ENGINEERING & HYDROGEOLOGIC CHARACTERISTICS OF ROCKS (03)

I Main Topics

A Engineering & hydrogeologic characteristics of rocks

B Engineering uses of rocks: Recognition of potential uses

C Main rock types on Oahu

II Engineering & hydrogeologic characteristics of rocks: general trends

A "Hard" rocks generally have higher unconfined (uniaxial) compressive strengths and higher Young's moduli (E) than "soft" rocks

B Compressive strength generally greater than tensile strength by a factor of ~10

Crystalline Rock Properties

Name	Composition	Uniaxial Strength (MPa) Compression / Tension	Poisson's Ratio	Chemical Stability	Grain size
Plutonic					
Granite	Silicate	100-900 / 15-35	(0.28)-0.30	Stable	mm-cm
Gabbro	Silicate	130-200 / 15-30	0.33	Stable	mm-cm
Diorite	Silicate	100-800 / 15-30	0.22-0.30	Stable	mm-cm
Volcanic					
Basalt	Silicate	150-300 / 10-30	0.09-0.35	Stable	mm
Andesite	Silicate	?	0.18	Stable	mm
Welded tuff	Silicate glass	57-90 / 3.9-6.3	0.24	Varies	µm-dm
Unwelded tuff	Silicate glass	?	0.31	Varies	µm-dm
Metamorphic					
Slate	Silicate	100-200 / 7-20	0.23-0.36	Stable	µm
Schist	Silicate	25-62 / ?	0.11-0.43	Stable	mm-cm
Gneiss	Silicate	50—230 / 5-20	0.06-0.29	Stable	mm-cm
Quartzite	Silicate	150—629 / 10-30	0.10-0.20	Stable	mm
Marble	Silicate	55-274 / 7-20	0.17-0.30	Stable	mm

Crystalline Rock Properties

Name	Composition	Uniaxial Strength (MPa) Compression / Tension	Poisson's Ratio	Chemical Stability	Grain size
Shale	Clay	2 - 216/ 2 – 10		Stable	
Siltstone	Mostly SiO_2	3 - 256/ ?	0.28 - 0.30	Stable	mm-cm
Sandstone	Varies	3 - 256/ 4 - 25	0.33	Stable	mm-cm
Conglomerate	Varies	100-800 / 15-30	0.22-0.30	Depends on cement	mm-cm
Breccia	Varies	?	?	Depends on cement	
Limestone	$CaCO_3$	6 - 245/ 5 - 25	0.09-0.35	Depends on climate	mm
Dolomite	$CaMg(CO_3)_2$	?	0.18	Stable	mm
Evaporite (halite)	NaCl	57-90 / 3.9-6.3	0.24	Varies	µm-dm
Evaporite (gypsum)	$CaSO_4 \bullet 2H_20$	?	0.31	Varies	µm-dm

Crystalline Rock Properties

Name	Composition	P-wave velocity (m/s)	S-wave velocity (m/s)	Young's modulus (GPa)
Plutonic				
Granite	Silicate	4500 - 6500	3500 - 3800	30 - 70
Gabbro	Silicate	4500 - 7000	0.33	40 - 100
Diorite	Silicate	4500 - 6700	?	?
Volcanic				
Basalt	Silicate	5000 - 7000	3660 - 3700	40 - 80
Andesite	Silicate	4500 - 6500	?	10 - 70
Welded tuff	Silicate glass	?	?	?
Unwelded tuff	Silicate glass	?	?	?
Metamorphic				
Slate	Silicate	3500 - 4500	?	20 - 90
Schist	Silicate	6100 - 6700	3460 - 4000	5 - 60
Gneiss	Silicate	5000 - 7500	?	30 - 80
Quartzite	Silicate	?	?	50 - 90
Marble	Silicate	5000 - 6000	?	30 - 70

Clastic Rock Properties

Name	Dry density (g/cm^3)	P-wave velocity (m/s)	S-wave velocity (m/s)	Young's Modulus (GPa)
Shale	2.0 – 2.4	2000 - 4600	?	5 - 30
Siltstone	1.57 – 2.76	?	?	?
Sandstone	1.91 – 2.58	1500 - 4600	?	15 - 50
Conglomerate	2.47 – 2.76	?	?	10 - 90
Breccia	?	?	?	?
Limestone	2.67 – 2.72	3500-6500	?	20 - 70
Dolomite	2.2 – 2.7	5500	?	30 - 70
Evaporite	?	?	?	?

Crystalline Rock Properties

Name	Discontinuities	Nature of permeability	Hydraulic conductivity m/sec	n %	Rock mass shape
Plutonic		If unfractured	1e-14 – 2e-10	0 - 5	
Granite	Fractures	Fractures and pores	7e-7 – 2e-4*	0 – 10*	Spheroidal/sheets
Gabbro	Fractures	Fractures and pores	See granite		Spheroidal/sheets
Diorite	Fractures	Fractures and pores	See granite		Spheroidal/sheets
Volcanic					
Basalt	Fractures/beds	Fractures and pores	1e-7 – 1e-2*	5-50	Tongues/sheets
Andesite	Fractures/beds	Fractures and pores			Tongues/sheets
Welded tuff	Fractures/beds	Fractures			Tongues/sheets
Unwelded tuff	Beds/fractures	Fractures and pores			Tongues/sheets
Metamorphic		If unfractured	See plutonic		
Slate	Foliation/ Fractures	Fractures	See plutonic		Sheets
Schist	Fractures	Fractures	See plutonic	4 - 49	Sheets
Gneiss	Fractures	Fractures	See plutonic		Spheroidal/sheets
Quartzite	Fractures	Fractures			Sheets
Marble	Fractures	Fractures and cavities			Sheets

* is for fractured rock

Clastic Rock Properties

Name	Discontinuities	Nature of permeability	Hydraulic conductivity m/sec	n %	Rock mass shape
Shale	Fractures/beds	Fractures	8e-14 – 8e-10	0-10	Sheets
Siltstone	Fractures/beds	Fractures and pores	< 1e-13 – 2e-10	21 - 41	Sheets
Sandstone	Fractures/beds	Fractures and pores	1e-10 – 2e-6	5 - 30	Sheets/tongues
Conglomerate	Fractures/beds	Fractures and pores	1e-10 – 1e-8	25 - 40	Tongues
Breccia	Fractures/beds	Fractures and pores	Probably like conglomerate	?	Aprons/tongues
Limestone	Fractures/beds	Fractures and pores	1e-13 – 1e-10	0 - 20	Tongues/sheets
Karst limestone	Fractures/beds	Fractures and pores	1e-6 – 1e-2	5 - 50	Tongues/sheets
Dolomite	Fractures/beds	Fractures and pores	1e-12 – 1e-11	0 - 20	Tongues/sheets
Evaporite (halite)	Fractures/beds	Fractures and caverns	1e-16 - 1e-13	?	Tongues/sheets

III Engineering uses of rocks

A Building stone

1 Granite (Good if fractures are not closely spaced)

http://en.wikipedia.org/wiki/Granite

Cathedral Peak, Yosemite National Park, CA

Quarry, Yosemite National Park, CA

III Engineering uses of rocks

2 Slate (Very durable, high tensile strength, difficult to work in some ways)

http://en.wikipedia.org/wiki/Slate

III Engineering uses of rocks

A Building stone

3 Sandstone (Durability depends on porosity and cement)

http://commons.wikimedia.org/wiki/File:Stanford_University_1978.jpg

III Engineering uses of rocks

A Building stone

4 Marble (e.g. Lincoln Memorial, Washington Monument)

220px-Aerial_view_of_Lincoln_Memorial_-_east_side_EDIT.jpeg

III Engineering uses of rocks

B Crushed stone (for road fill, dams, riprap; $3 B in 1973)
  1 Limestone (Needs to be pure and hard)
  2 Basalt
  3 Granite

http://en.wikipedia.org/wiki/Riprap

III Engineering uses of rocks

C Sand & gravel
  1 Greatest extracted tonnage of any resource
  2 U.S. 30 million metric tons in 2007
  3 Expensive to transport; needs to be available locally
D Concrete Aggregate
  1 Material should be clean, poorly sorted, strong, and stable
  2 Good rocks: granite, clean sandstone
  3 Reactive (bad) rocks: chert, opal, rhyolite, andesite, phyllite, shale, tuff, siliceous limestone, sulfide-bearing rocks

III Engineering uses of rocks

E Lime (CaO), Cement, plaster, de-acidification (buffering)
  1 Slightly impure limestone
  2 Coral
  3 Gypsum

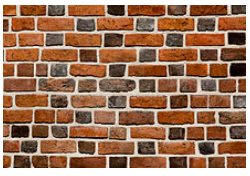
http://en.wikipedia.org/wiki/Concrete

III Engineering uses of rocks

F Clay and sand (ceramics, glass, & abrasives)
  1 Kaolinite clay for china, paper, paint, plastic, etc.
  2 Bentonite (Na-rich montmorillonite) for drilling mud and sealer; from devitrified volcanic ash
  3 Clays for bricks (e.g. kaolinite, gibbsite)
  4 Sand - needs to be 93%+ pure to avoid reactions and discoloration
    a Foundry molds
    b Glass
    c Abrasives

http://en.wikipedia.org/wiki/Porcelain

http://en.wikipedia.org/wiki/Bentonite

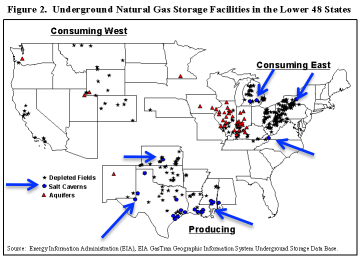


http://en.wikipedia.org/wiki/Brick

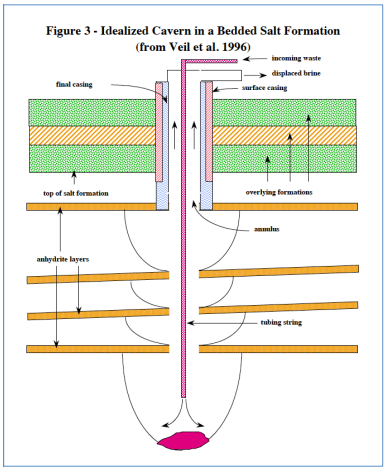
http://en.wikipedia.org/wiki/Glass

III Engineering uses of rocks

G Salt
Underground storage
- a Natural gas
- b Liquefied natural gas
- b Petroleum storage (~680 million barrels in SPR)
- c Petroleum waste
- d Nuclear waste



http://en.wikipedia.org/wiki/Natural_gas_storage



http://web.ead.anl.gov/saltcaverns/doc/saltnorm.pdf

IV Main Rock Types on Oahu

A Basaltic Volcanic Rocks
1. Lava flows
2. Tuff (and cinders)
3. Dikes

Basalt at Makapuu

IV Main Rock Types on Oahu

A Basaltic Volcanic Rocks
- 1 Lava flows
- 2 Tuff (and cinders)
- 3 Dikes

Tuff of Koko Crater
Between Sandy Beach and Hanauma Bay

Cinders along Round Top Drive

IV Main Rock Types on Oahu

A Basaltic Volcanic Rocks
- 1 Lava flows
- 2 Tuff
- 3 Dikes

Dikes
In the
Waianae
Range

http://hi.water.usgs.gov/studies/GWRP/hydrogeology.html

http://satftp.soest.hawaii.edu/space/hawaii/vfts/oahu/oahu_sw/kp_items.html

IV Main Rock Types on Oahu

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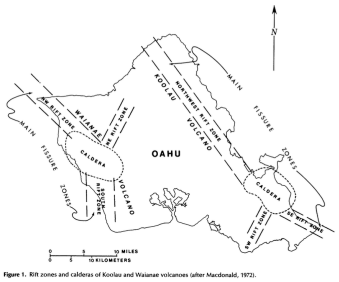

Figure 1. Rift zones and calderas of Koolau and Waianae volcanoes (after Macdonald, 1972).

http://pubs.usgs.gov/wsp/2217/report.pdf

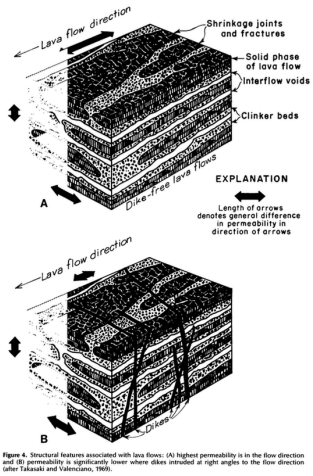

Figure 4. Structural features associated with lava flows: (A) highest permeability is in the flow direction and (B) permeability is significantly lower where dikes intruded at right angles to the flow direction (after Takasaki and Valenciano, 1969).

http://pubs.usgs.gov/wsp/2217/report.pdf

IV Main Rock Types on Oahu

B Sedimentary rocks
1 Limestone ($CaCO_3$)
2 Sandstone ($CaCO_3$)
(dune deposits)

Emergent reef limestone, Kaeana Point

http://satftp.soest.hawaii.edu/space/hawaii
/vfts/oahu/oahu_sw/kp_items.html

Sand dune(?) deposits (white) overlain by tuff
South side of Diamond Head