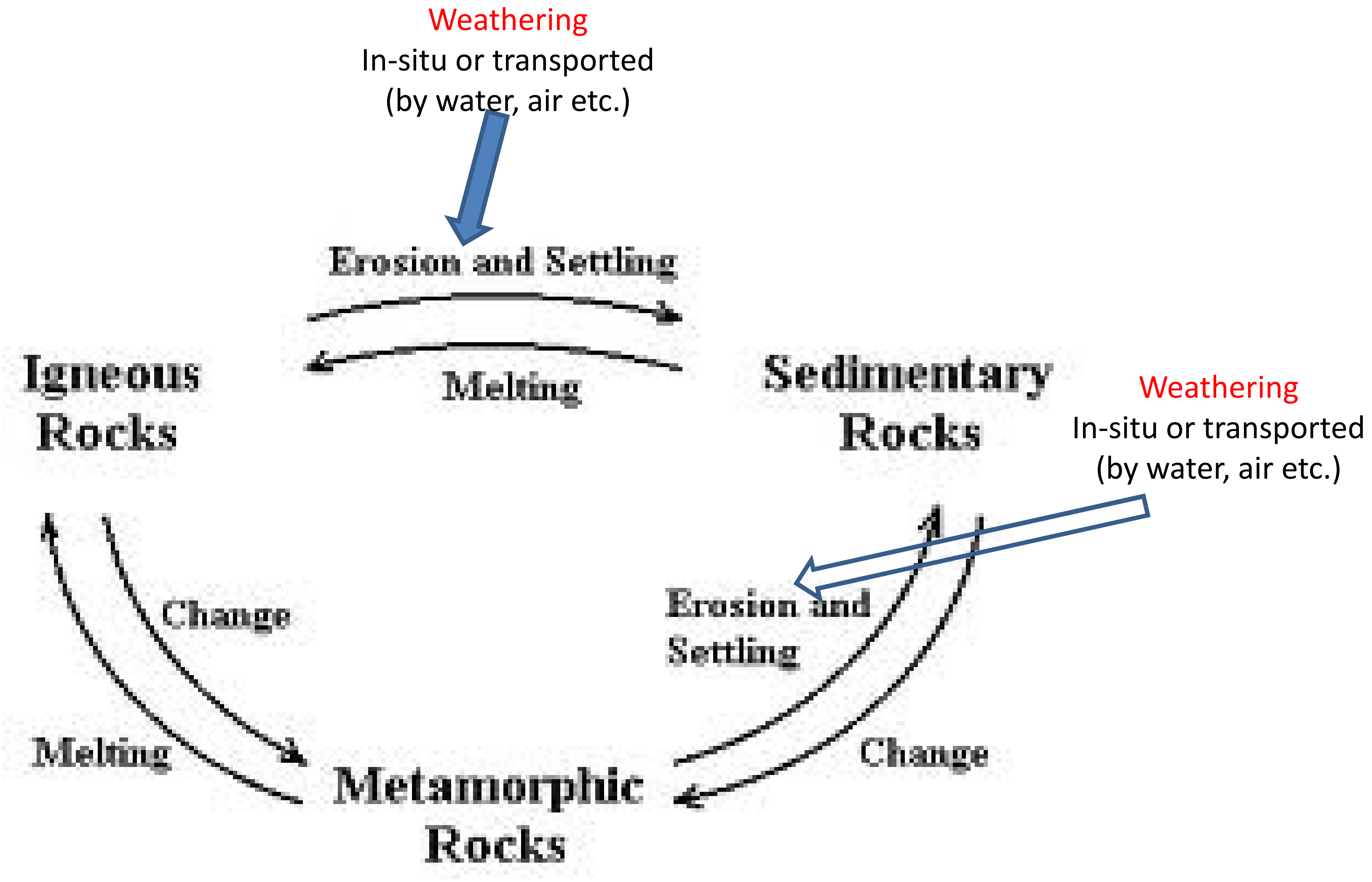
http://aves.istanbul.edu.tr/SorguDokumanlarim.aspx?Sorgu=3217

Textbook: Geology for Civil Engineers by Marcus Matthews, Noel Simons and Bruce Menzies. A publ. of Thomson Telford.

Engineering Geology, Bell F.G, Second edition 2007, Butterworth-Heinemann, Elsevier

1) Introduction, the role of geology and engineering geology in civil engineering
2) The structure of the Earth's crust
3) Minerals and Rocks, classifications
4) Engineering properties of rocks
5) Topographic maps, geological maps and cross sections
6) Engineering geological maps
7) Earthquakes
8) Mass movements
9) Stability of rock slopes
10) Engineering geology in dams
11) Tunnelling
12) Groundwater
13) Natural and dimension stones
14) Environmental geology



Weathering
In-situ or transported
(by water, air etc.)

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Simplified rock cycle

WEATHERING

Weathering is the process of alteration and breakdown of rock and soil materials at and near the Earth's surface by physical, chemical and biological processes to form clay, iron oxides, and other weathering products.

Weathering is the process of physical disintegration and chemical decomposition of the rock

WEATHERING - TYPES

MECHANICAL / PHYSICAL

Disintegration of rocks and minerals by a physical or mechanical process

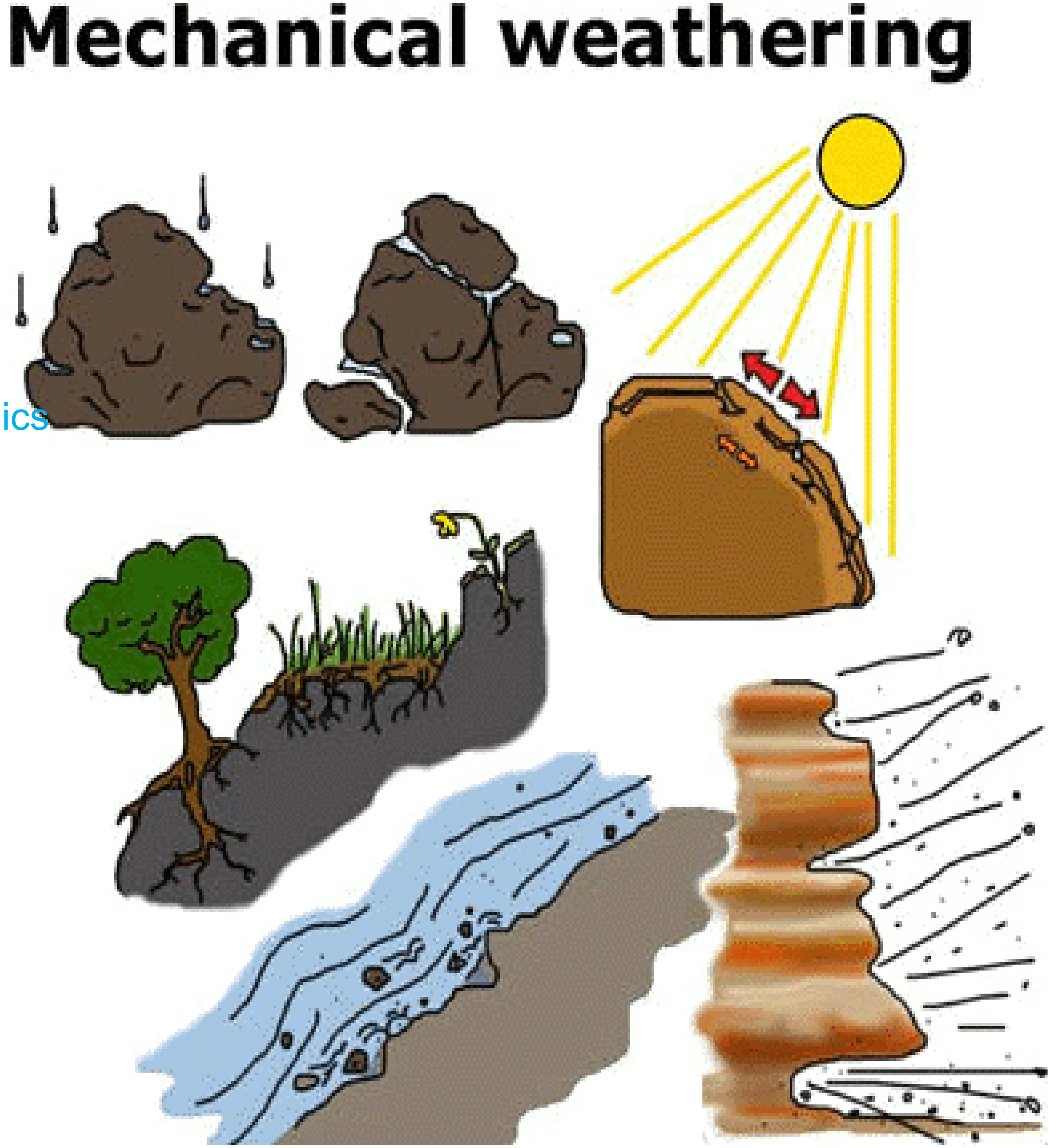
CHEMICAL

Chemical alteration or decomposition of rocks and minerals

BIOLOGICAL

Roots, animal activity etc

WEATHERING - MECHANICAL / PHYSICAL



1) Development of Joints:
    - Stress relief_exfoliation*, tectonics
2) Crystal Growth
3) Frost Action:
    - Freeze-thaw, frost wedging etc.
4) Changes in temperature:
    - Wet-dry cycles, slope aspect
5) Plant roots
6) Abrasion
7) Exfoliation **

WEATHERING - CHEMICAL

1) Hydrolisis

$$\underset{\text{Orthoclase}}{4KAlSi_3O_8} + \underset{\text{Hydrogen ion}}{4H^+} + \underset{\text{water}}{2H_2O} \longrightarrow \underset{\text{Potassium ion}}{4K^+} + \underset{\text{Kaolinite (clay mineral)}}{Al_4Si_4O_{10}(OH)_8} + \underset{\text{quartz}}{8\ SiO_2}$$

2) Oxidation

$$\underset{\text{Pyroxene}}{3Fe^{+2}SiO_3} + \underset{\text{Oxygen}}{1/2O_2} \longrightarrow \underset{\text{Magnetite}}{Fe_3O_4} + \underset{\text{Quartz}}{3SiO_2}$$

3) Dissolution

$$\underset{\text{Calcite}}{CaCO_3} + \underset{\text{Carbonic Acid}}{H_2CO_3} \longrightarrow \underset{\text{Calcium ion}}{Ca^{2+}} + \underset{\text{Bicarbonate ion}}{2(HCO_3)^-}$$

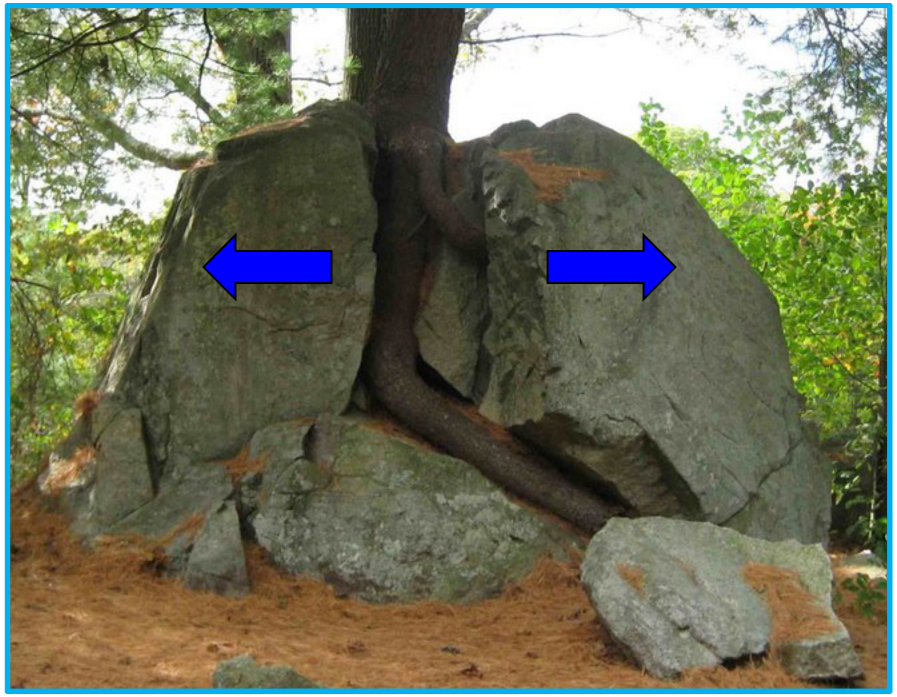
4) Hydration - Dehydration

$$\underset{\text{Goethite}}{2FeO\cdot OH} \longrightarrow \underset{\text{Hematite}}{Fe_2O_3} + \underset{\text{water}}{H_2O}$$

WEATHERING - BIOLOGICAL

1) Plant Roots

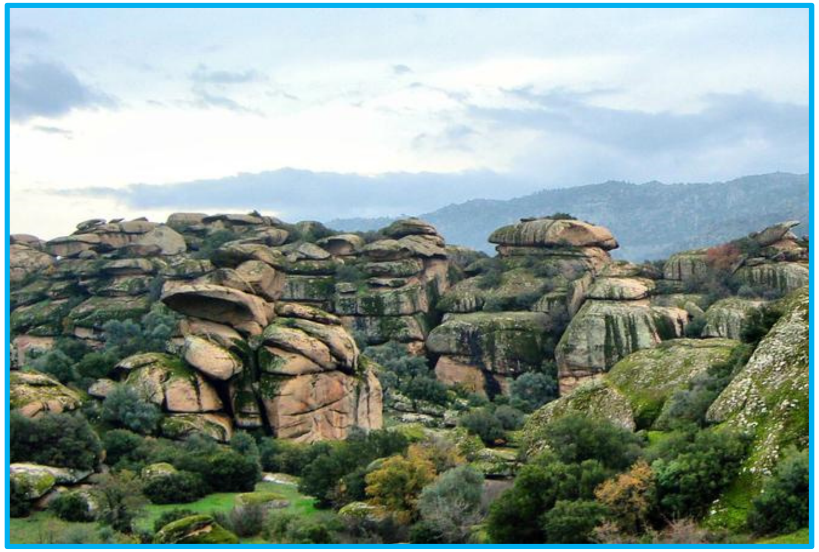
2) Organic Activities: algea, lichens, bacteria, movement of animals within rock (especially after completely weathered stage)



Modified from
http://toms-randomthoughts.blogspot.com/2010/12/rocks.html

www.shutterstock.com

WEATHERING - LANDSCAPES



1) Aydın - Turkey

2) Kapadokya - Turkey

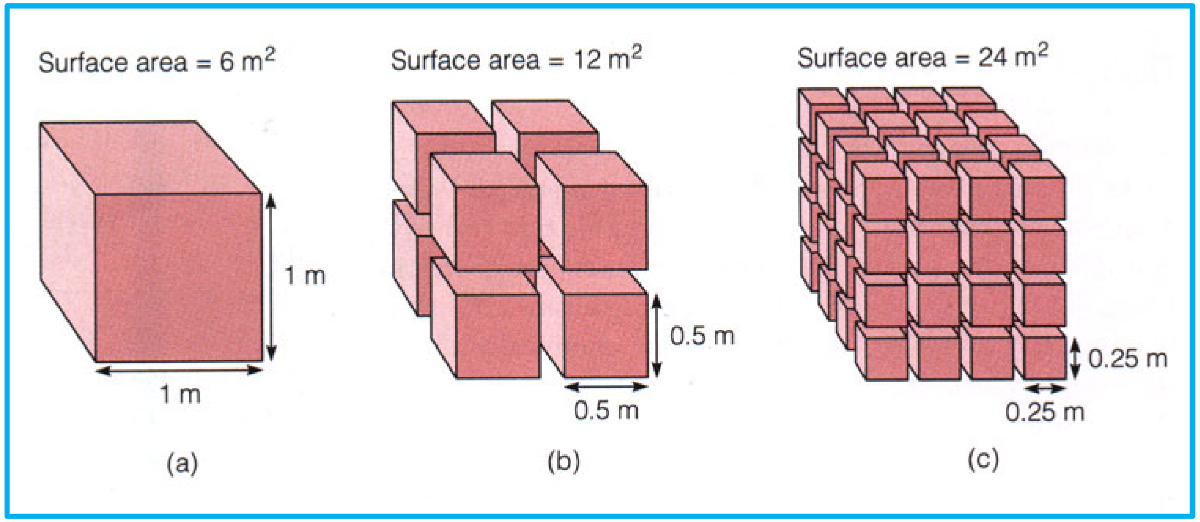
3) Antequera - Spain_The World Geography

4) Grand Canyon - USA_National Geographic

WEATHERING - INFLUENCING FACTORS

1) Rock Type:

2) Particle Size:



3) Climate:

4) Time & Exposure

5) Topography:

6) Vegetation & Animal activities

WEATHERING - IMPACTS

WHY ARE WE INTERESTED IN WEATHERING?

1) Soil Development

2) Slope Stability

3) Tunnelling

4) Geological Materials

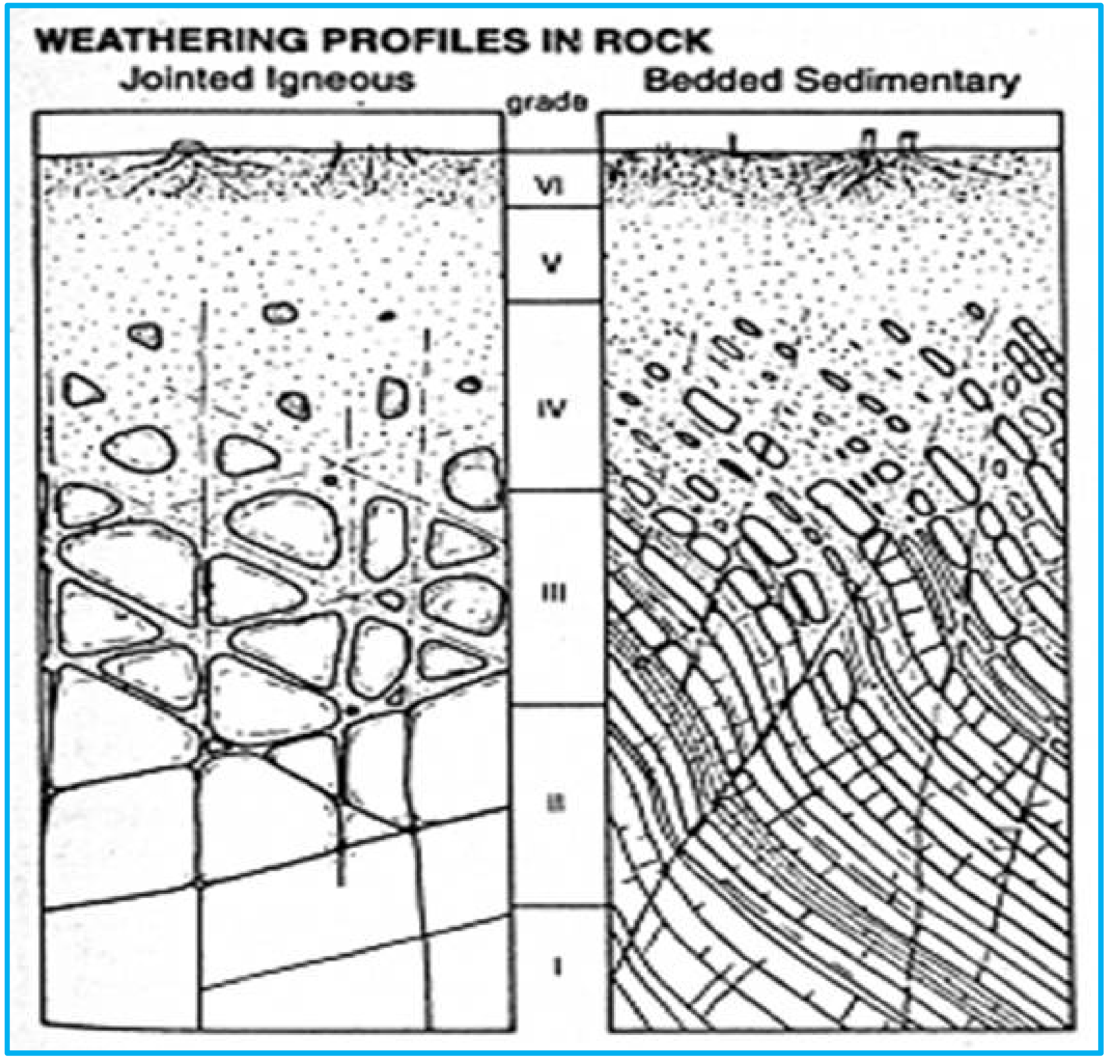
5) Agriculture etc.

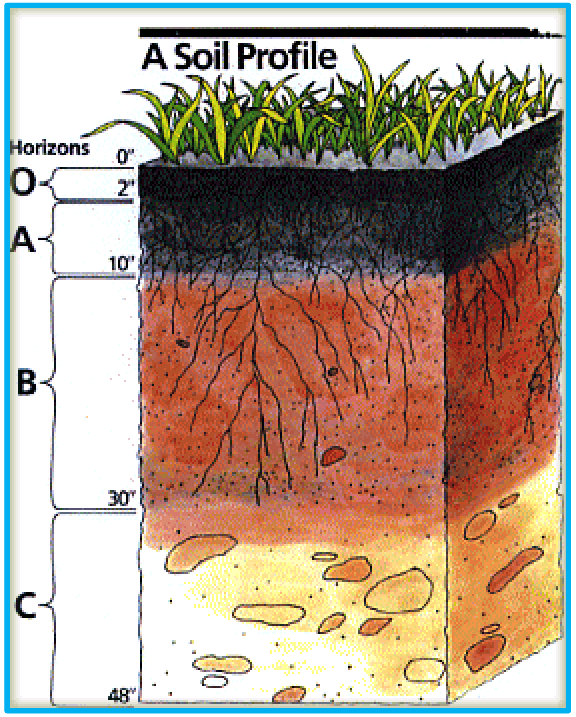
WEATHERING CLASSIFICATION

Weathering grades	
VI	Residual soil Soil derived by in situ weathering but having lost original texture and fabric
V	Completely weathered Considerably weakened . Slakes in water. Original texture apparent
IV	Highly weathered Large pieces can be broken by hand. Does not readily disaggregate (slake) when dry sample immersed in water.
III	Moderately weathered Considerably weakened, penetrative discoloration. Large pieces cannot be broken by hand
II	Slightly weathered Slight discoloration slight weakening
I	Fresh Unchanged from original state

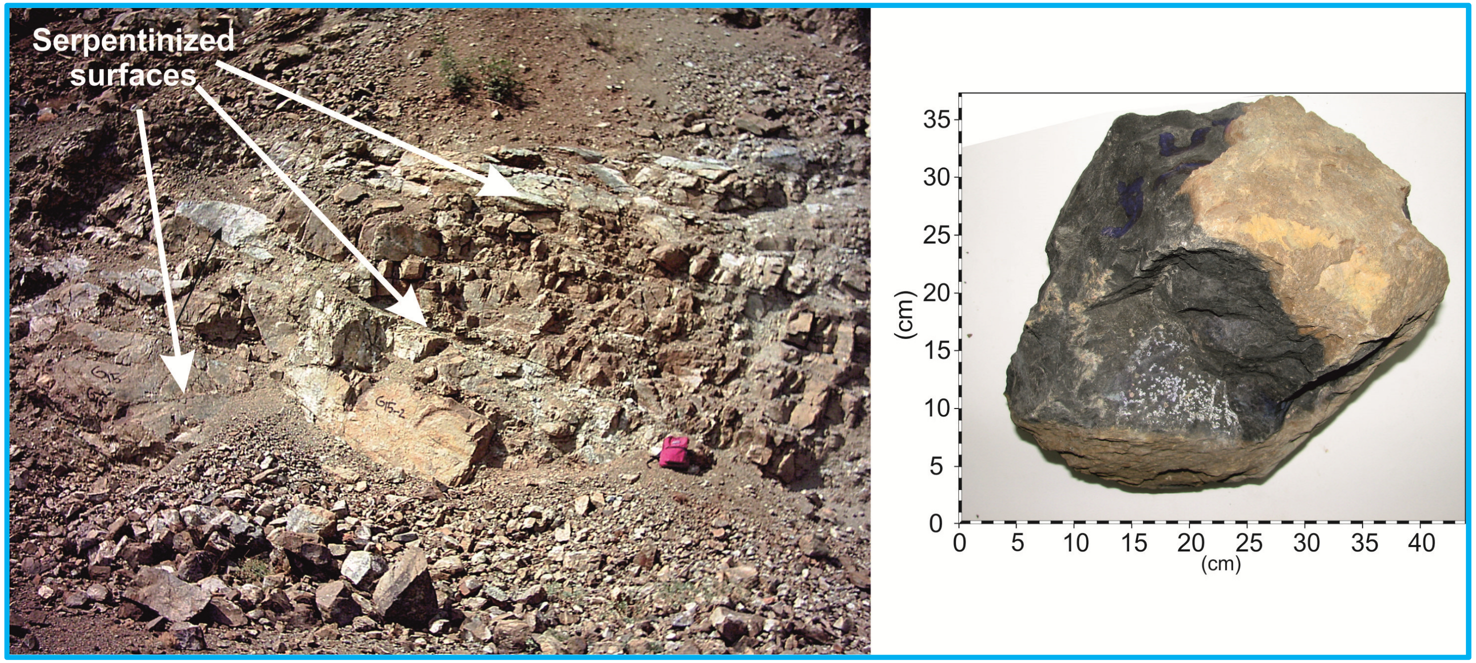
Simplified from ANON, 1995

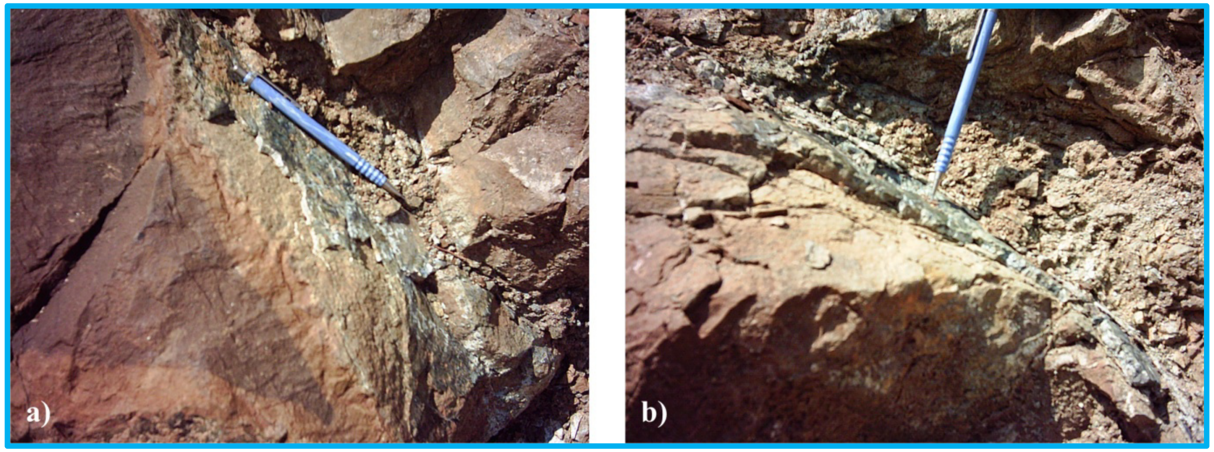
WEATHERING - PROFILES_Rock Based



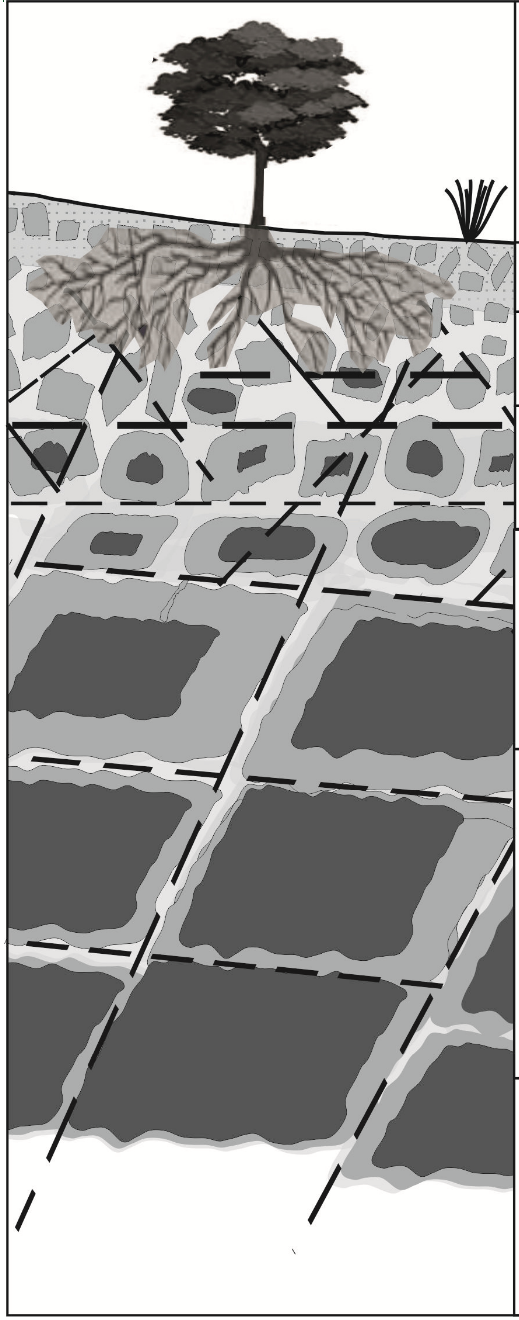


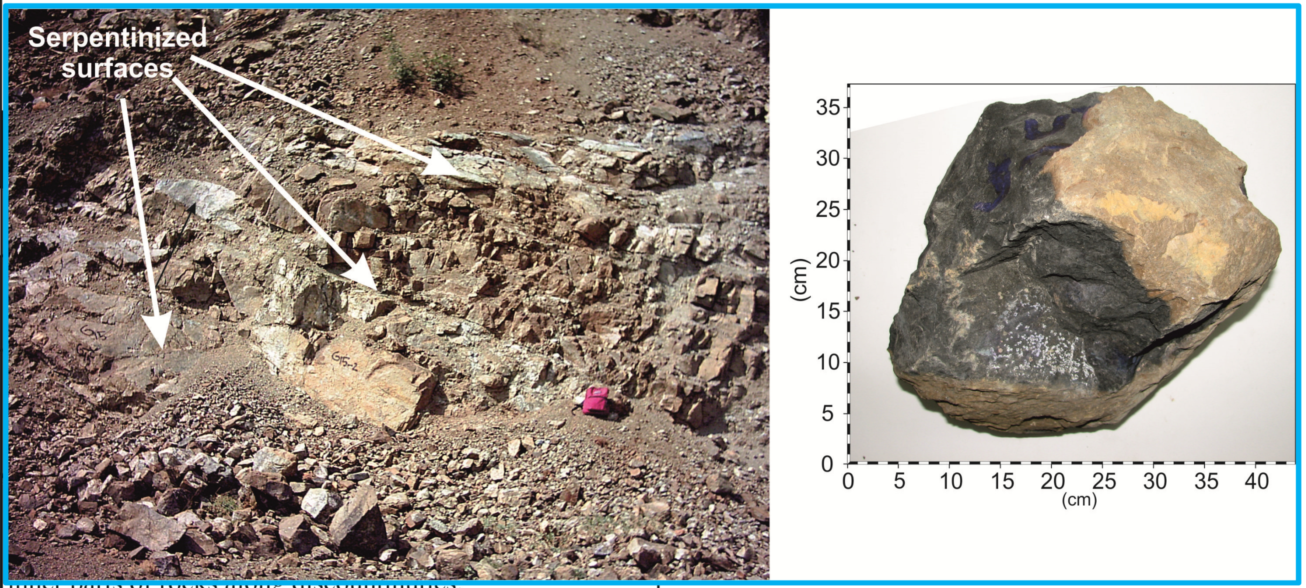
WEATHERING of ULTRAMAFIC ROCKS





WEATHERING PROFILE of ULTRAMAFIC ROCKS





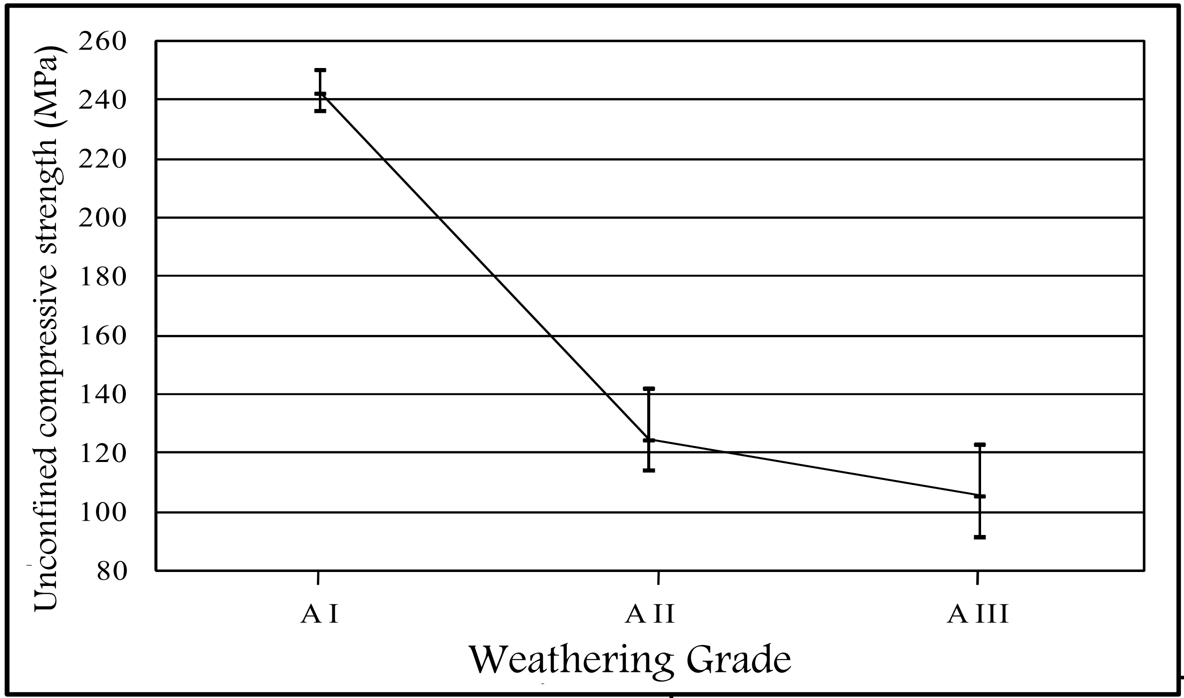
VI	
V	
IV	
III	inner parts of rocks along discountinuities. Can be broken by some hammer blows
II	Serpentinization along discountinuities. Discolouration due to iron oxide. Olivine and pyroxene minerals can be observed in the field. Many blows with a 5 kg hammer are needed to break the rock.
I	No sign of weathering. Slight discolouration along cracks. Olivines can be identified with naked eyes. Many hard blows are needed with a 5kg hammer to break a piece.

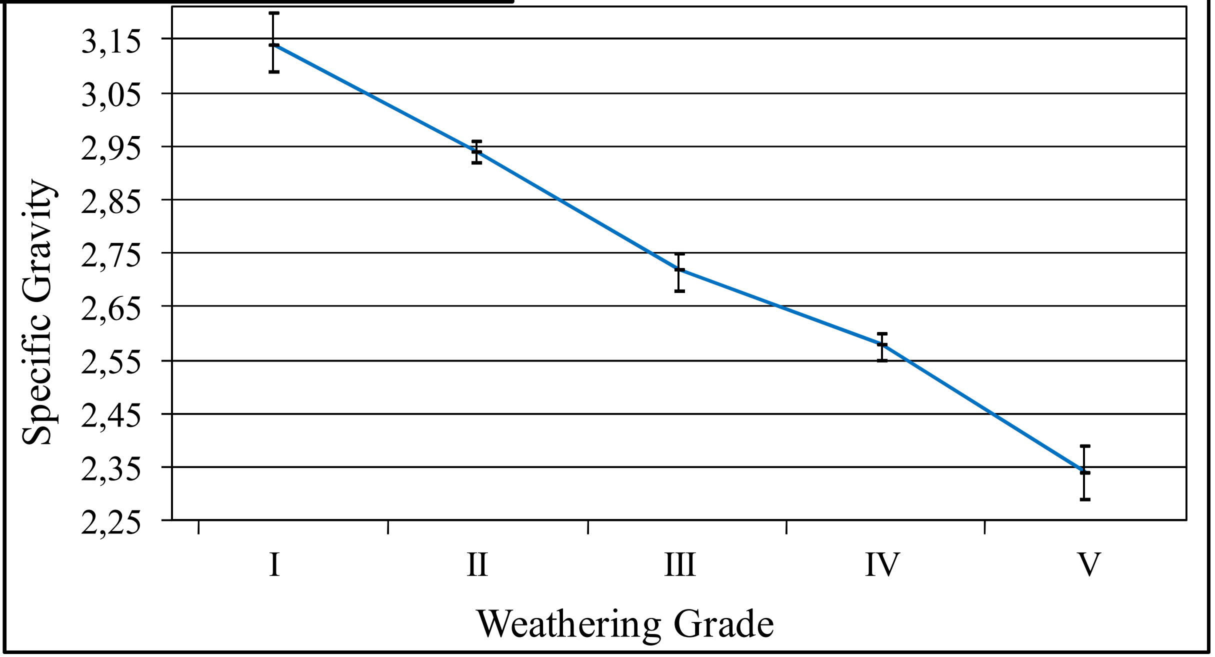
WEATHERING of ULTRAMAFIC ROCKS

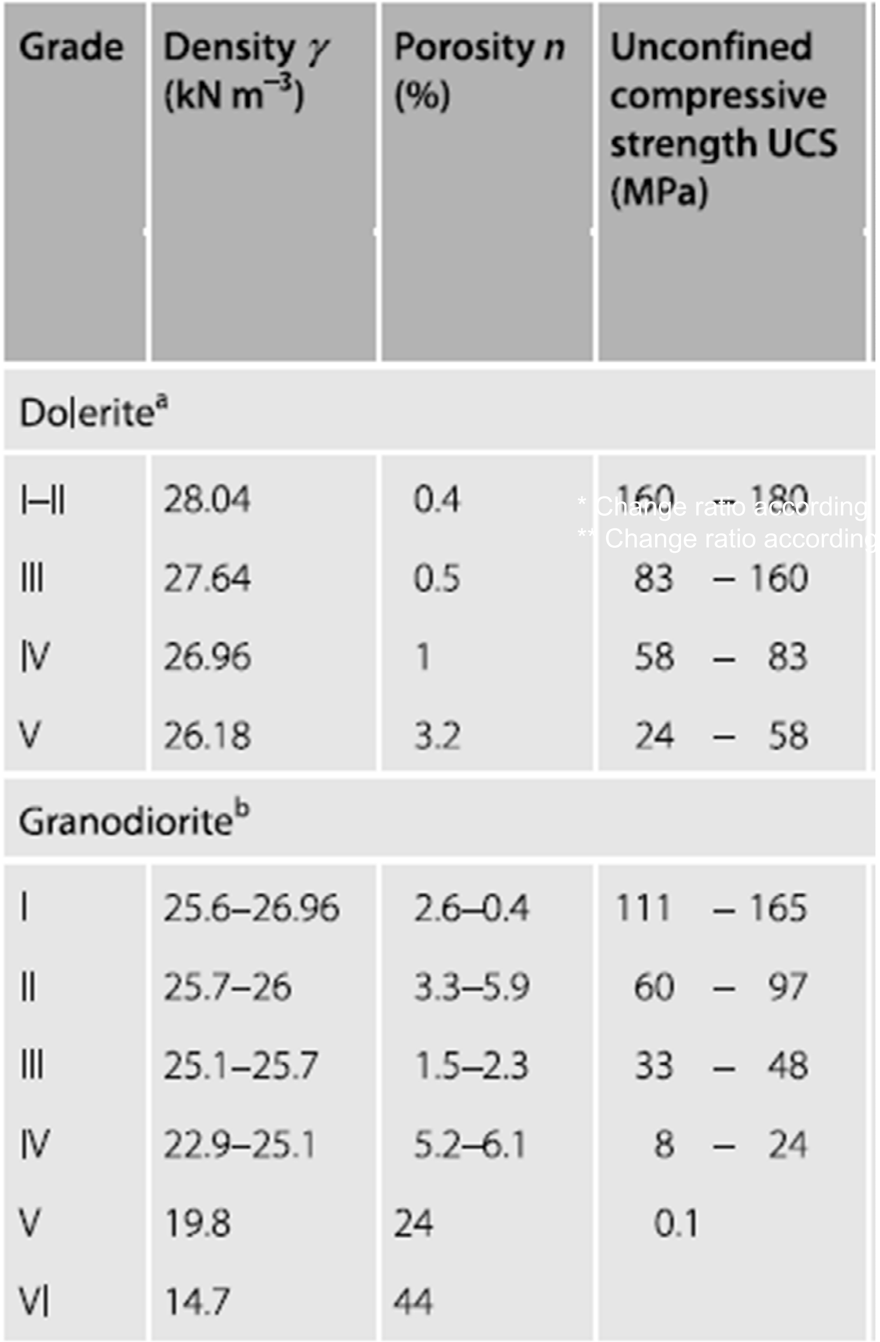
WEATHERING of ULTRAMAFIC ROCKS

WEATHERING

WEATHERING of ULTRAMAFIC ROCKS


Unconfined compressive strength (MPa)
260
240
220
200
180
160
140
120
100
80
A I
A II
A III
Weathering Grade


Specific Gravity
3,15
3,05
2,95
2,85
2,75
2,65
2,55
2,45
2,35
2,25
I
II
III
IV
V
Weathering Grade



Grade	Density γ (kN m^{-3})	Porosity n (%)	Unconfined compressive strength UCS (MPa)
Dolerite[a]			
I–II	28.04	0.4	160 – 180
III	27.64	0.5	83 – 160
IV	26.96	1	58 – 83
V	26.18	3.2	24 – 58
Granodiorite[b]			
I	25.6–26.96	2.6–0.4	111 – 165
II	25.7–26	3.3–5.9	60 – 97
III	25.1–25.7	1.5–2.3	33 – 48
IV	22.9–25.1	5.2–6.1	8 – 24
V	19.8	24	0.1
VI	14.7	44	

* Change ratio according

** Change ratio according

Due to weathering

- Colours of the rock changes
- Porosity increases
- Grains get weaker
- The bonds between grains weakens
- Increase of micro-cracks

Consequently,

- Rock loses the strength
- Permeability may subject to change
- Shear strength values decreases along discountinuities
- Specific gravity decreases

The depth of weathered zone
and
weathering grades should be determined

ENGINEERING PROPERTIES of ROCKS

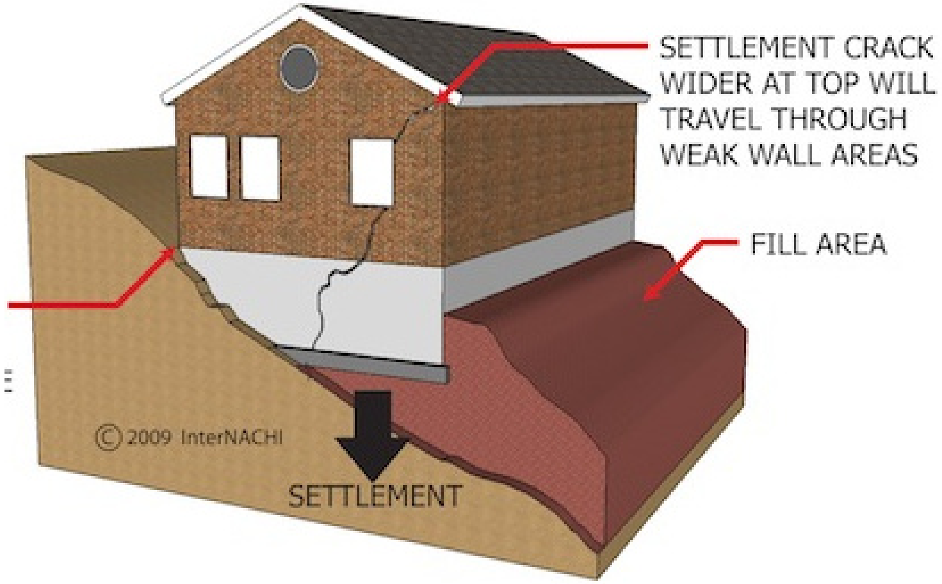
Rocks can be used as

1) Construction material
    a) Fill materail (highways, dams etc.)
    b) Industrial use as dimensional stones or aggregates

2) Foundation material
    a) Building, viaduct, dam etc.
    b) Tunnel, dam, slopes etc.

ENGINEERING PROPERTIES of ROCKS

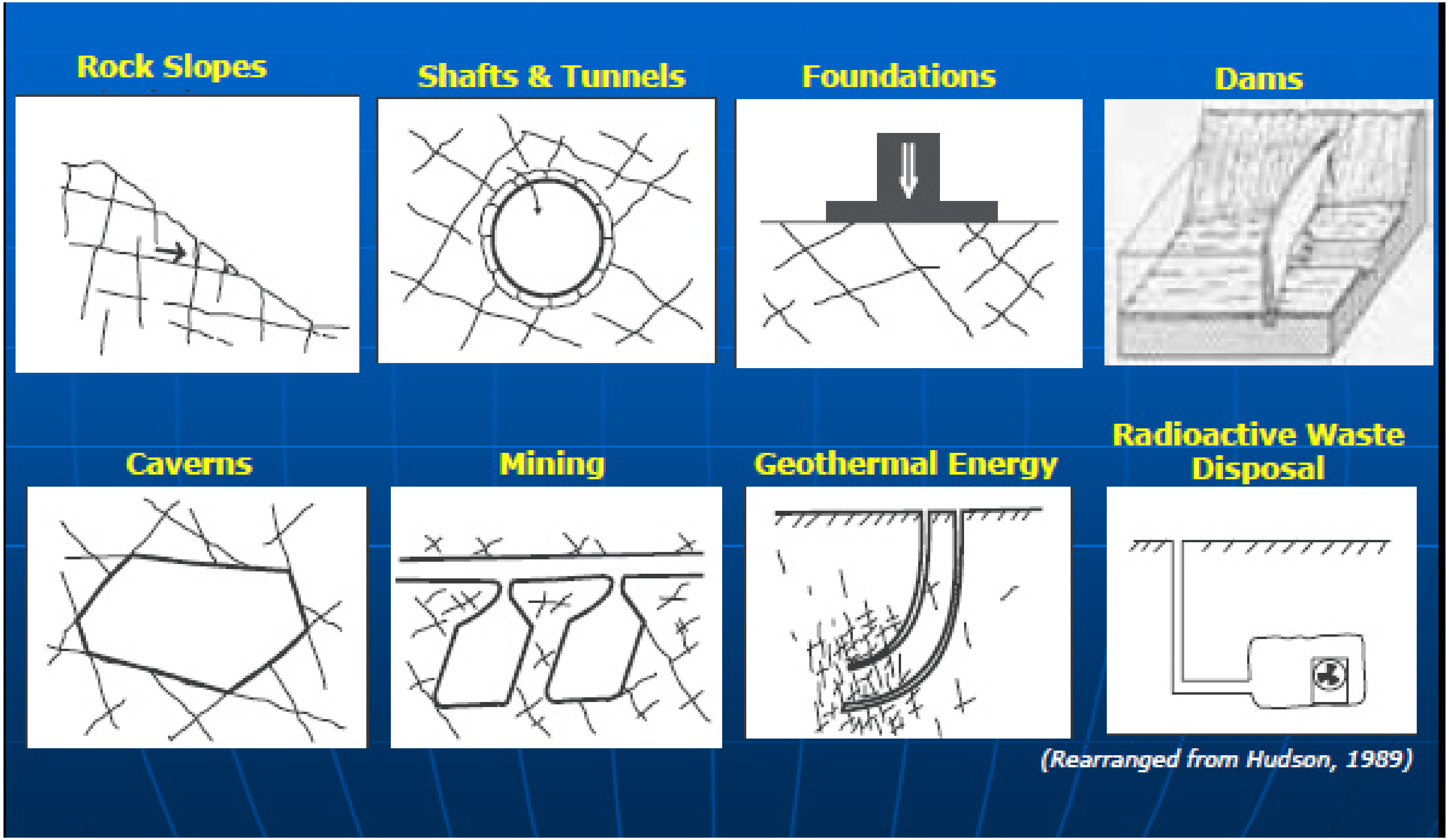
Construction material



ENGINEERING PROPERTIES of ROCKS

Natural stone, dimension stone, aggregate for varying purposes

ENGINEERING PROPERTIES of ROCKS



Rock Slopes

Shafts & Tunnels

Foundations

Dams

Caverns

Mining

Geothermal Energy

Radioactive Waste Disposal

(Rearranged from Hudson, 1989)

ENGINEERING PROPERTIES of ROCKS

ENGINEERING PROPERTIES of ROCKS

ENGINEERING PROPERTIES of ROCKS

1. Density, specific gravity, porosity, and void ratio
2. Rock strength
    - Definition of stress, normal and shear stress
    - Rock strength: tensile, shear, and compressive
    - Failure criteria: tensile, compressive
    - Failure criterion: shear failure

3) Discontinuity properties of rocks

ENGINEERING PROPERTIES of ROCKS

Rock are significant for two major reasons in engineering

1) Building materials for constructions
2) Foundations on/in which the constructions are build

The consideration of rocks as construction material the engineers concern about

a) Density (to some extent)
b) Strength
c) Durability (the ability of a material to resist degradation by mechanical or chemical agents)

For the consideration of rocks as the construction foundation the engineers concern about

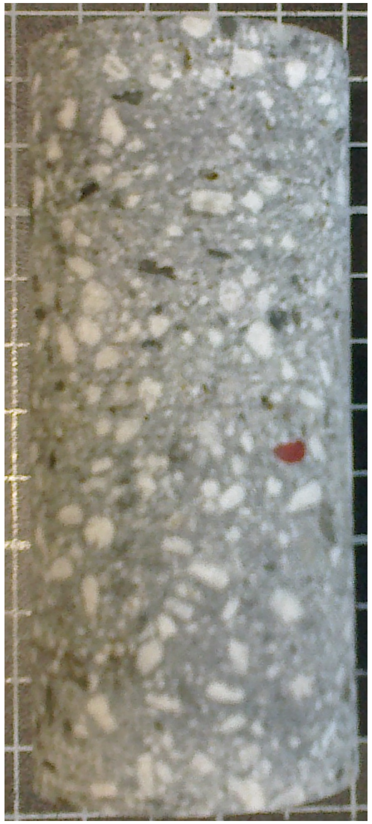
a) Density
b) Strength
c) Deformation
d) Discontinuity properties

ENGINEERING PROPERTIES of ROCKS

1. Density, specific gravity, porosity, and void ratio

Specific gravity

$$G_s = \frac{\rho_s}{\rho_w}$$



Specific Gravity is determined in crushed (powdered) specimen and specific gravities of most rock-forming minerals range from 2.5 to 2.8, although some heavier minerals are from 3 to 5 and/or higher

ENGINEERING PROPERTIES of ROCKS

Density, specific gravity, porosity, and void ratio

Density

$$\rho = \frac{m}{v}$$

Density is obtained from representative piece of the rock itself.

ENGINEERING PROPERTIES of ROCKS

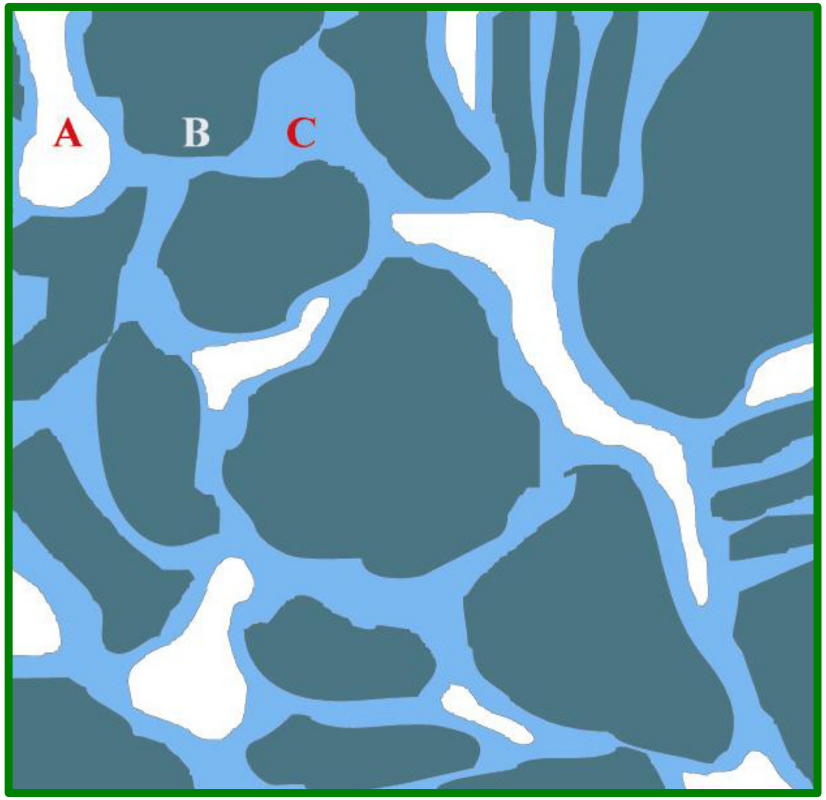
Density, specific gravity, porosity, and void ratio

Porosity

$$n = \frac{v_{pore}}{v_{total}}$$

Void ratio

$$e = \frac{v_{pore}}{v_{skeleton}}$$



Schematic representation of porous medium indicating relationship between air (A), solid (B) and water (C).

ENGINEERING PROPERTIES of ROCKS

Density, specific gravity, porosity, and void ratio

Porosity

$$n = \frac{v_{pore}}{v_{total}}$$

Void ratio

$$e = \frac{v_{pore}}{v_{solid}}$$

Porosity depends largely on rock origin. Slowly cooling igneous magma results in relatively nonporous rock, whereas rapid cooling associated with escaping gases yields a porous mass.

Sedimentary rocks depend on amount of cementing materials present and on size, grading, and packing of particles.

ENGINEERING PROPERTIES of ROCKS

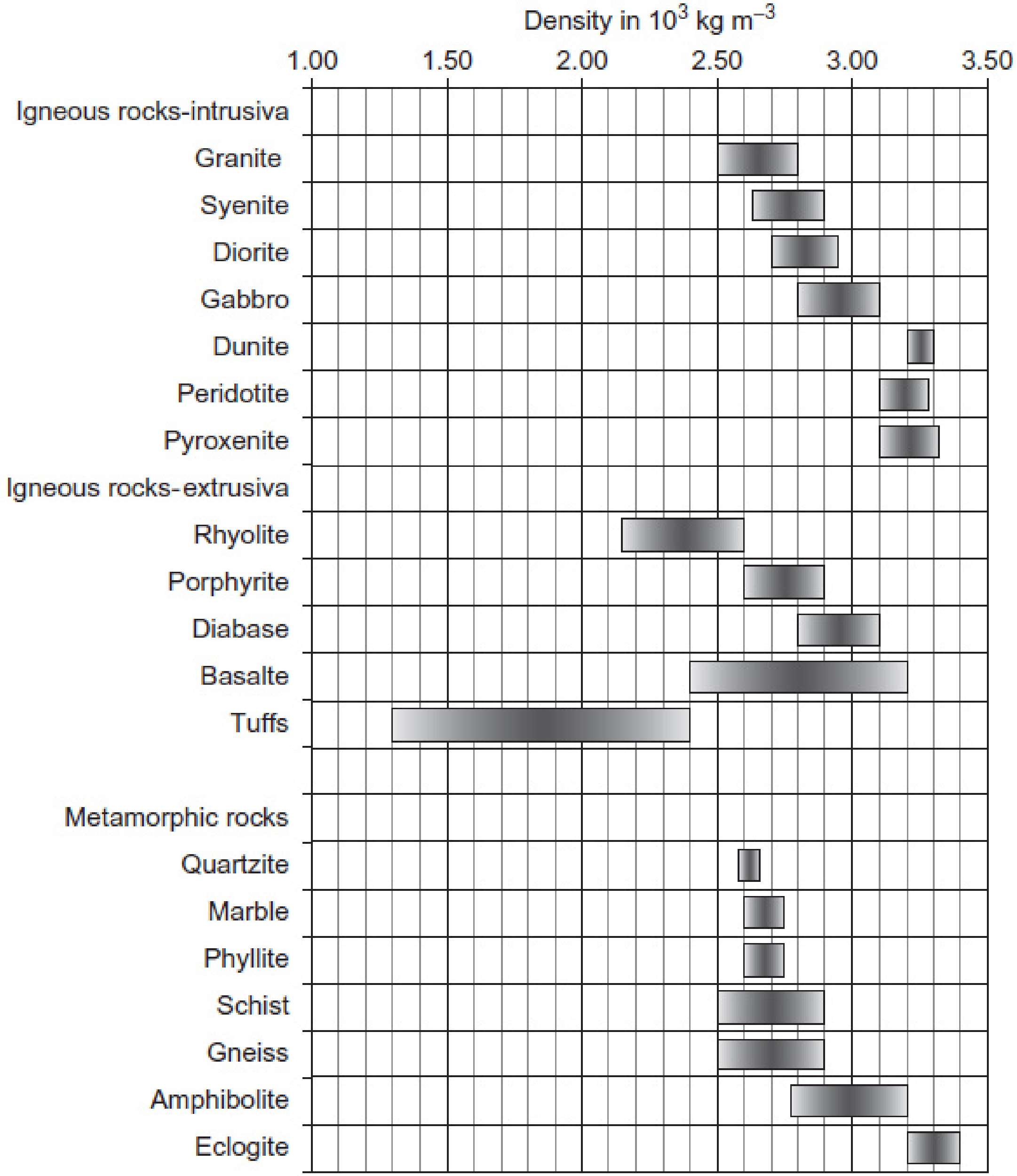


FIGURE 4.3 Mean range of density for igneous and metamorphic rocks.

ENGINEERING PROPERTIES of ROCKS

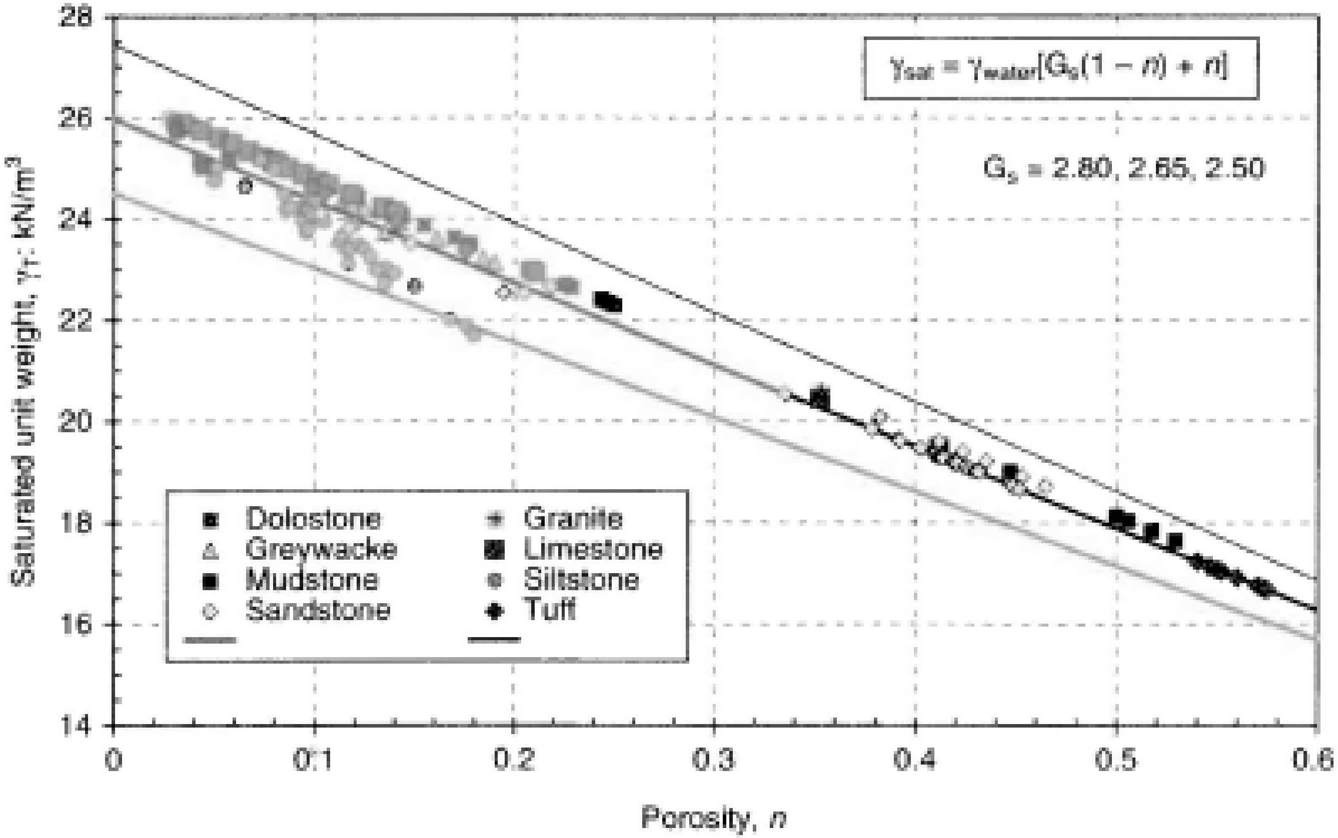


Fig. 9.4 Saturated rock unit weight in terms of porosity and specific gravity

ENGINEERING PROPERTIES of ROCKS

The limits of the value of porosity

$$\max(n) = \frac{v_{pore}}{v_{total}} = 1$$

$$\min(n) = \frac{v_{pore}}{v_{total}} = 0$$

The limits of the value of void ratio

$$\max(e) = \frac{v_{pore}}{v_{solid}} \rightarrow \infty$$

$$\min(e) = \frac{v_{pore}}{v_{solid}} = 0$$

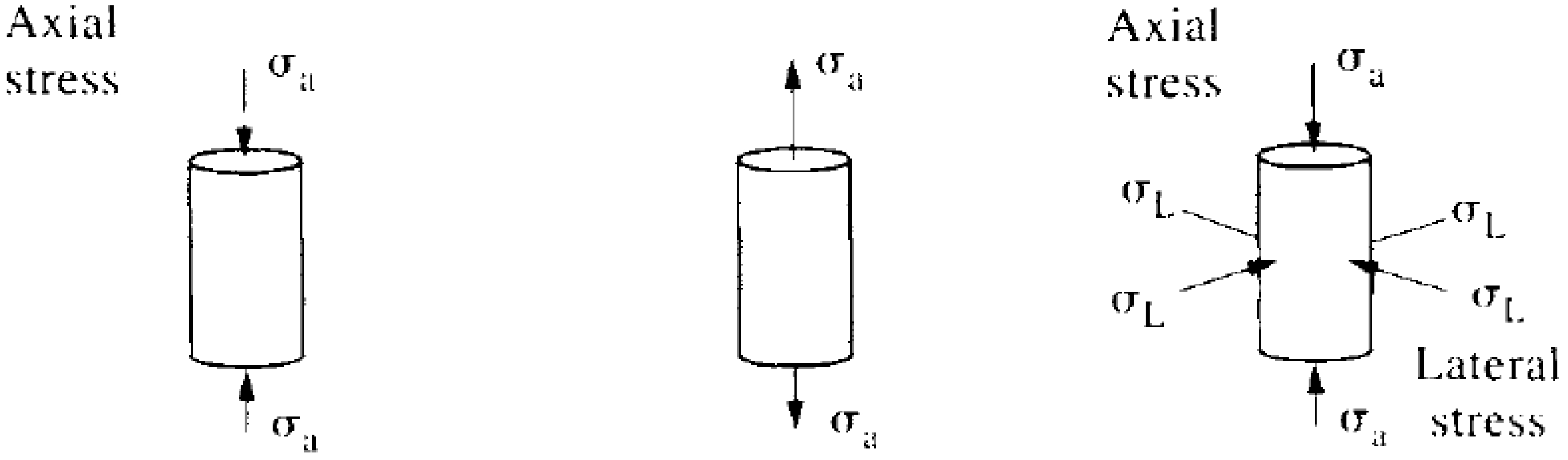
$$n = \frac{e}{1+e}$$

$$e = \frac{n}{1-n}$$

ENGINEERING PROPERTIES of ROCKS

2. Rock strength,

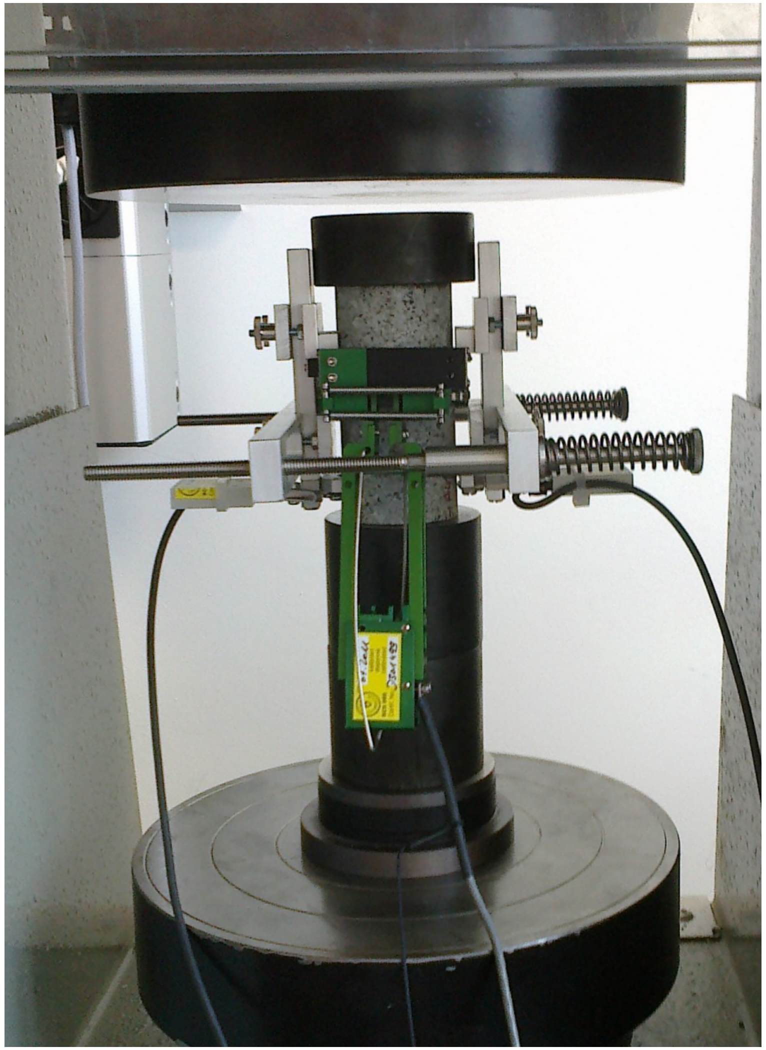
is the peak stress to break down the rock sample *in a uniaxial or triaxial* compression process (modified from Farmer, 1982)

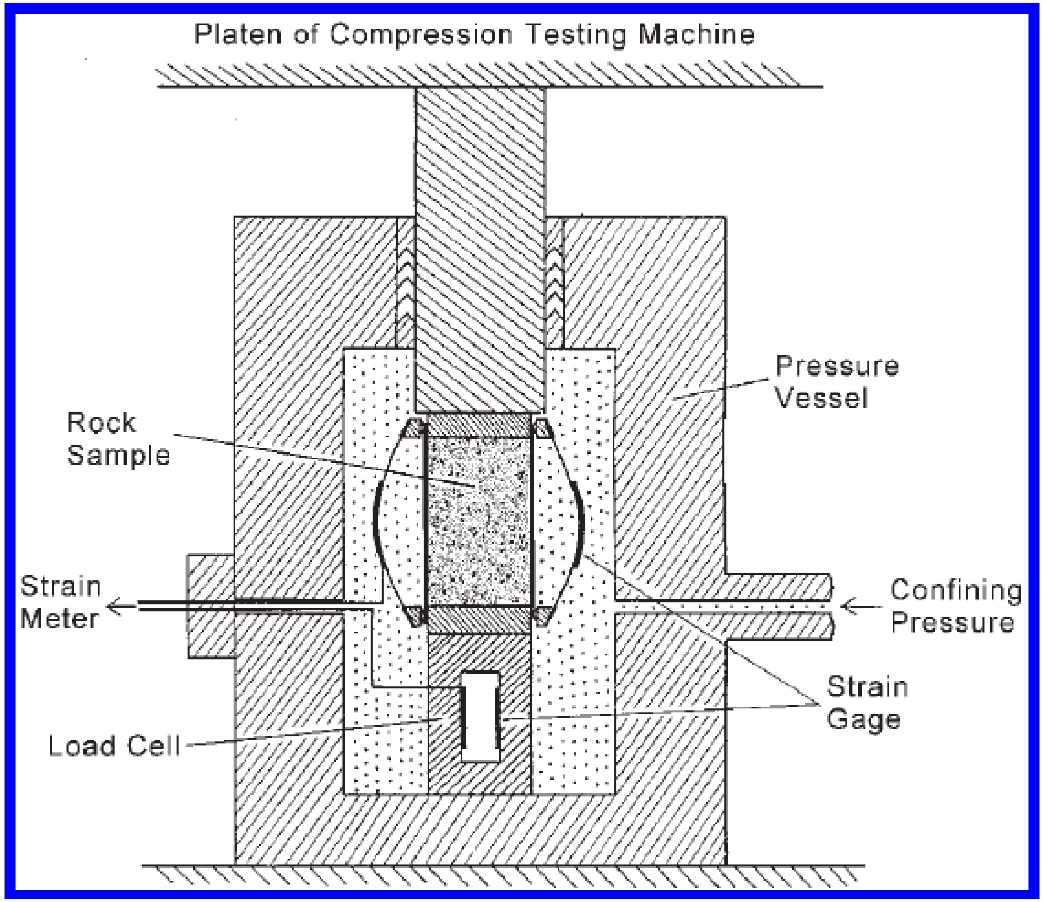


Uniaxial compression
Uniaxial tension
Triaxial compression

ENGINEERING PROPERTIES of ROCKS

Rock strength, *is the peak stress* to break down the rock sample *in a uniaxial or triaxial* compression process (modified from Farmer, 1982)

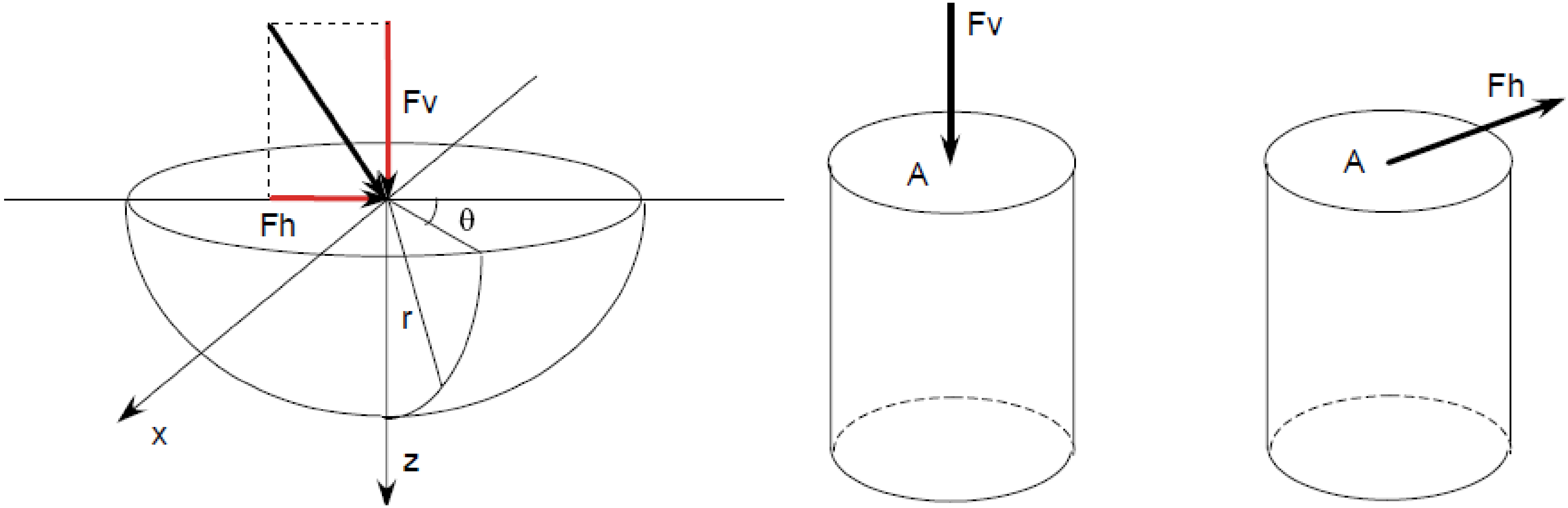




ENGINEERING PROPERTIES of ROCKS

What is stress?

Stress is the force per area applied on the object



σ_n = normal stress

σ_s = shear stress

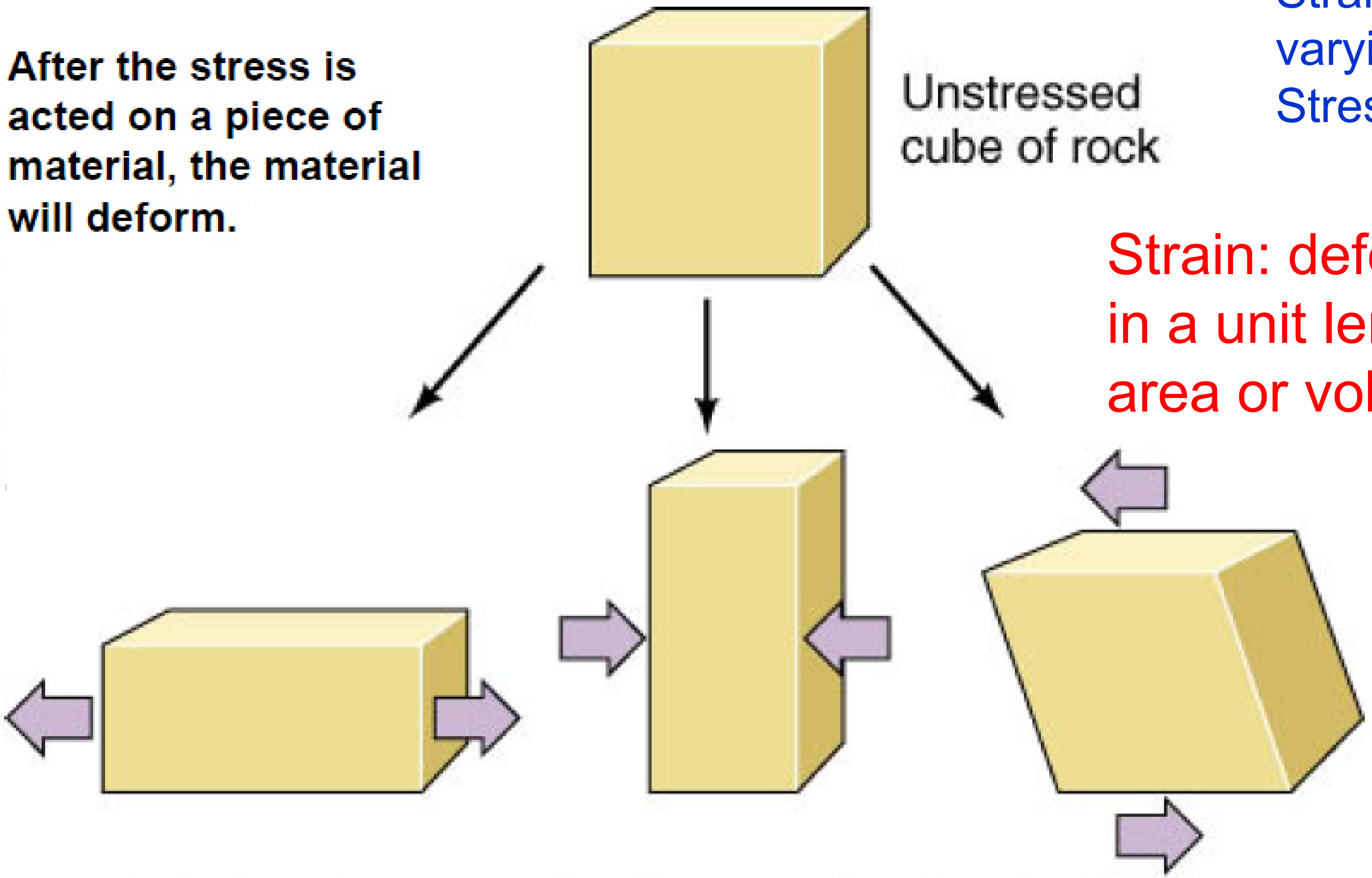
$$\sigma_n = \frac{F_v}{A} \qquad \sigma_s = \frac{F_h}{A}$$

ENGINEERING PROPERTIES of ROCKS

Strain types under varying
Stress directions

After the stress is acted on a piece of material, the material will deform.

Strain: deformation in a unit length, area or volume



A Tensional stress → Tensional strain

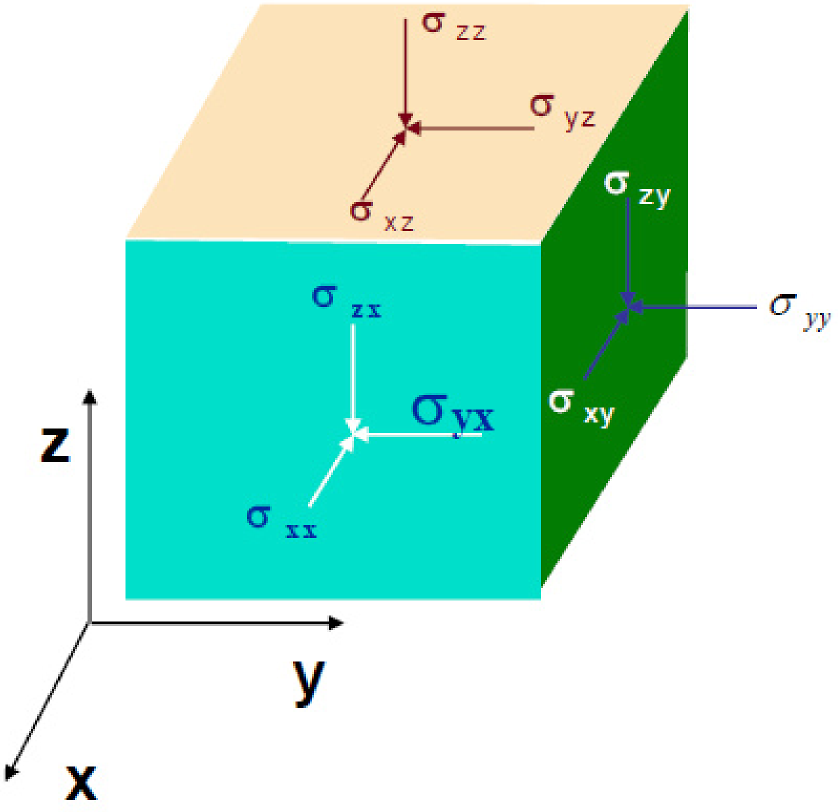
B Compressional stress → Compressive strain

C Shear stress → Shear strain

ENGINEERING PROPERTIES of ROCKS

Actually, since the force is a vector, and can act on any direction, it can be dissolved into 3 orthogonal directions (e.g., x, y, z, in Cartesian coordinate); a surface in or on the solid can face any direction, too. The normal of that surface is also a function of x, y, z. Consequently, a complete stress should be a tensor with 9 elements.

$$\boldsymbol{\sigma} = \begin{bmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{bmatrix}$$



ENGINEERING PROPERTIES of ROCKS

Rock strength

As the stress can be divided into normal stress (compressive and tensile) and shear stress. Similiarly the rock should also have;

compressive strength (CS)

shear strength (τ_0)

tensile strength (T)

For the same kind of rock usually

$$CS > \tau_0 > T$$

ENGINEERING PROPERTIES of ROCKS

Rock strength and failure criteria

However, the shear failure is not as simple as the tensile and compressive failure criteria. (Because it involves both normal and shear stresses). Laboratory experiments in rock mechanics shows that the shear failure is more complicated and follows the Coulomb Criterion stated as

$$\tau > \tau_0 + \mu\sigma$$

The Coulomb Criterion shows that shear stress tends to cause failure across a plane, it is resisted by the sum of the shear strength (cohesion) of the material and a constant times the normal stress across the plane. This constant is the coefficient of friction. When the shear stress is equal to or greater than that sum, shear failure occurs.

ENGINEERING PROPERTIES of ROCKS

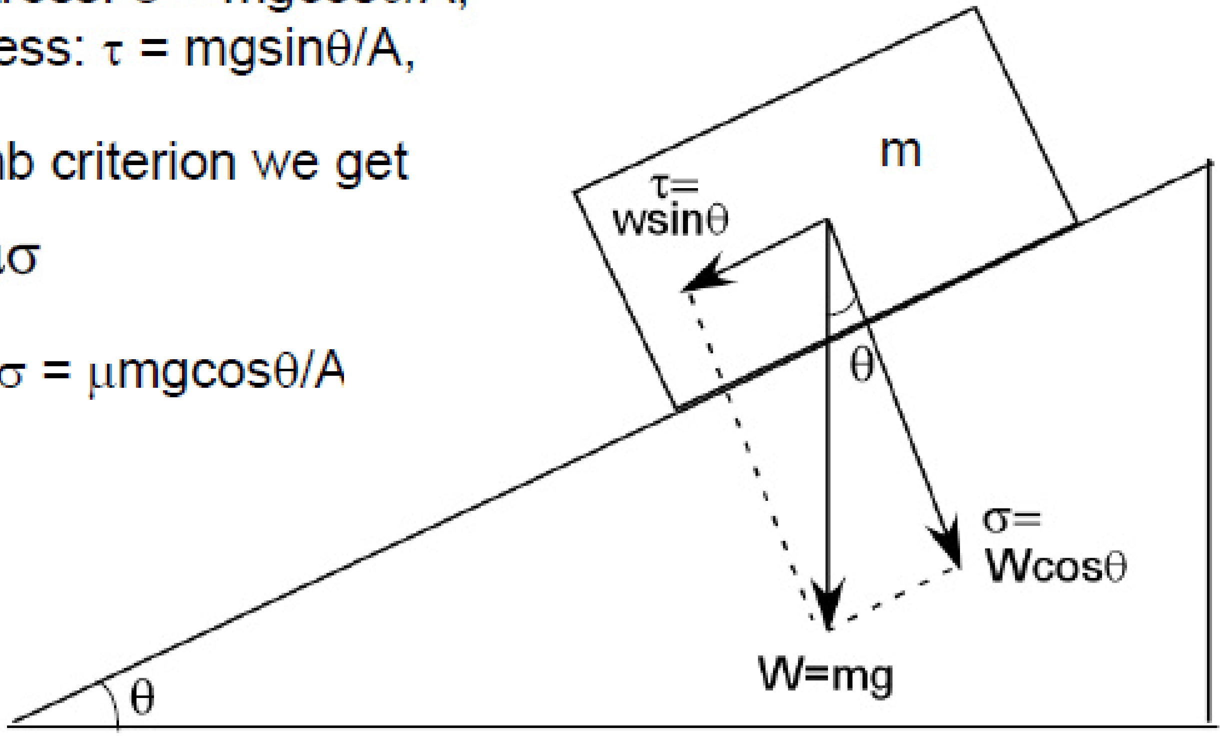
Let's illustrate the Coulomb criterion for shear failure by a very common test (see the sketch below). First, assume that there is no inherent shear strength (cohesion) between the block (with a mass of m) and the underlying slope. The contact area is A, and the slope on which the block is possible sliding has a dip angle of θ. We have the following relations:

cohesion: $\tau_0 = 0$,
normal stress: $\sigma = mg\cos\theta/A$,
shear stress: $\tau = mg\sin\theta/A$,

Put into the Coulomb criterion we get

$$\tau > \tau_0 + \mu\sigma$$

$$mg\sin\theta/A = \tau_0 + \mu\,\sigma = \mu mg\cos\theta/A$$



ENGINEERING PROPERTIES of ROCKS

Rock strength and failure criteria

Tensile failure occur

$$|\sigma| > T$$

Compressive failure occur

$$|\sigma| > CS$$

Shear failure occur (Coulomb criterion)

$$\tau > \tau_0 + \mu\sigma$$

ENGINEERING PROPERTIES of ROCKS

Strain

Change in shape or size of an object in response to an applied stress.

= *Deformation*

Three Types of Strain

- **Elastic**
- **Ductile (Plastic)**
- **Brittle (Rupture)**

Elastic Deformation

A temporary change in shape or size that is recovered when the applied stress is removed.

If the response of the material to the load/unload is instantaneous, it is a pure elastic material;

If the response of the material to the load/unload needs finite time, it is a visco-elastic material;

Ductile (Plastic) Deformation

- **A permanent change in shape or size that is not recovered when the stress is removed.**

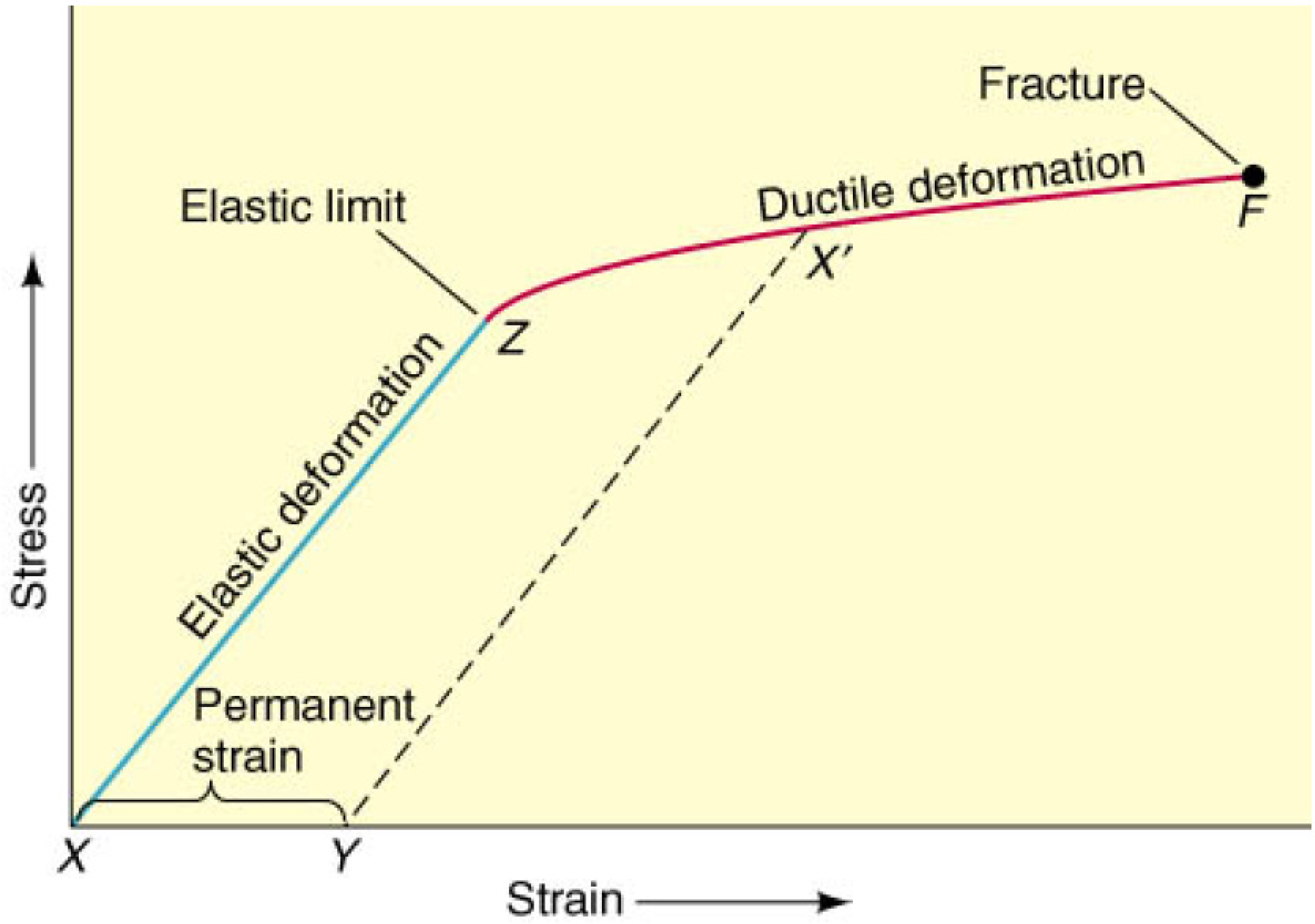
- **i.e. it flows or bends**

ENGINEERING PROPERTIES of ROCKS

BRITTLE DEFORMATION

The failure of a specimen without any visible plastic deformation

ENGINEERING PROPERTIES of ROCKS

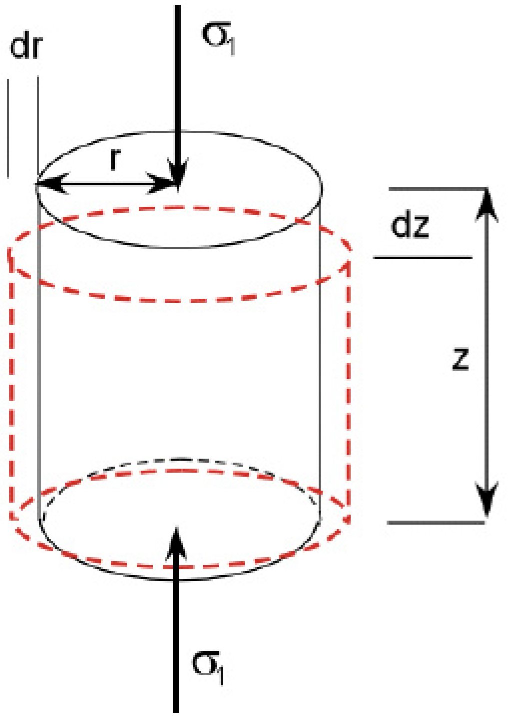


ENGINEERING PROPERTIES of ROCKS

Young's modulus E

Young's modulus is the stress needed to compress the solid to shorten in a unit strain.

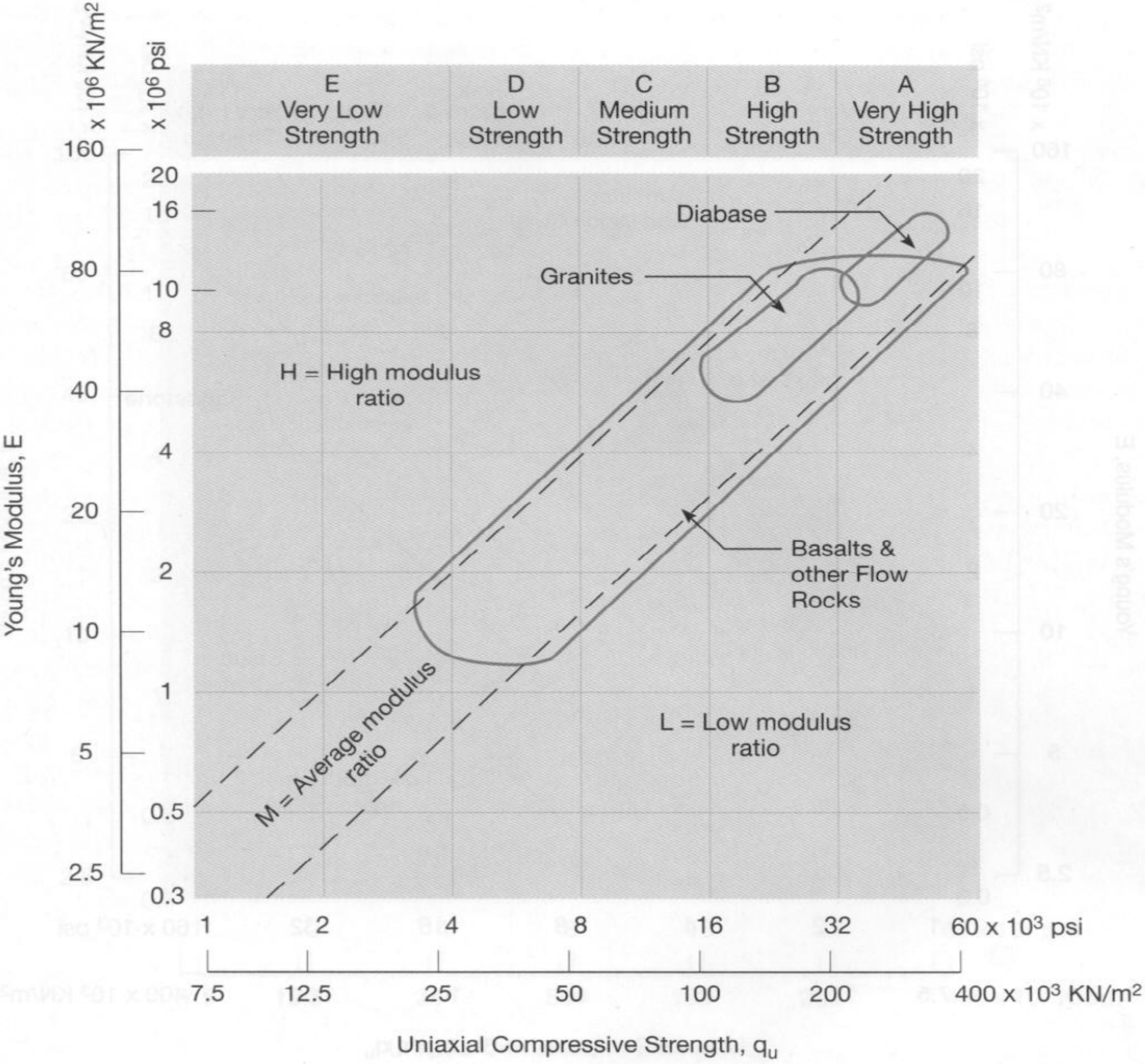
$$E = \frac{\sigma_1}{\Delta z / z}$$



Poisson's ratio ν

Poisson's measures the relativity of the expansion in the lateral directions and compression in the direction in which the uni-axial compression applies.

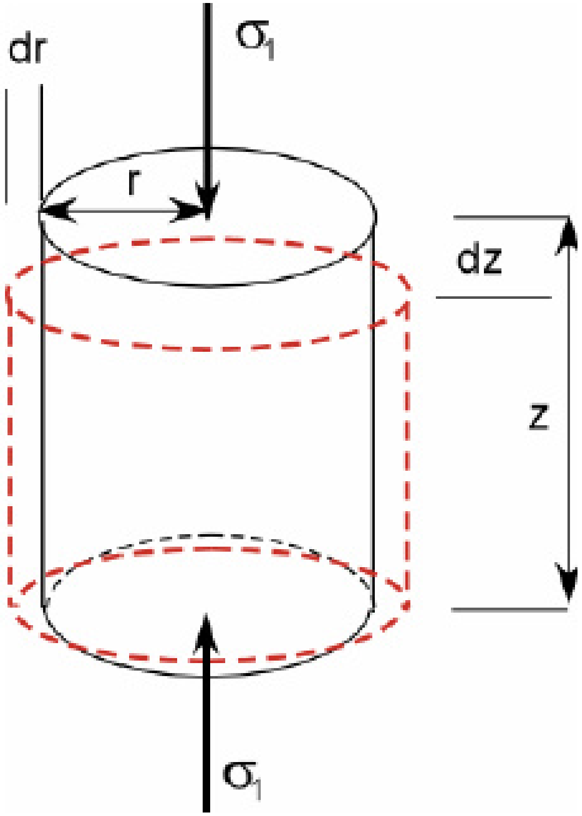
$$\nu = -\frac{\Delta r / r}{\Delta z / z}$$


x 10⁶ KN/m²
x 10⁶ psi
E
Very Low
Strength
D
Low
Strength
C
Medium
Strength
B
High
Strength
A
Very High
Strength
160
80
40
20
10
5
2.5
20
16
10
8
4
2
1
0.5
0.3
Young's Modulus, E
Diabase
Granites
H = High modulus ratio
M = Average modulus ratio
L = Low modulus ratio
Basalts & other Flow Rocks
1
2
4
8
16
32
60 x 10³ psi
7.5
12.5
25
50
100
200
400 x 10³ KN/m²
Uniaxial Compressive Strength, q_u

ENGINEERING PROPERTIES of ROCKS

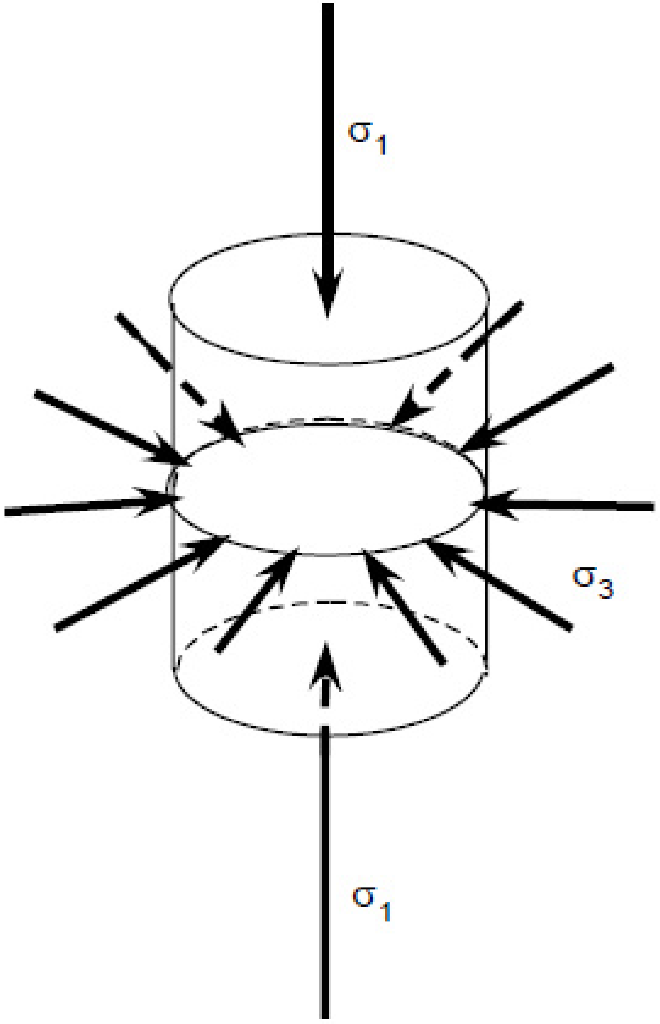
Uni-axial Compression Test

In a uni-axial compression test, the direction of the load is called the maximum principal direction and there are no other loads (forces) working on other direction.



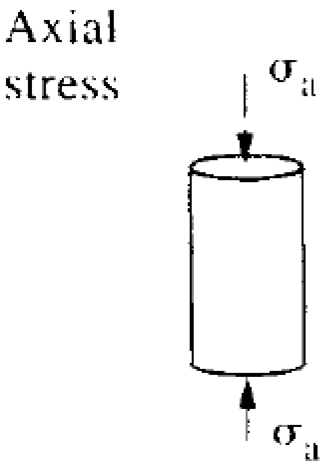
ENGINEERING PROPERTIES of ROCKS

In a triaxial compression test, the direction of the load is called the maximum principal direction and the direction of the confining pressure applied is the minimum principal direction.

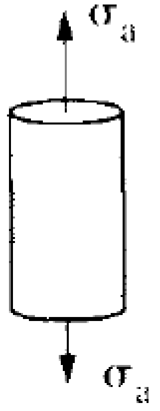


triaxial

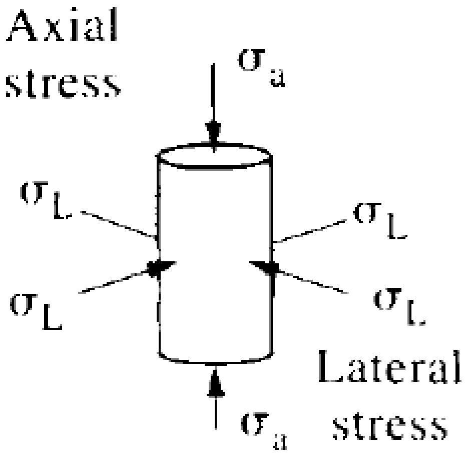
ENGINEERING PROPERTIES of ROCKS



Uniaxial compression

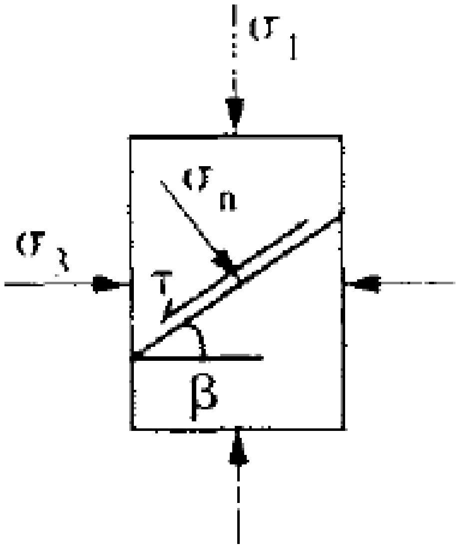


Uniaxial tension



Triaxial compression

Rock fails at a critical combination of normal and shear stresses:



$$|\tau| = \tau_0 + \mu\sigma_n$$

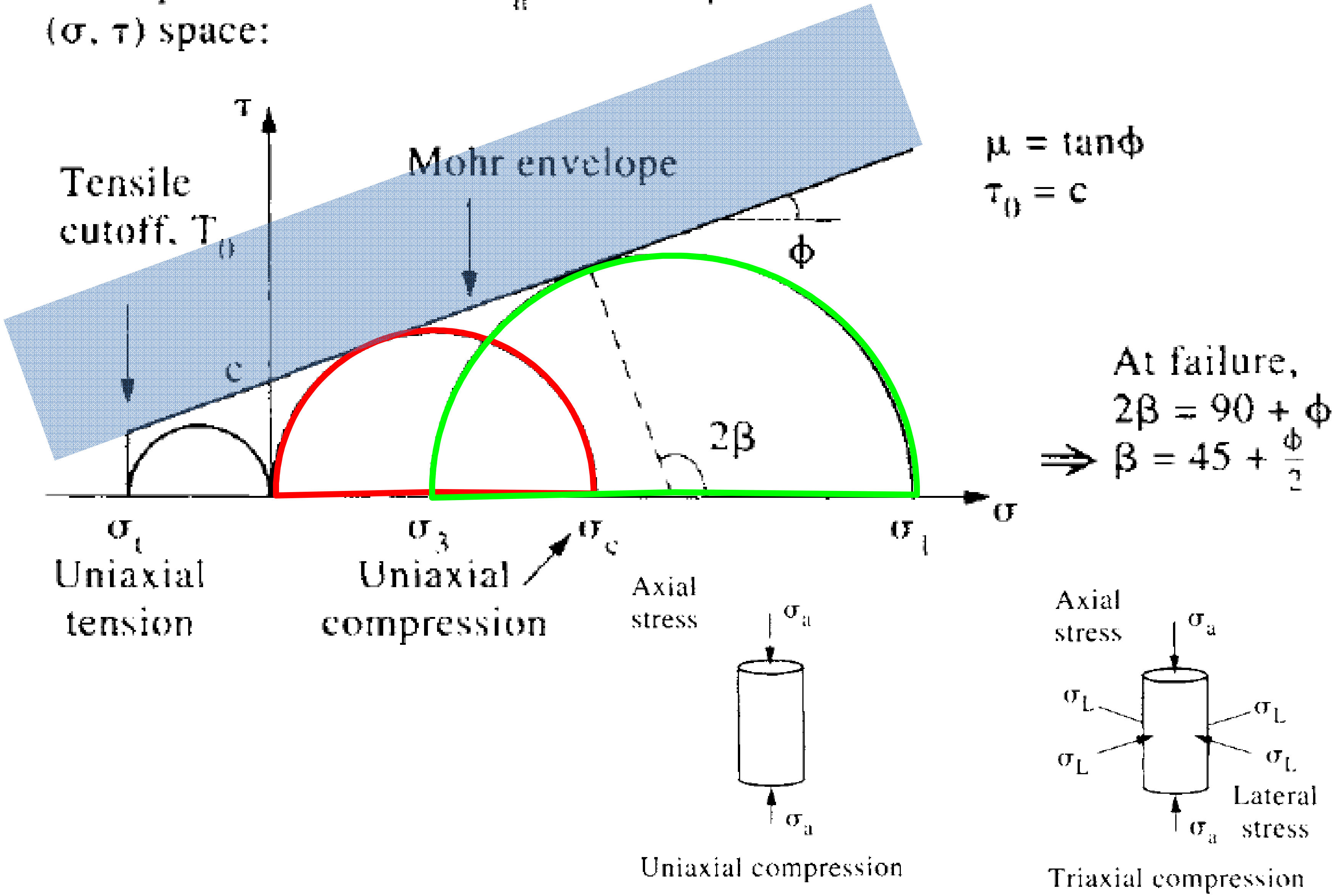
τ_0 = cohesion μ = coeff. of friction

$$|\tau| = \frac{1}{2}(\sigma_1 - \sigma_3)\sin 2\beta$$

$$\sigma_n = \frac{1}{2}(\sigma_1 + \sigma_3) + \frac{1}{2}(\sigma_1 - \sigma_3)\cos 2\beta$$

ENGINEERING PROPERTIES of ROCKS

The equation for $|\tau|$ and σ_n are the equations of a circle in (σ, τ) space:



$\mu = \tan\phi$

$\tau_0 = c$

At failure,

$2\beta = 90 + \phi$

$\Rightarrow \beta = 45 + \frac{\phi}{2}$

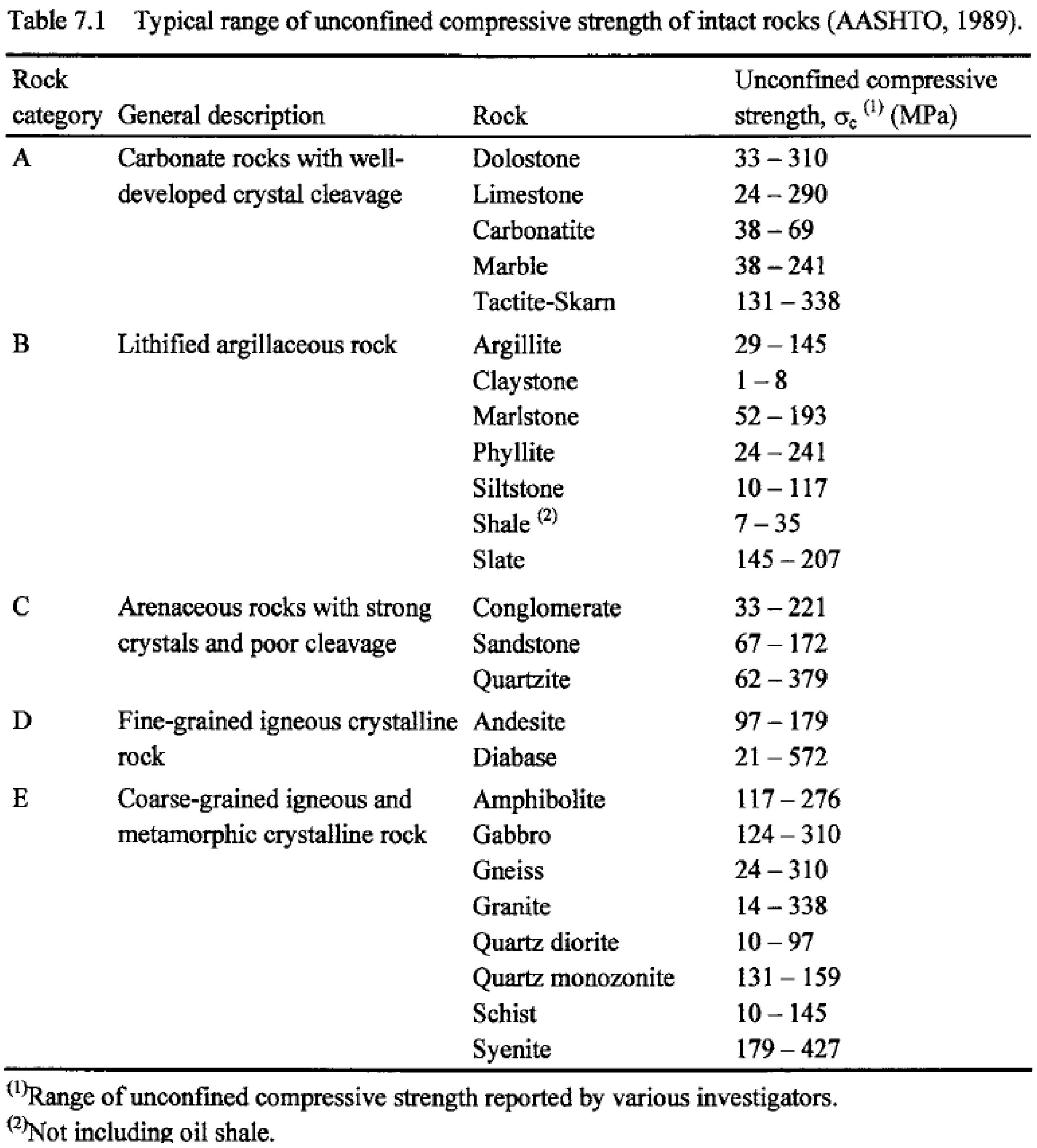


Table 7.1 Typical range of unconfined compressive strength of intact rocks (AASHTO, 1989).

Rock category	General description	Rock	Unconfined compressive strength, σ_c (1) (MPa)
A	Carbonate rocks with well-developed crystal cleavage	Dolostone	33 – 310
		Limestone	24 – 290
		Carbonatite	38 – 69
		Marble	38 – 241
		Tactite-Skarn	131 – 338
B	Lithified argillaceous rock	Argillite	29 – 145
		Claystone	1 – 8
		Marlstone	52 – 193
		Phyllite	24 – 241
		Siltstone	10 – 117
		Shale (2)	7 – 35
		Slate	145 – 207
C	Arenaceous rocks with strong crystals and poor cleavage	Conglomerate	33 – 221
		Sandstone	67 – 172
		Quartzite	62 – 379
D	Fine-grained igneous crystalline rock	Andesite	97 – 179
		Diabase	21 – 572
E	Coarse-grained igneous and metamorphic crystalline rock	Amphibolite	117 – 276
		Gabbro	124 – 310
		Gneiss	24 – 310
		Granite	14 – 338
		Quartz diorite	10 – 97
		Quartz monozonite	131 – 159
		Schist	10 – 145
		Syenite	179 – 427

(1)Range of unconfined compressive strength reported by various investigators.

(2)Not including oil shale.

ENGINEERING PROPERTIES of ROCKS

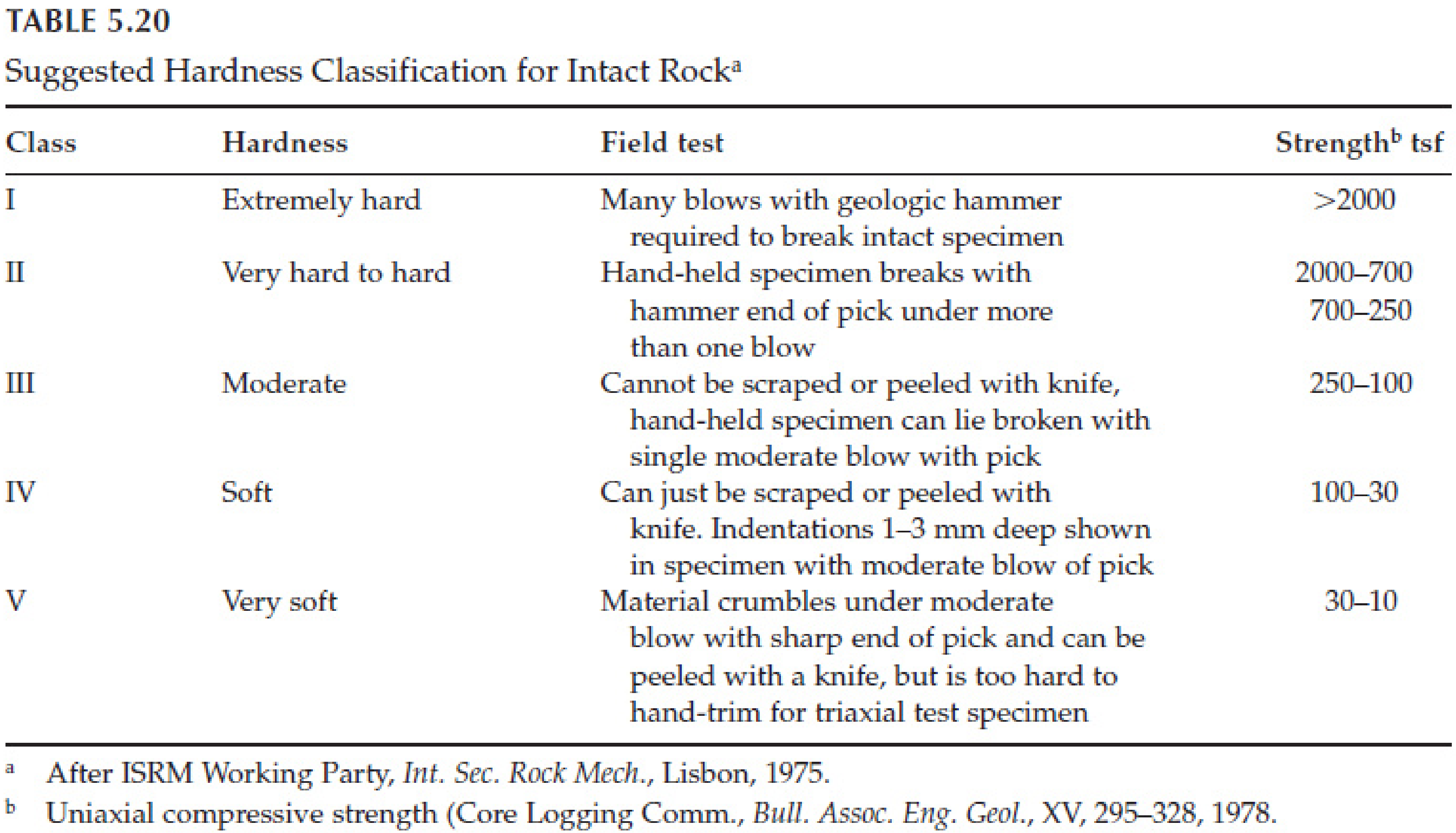


TABLE 5.20

Suggested Hardness Classification for Intact Rock[a]

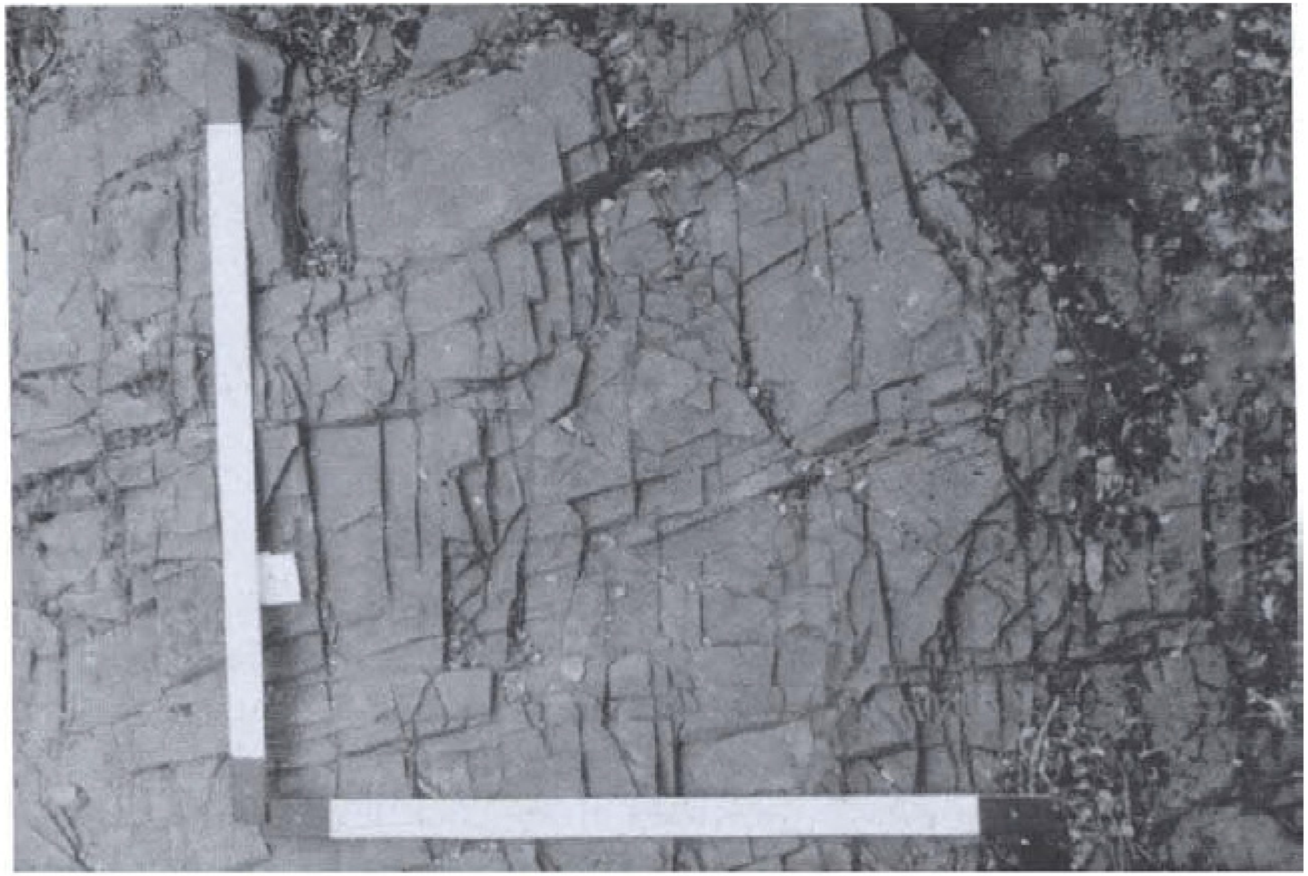
Class	Hardness	Field test	Strength[b] tsf
I	Extremely hard	Many blows with geologic hammer required to break intact specimen	>2000
II	Very hard to hard	Hand-held specimen breaks with hammer end of pick under more than one blow	2000–700 700–250
III	Moderate	Cannot be scraped or peeled with knife, hand-held specimen can lie broken with single moderate blow with pick	250–100
IV	Soft	Can just be scraped or peeled with knife. Indentations 1–3 mm deep shown in specimen with moderate blow of pick	100–30
V	Very soft	Material crumbles under moderate blow with sharp end of pick and can be peeled with a knife, but is too hard to hand-trim for triaxial test specimen	30–10

[a] After ISRM Working Party, *Int. Sec. Rock Mech.*, Lisbon, 1975.

[b] Uniaxial compressive strength (Core Logging Comm., *Bull. Assoc. Eng. Geol.*, XV, 295–328, 1978.

ENGINEERING PROPERTIES of ROCKS

3) Discontinuity properties of rocks



ENGINEERING PROPERTIES of ROCKS

3) Discontinuity properties of rocks

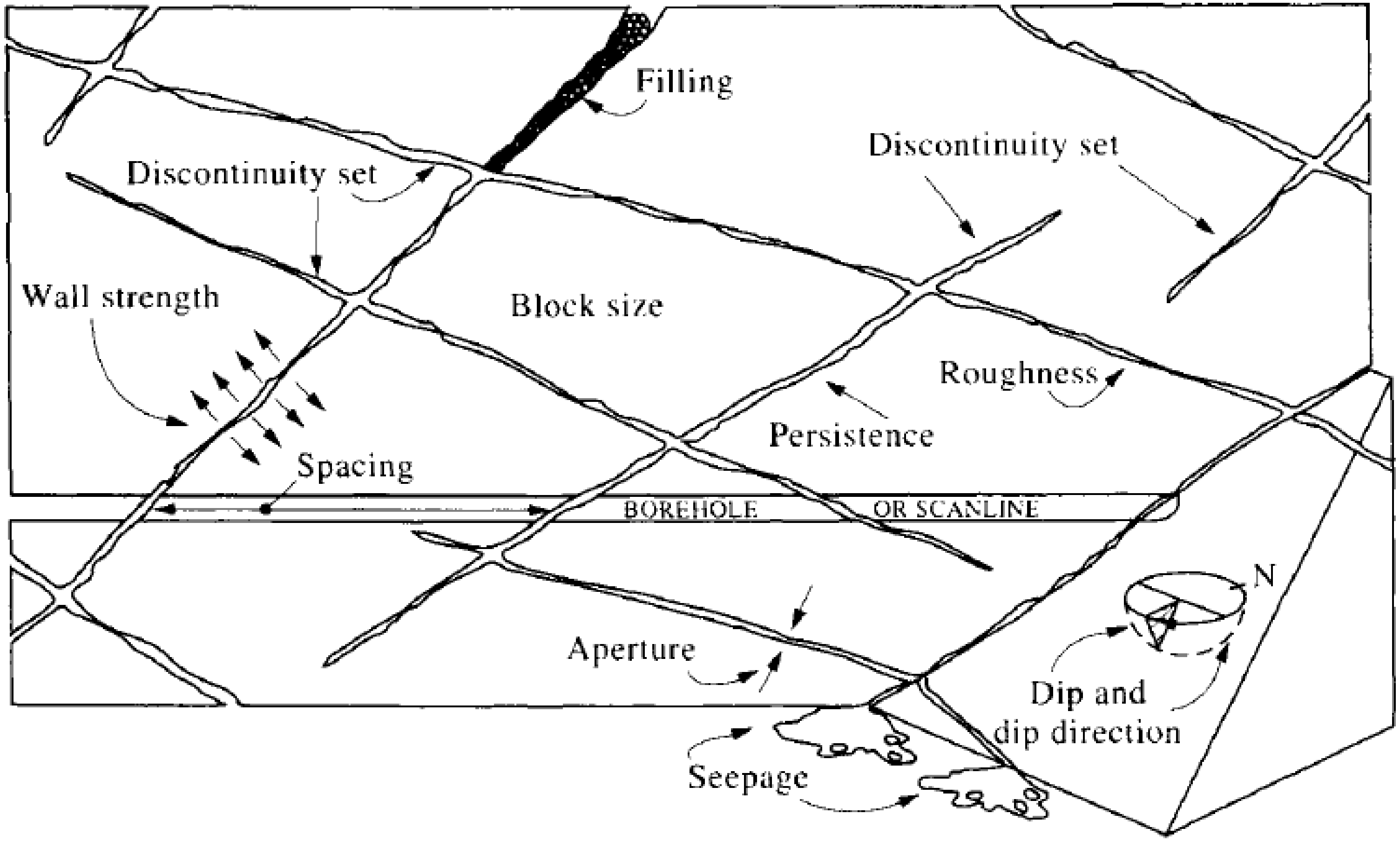


Figure 7.3 Schematic of the primary geometrical properties of discontinuities in rock (from Hudson, 1989).

ENGINEERING PROPERTIES of ROCKS

Discontinuity properties of rocks

1. **Orientation:** The attitude of a discontinuity in space. It is described by the dip direction (azimuth) and dip of the line of steepest declination in the plane of the discontinuity.
2. **Spacing:** The perpendicular distance between adjacent discontinuities. It normally refers to the mean or modal spacing of a set of discontinuities.
3. **Persistence:** The discontinuity trace length as observed in an exposure. It may give a crude measure of the areal extent or penetration length of a discontinuity. Termination in solid rock or against other discontinuities reduces the persistence.
4. ***Roughness:*** The inherent surface roughness and waviness relative to the mean plane of a discontinuity. Both roughness and waviness contribute to the shear strength. Large scale waviness may also alter the dip locally.
5. **Wall strength:** The equivalent compressive strength of the adjacent rock walls of a discontinuity. It may be lower than rock block strength due to weathering or alteration of the walls. It is an important component of shear strength if rock walls are in contact.

ENGINEERING PROPERTIES of ROCKS

Discontinuity properties of rocks

6. Aperture: The perpendicular distance between adjacent rock walls of a discontinuity, in which the intervening space is air or water filled.

7. Filling: The material that separates the adjacent rock walls of a discontinuity and that is usually weaker than the parent rock. Typical filling materials are sand, silt, clay, breccia, gouge, mylonite. It also includes thin mineral coatings and healed discontinuities such as quartz and calcite veins.

8. Seepage: The water flow and free moisture visible in individual discontinuities or in the rock mass as a whole.

9. Number of Sets: The number of discontinuity sets comprising the intersecting discontinuity system. The rock mass may be further divided by individual discontinuities.

10.Block Size: The rock block dimensions resulting from the mutual orientation of intersecting discontinuity sets, and resulting from the spacing of the individual sets. Individual discontinuities may further influence the block size and shape.

ENGINEERING PROPERTIES of ROCKS

Discontinuity properties of rocks

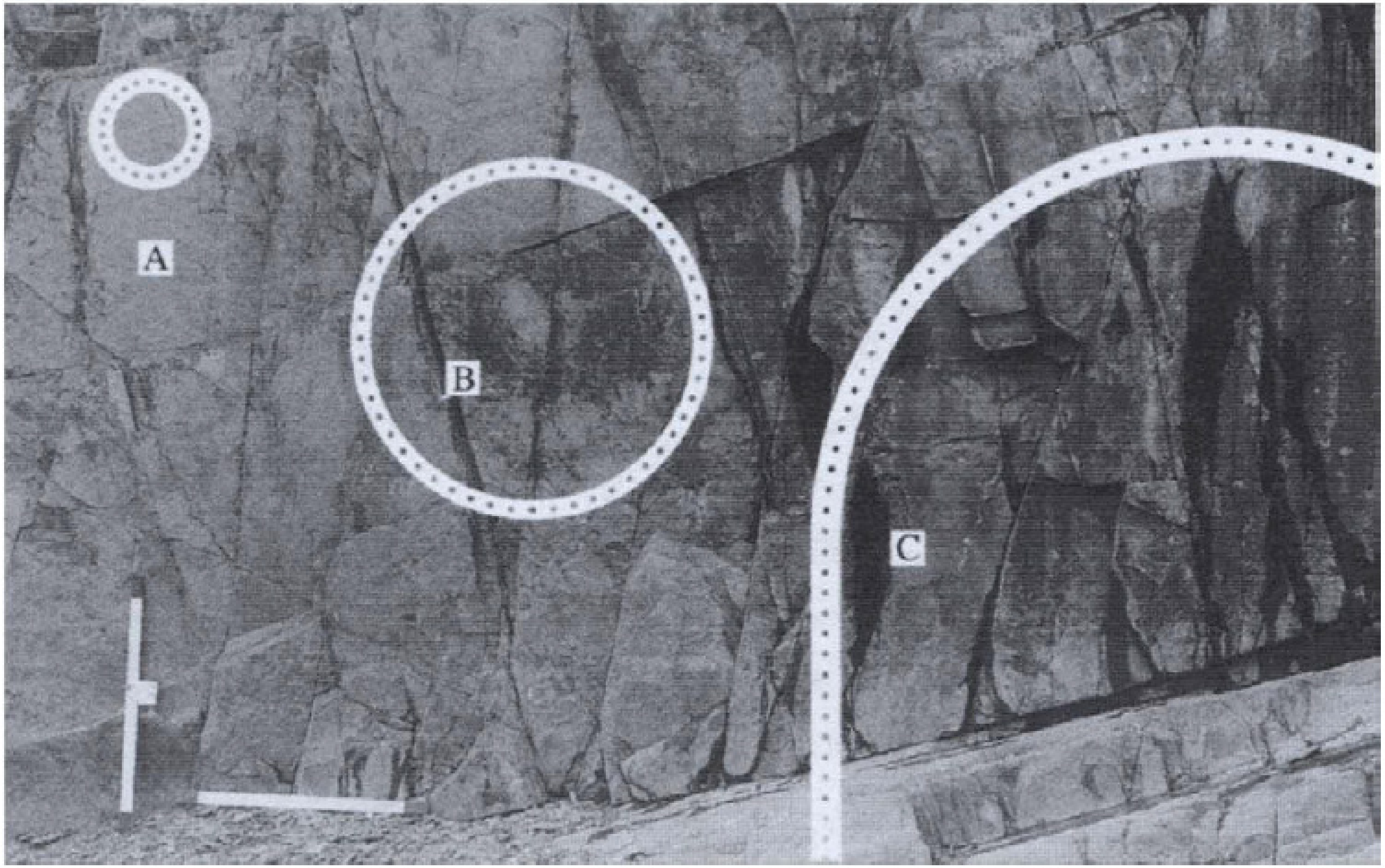
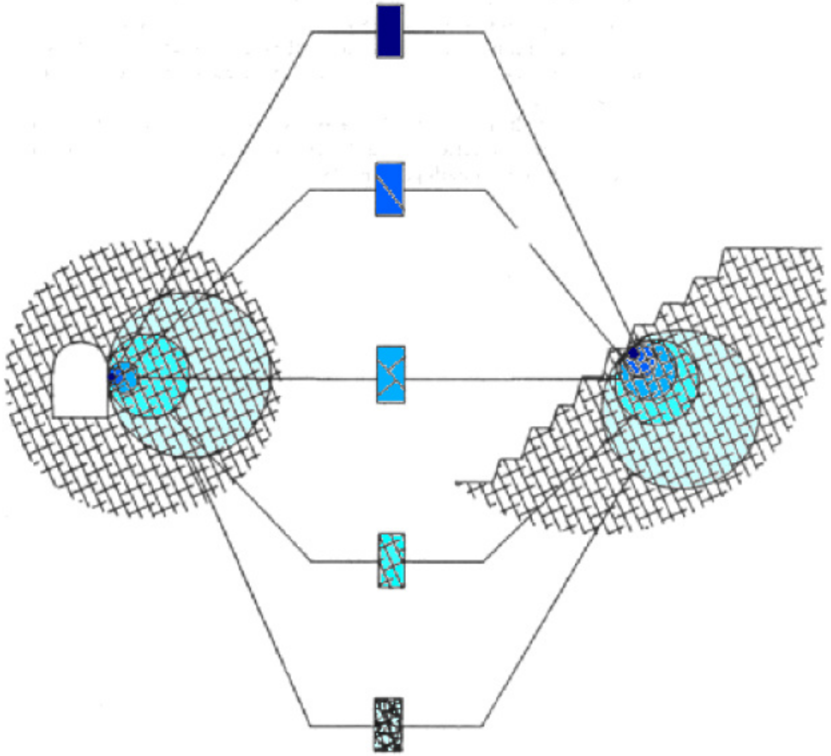


Figure 7.2 Discontinuities in rock and the engineered structure (A, borehole; B, tunnel; C, large excavation).

ENGINEERING PROPERTIES of ROCKS

Discontinuity properties of rocks

Scale Effects in Rock Masses



… varying rock mass conditions dependent on scale …
intact to highly fractured …

The properties of discontinuities and rock mass classifications will be discussed in detail in following weeks (e.g. 5, 6, 8,9 and 11)

SEE YOU NEXT WEEK