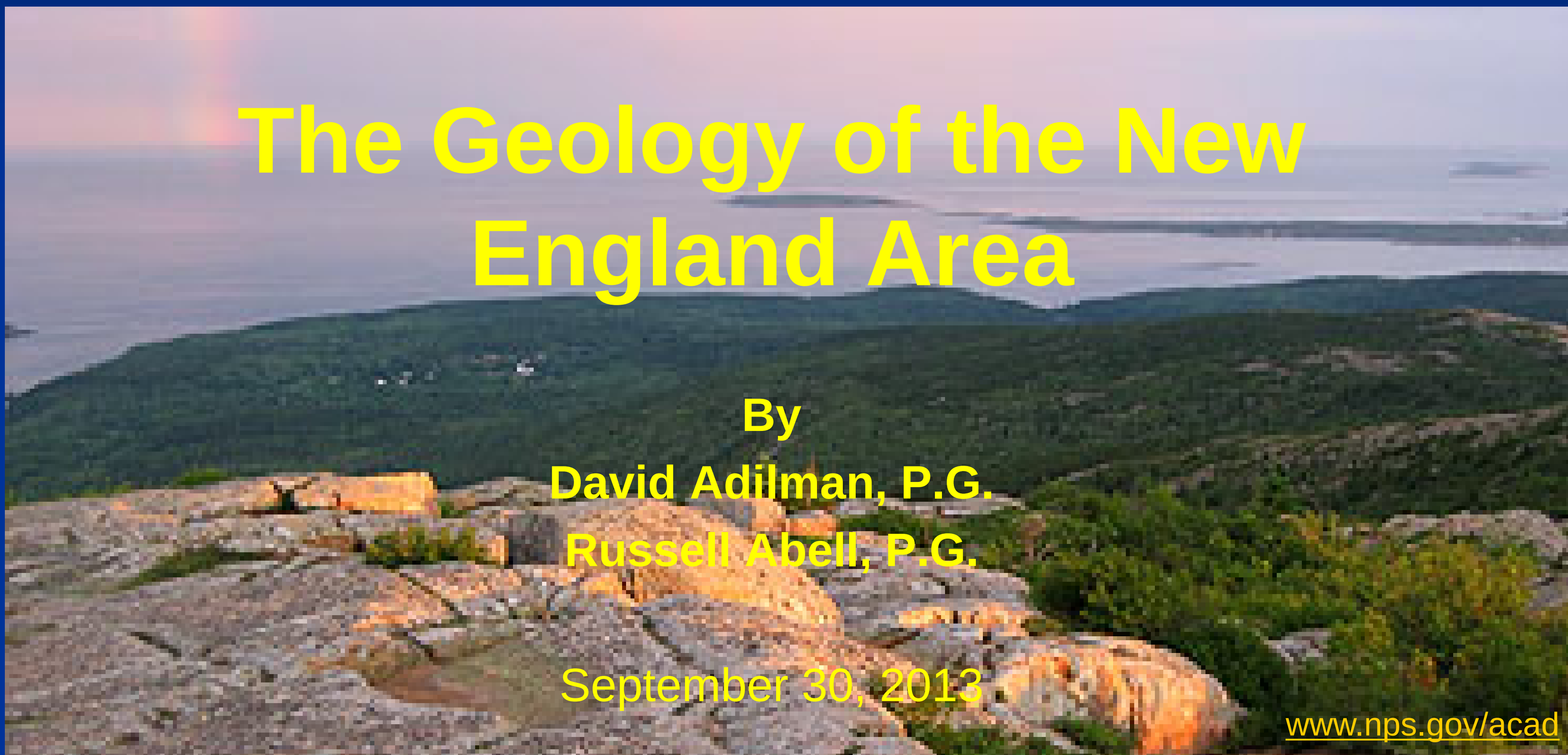
SUBSURFACE EXPLORATIONS



The Geology of the New England Area

By

David Adilman, P.G.
Russell Abell, P.G.

September 30, 2013

www.nps.gov/acad

University of Massachusetts School of Engineering
ASCE Lecture
In conjunction with 14.533 Advanced Foundation Engineering class

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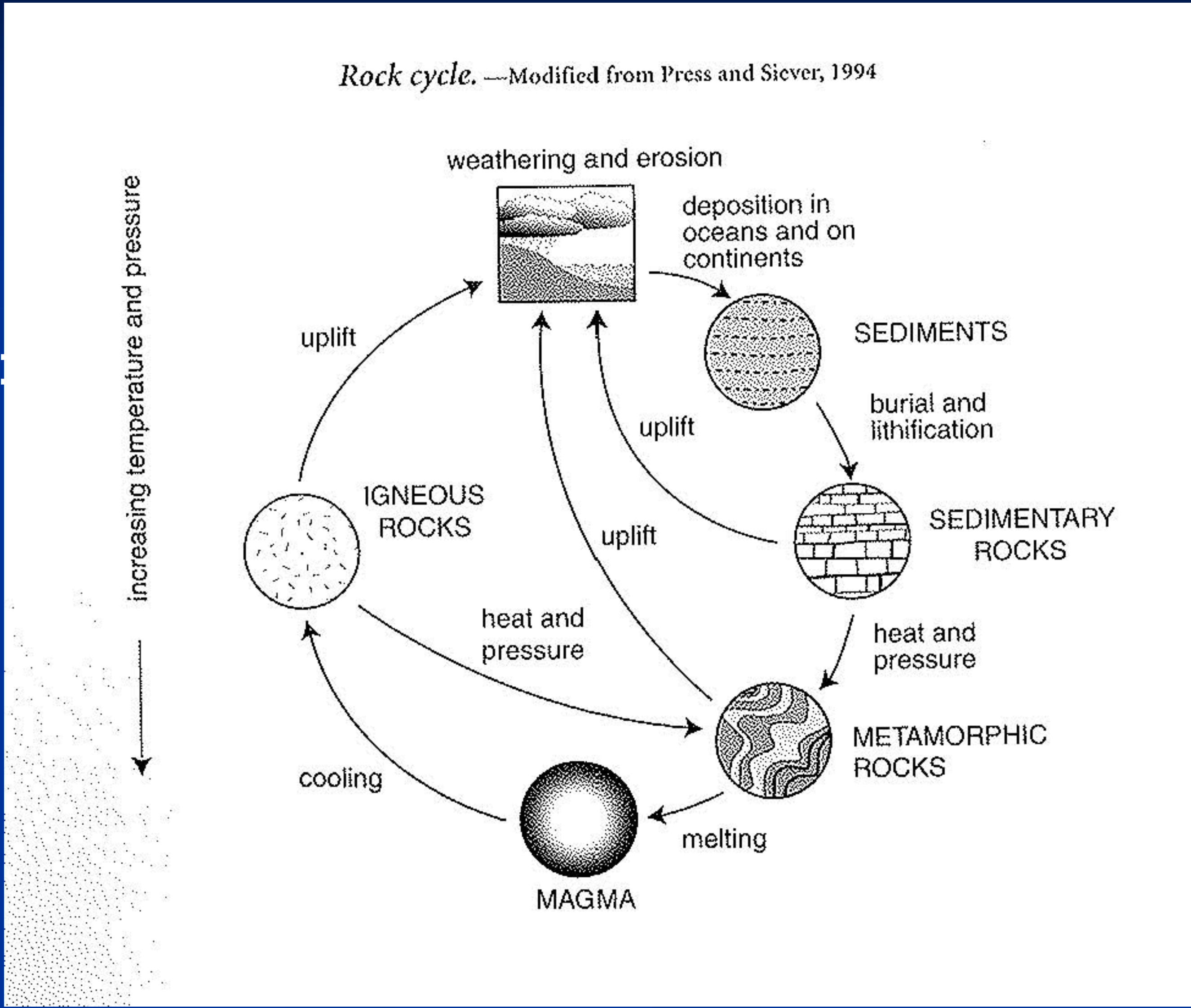
Agenda

1. ASCE Student Chapter and AFE 14.533 Class
   - New England Bedrock Geology Overview
     - Bedrock Geology 101
     - General Geologic Terranes in New England
     - General Bedrock Types in New England
2. AFE 14.533 Class
   - Rock Core Viewing
   - New England Surficial Geology Overview
     - Unconsolidated Material (Overburden) Types
     - Typical Overburden Stratigraphic Sequences
     - Examples of Applied Subsurface Evaluation

Geology 101 – A Recap

Three Rock Types:

- Igneous
- Metamorphic
- Sedimentary



(Skehan, 2003)

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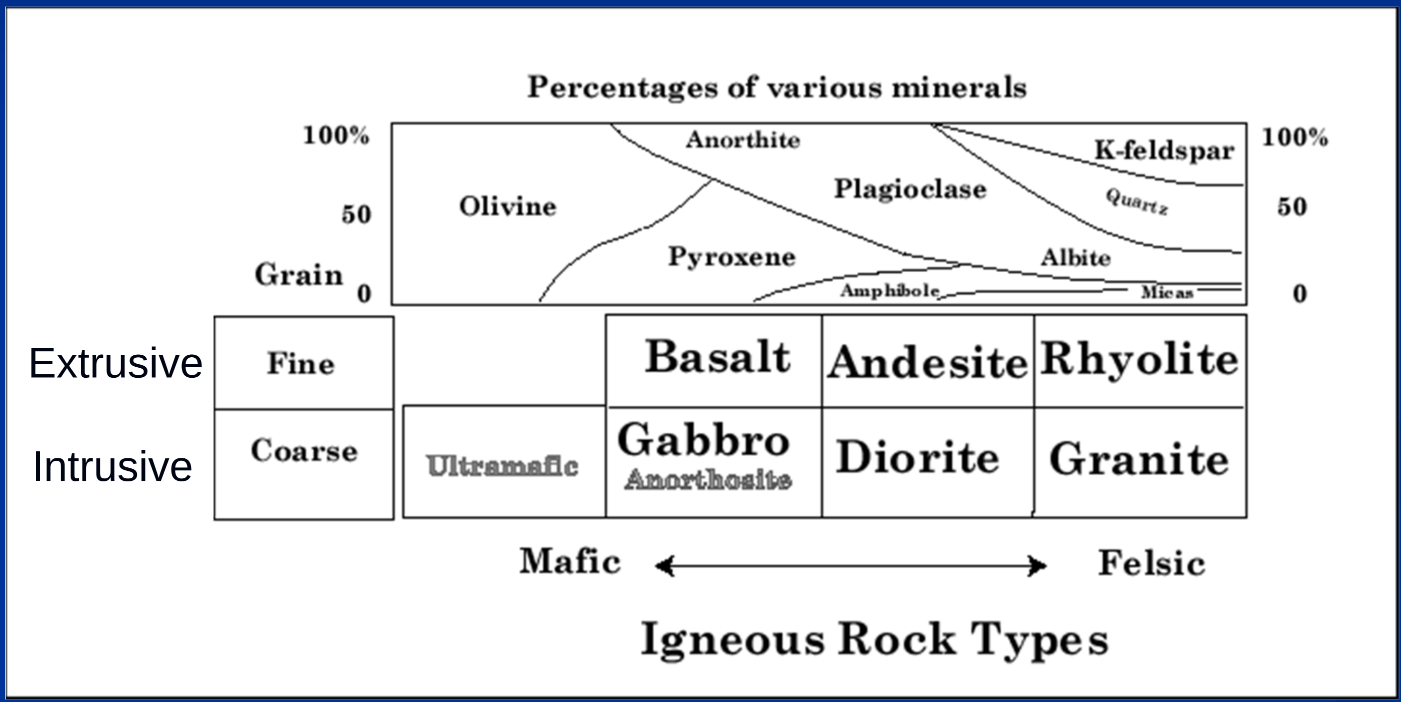
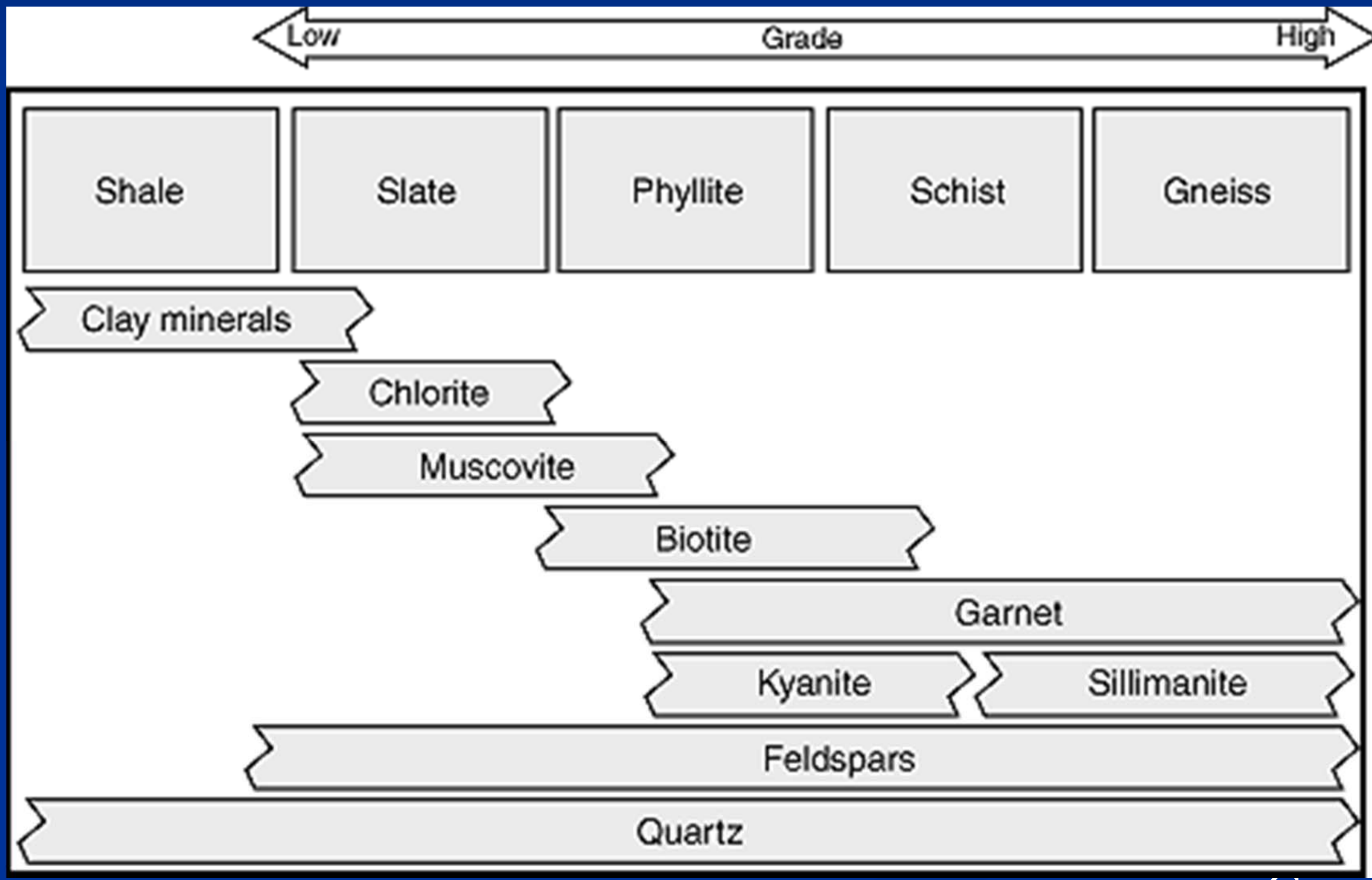
Igneous Rock Types



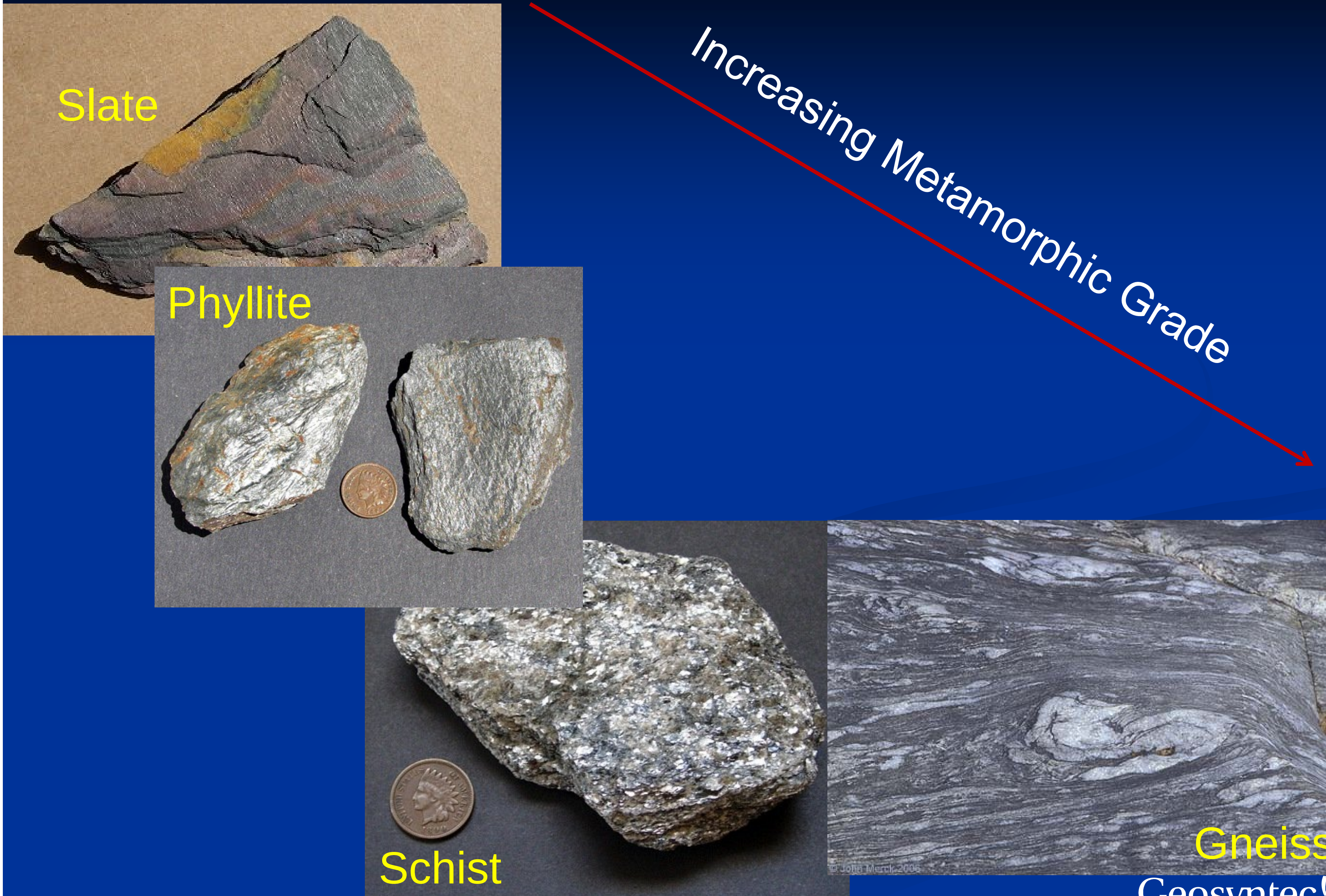
http://dept.astro.lsa.umich.edu/~cowley/intro2.html

Regional Metamorphic Rocks – Shale Protolith

Lineation, Schistosity, Foliation



http://www.geol.umd.edu/~jmerck/geol100/lectures/17.html



http://www.geol.umd.edu/~jmerck/geol100/lectures/17.html

Sedimentary Rock Types

Clastic Sedimentary Rocks		
Name of Rock	Sediment Type	Texture
Conglomerate	gravel – rounded fragments	course over 2 mm
Breccia	gravel – angular fragments	course over 2 mm
Sandstone	sand	medium 1/16 to 2mm
Siltstone	mud	fine 1/256 to 1/16 mm
Shale	mud	very fine less than 1/256 mm

Chemical Sedimentary Rocks		
Name of Rock	Composition	Texture
Crystalline Limestone	Calcite - $CaCo_3$	corse to fine Crystalline
Fossiliferous Limestone	Calcite - $CaCo_3$	visible fragments of shells
Chalk	Calcite - $CaCo_3$	microscopic shells and clay
Chert	Quartz - SiO_2	very fine crystalline
Gypsum	Gypsum - $CaSO_4$-$2H_2O$	fine to course crystalline
Rock Salt	Halite - NaCl	fine to course crystalline
Bituinous Coal	Organic Matter	fine

http://www.rocksandminerals4u.com/sedimentary_rock.html

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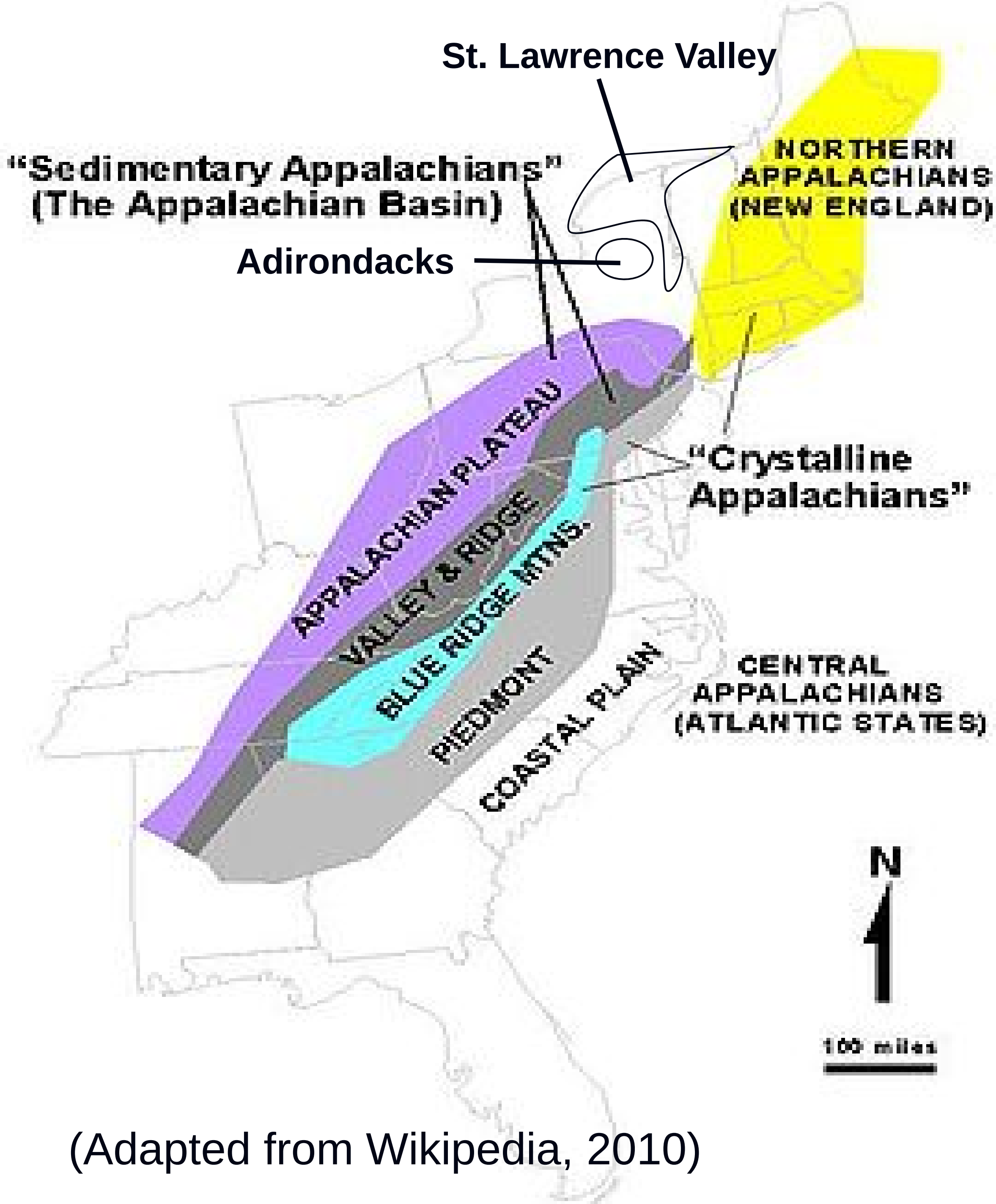

(Adapted from Wikipedia, 2010)

Physiographic Regions of the Northeastern U.S.

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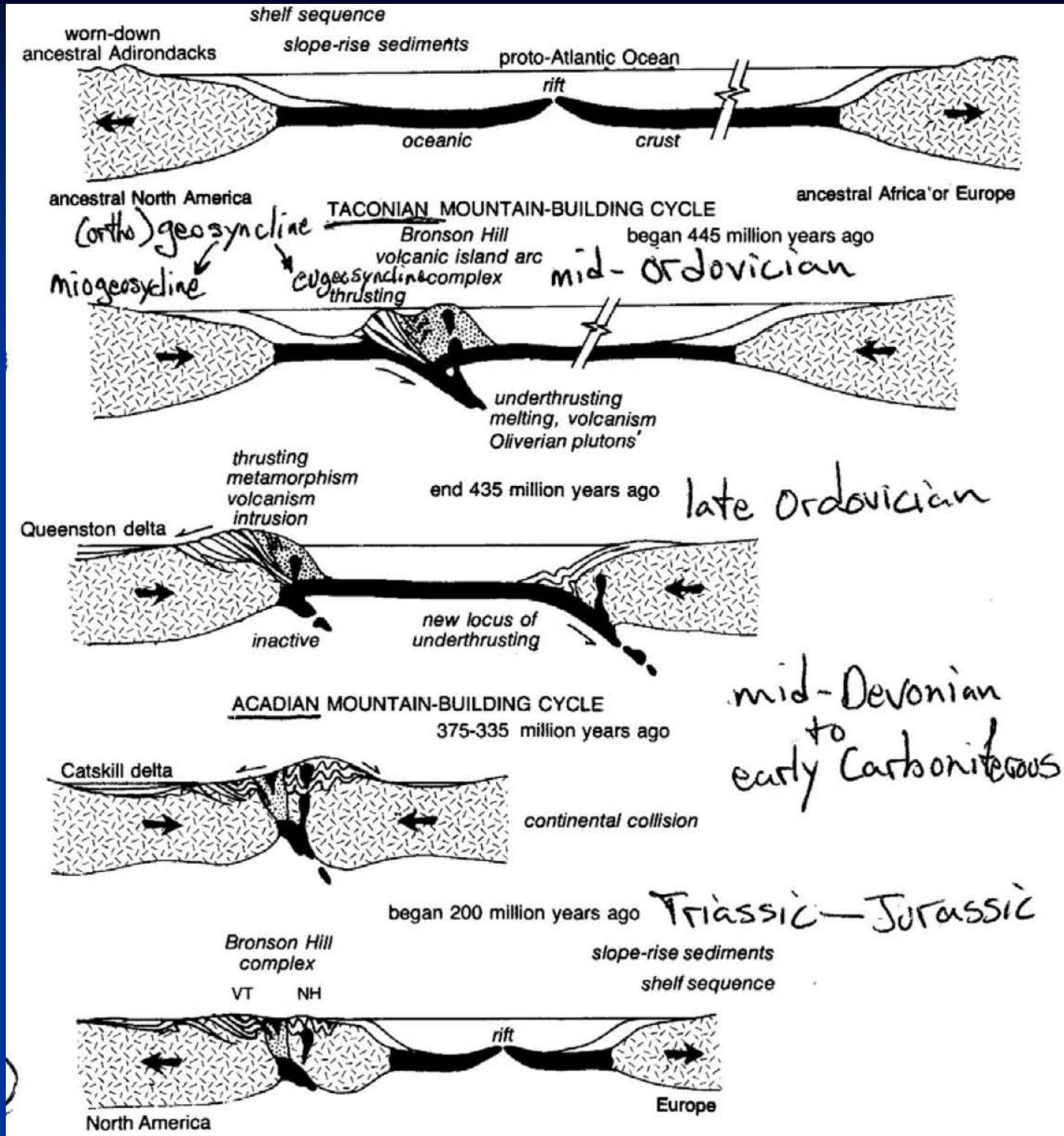
Tectonic History of Eastern North America



Hypothetical sequence of events leading to Taconian and Acadian mountain-building followed by opening of the modern Atlantic basin, beginning about 200 million years ago.

Van Diver, 1987

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Chronology of MA Geologic Events

Glacial Advance/Retreat

Failed Rift Basins

Alleghanian Orogeny

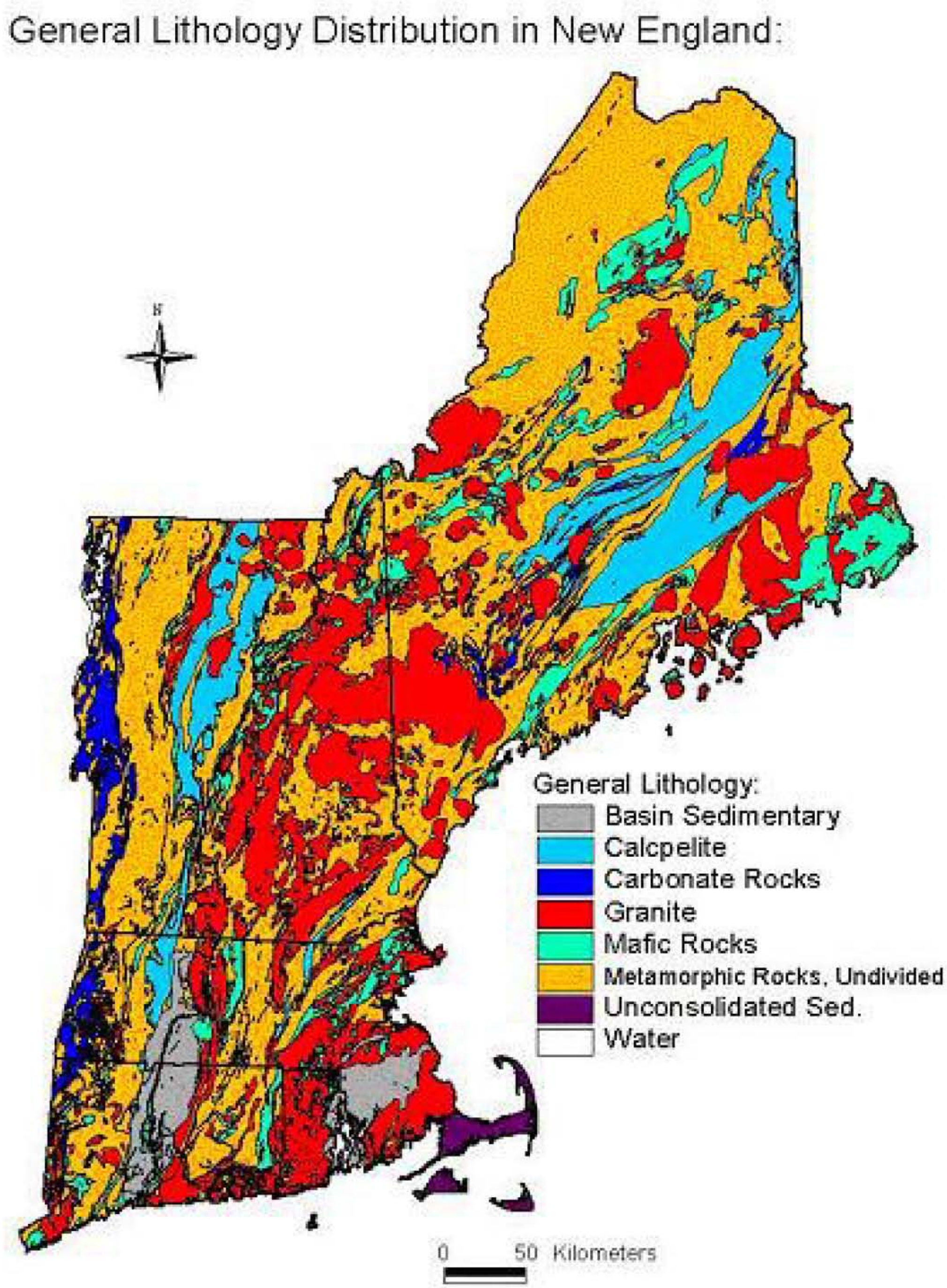
Acadian Orogeny

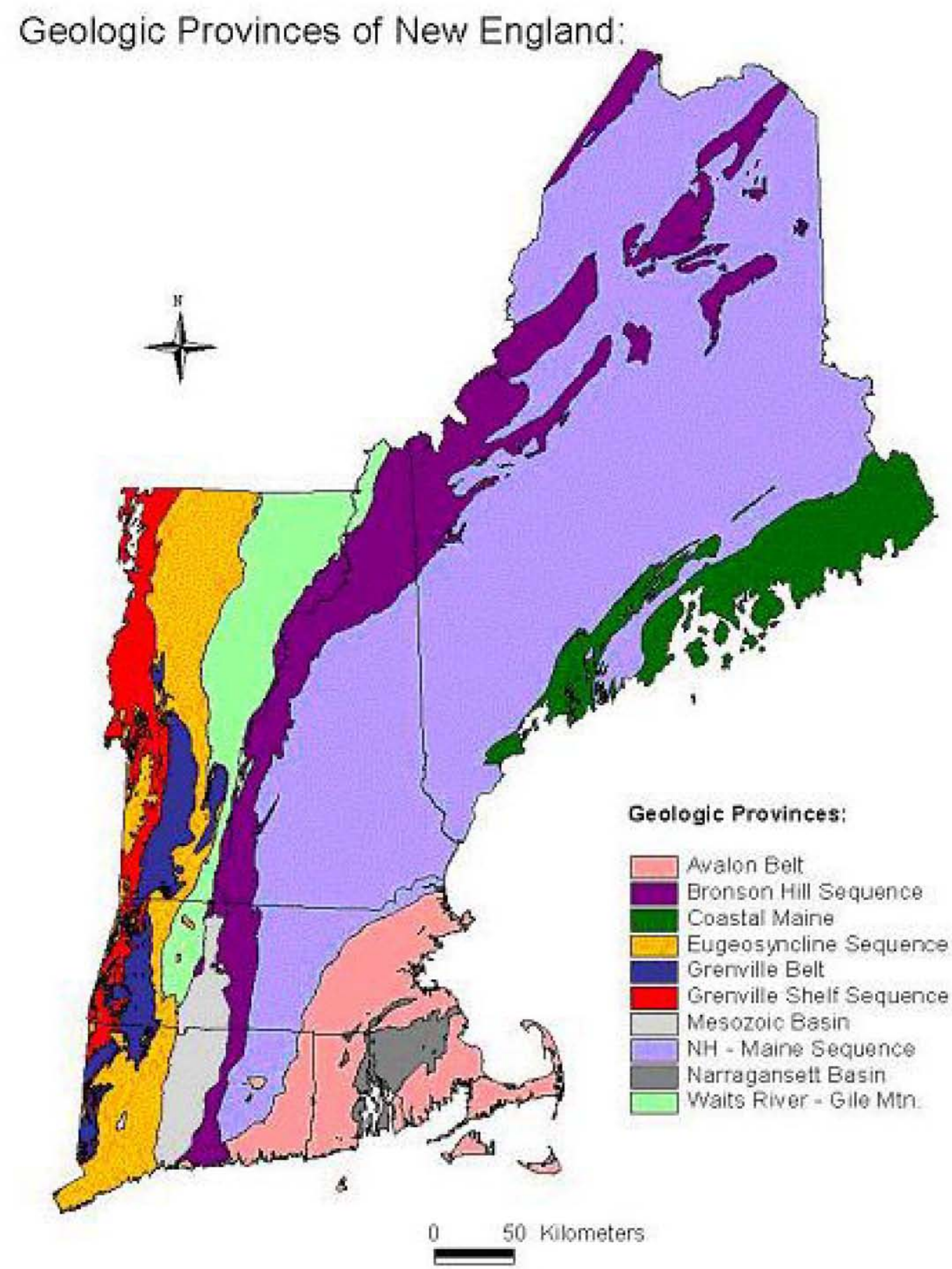
Taconic Orogeny

Grenville Uplift

(Skehan, 2003)

ERA	PERIOD	EPOCH (million years ago)	IMPORTANT GEOLOGIC EVENTS IN MASSACHUSETTS
CENOZOIC	QUATERNARY	Pleistocene	Wisconsinan ice age begins 80,000 years ago and covers Massachusetts between 25,000 and 15,000 years ago. Marine sediments deposited during Sangamon interglacial stage. Remnant till of Illinoian ice sheet deposited 140,000 years ago.
		1.6	
	TERTIARY	Pliocene	
		5	
		Miocene	Deposition of glauconitic sands, coarse sands, and gravel.
		24	
		Oligocene	
		36	
		Eocene	
		58	
		Paleocene	
		65	
MESOZOIC	CRETACEOUS		Intrusive rhyolite in northeastern Massachusetts. Deposition of variegated clays, silts, and lignite coal at Gay Head. Marine sediments of coastal plain deposited far inland.
		145	
	JURASSIC		Rift volcanism initiates opening of Atlantic Ocean and breakup of Pangaea. Rift basins open in the Connecticut Valley region. Basalt flows and dikes, including Medford dike. Deposition of fossiliferous redbeds. Dinosaurs leave tracks.
		208	
	TRIASSIC		Deposition of coarse clastic sediments.
		245	
PALEOZOIC	PERMIAN		Final assembly of Pangaean supercontinent during the Alleghanian orogeny, 275 to 250 million years ago.
		286	
	PENNSYLVANIAN		Narragansett Basin and other coal basins form in Avalon terrane.
		320	
	MISSISSIPPIAN		Rapid uplift of Nashoba terrane.
		360	
	DEVONIAN		Continued sedimentation. Acadian mountain building event—Merrimack, Nashoba, and Avalon microcontinents collide with Laurentia and its associated volcanic island chains. Collision produces extensive plutonism and dome uplift. Rift plutonism and volcanism in Avalon terrane.
		417	
	SILURIAN		Initial stage of Acadian mountain building event. Sedimentary rocks deposited unconformably on Bronson Hill volcanic belt of Laurentia. Edge of Avalon terrane sinks beneath Nashoba terrane in subduction zone, generating more Burlington mylonite. Volcanic and plutonic activity begun in Ordovician time continues to build Nashoba and Merrimack terranes.
		443	
	ORDOVICIAN		Shelburne Falls and possibly Bronson Hill volcanic island chains, which formed along margin of Laurentia, collide with continent in the Taconic mountain building event. Rifts open in Avalon and produce alkaline plutonic activity.
		495	
	CAMBRIAN		Fossiliferous continental shelf sediments—Stockbridge marble and Cheshire quartzite—deposited on Laurentian margin. Trilobite-bearing sediments deposited on margins of Avalon.
		545	
PRECAMBRIAN	PROTEROZOIC EON		Avalon and associated microcontinents separate from Gondwana 550 million years ago. Boston rift basin forms in Avalon about 570 million years ago. Major faulting and shearing along margin of Gondwana forms the Burlington mylonite. Magmas from the Avalon volcanic chain intruded the mylonite, forming the Dedham and Milford granites. Rodinia supercontinent completely assembled by 750 million years ago, then breaks up, giving rise to Gondwana supercontinent.
		2,500	
	ARCHEAN EON		Grenvillian mountain building event affects Grenville gneisses on eastern margin of Laurentia, 1.2 to 1.1 billion years ago.


General Lithology Distribution in New England:
N
General Lithology:
Basin Sedimentary
Calcpelite
Carbonate Rocks
Granite
Mafic Rocks
Metamorphic Rocks, Undivided
Unconsolidated Sed.
Water
0 50 Kilometers



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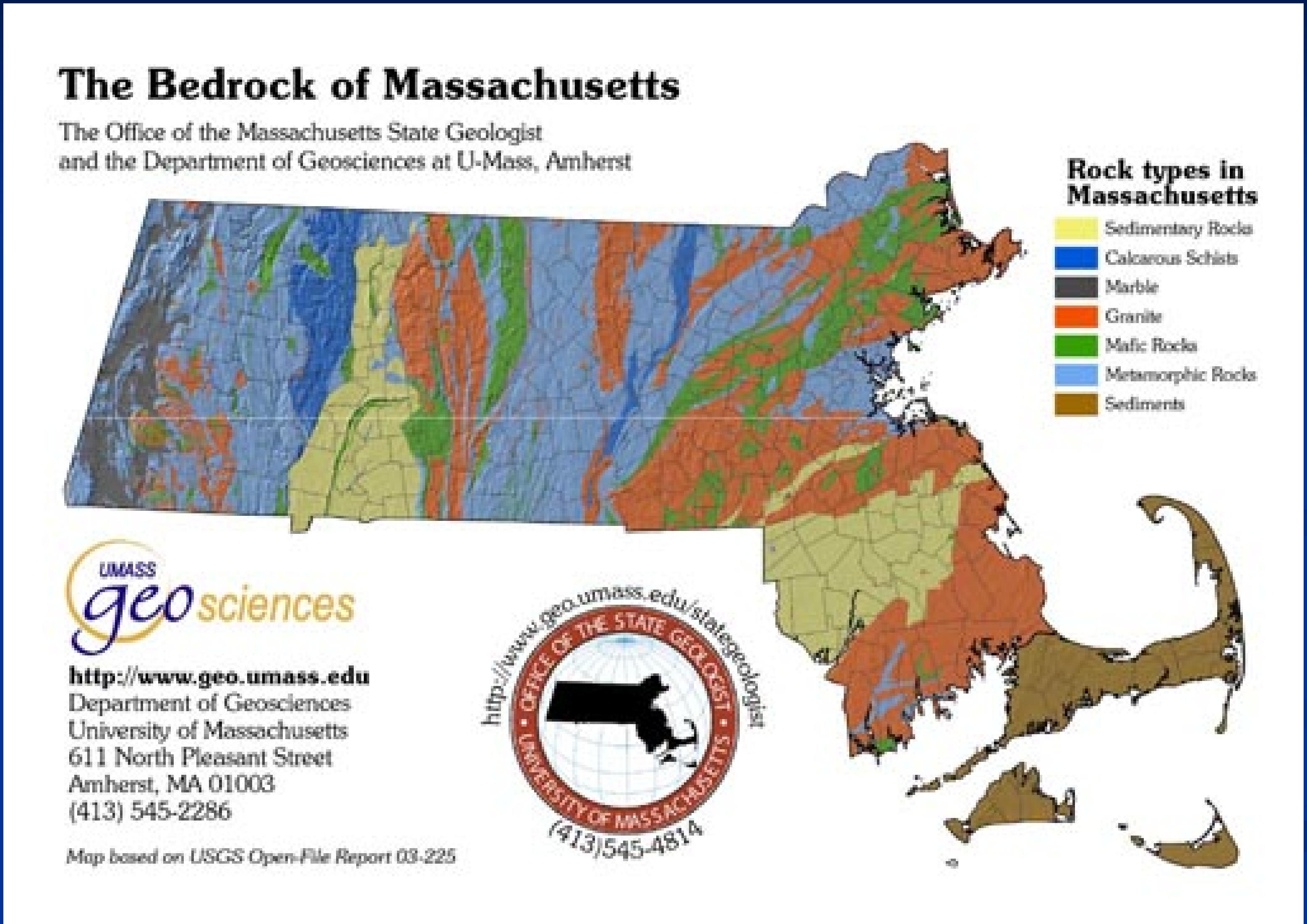
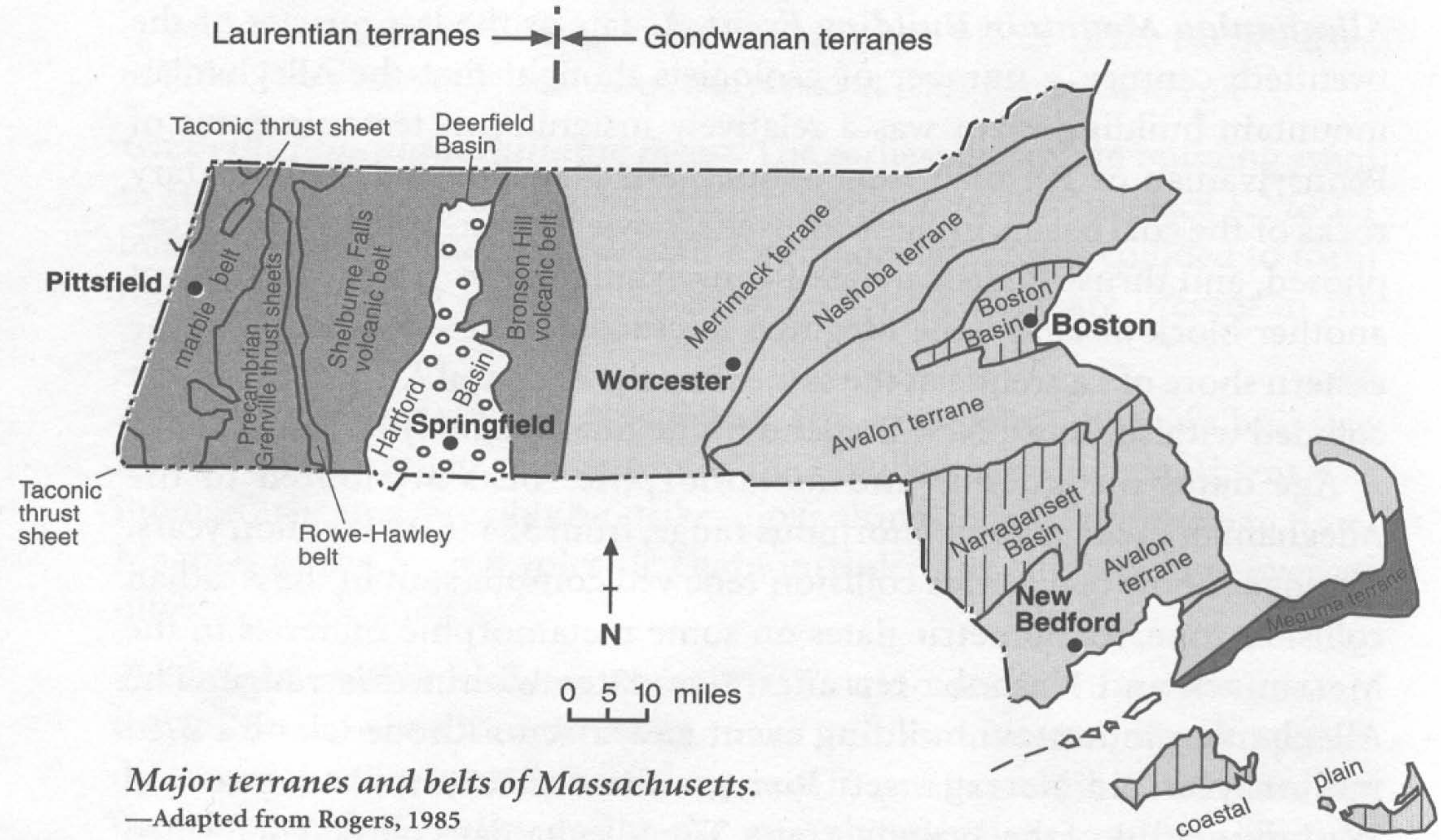
General MA Bedrock Geology



(From OSMG website, 2010)

MA Geologic Terranes



Major terranes and belts of Massachusetts.
—Adapted from Rogers, 1985

(Skehan, 2003)

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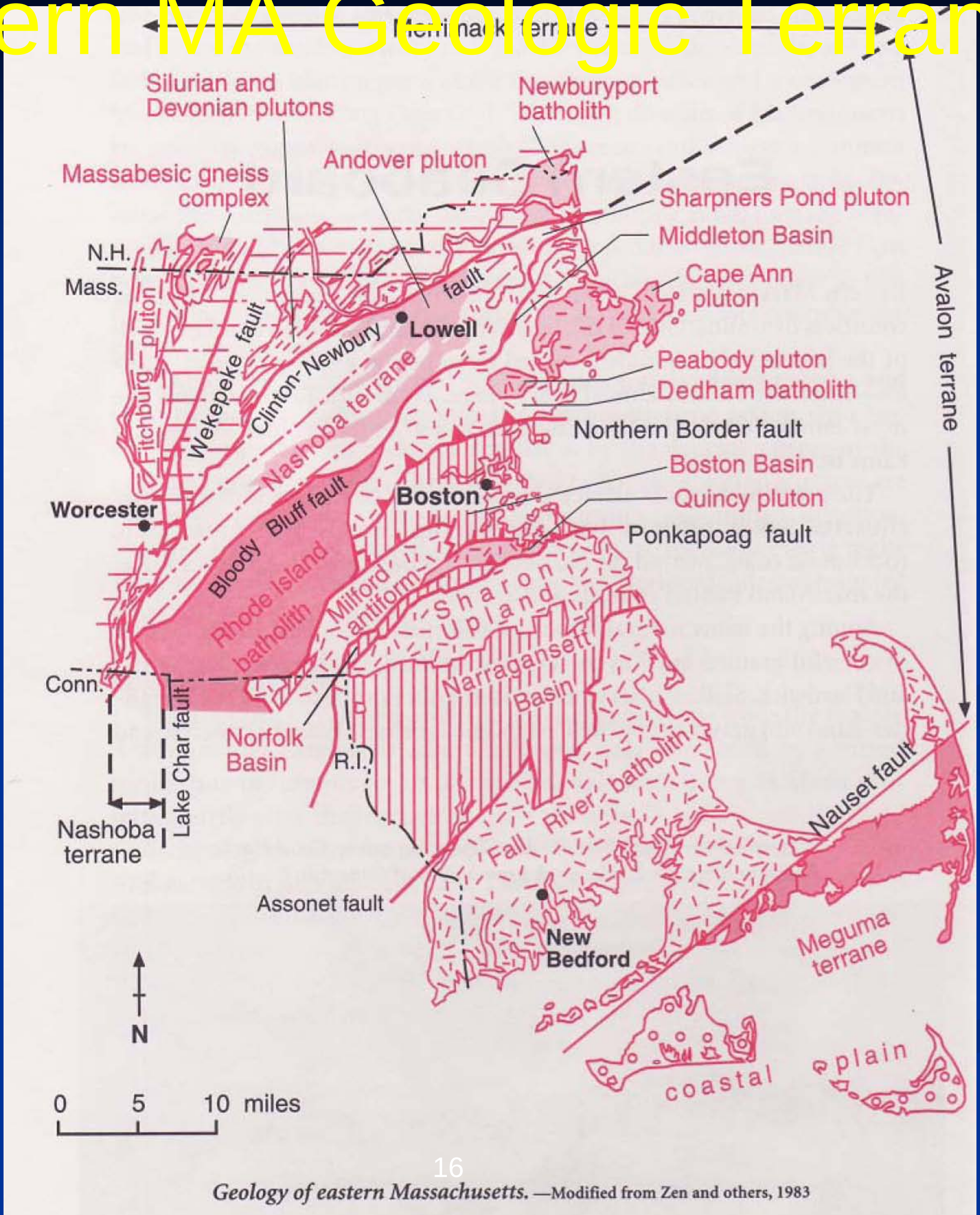
MA Topographic Relief

(geology.com, 2010)

Eastern MA Geologic Terranes



Geology of eastern Massachusetts. —Modified from Zen and others, 1983

(Skehan, 2003)

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Cambridge Argillite (Little Brewster Island) Boston

Civil Engineering Practice, Journal of the Boston Society of Civil Engineers Section/ASCE, Volumes 26&27, 2011/2012

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Roxbury Conglomerate (Pudding Stone) – Eastern MA

(Wikipedia, 2010)

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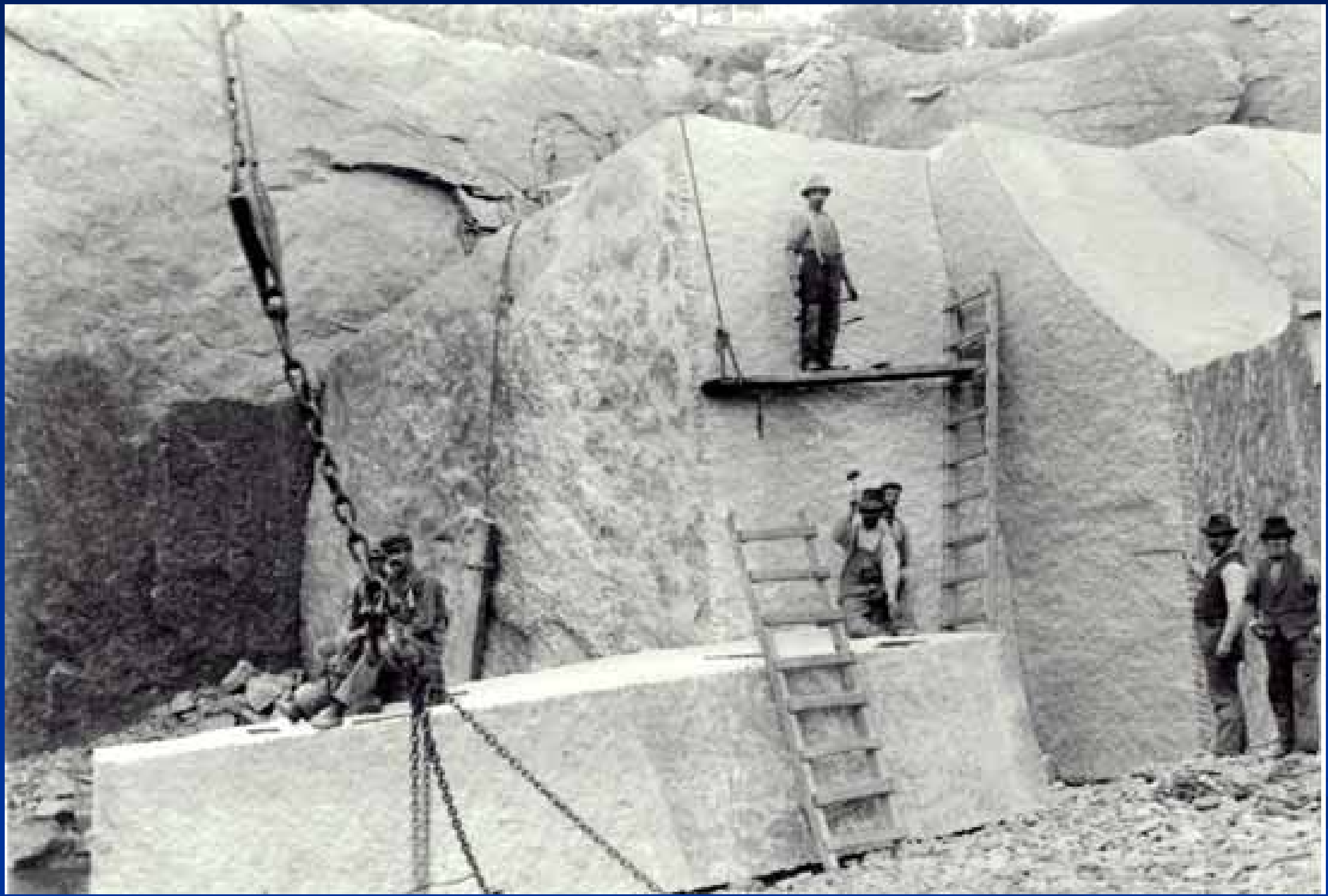
Cape Ann Granite – Eastern MA



(capeannmuseum.com, 2010)

Nashoba Formation – Central MA

(Walsh, 2001)

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Marble/Limestone – Western MA

http://clui.org/ludb/site/lee-marble-quarry

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Mesozoic Sandstone, CT River Valley

(E.B. Keck, 1999)

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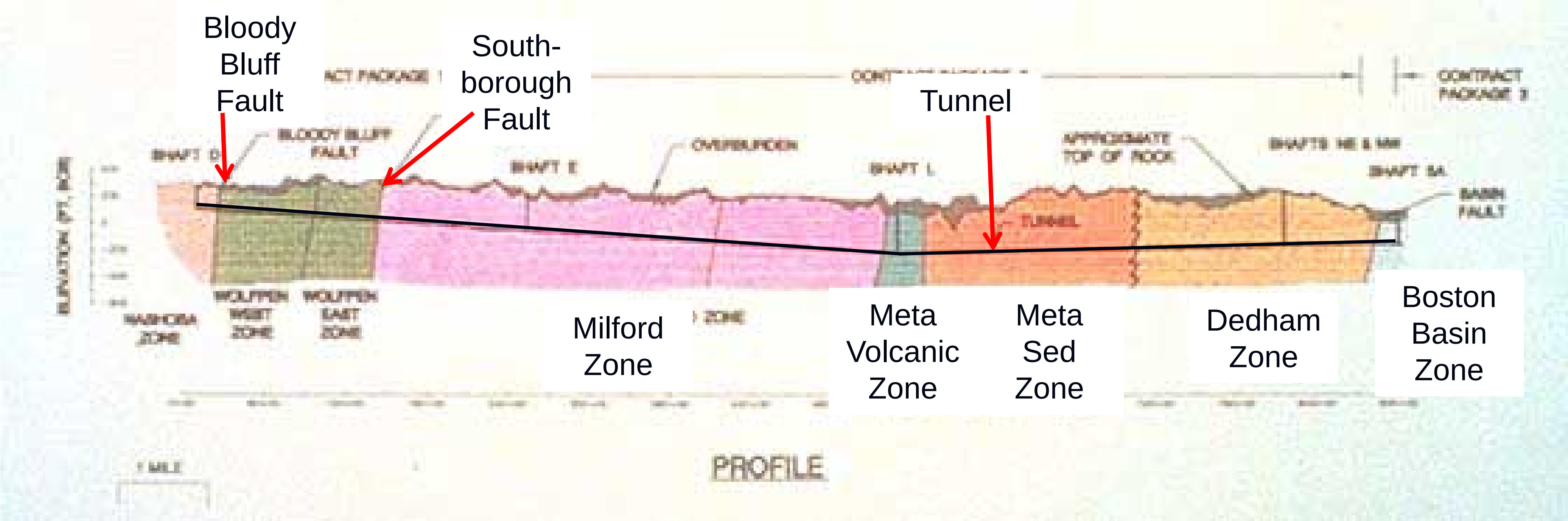
Engineering Properties of Boston Geologic Units

Unit	Description	Sat. Unit Weight (kg/m3)	Atterberg Limits (%)	Undrained Shear Strength (kg/m2)	Allowable Bearing Pressure (kg/m2)
Outwash Deposits	M - f sand with gravel	1760-2160	---------------	--------------	19500-48800
Marine Clay	Stiff, silty clay	1840-2000	40-55 (LL) 15-30 (PI)	3900-9760	14650-39000
Marine Clay	Soft - v soft silty clay	1810-1890	40-55 (LL) 15-30 (PI)	1950-3900	4880-9760
Glacial Till	Dense silt & clay with sand, gravel	2000-2240	15-30 (LL) 10-20 (PI)	9760-39000	39000-98000
Bedrock	Cambridge Argillite	--------------	--------------	--------------	78000-1950000
Bedrock	Roxbury Conglom.	-------------	-------------	-------------	1950000-9750000

(Johnson, 1989)

Geologic Cross-Section – MetroWest Tunnel Project



(http://www.auca.org/month/project1298.html)

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Geologic Risk Factor Engineering

(Hager and Carnevale, undated.
http://www.hagergeoscience.com/pdf_files/borehole_logging.pdf)

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Rock Coring

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Rock Coring

RQD = Rock Quality Designation

$$RQD = \frac{\Sigma \text{pieces} > 10\text{cm}}{\text{Total Core run}} \times 100$$

RQD	Rock mass quality
<25%	very poor
25-50%	poor
50-75%	fair
75-90%	good
90-100%	excellent

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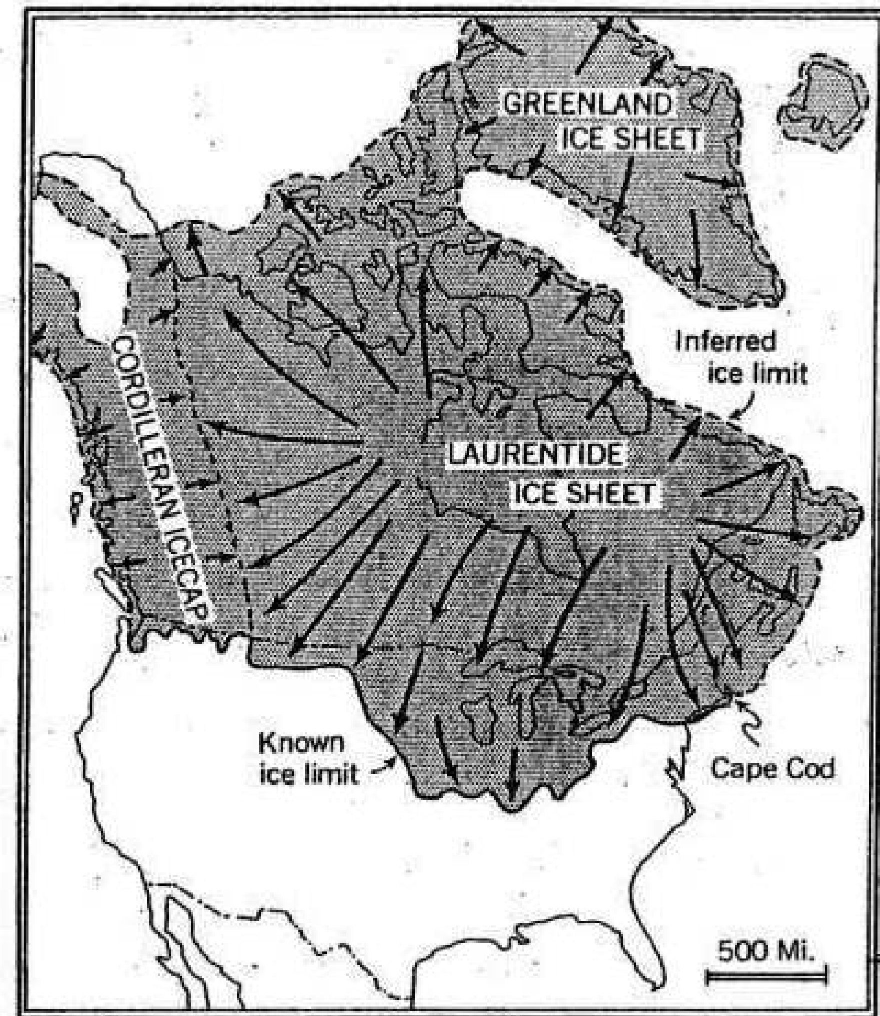
Glacial Geology of New England

- History
- Deposits and Landforms
- Typical Glacial Stratigraphy in New England

New England- 300 MYA

Full Glacial Extent During Pleistocene

80,000 to 13,000 Years ago



2. The shaded area on this map represents the fullest extent of the ice sheets of the Pleistocene Epoch. Directions of ice flow are shown by heavy arrows. Cape Cod lies at the edge of the ice advance. (Based on data of Professor Richard F. Flint of Yale University.)

Strahler, 1966, Geologist's View of Cape Cod

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Glacial Advance in New England

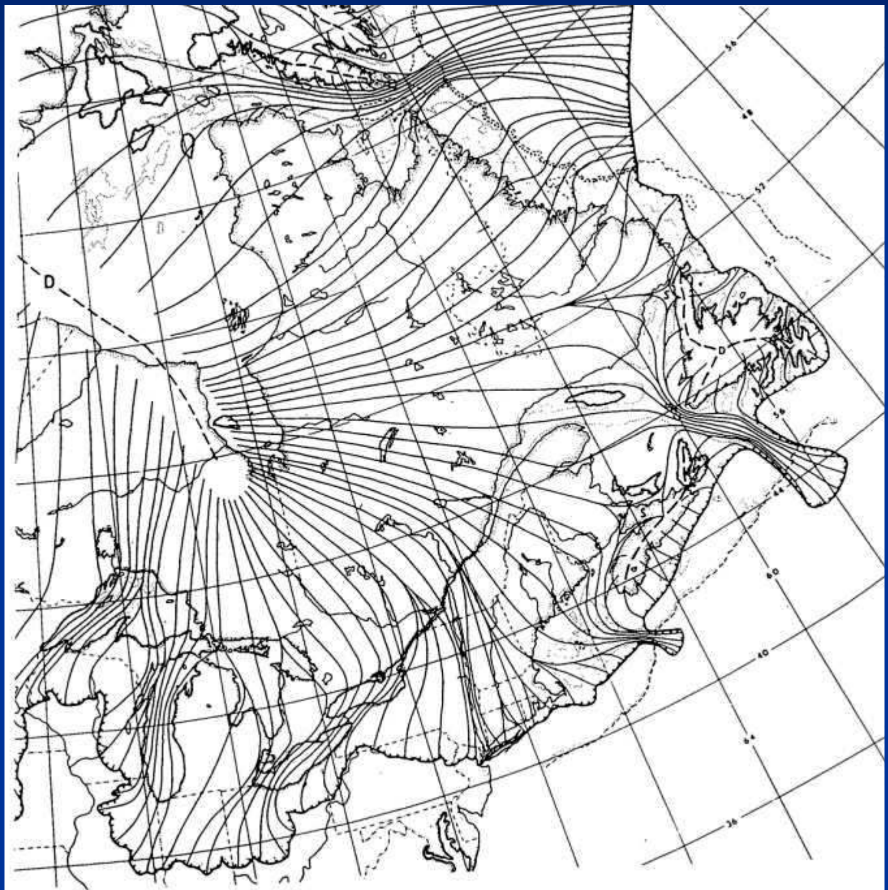
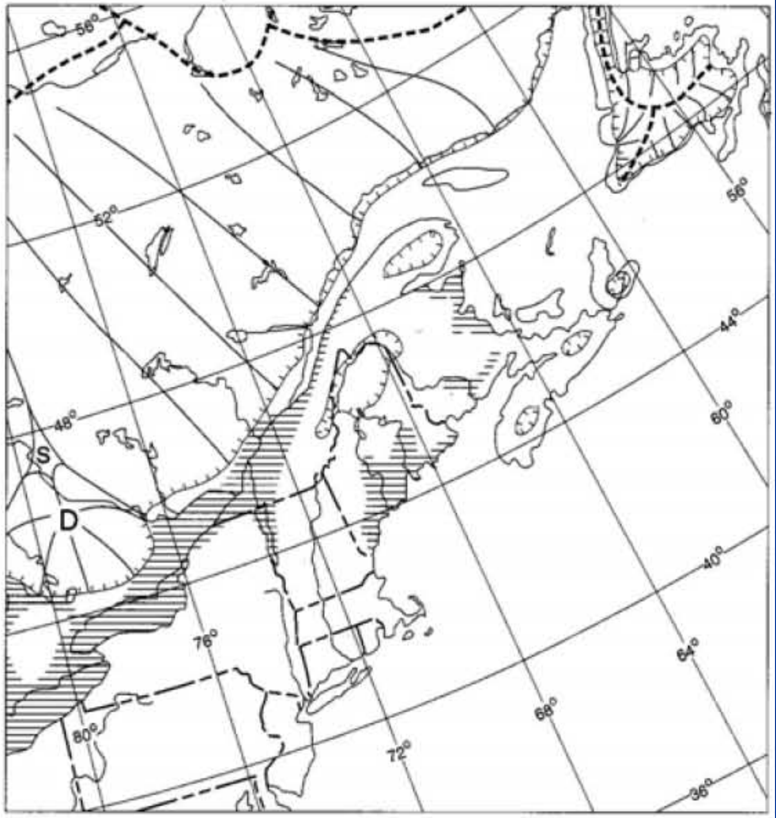


Figure 2. The eastern Laurentide flow regime at the 18,000 years B.P. glacial maximum. A single dome (labeled D) is postulated for the ice divide over Hudson Bay, and ice divide saddles (labeled S) separate Laurentide ice from ice over Newfoundland and Nova Scotia, where local ice divides are postulated.



C. **12,000 years BP.—Small residual ice cap is all that remains of the ice sheet in New England. Horizontal lines show lakes and marine transgressions between 14,000 and 12,000 years BP**

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Glacial Ice Sheets

- Modern example- Western Chugach Mountains, Alaska

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Glacial Retreat – Maine

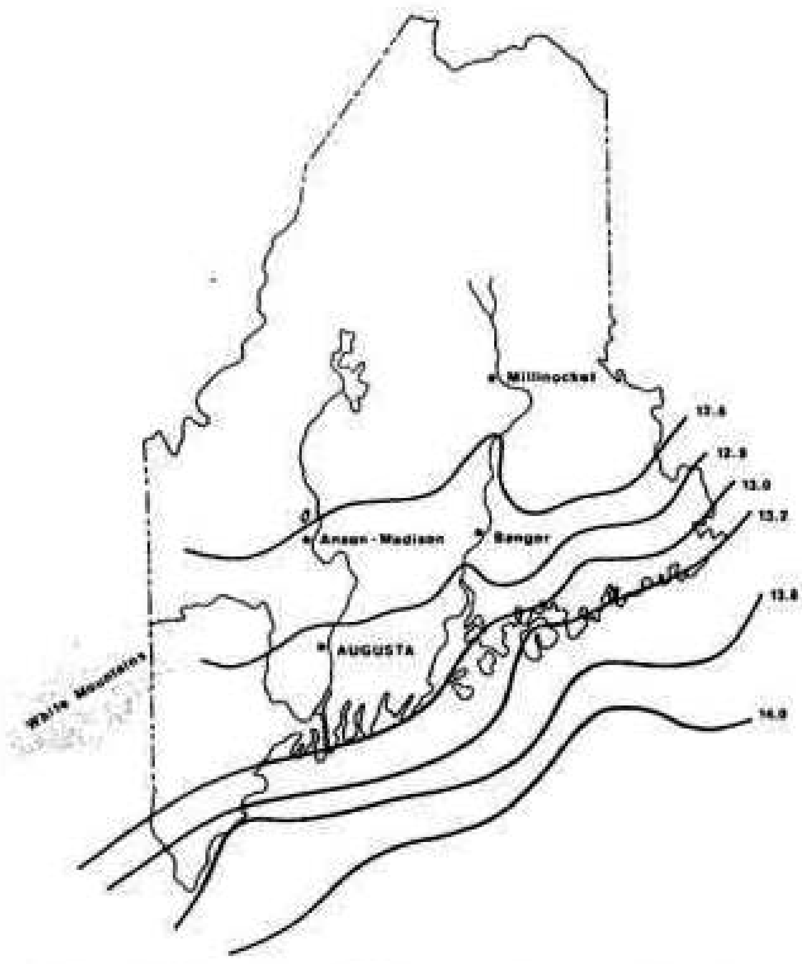

Figure 11. Composite model of ice retreat from coastal Maine.

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Glacial Ice Sheets Reduced to Valley Glaciers

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Post Glacial Valley

Alaska

NH

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Types of Glacial Deposits/ Landforms

MORAINES (material pushed by glaciers)

END MORAINES - (unsorted and hummocky with ridges) deposited at end of glacier.

LATERAL MORAINES - (unsorted) Deposited at sides (laterals of glacier)

ICE-CONTRACT DEPOSITS (large variety)

TILLS - Basal or Lodgment Till (dense, unsorted, clay rich) deposited beneath ice

Ablation Till (less consolidated) material in and on glacier “let down” from melting ice

KAMES - (sorted to unsorted)deposited between ice-sheet and valley wall deltaic in nature

ESKERS - (stratified, with well rounded cobbles) sinuous or meandering ridge of sand and gravel

STRATIFIED DRIFT (alluvial material deposited from melting glaciers)

OUTWASH PLAINS - Alluvium form meltwater not in close proximity to glaciers. Coarser and less sorted near source.

LACUSTRINE DEPOSITS - Fine grained lake bottom deposits. Commonly silts and clays, sometimes varved.

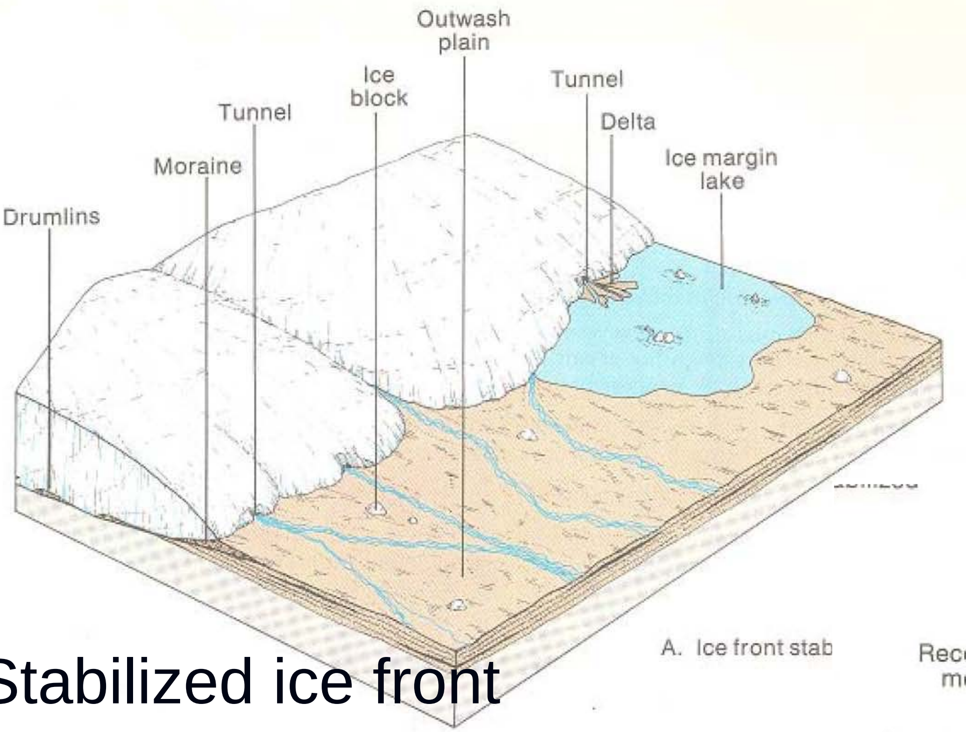
GLACIAL MARINE SEDS - Clay rich marine deposits from wasting ice sheets near ocean front.

GLACIAL LANDFORMS

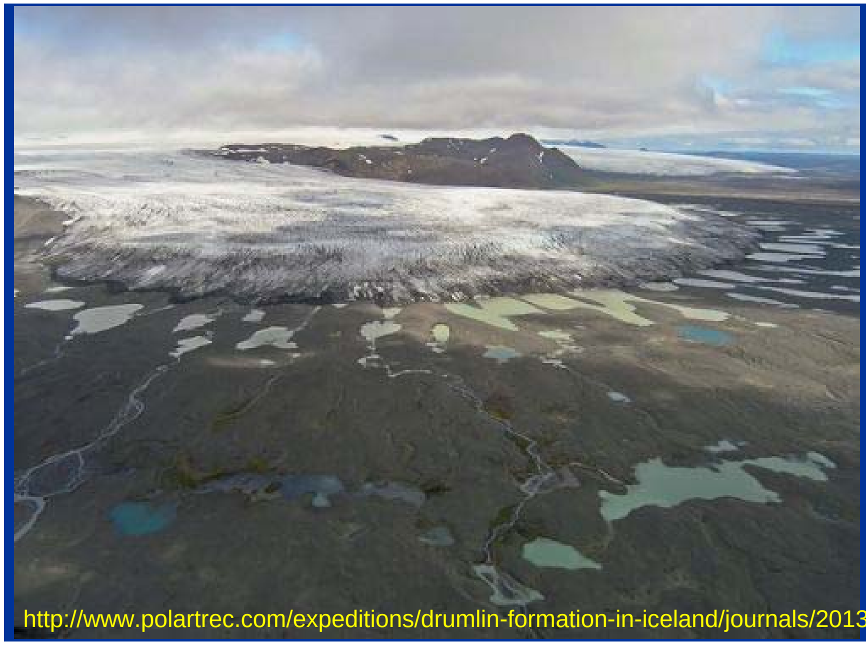
DRUMLINS - Streamlined ice-molded forms made of till

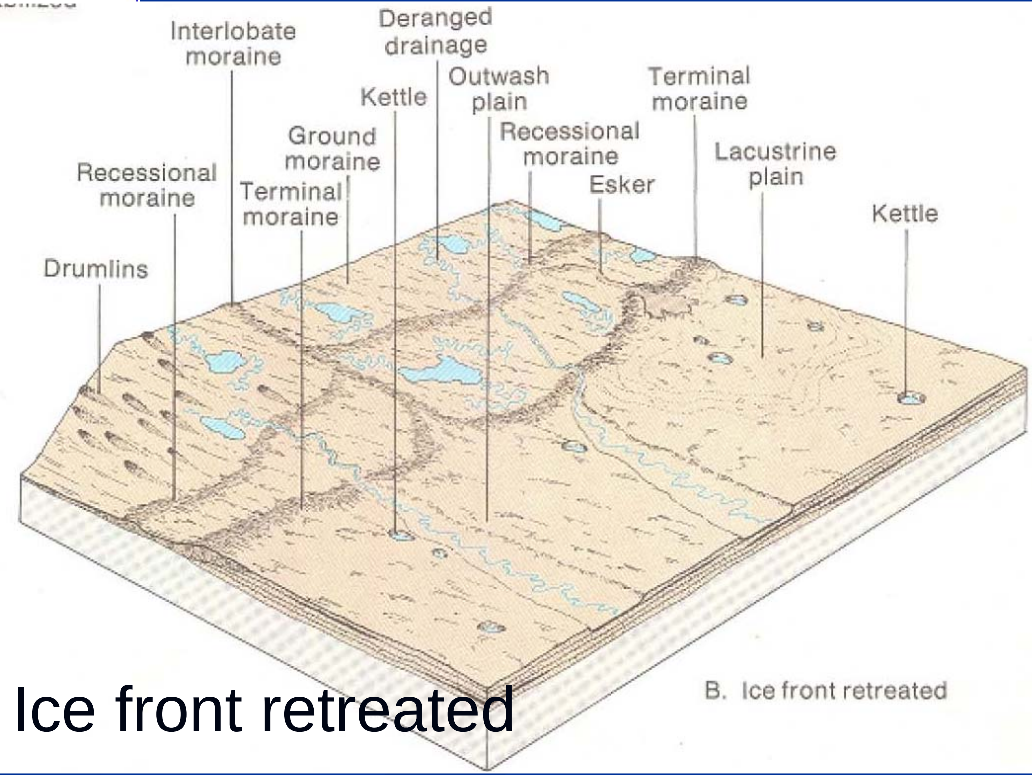
KETTLE HOLES - Basin of non-deposition due to remnant ice block buried

Schematic of Glacial Landforms/Deposits



Stabilized ice front

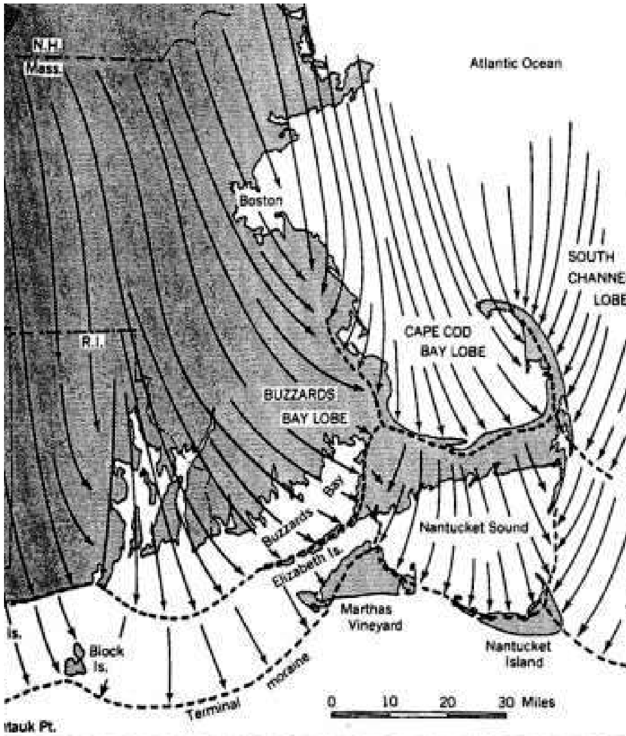


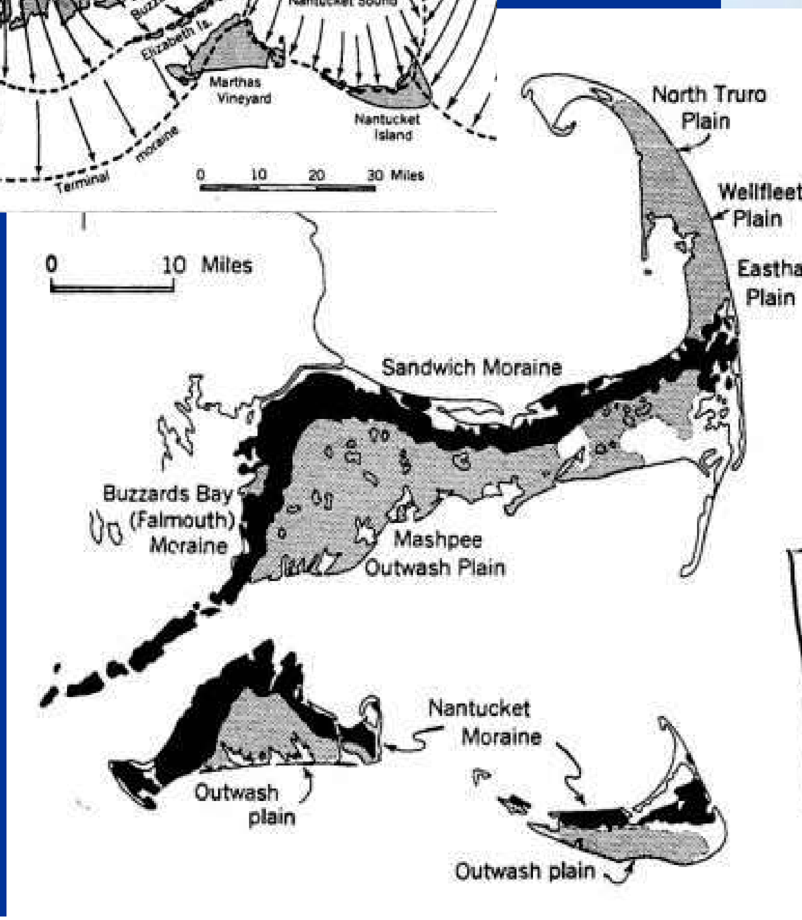


Ice front retreated

http://www.polartrec.com/expeditions/drumlin-formation-in-iceland/journals/2013-06-14

End Moraines and Outwash Plains





Strahler, 1966, Geologist's View of Cape Cod

Lateral Moraines- Everyone's Favorite

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End Moraine
Nepal

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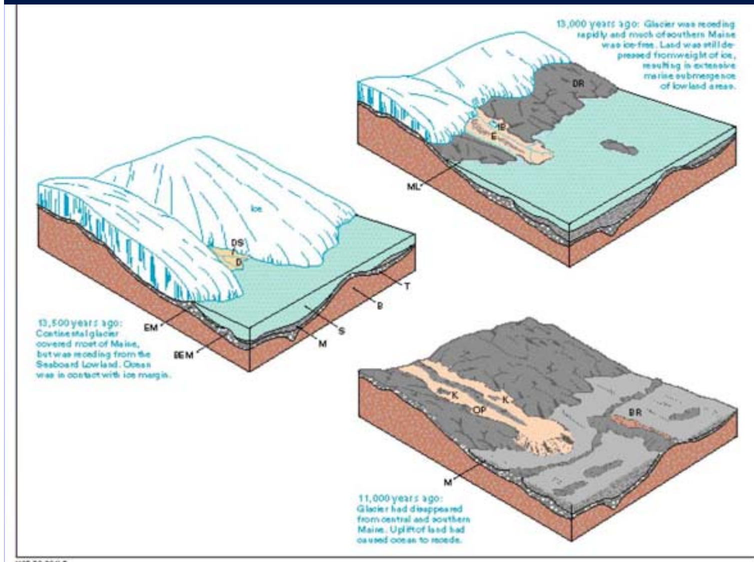
Ice Contact Deposits- Till



NOT TO SCALE

Modified from Thompson, W.B., and Borns, H.W., Jr., 1985, Surficial geologic map of Maine: Maine Geological Survey, 1 sheet, scale 1:500,000.

EXPLANATION

BEM	**Buried end moraine (till)**	IB	**Ice block**
B	**Bedrock**	K	**Kettle**
BR	**Bedrock ridge**	M	**Marine deposits (clay and silt)**
D	**Delta (outwash deposits)**	ML	**Marine limit**
DR	**Drumlins (till)**	OP	**Outwash plain**
DS	**Distributary streams**	S	**Seawater**
E	**Esker (ice-contact deposit)**	T	**Till**
EM	**End moraine (till)**		

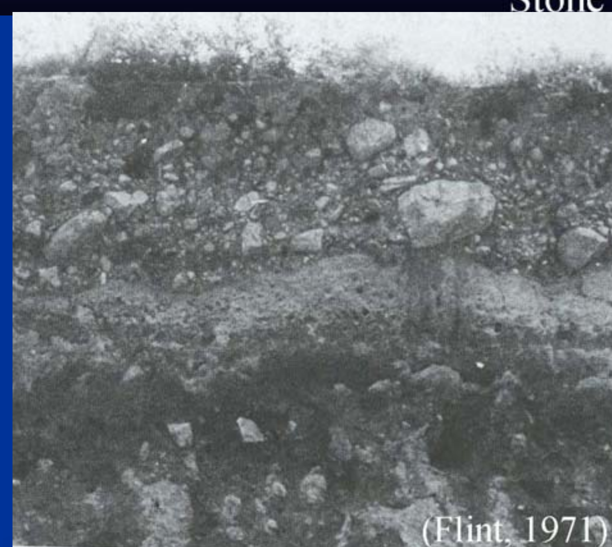
Figure 14. Most till was laid down directly by glacial ice, whereas most other types of glacial depositional features were formed by meltwater as the glaciers receded. As the glaciers melted and sea level rose, lowland areas that had been depressed by the weight of the glacial ice were partly covered by the ocean. Marine clay and silt were deposited in these lowland areas until the land rebounded and the ocean receded.

Typical exposure of thin till overlying metamorphic bedrock in the Eastern and Western Highlands. Exposure is in Deep River, Conn. Photograph by Janet Radway Stone.

Stone and others, 199

Basal Till

Bedrock



Ablation Till

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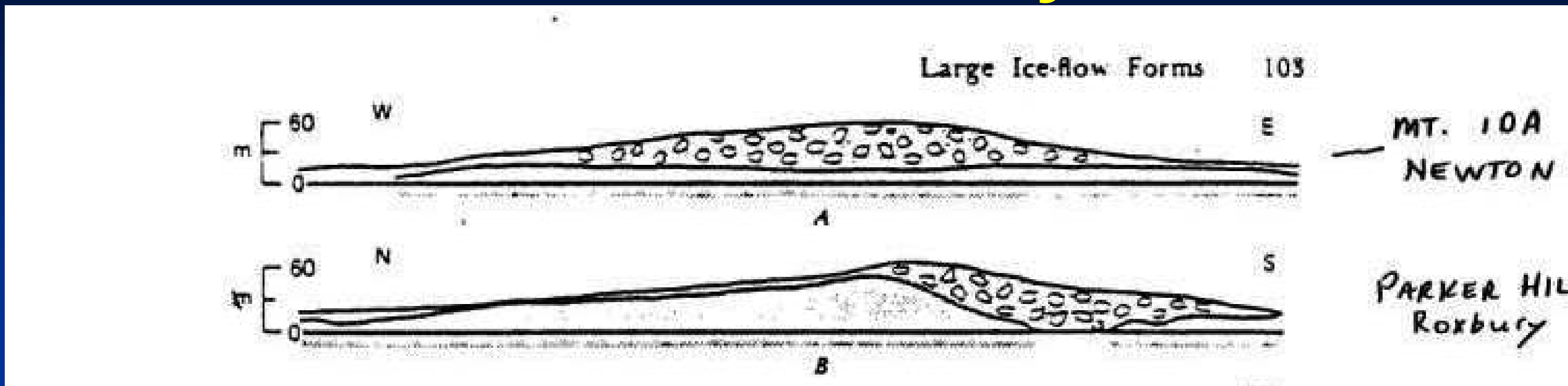
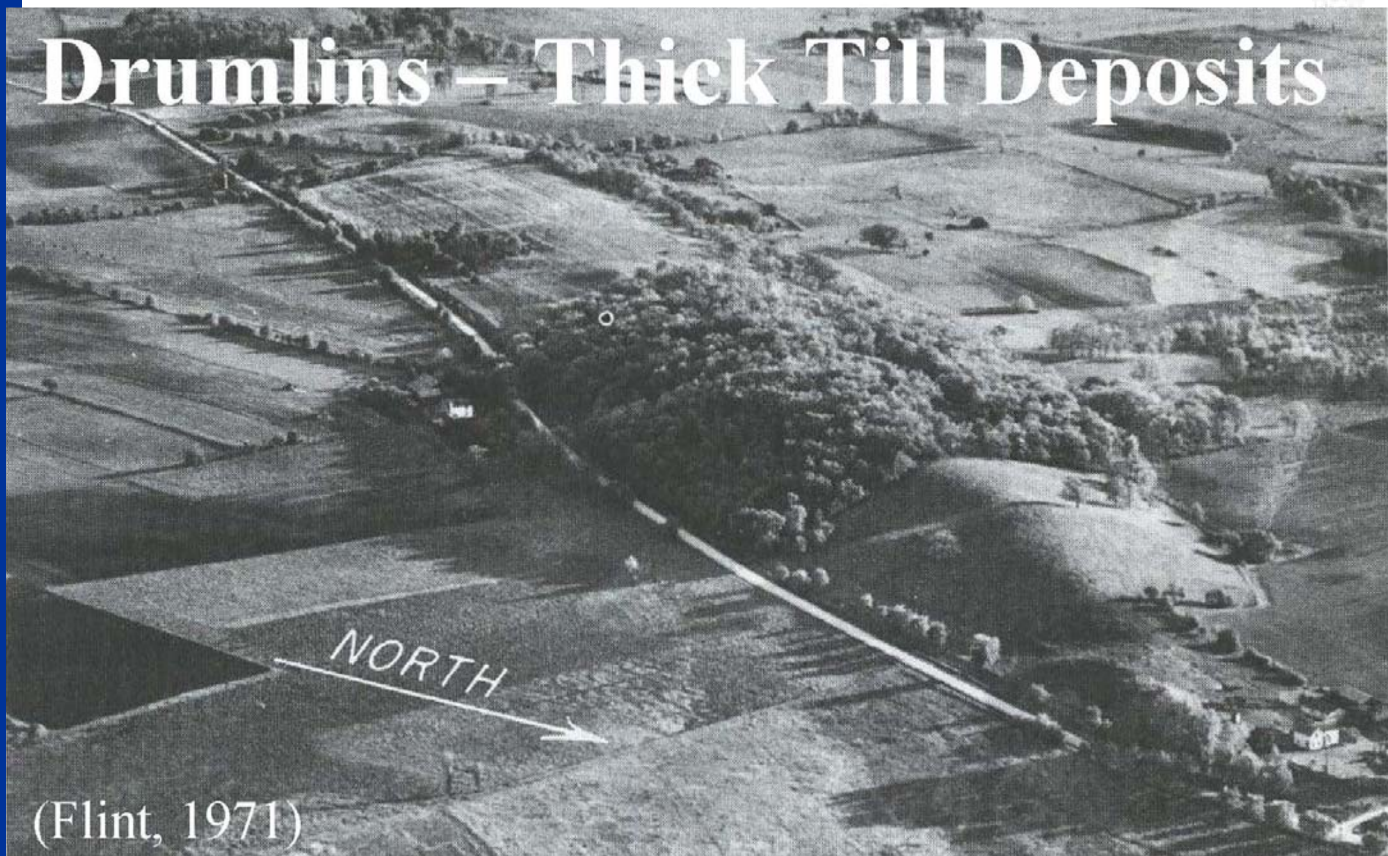
Drumlins You May Know





Depositional Model for Glacial Deposits

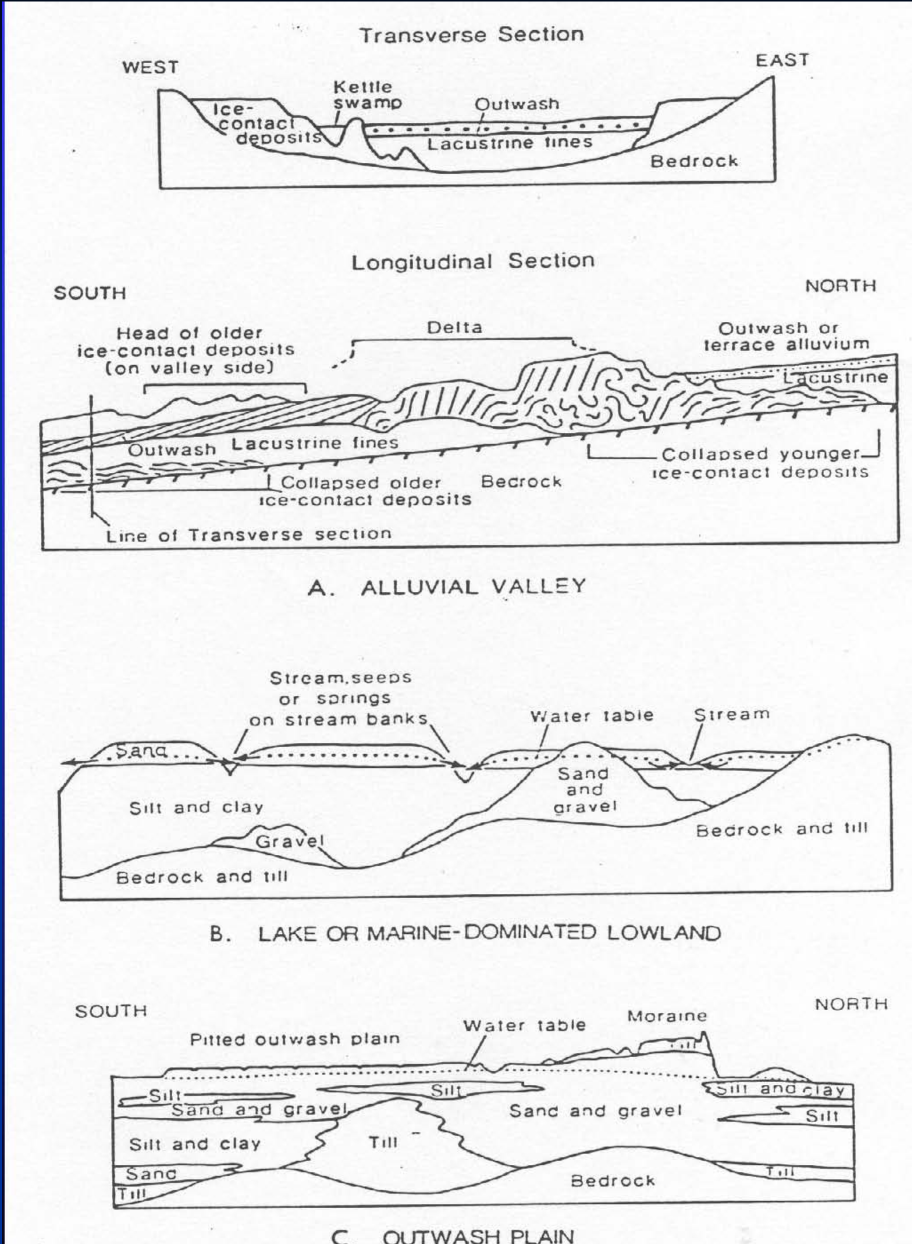


Figure 4. Idealized sections showing geometry of stratified drift.

Proximal Stratified Drift (Deltaic) Deposits

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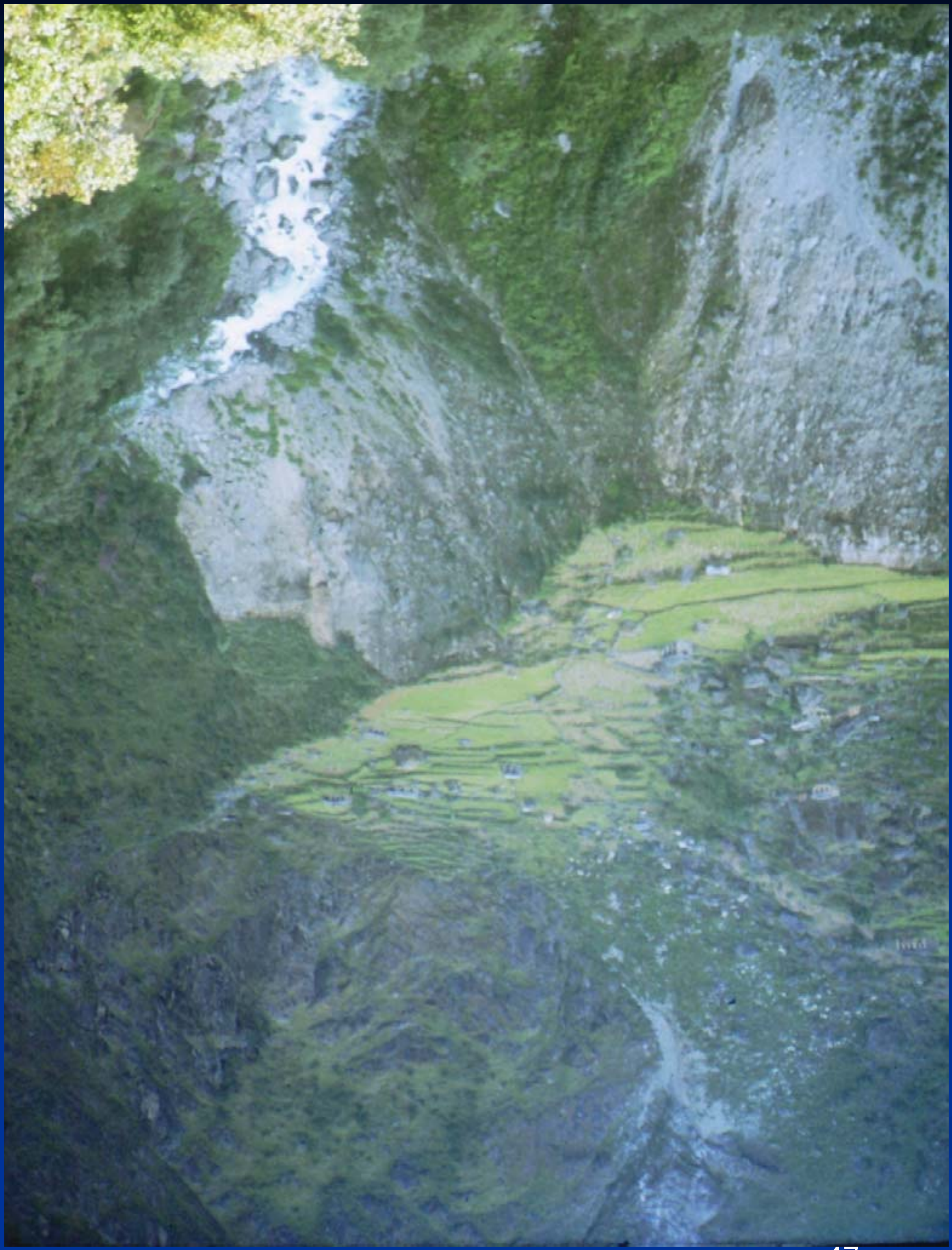

Kame Terrace, Nepal

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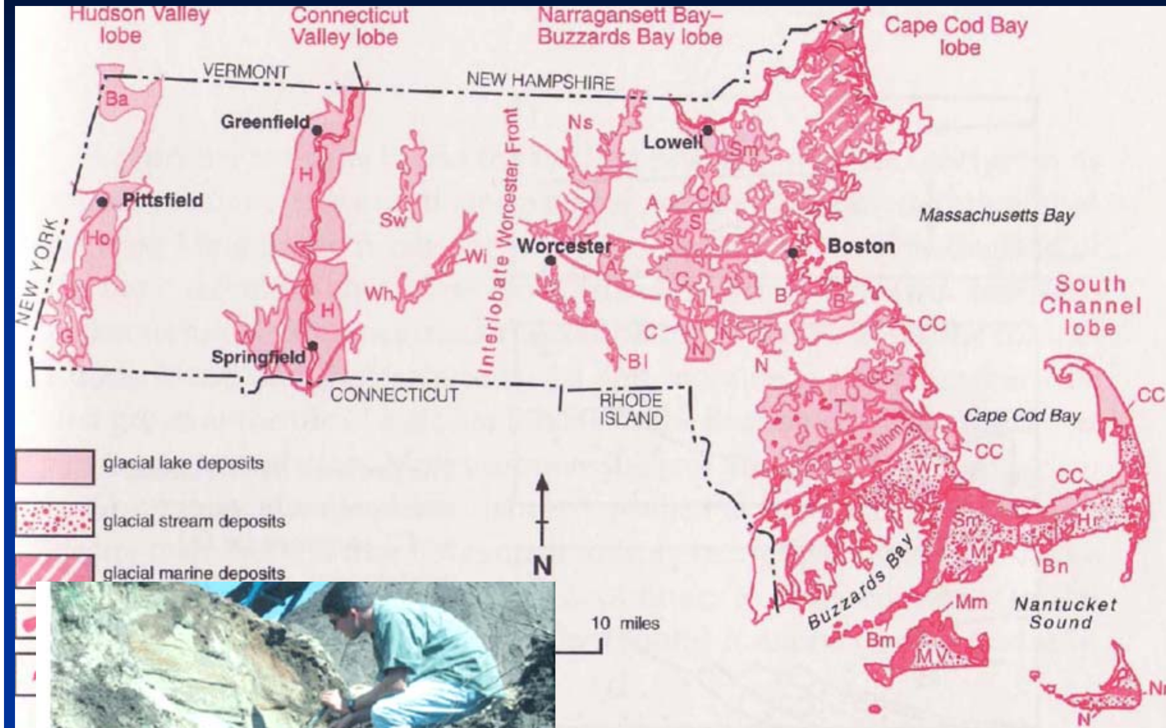
Pro-Glacial Lake Deposits

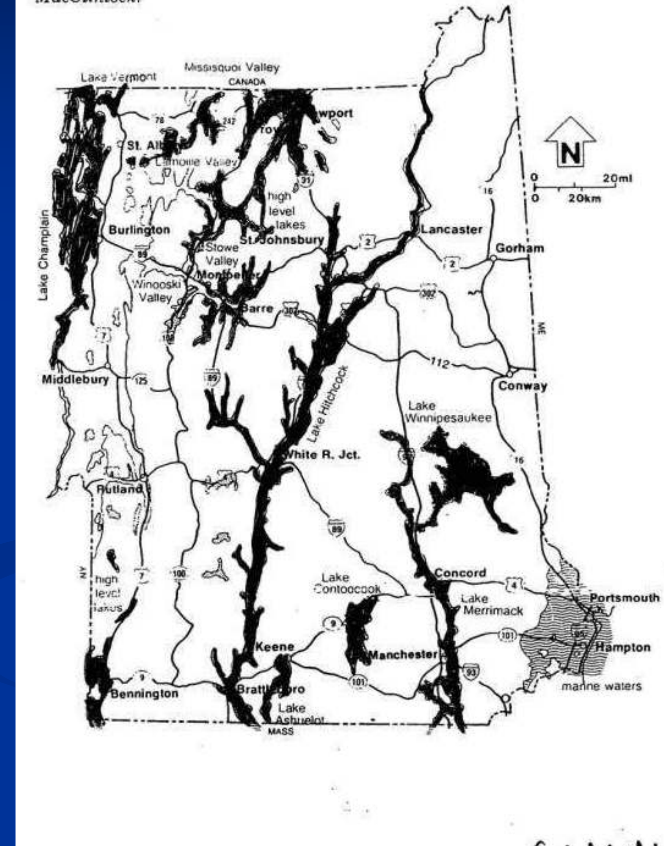


Massachusetts

(Skehan, 2001)

Lacustrine varves, Glacial Lake

Major glacier lakes of Vermont and New Hampshire and marine submersion of New Hampshire seacoast. Outlines are approximate, based on Stewart and MacClintock.



New Hampshire – Vermont

Van Diver, 1987

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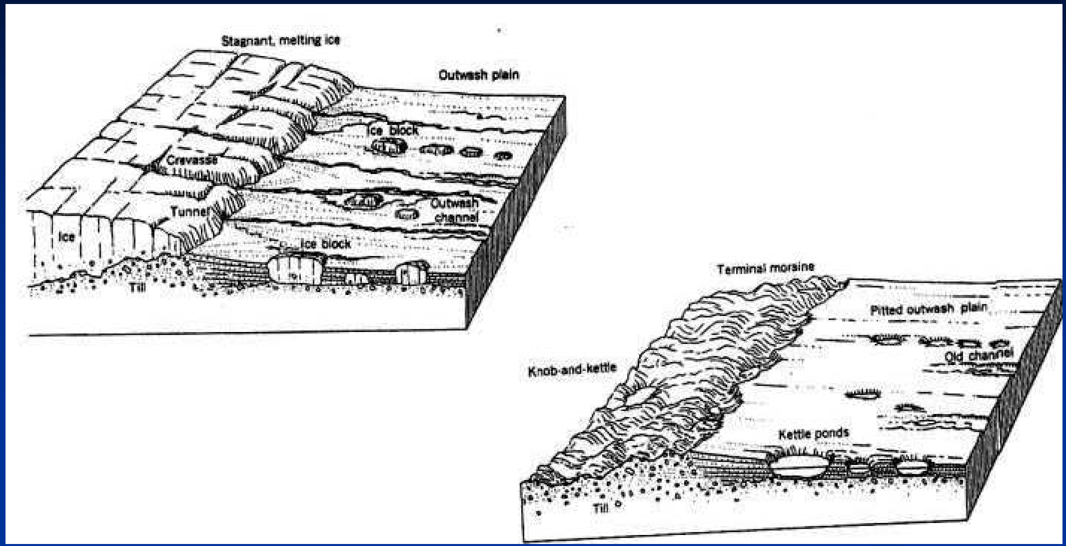
Outwash Deposits

http://www.capecodbeachchair.com/beachguide/index.cfm?page=3&BeachId=64

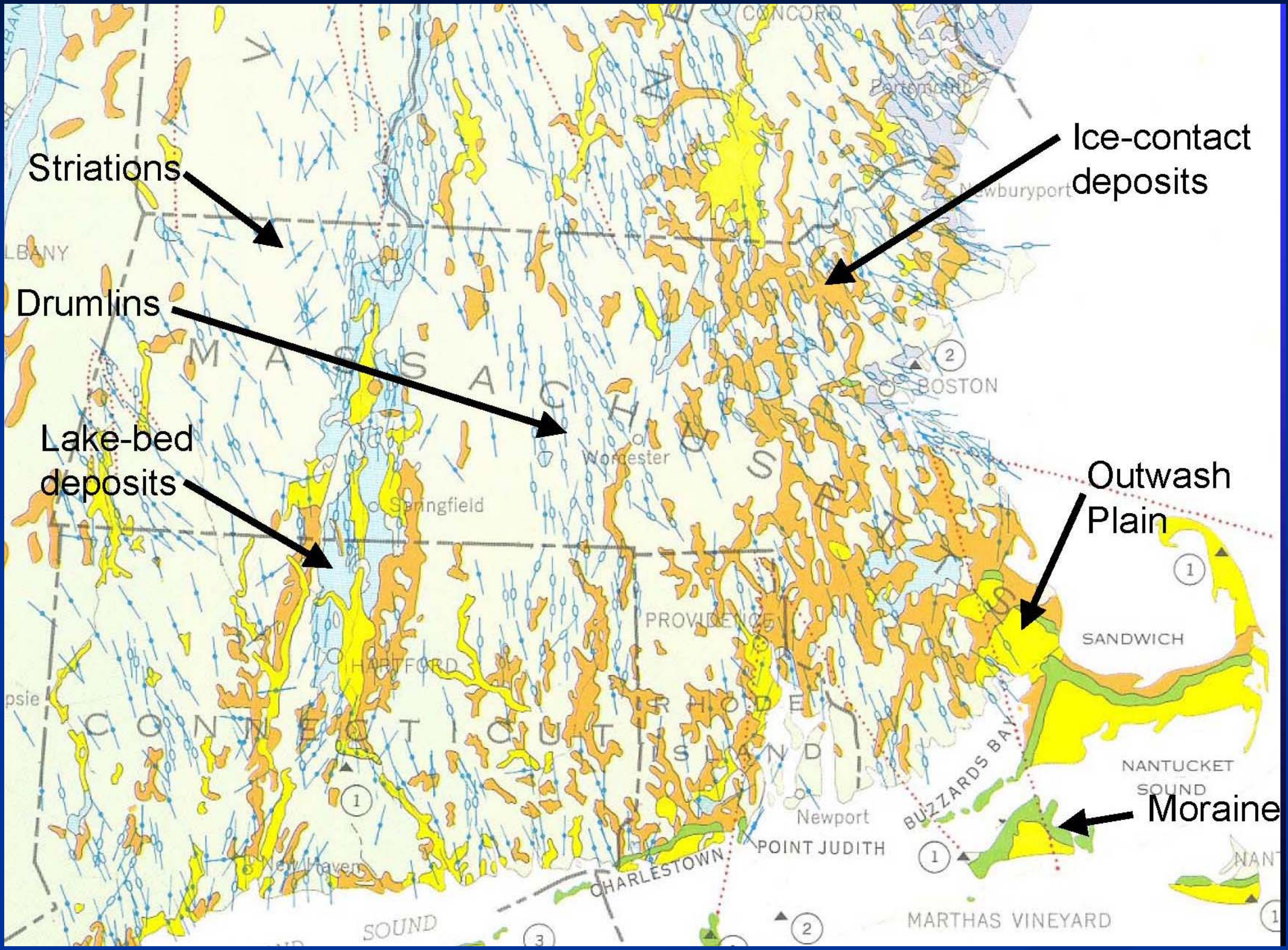
Kettle Pond Formation



Strahler, 1966, Geologist's View of Cape Cod

Glacial Erratics

Southern New England Glacial Map



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New England Cross-Sections

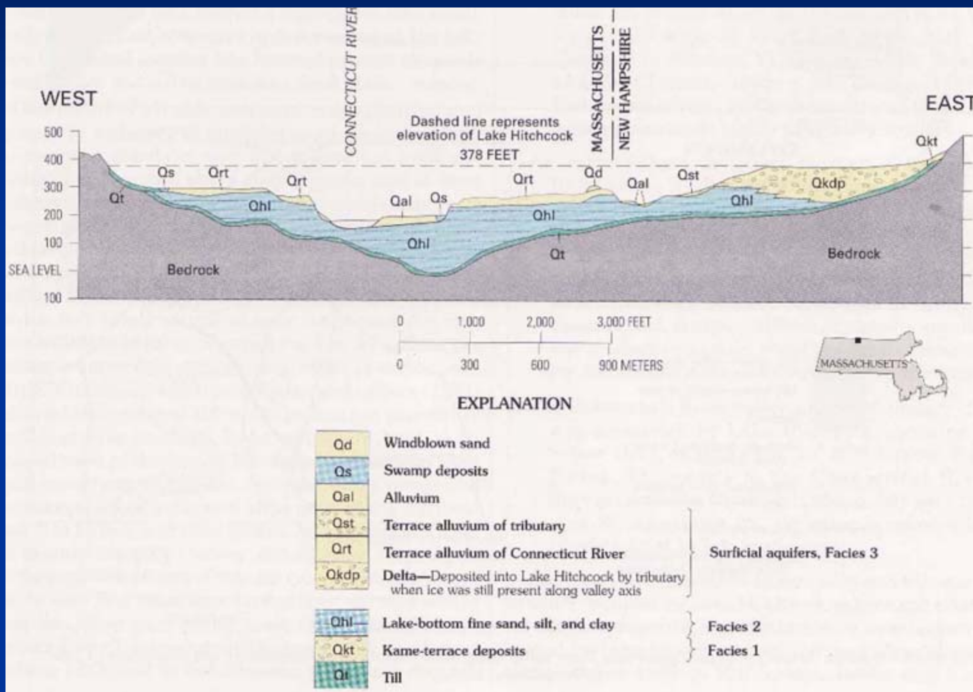
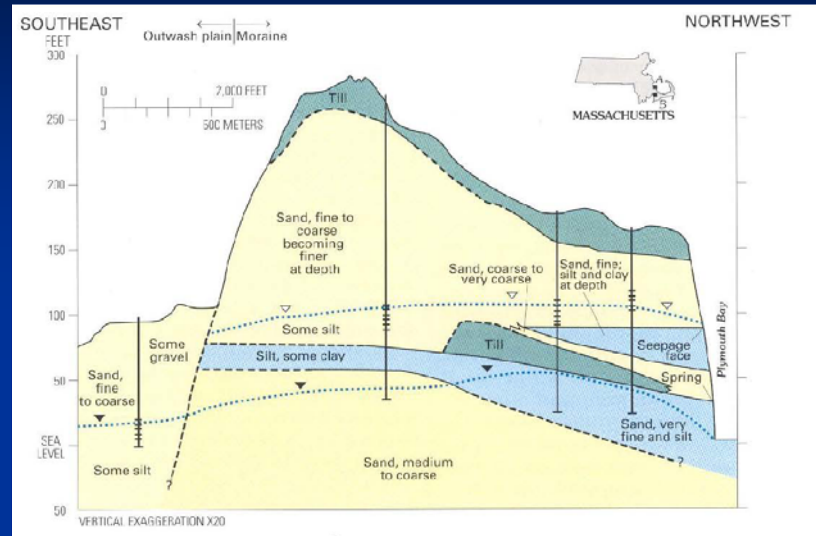
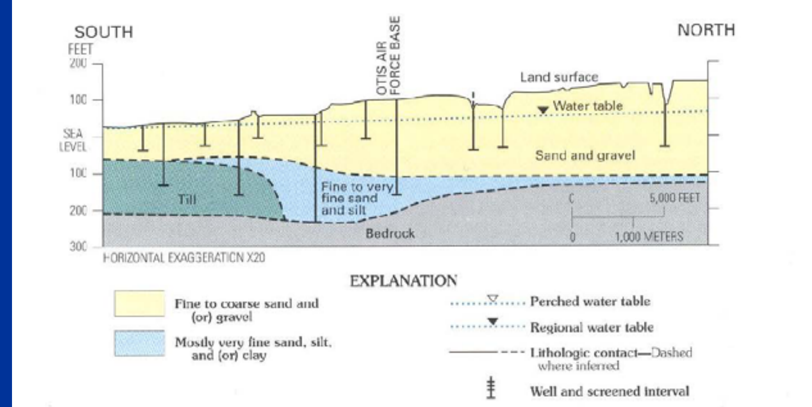


FIGURE 57.—Generalized section across the Connecticut River valley. Line of section nearly coincides with northern border of Massachusetts. (Modified from Campbell and Hartshorn, 1980.)



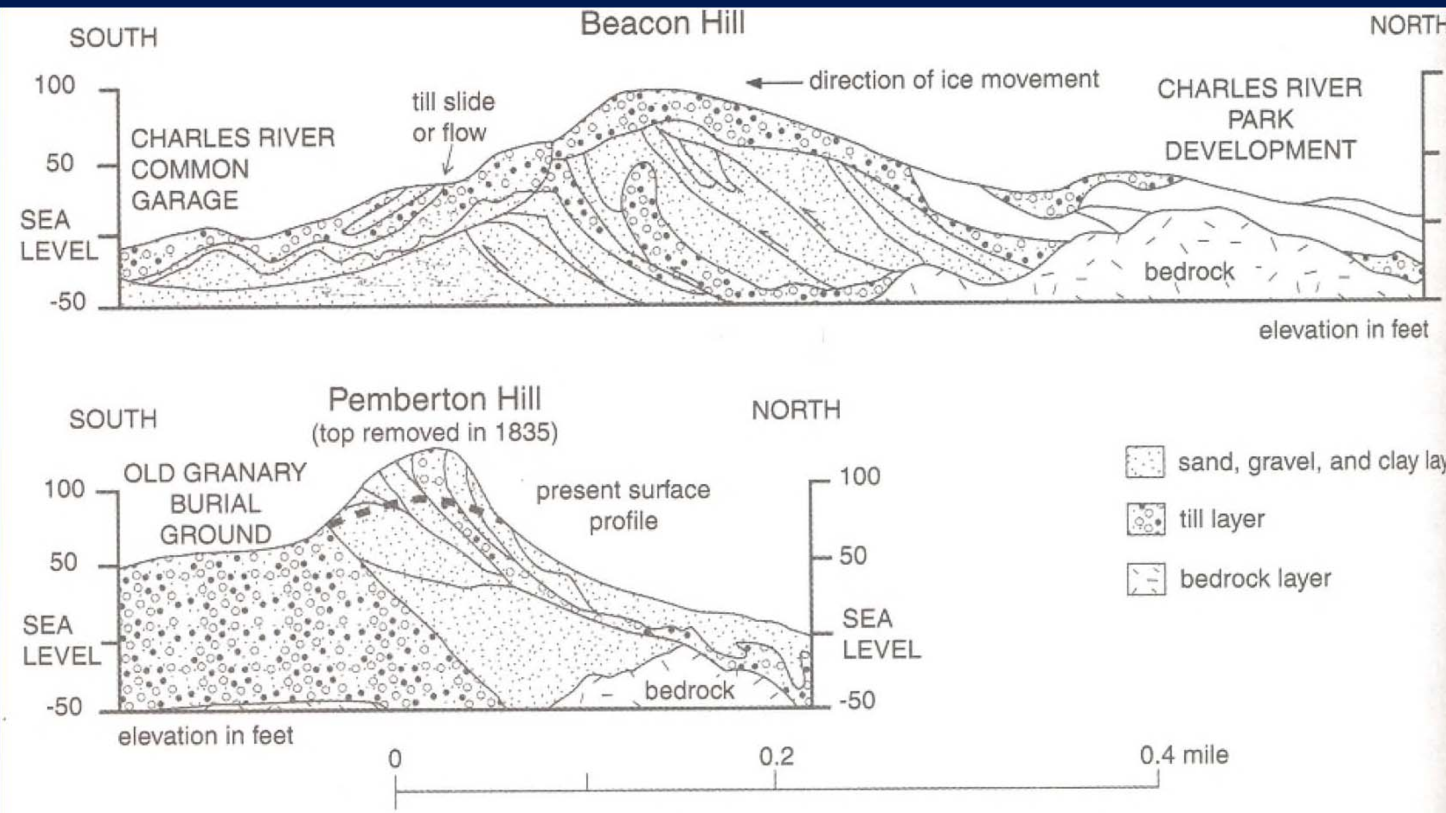
A. Section across moraine in the town of Plymouth, Mass. (From Hansen and Lapham, 1992, fig. 9)



B. Section south of moraine in the towns of Sandwich and Falmouth, Mass. (From LeBlanc and others, 1986, sheet 1)

FIGURE 42.—Geologic sections in outwash plains in southeastern Massachusetts.

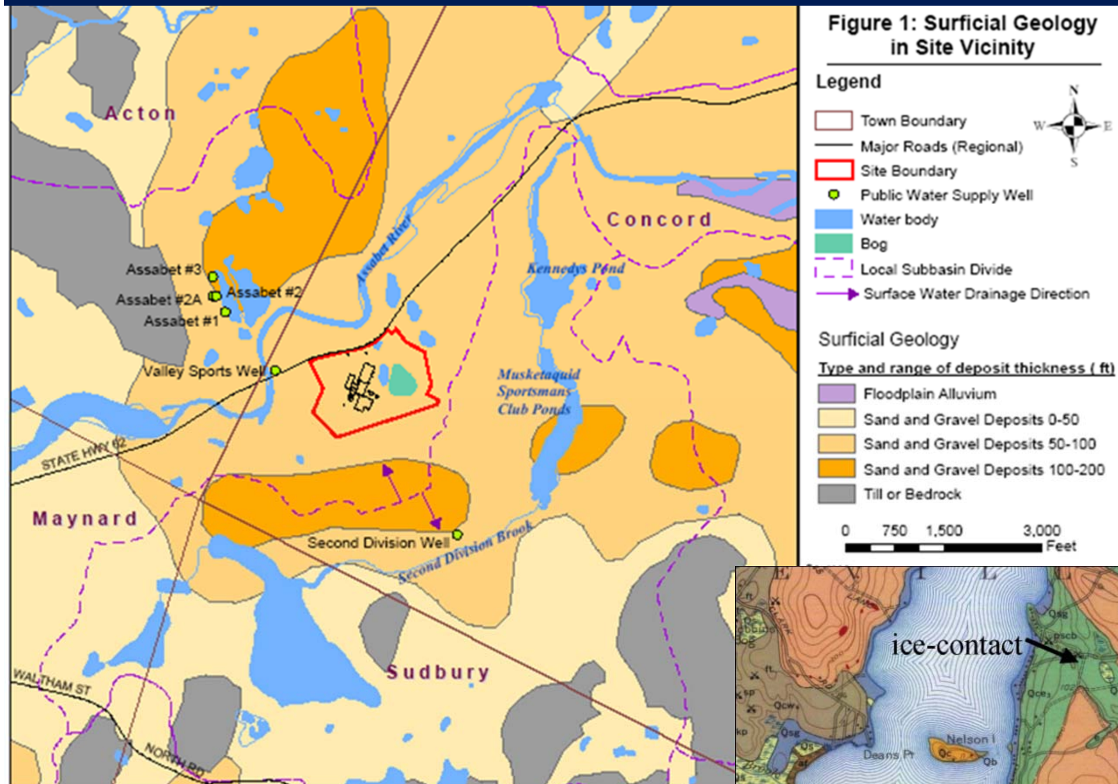
Boston Glacial Cross-Section



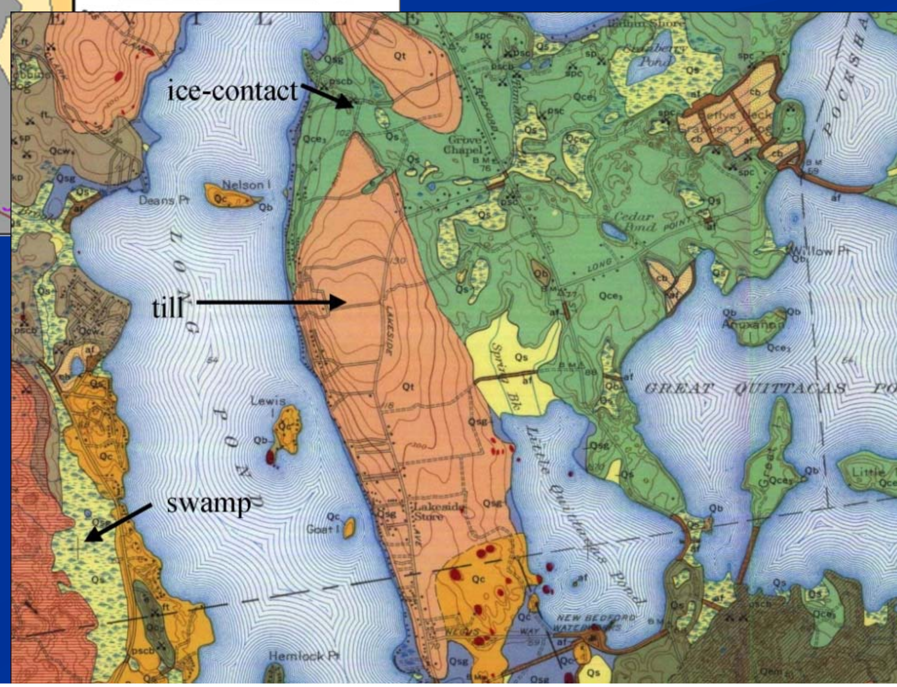
Simplified geological cross sections through Beacon Hill and Pemberton Hill show complex repetition of till, sand, and gravel layers produced by southward thrusting of glacial ice. —Modified after Kaye, 1976

(Skehan, 2001)

Surficial Geologic Maps



MassGIS



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Agenda

1. ASCE Student Chapter and AFE 14.533 Class
   - New England Bedrock Geology Overview
     - Bedrock Geology 101
     - General Geologic Terranes in New England
     - General Bedrock Types in New England
2. **AFE 14.533 Class**
   - **Rock Core Viewing**
   - New England Surficial Geology Overview
     - Unconsolidated Material (Overburden) Types
     - Typical Overburden Stratigraphic Sequences
     - **Examples of Applied Subsurface Evaluation**

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Direct Push – Soil Sampling

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More Direct Push-Soil Sampling

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Sonic Drilling – Sample Recovery

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Soil Sampling

Split Spoon Sampler

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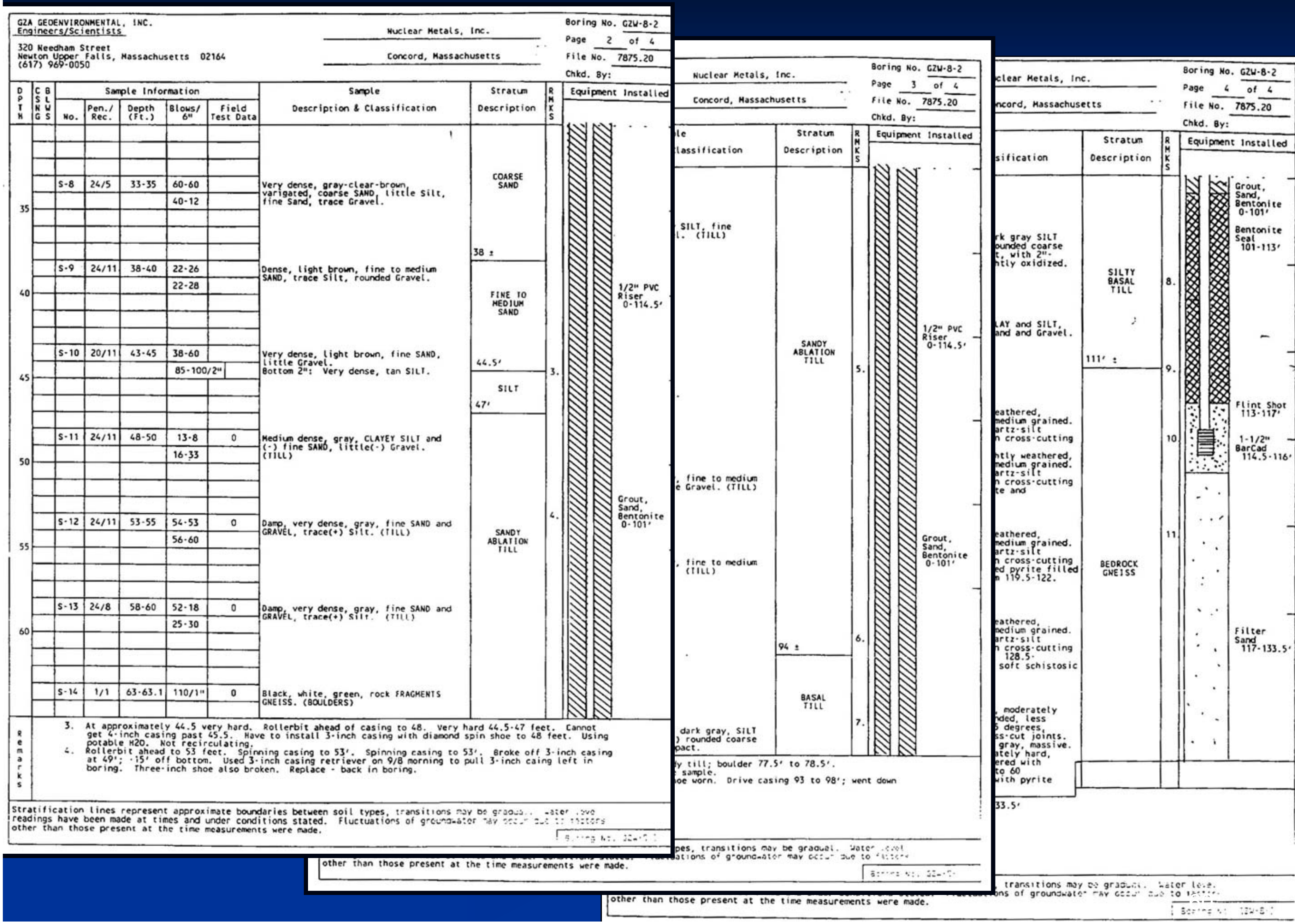
Glacial Stratigraphy – Concord, MA



GZA GEOENVIRONMENTAL, INC.
Engineers/Scientists
320 Needham Street
Newton Upper Falls, Massachusetts 02164
(617) 969-0050

Nuclear Metals, Inc.
Concord, Massachusetts

Boring No. GZW-8-2
Page 2 of 4
File No. 7875.20
Chkd. By:

DEPTH	CSNG	BLWS	No.	Pen./Rec.	Depth (Ft.)	Blows/6"	Field Test Data	Sample Description & Classification	Stratum Description	RMKS	Equipment Installed
			S-8	24/5	33-35	60-60		Very dense, gray-clear-brown, varigated, coarse SAND, little Silt, fine Sand, trace Gravel.	COARSE SAND		
35						40-12					
									38 ±		
			S-9	24/11	38-40	22-26		Dense, light brown, fine to medium SAND, trace Silt, rounded Gravel.			
40						22-28			FINE TO MEDIUM SAND		1/2" PVC Riser 0-114.5'
			S-10	20/11	43-45	38-60		Very dense, light brown, fine SAND, little Gravel. Bottom 2": Very dense, tan SILT.	44.5'		
45						85-100/2"			SILT	3.	
									47'		
			S-11	24/11	48-50	13-8	0	Medium dense, gray, CLAYEY SILT and (-) fine SAND, little(-) Gravel. (TILL)			
50						16-33					
										4.	Grout, Sand, Bentonite 0-101'
			S-12	24/11	53-55	54-53	0	Damp, very dense, gray, fine SAND and GRAVEL, trace(+) Silt. (TILL)	SANDY ABLATION TILL		
55						56-60					
			S-13	24/8	58-60	52-18	0	Damp, very dense, gray, fine SAND and GRAVEL, trace(+) Silt. (TILL)			
60						25-30					
			S-14	1/1	63-63.1	110/1"	0	Black, white, green, rock FRAGMENTS GNEISS. (BOULDERS)			

Remarks:
3. At approximately 44.5 very hard. Rollerbit ahead of casing to 48. Very hard 44.5-47 feet. Cannot get 4-inch casing past 45.5. Have to install 3-inch casing with diamond spin shoe to 48 feet. Using potable H2O. Not recirculating.
4. Rollerbit ahead to 53 feet. Spinning casing to 53'. Spinning casing to 53'. Broke off 3-inch casing at 49'; -15' off bottom. Used 3-inch casing retriever on 9/8 morning to pull 3-inch caing left in boring. Three-inch shoe also broken. Replace - back in boring.

Stratification lines represent approximate boundaries between soil types, transitions may be gradual. Water level readings have been made at times and under conditions stated. Fluctuations of groundwater may occur due to factors other than those present at the time measurements were made.

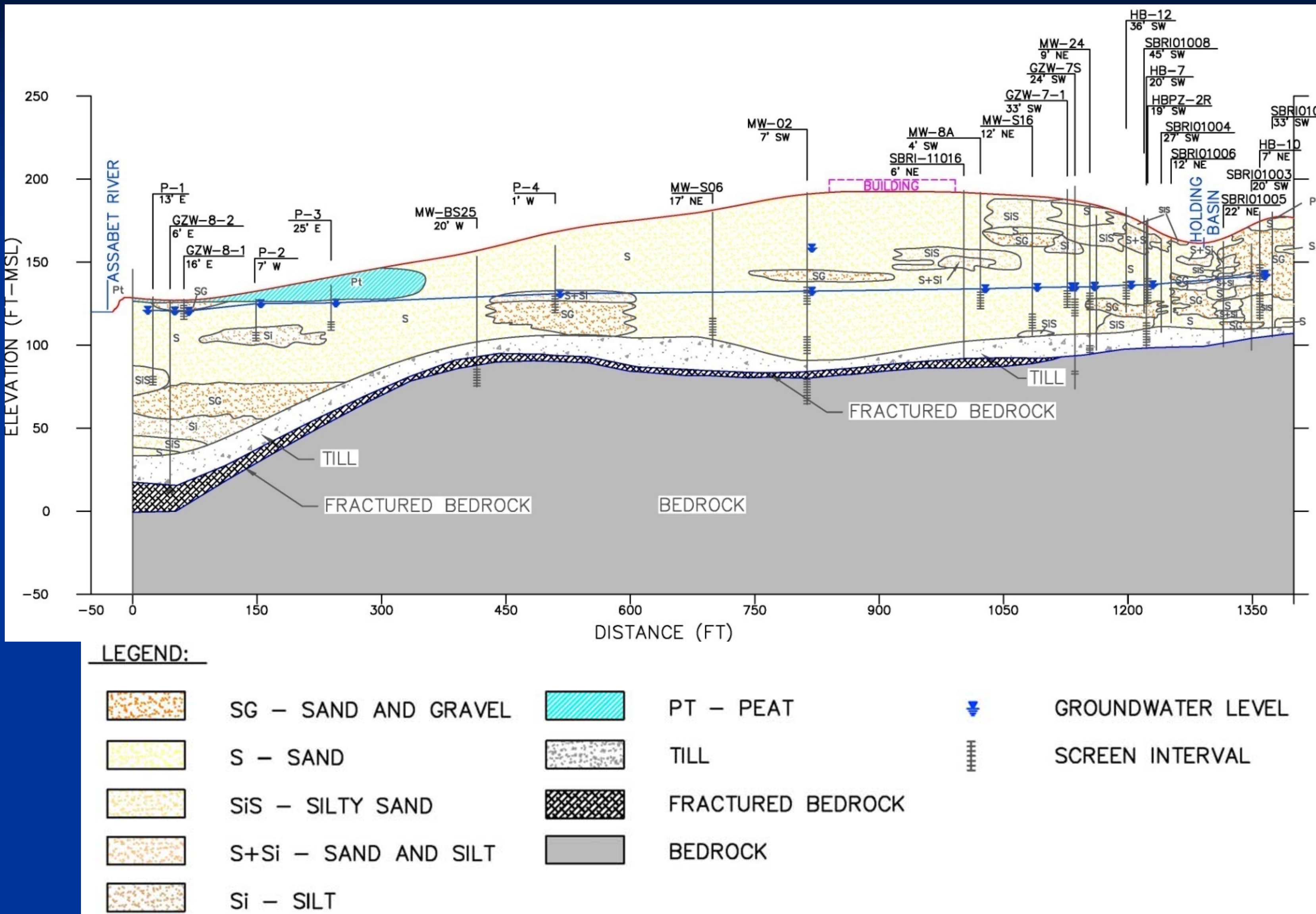
Nuclear Metals, Inc.
Concord, Massachusetts
Boring No. GZW-8-2
Page 3 of 4
File No. 7875.20
Chkd. By:

Stratum Description: SANDY ABLATION TILL; 94 ±; BASAL TILL
Equipment Installed: 1/2" PVC Riser 0-114.5'; Grout, Sand, Bentonite 0-101'

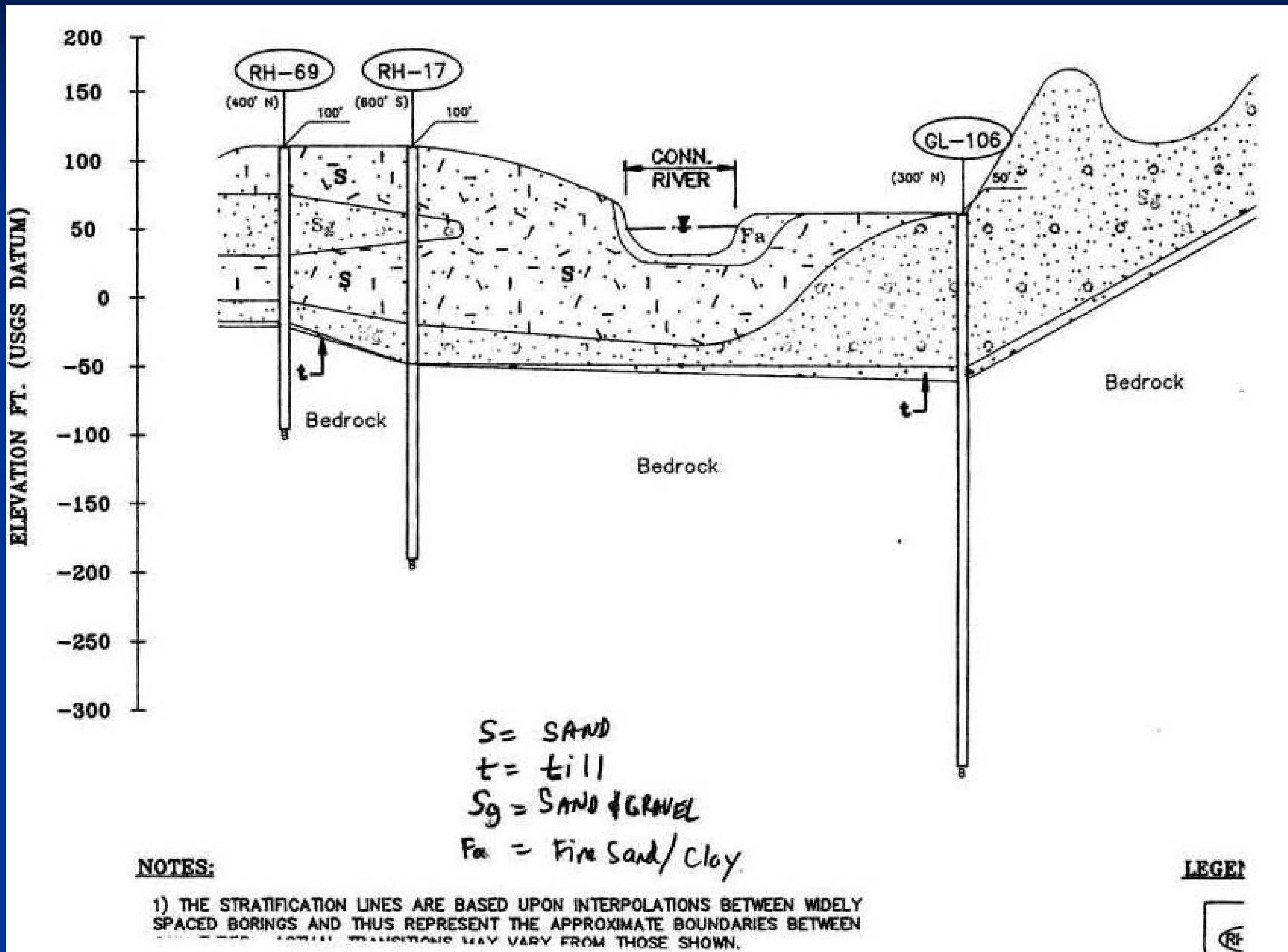
Boring No. GZW-8-2
Page 4 of 4
File No. 7875.20
Chkd. By:

Stratum Description: SILTY BASAL TILL; 111' ±; BEDROCK GNEISS
Equipment Installed: Grout, Sand, Bentonite 0-101'; Bentonite Seal 101-113'; Flint Shot 113-117'; 1-1/2" BarCad 114.5-116'; Filter Sand 117-133.5'

Glacial Stratigraphy – Concord, MA (2)



Glacial Stratigraphy – Glastonbury, CT



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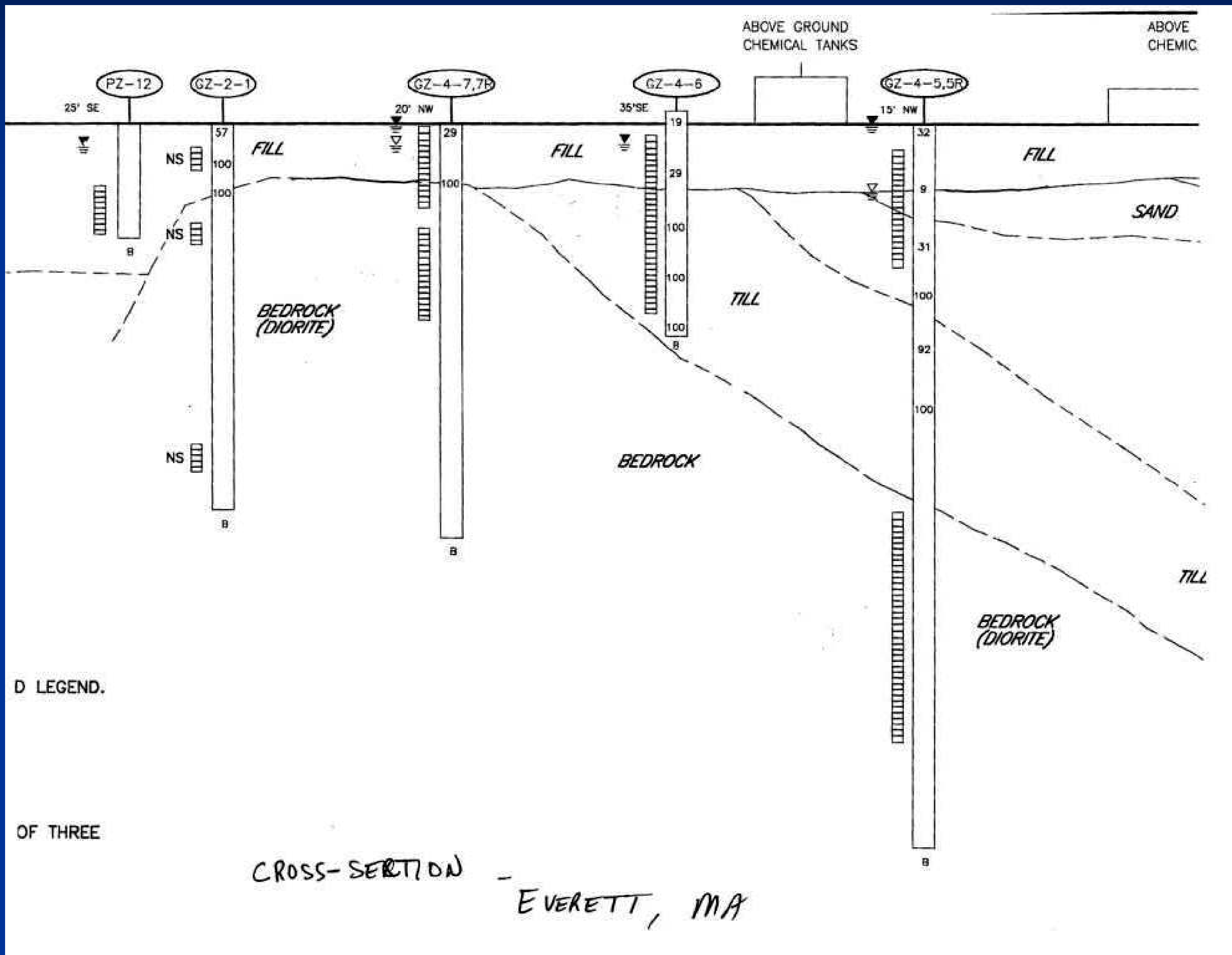
Glacial Stratigraphy – Everett, MA



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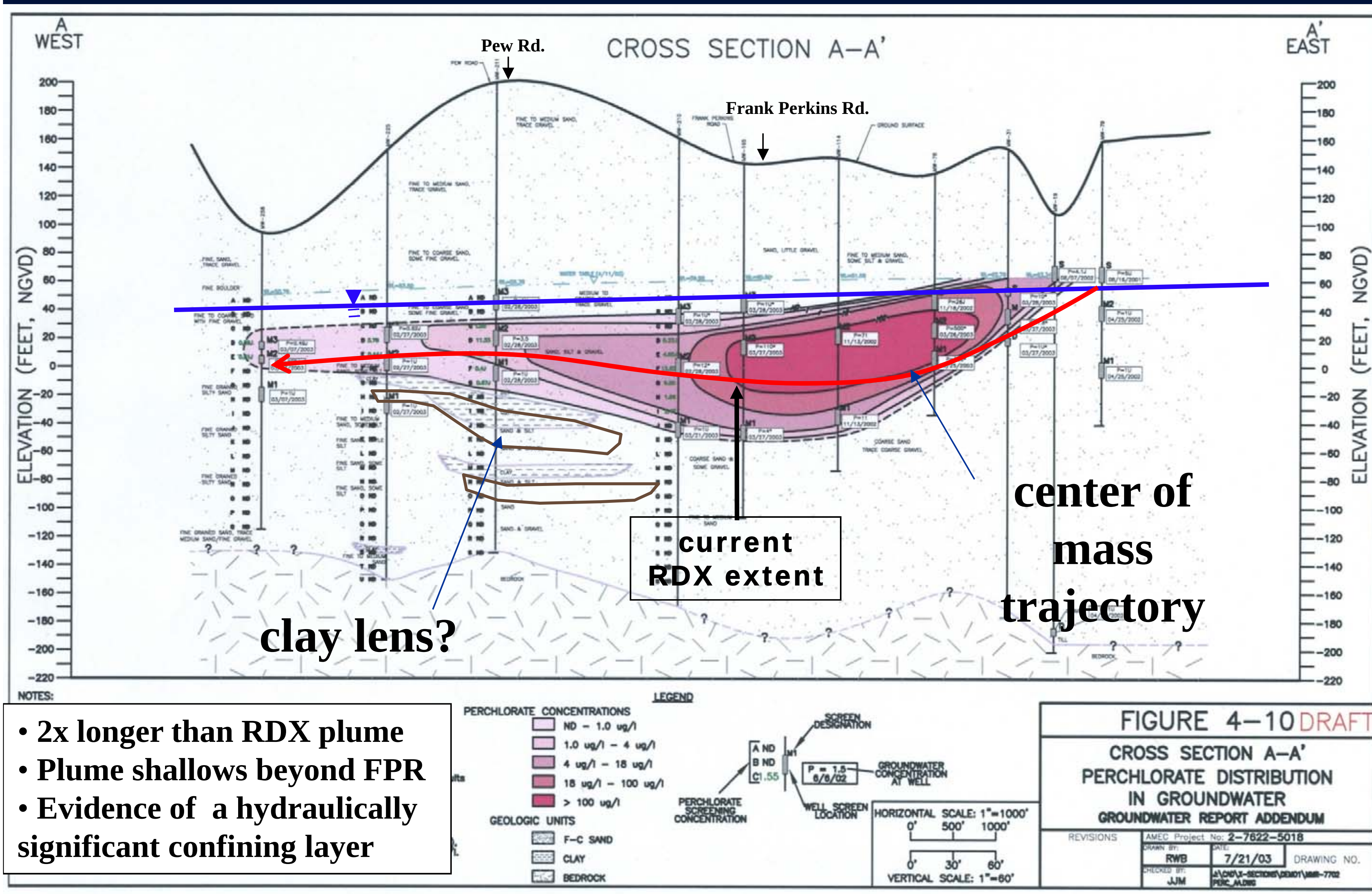
Glacial Stratigraphy- Cape Cod, the Mass Military Reservation



- 2x longer than RDX plume
- Plume shallows beyond FPR
- Evidence of a hydraulically significant confining layer

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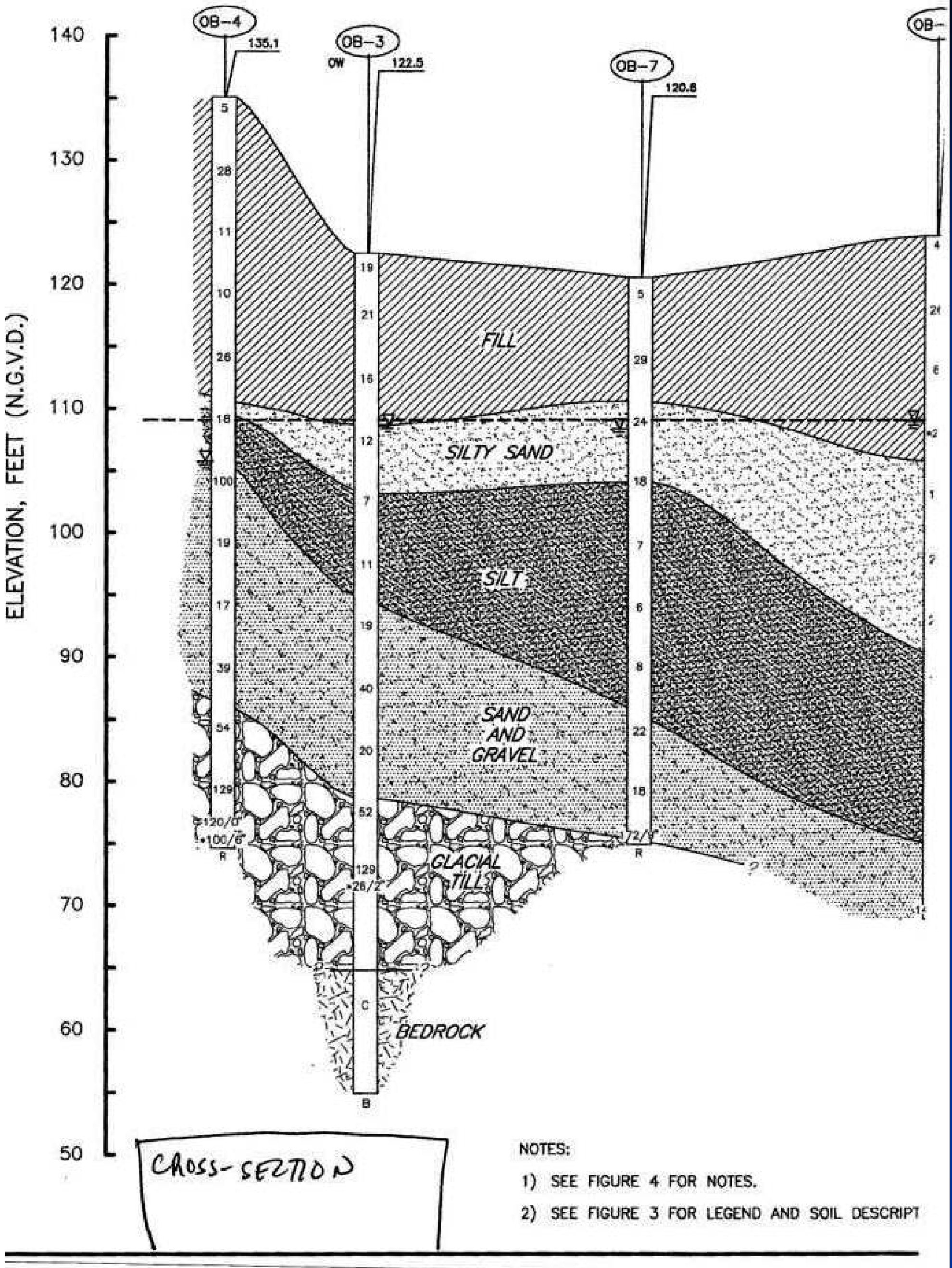

Glacial Stratigraphy-Western MA

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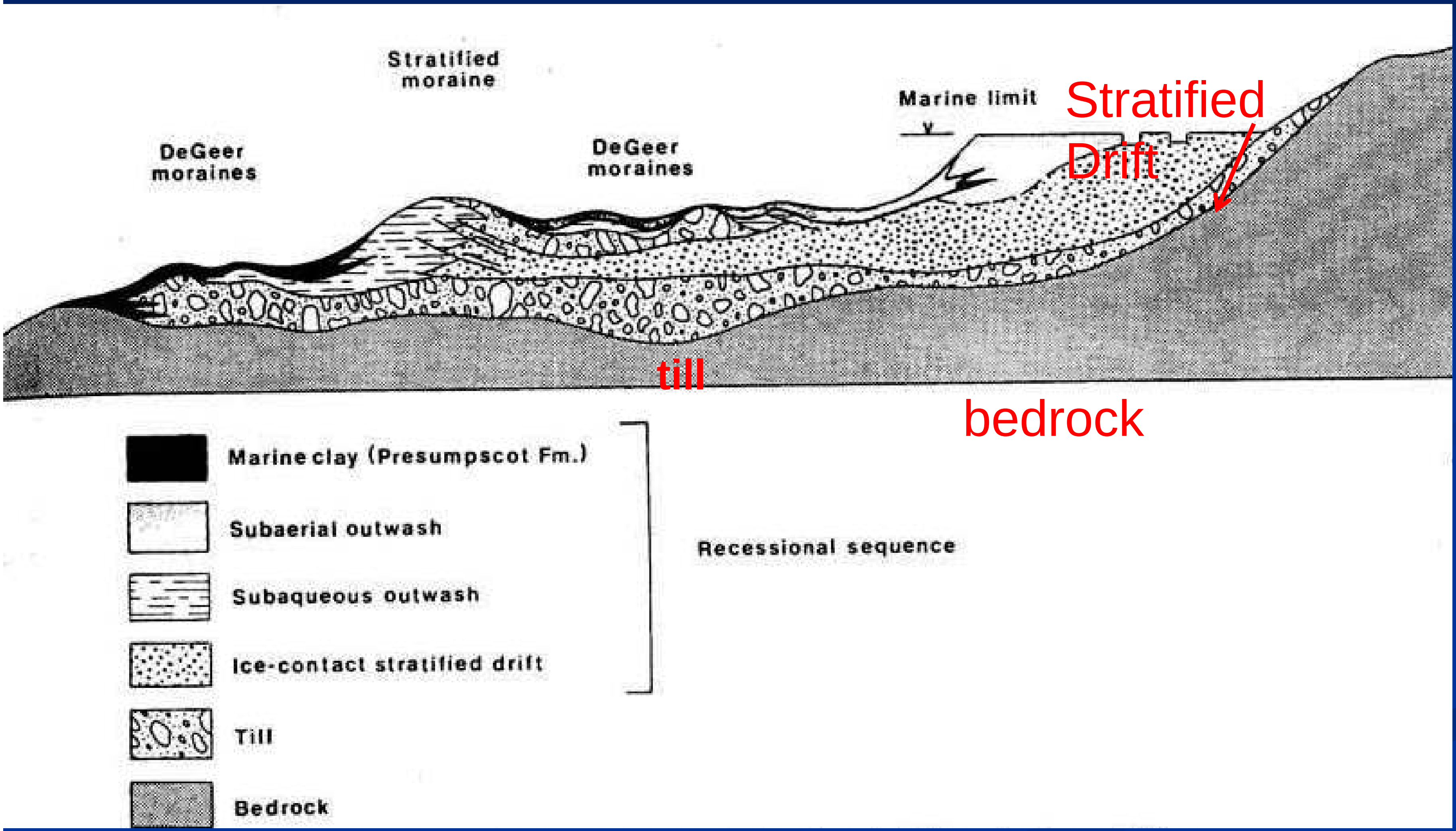
Glacial Stratigraphy - Maine



Glacial Stratigraphy – Midwest Schematic

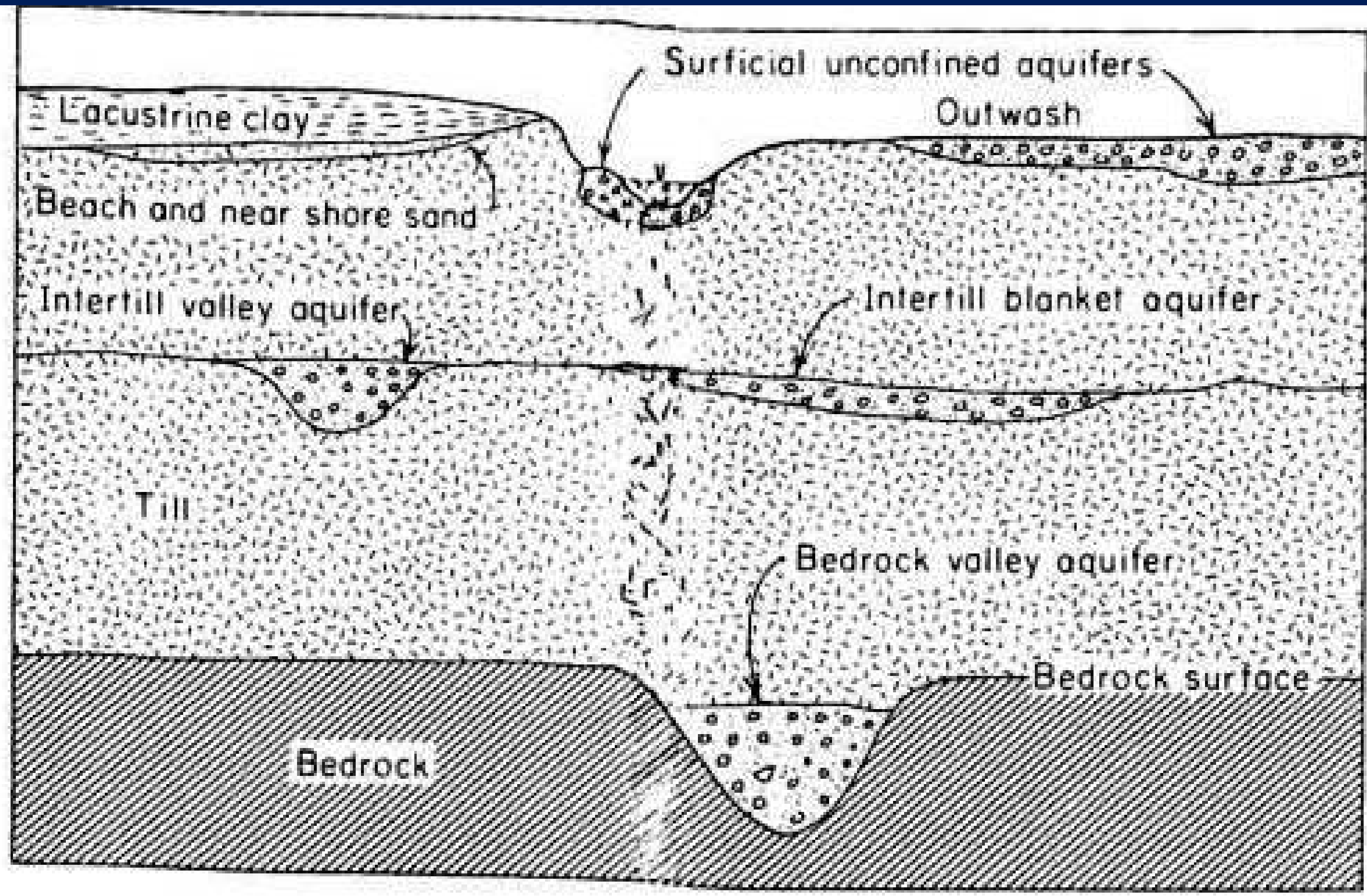


Figure 4.3 Schematic diagram of aquifer occurrence in the glaciated regions of the Midwest and Great Plains physiographic provinces.

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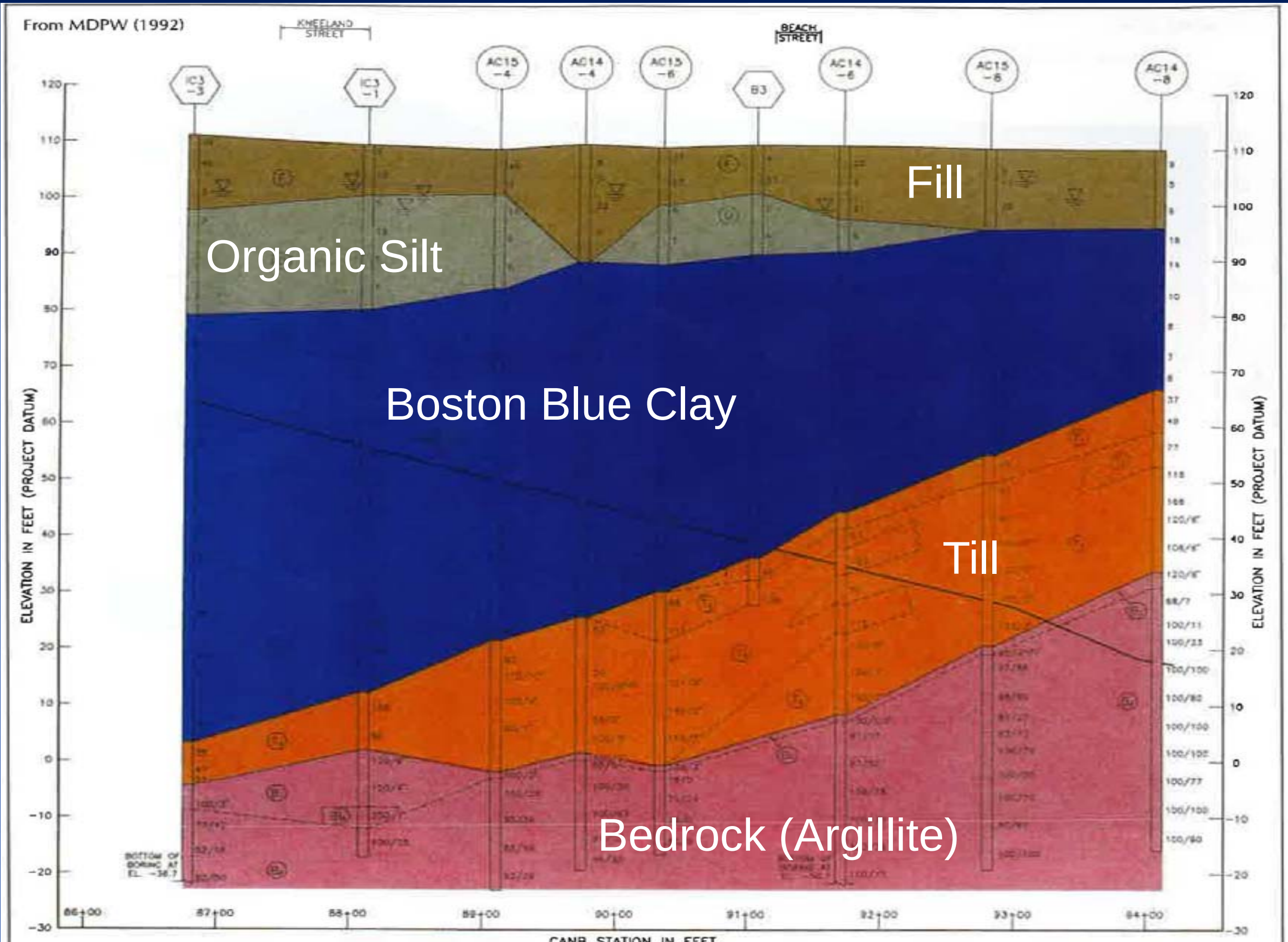
Central Artery Stratigraphy



B_1 = Completely to severely weathered Cambridge Argillite
B_2 = Severely to moderately weathered Cambridge Argillite
B_3 = Moderately to unweathered Cambridge Argillite

T_1 = Dense cohesive till
T_2 = Very dense cohesive till
T_3 = Granular till
G = Glaciomarine deposit
C_1 = Very stiff clay
C_2 = Stiff clay

C_3 = Medium stiff clay
C_4 = Hard clay
O = Organic silt & sand
F = Fill
Traversing lines = base of Central Artery Tunnels

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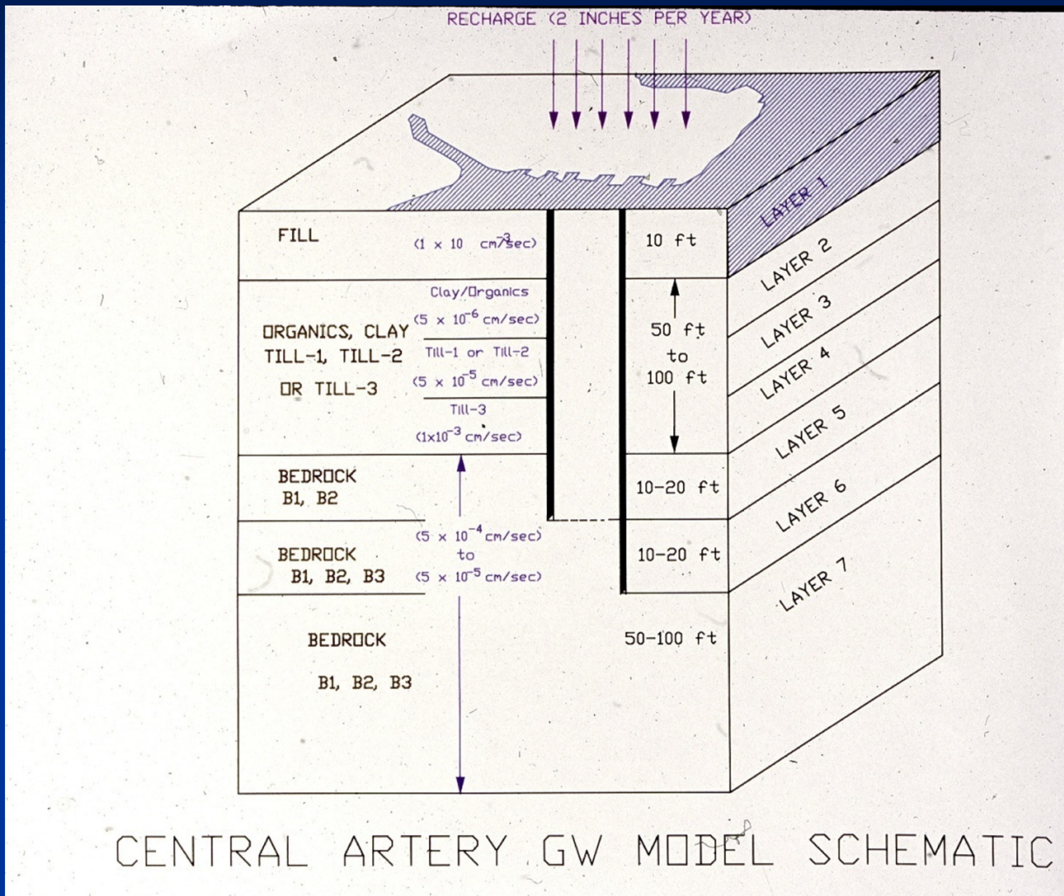
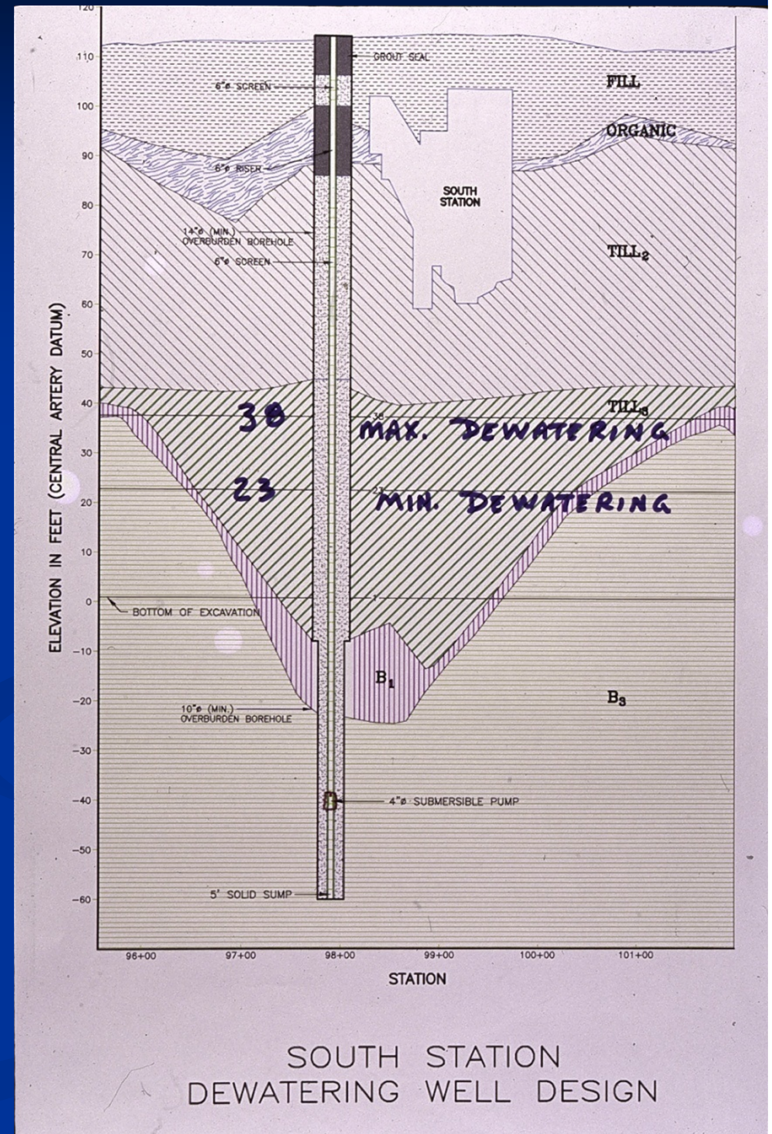
Boston- The Central Artery





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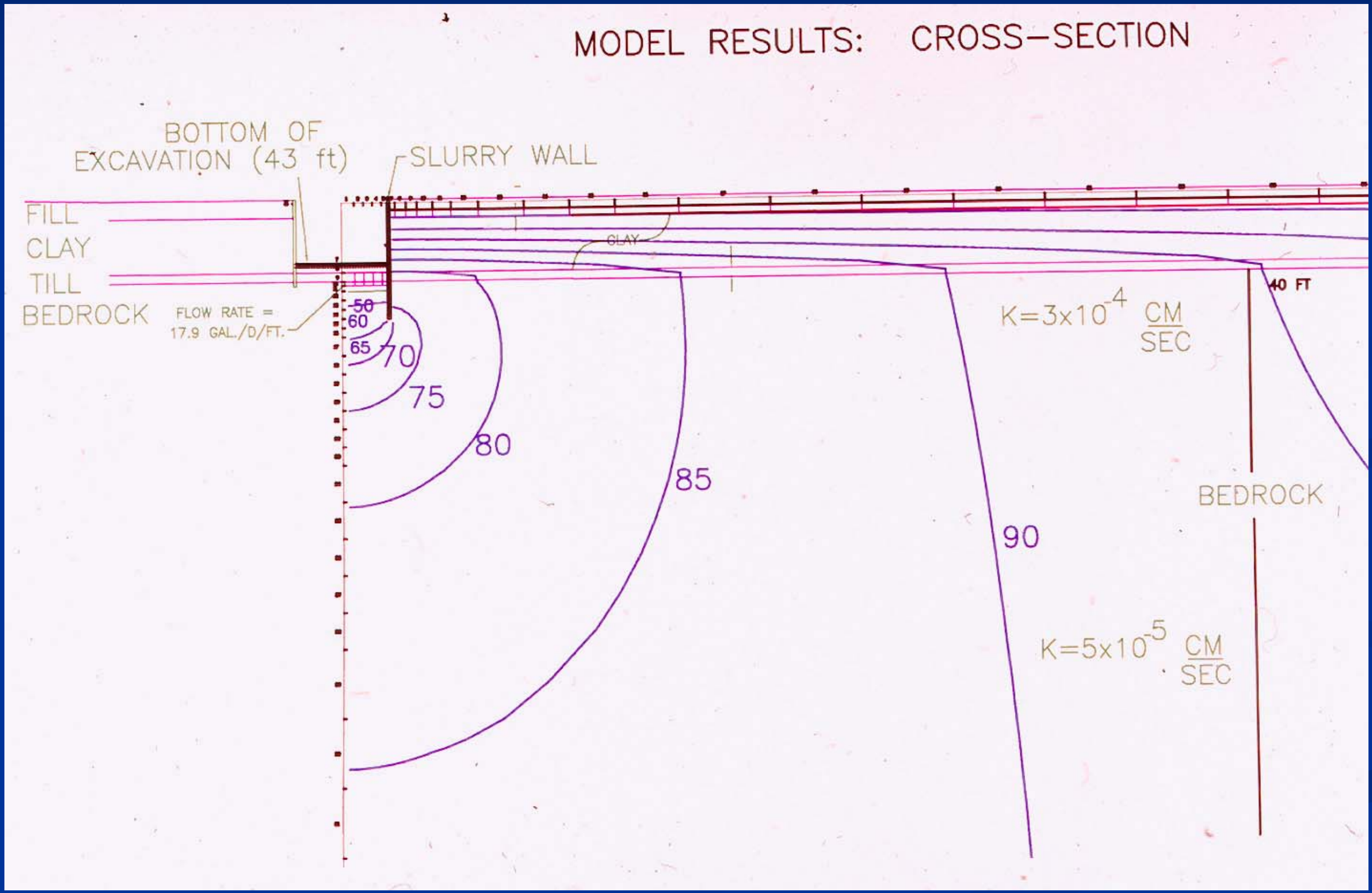
Boston- Central Artery Dewatering Model Results



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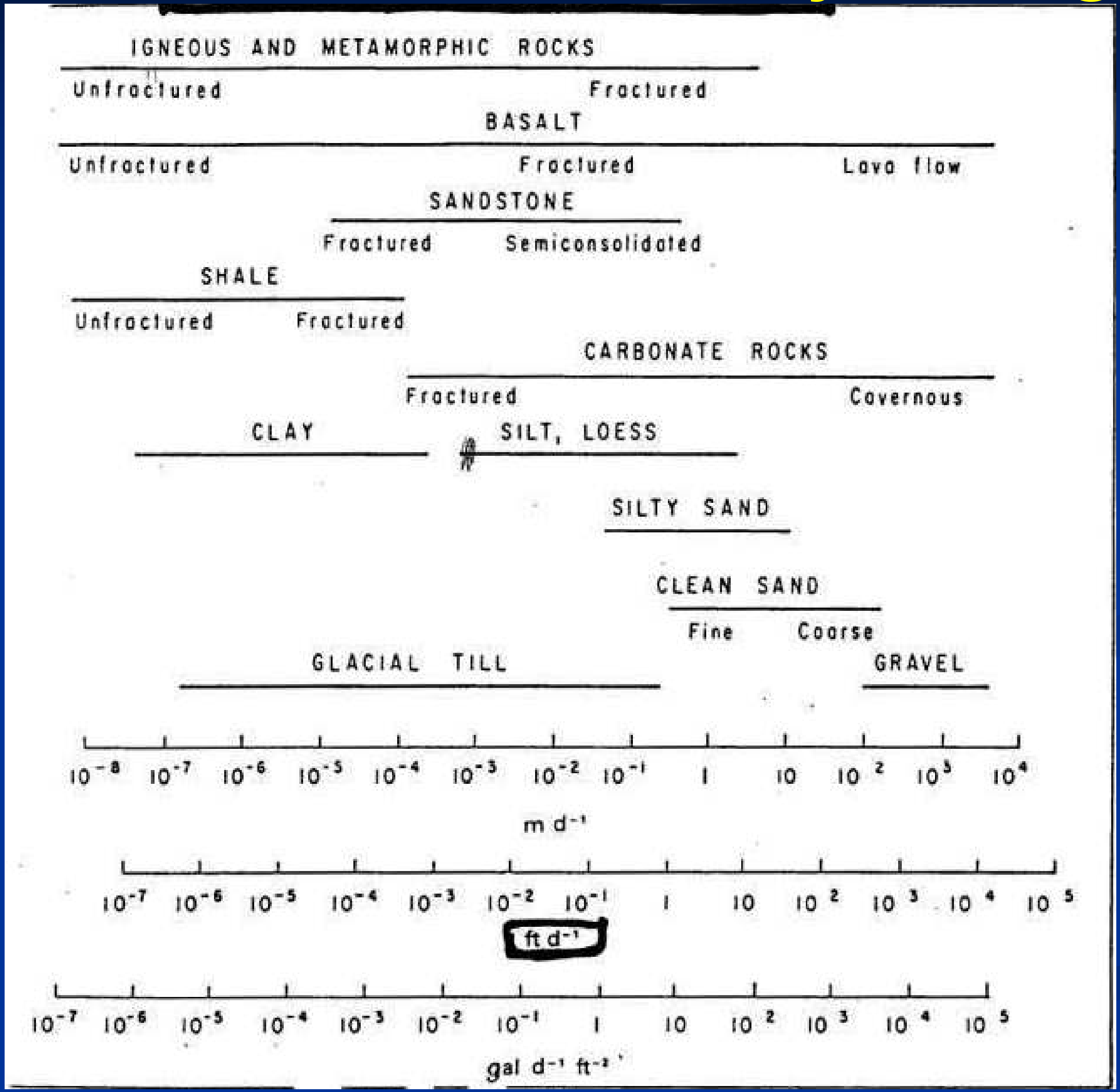
Hydraulic Conductivity Ranges



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Engineering Characteristics of Glacial Deposits

Characteristic	Lodgement (Basal) Till	Ablation Till	Outwash
Particle Size Gradation	Well-graded; very heterogeneous	Moderately well-graded heterogeneous	Gap-graded/poorly sorted semi-homogeneous
Presence of Boulders	Many, including erratics	Fewer, including erratic	Few to nil
Percent (-)200 Sieve	20-60	0-15	0-10
Percent (-) 0.02 mm	5-30	0-10	0-5
Effect of Fines	Governs engineering properties	Negligible	Nil
Relative Density	Stiff - hard	Loose - moderately compact	Loose - moderately compact
Dry Unit Weight (Kg/M^3)	1.8-2.1	1.7-1.9	1.6-1.9
Particle Shape	Angular-subangular	Subangular-subrounded	Subangular-rounded
Liquid Limit	15-30	Non-plastic	Non-plastic
Plasticity Index	0-20	Non-plastic	Non-plastic
SPT Range (N values)	20-200+	10-50+	0-20+
Cohesion (KN/m^2)	0-25	≈0	≈ 0
Friction Angle (°)	15-33	30-40	25-45
Consolidation Ratio	Overconsolidated	Normal to underconsolidated	Normal to underconsolidated
Permeability (in-situ) (cm/sec)	10^{-5} to 10^{-9}	10^{-3} to 10^{-5}	10^{-2} to 10^{-5}

END

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