Hidden Treasures

Nashoba Woodlands:

George and Lucy Yapp,

Cobb Memorial Forest, Shaker Lane and Morrison Extension Conservation Lands.

By: William R. Vales

May 19, 2018

Acknowledgment

I would like to acknowledge the work of Art Lazarus in researching and sharing his knowledge on geology, conservation and the natural world.

The work I do in researching Littleton geology draws on the solid base that Art put together and so generously shared with all of us.

I dedicate this work to Art Lazarus.

Nashoba Woodlands – Part 1

Rock Cycle/Plate Tectonics/ Rock Types

Nashoba Woodlands:
George and Lucy Yapp Conservation Land and Cobb Forest

Introduction

- The purpose of this presentation is to provide some information on the geology of Nashoba Woodlands and nearby areas.
- The focus is on the significant geologic processes that have shaped the Nashoba Woodlands, Littleton and surrounding areas.
- I have walked this land for several years and observed the landscape through the seasons. I used several tools and documents available for free on the internet that helped in my research. I urge the interested reader to try them out.
- There are numerous pictures taken at Nashoba Woodlands and other local areas that help to illustrate the geologic features and concepts.
- I hope this presentation sparks interest in the reader to get outside and explore the environment.

Topics

Part 1 – Rock Cycle / Plate Tectonics / Rock Types

- Rock cycle
- Tectonic processes
- Geologic time
- Bedrock geology
- Rock Types

Part 2 – Surficial geology

- Pleistocene Ice Age
- Glacial structures
  - Glacial till
  - Moraines
  - Glacial erratics
    - Stone Walls
  - Drumlins
  - Kettle Ponds/Kettle Holes
  - Eskers
- Soil Profiles

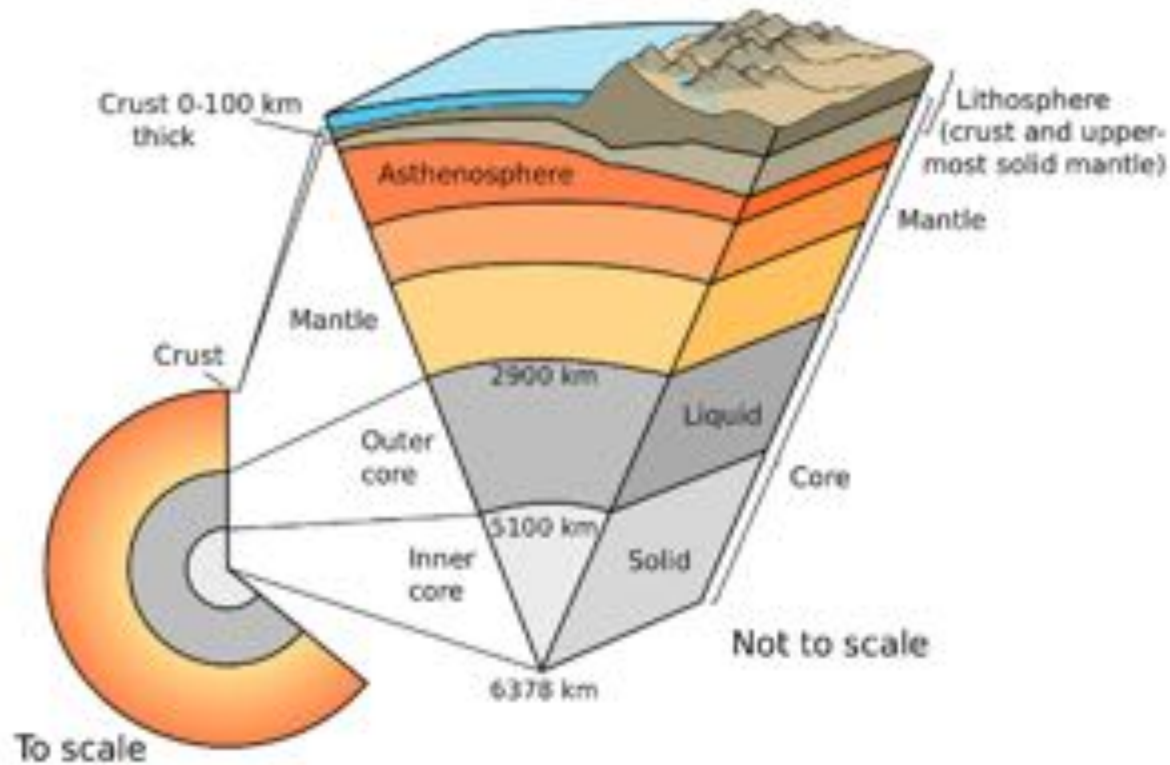
- Watersheds

Rock Cycle

- There are 3 main type of rocks: igneous, sedimentary and metamorphic.
- Any rock type can become any other rock type if the rock is subjected to various processes; e.g. erosion, weathering, burial, compaction, melting.
- Plate tectonics is the driving force for the rock cycle.

Plate Tectonics

- The earth is made up of layers that vary in composition from the surface to the core.



- The crust and upper mantle is called the lithosphere. The lithosphere or lithospheric plates of the continents and oceans "float" on the viscous layer below which is called the athenosphere.
- This crustal movement is called **plate tectonics**.

Plate Tectonics

- The earth is comprised of 7 or 8 major plates and approximately 20 minor sized lithospheric plates that move over the surface of the globe.
- A terrane is a smaller piece of continental crust that has broke off a lithospheric plate and is added to another plate. Eastern Massachusetts including Littleton is made up of terranes.

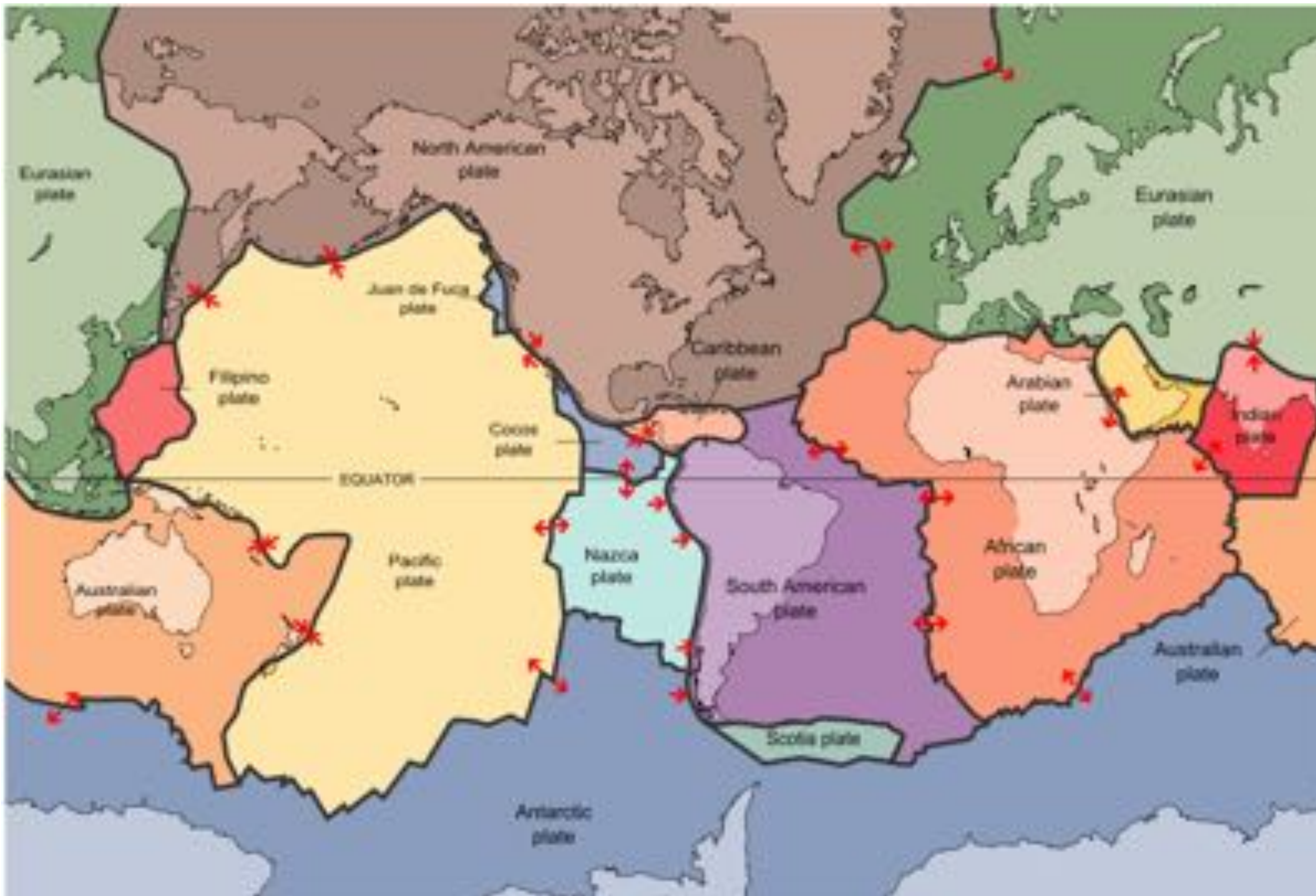
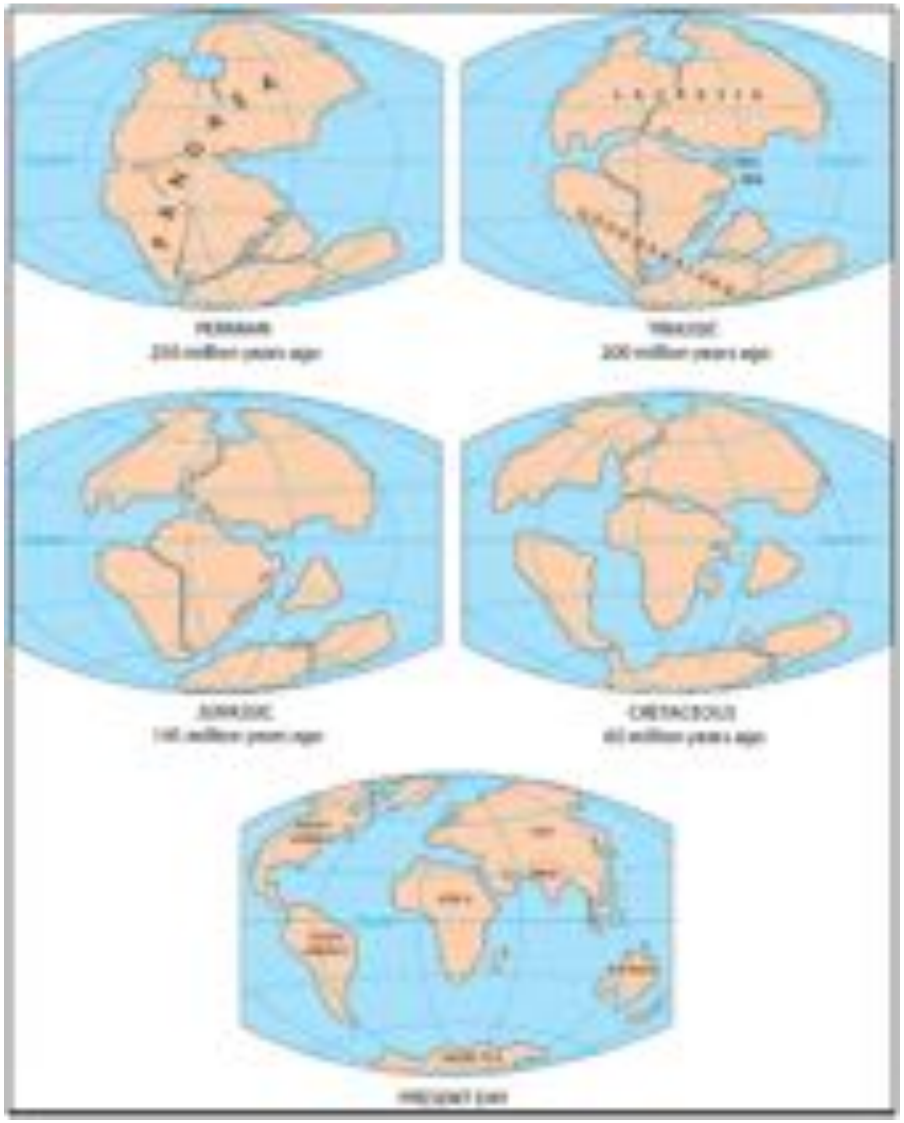


Plate Tectonics



The slide depicts the movement of continents on the lithospheric plates starting from 250 mya until present day. Note the different positions of the continents over time.

Note that the movement of continents has gone on since the formation of the earth, ~4.5 billion years ago. This example arbitrarily started at 250 mya to illustrate the concept.

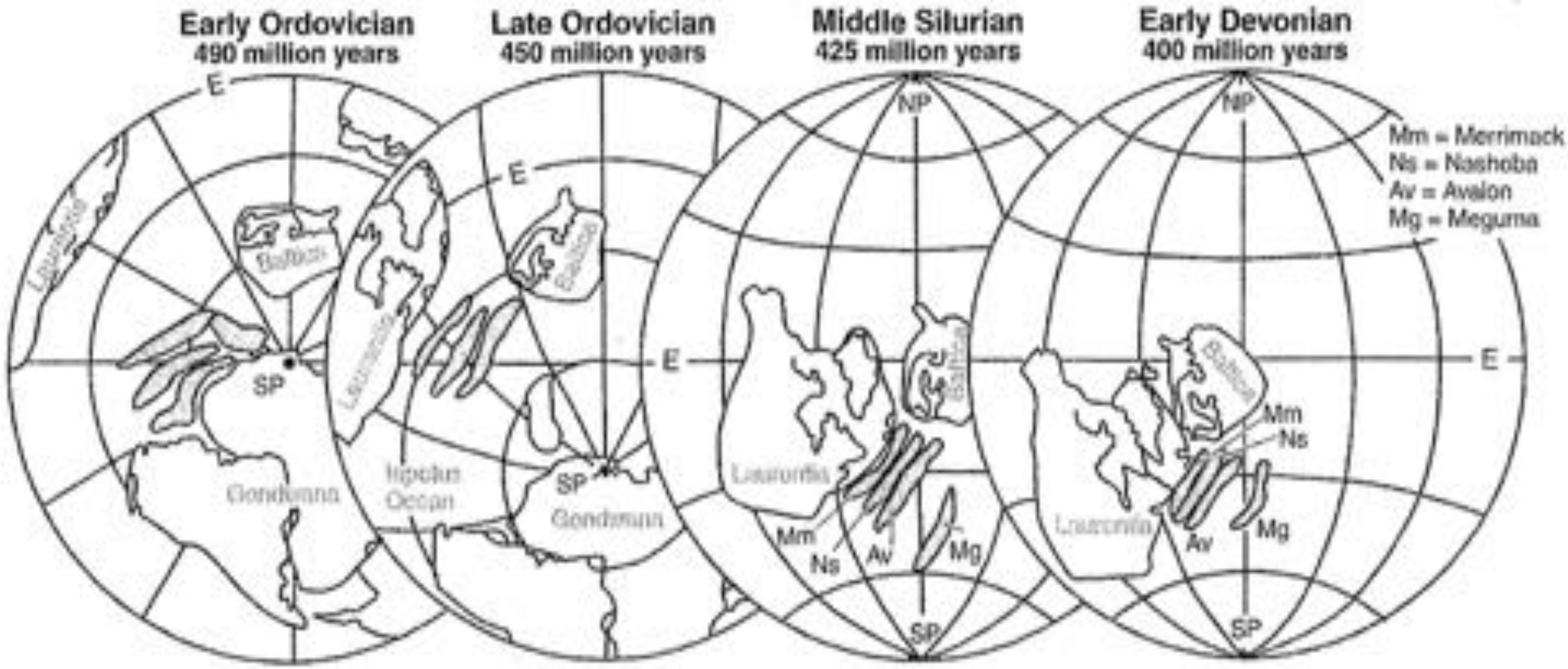
Plate Tectonics
Gondwana and Laurentia

- Around 500 million years ago (mya) the world was quite a different place than it is today. Littleton and the Nashoba Woodlands were also quite different.
- Continents were in different shapes and positions then they are now. What is now Littleton along with eastern parts of Massachusetts was off the coast of a super continent called Gondwana. Gondwana was a super continent that combined parts of what we think of as Africa and South America. Another super continent called Laurentia was the proto-continent of what would become North America.
- Gondwana and Laurentia would join together and then split up again under the power of the geologic force of plate tectonics. This phase of the plate tectonics dynamic took place starting ~500 million years and continues today.

Terranes, docking to Laurentia and the formation of Massachusetts and Littleton

- After 400 million years the various terranes reached the coast of Laurentia and fused together to form what we think of as North America. Tremendous forces driven by plate tectonics resulted in these terranes colliding, resulting in them coalescing into one land mass. In some places, land stretched apart, to form valleys and ocean basins. Some land masses were buried many miles below the surface under great heat and pressure which caused the rocks/minerals to melt and form new rocks/minerals. Fractures in the earth occur which are called faults.
- The terranes that broke away from the western side of Gondwana and traveled to and accreted to Laurentia are: (from west to east): Merrimack, Nashoba, Avalon and Meguma terranes.
- These events resulted in the Massachusetts and Littleton we know today. Plate tectonics continue to shape the continents and oceans to this day.

Positions of continents and terranes from 490 mya – 400 mya

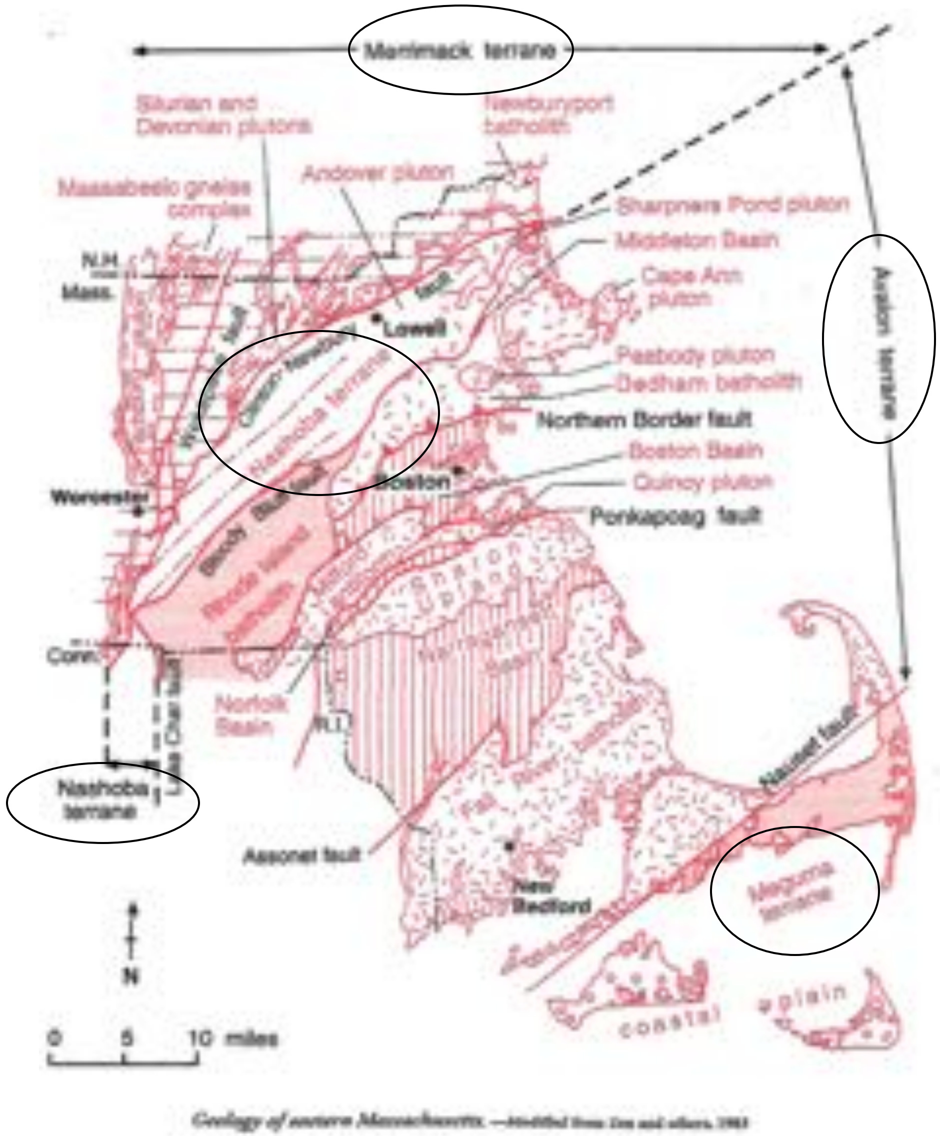


The Merrimack (Mm), Nashoba (Ns), Avalon (Av), and Meguma (Mg) terranes that fringed the Gondwanan supercontinent broke away possibly about 500 million years ago, in early Ordovician time. Equator (E); North Pole (NP); South Pole (SP).

—Modified from Torsvik and others, 1992; Meissner and others, 1994

Reproduced from : Roadside Geology of Massachusetts – James W. Skehan

Assembling of Terranes for Eastern Massachusetts



Circles highlight the terranes

Reproduced from : Roadside Geology of Massachusetts – James W. Skehan

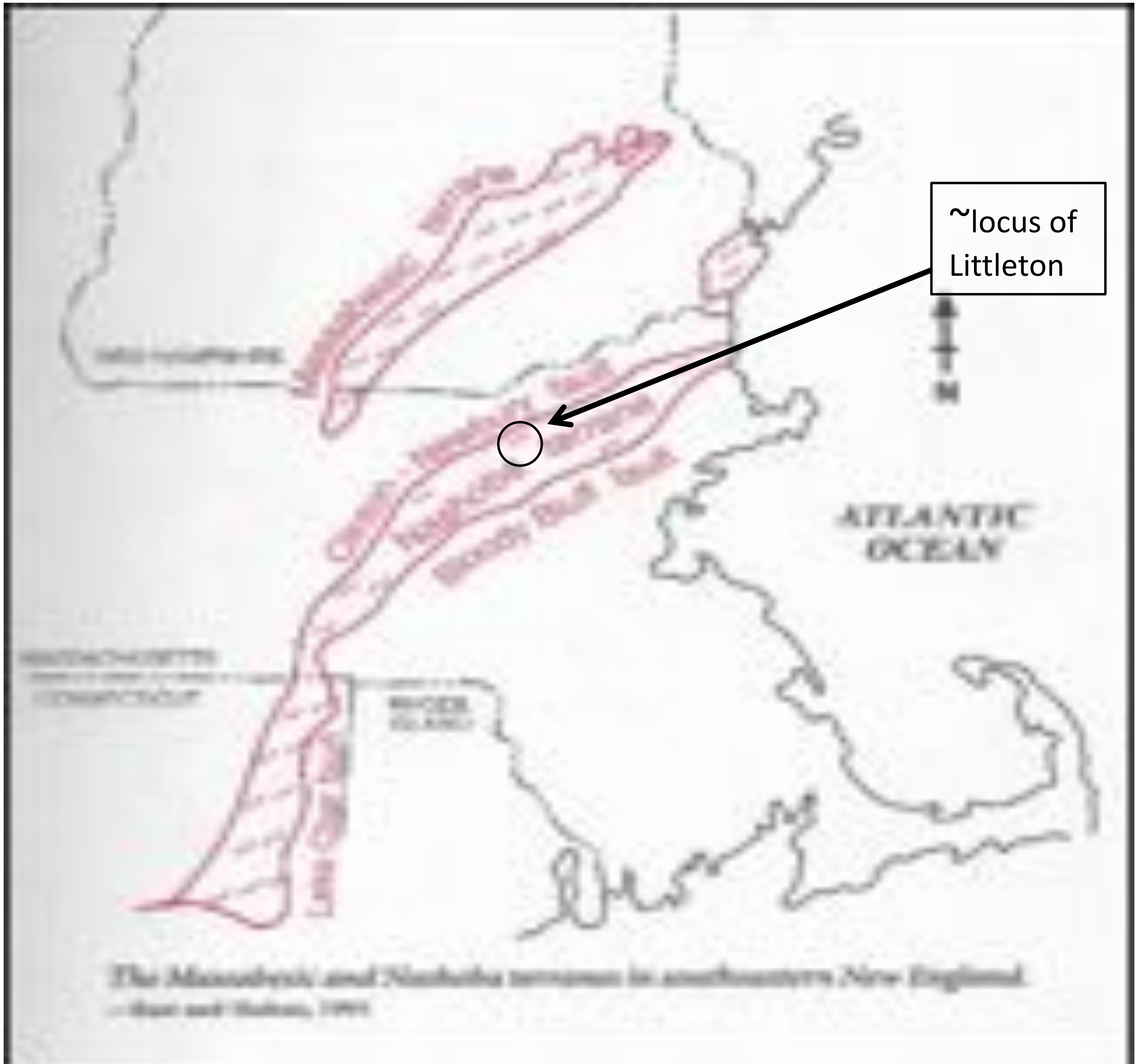
Nashoba Terrane

- The primary bedrock member of the Nashoba Woodlands is Nashoba Terrane (NT). Most of Littleton is comprised of NT. NT consists of metamorphic rock which grades from **phylite to schist to gneiss**. Within the NT are intrusions of granitic rock.
- NT consists of many different rock members or rock units. By units I mean the rock can vary greatly in mineral composition, color, texture, grain size or structure.
- A small part of western Littleton is Merrimack Terrane.
- NT with parts of what was to become Littleton originated off the coast of Gondwana ~490 million years ago.
- There are some nice bedrock exposures of NT on the Nashoba Woodlands. However, much of the area is covered by vegetation and glacial till.
- To see large beautiful outcrops of gneiss NT take a ride to the intersection of Route 111 and 495 across from Swanson Road in Boxborough. Observe the schist and gneiss of NT along with granitic intrusions. Smaller outcrops are found throughout Littleton. Pictures in section on bedrock.

Clinton-Newbury Fault

- Most of Littleton is located on Nashoba Terrane. A little bit of western Littleton is on Merrimack Terrane. The area between these two terranes is the location of the Clinton-Newbury Fault (CNF).
- The CNF is the location where the Nashoba Terrane subducted under the Merrimack Terrane.
- The CNF is a fault system that runs from eastern Connecticut to Newbury, Ma. It is ~1.5 miles wide in some locations.
- The CNF is no longer active.

Clinton-Newbury Fault and Nashoba Terrane



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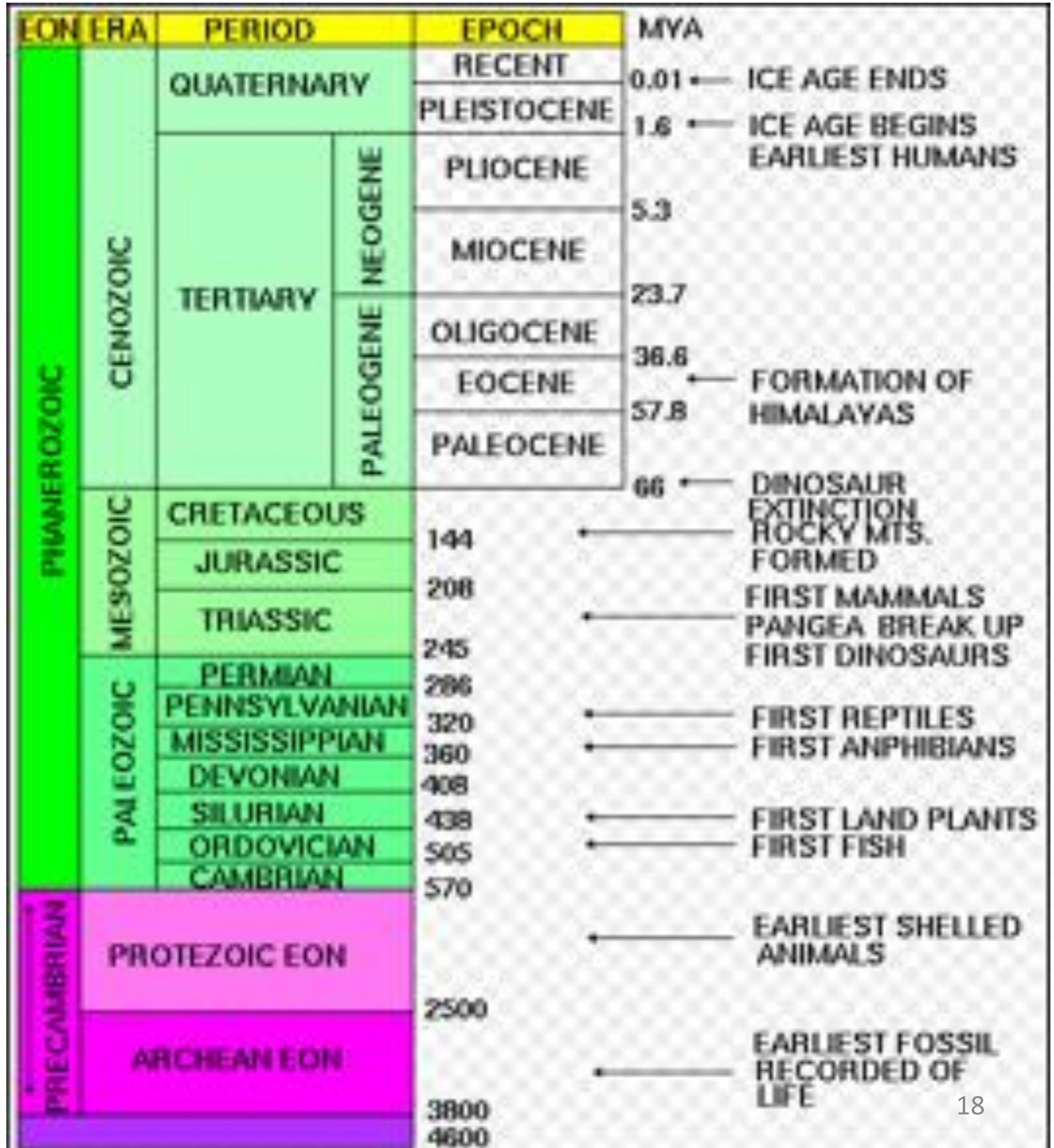
Geologic Time Scale

- The earth has a long history. Scientists estimate the earth is 4.5 billion years old.
- Look at the chart to the right. A lot of events have taken place during this time.
- Putting the events in order is important to understand the history of the earth.
- The order for many events is "written" in the rocks.
- You just need to know how to read the rocks.



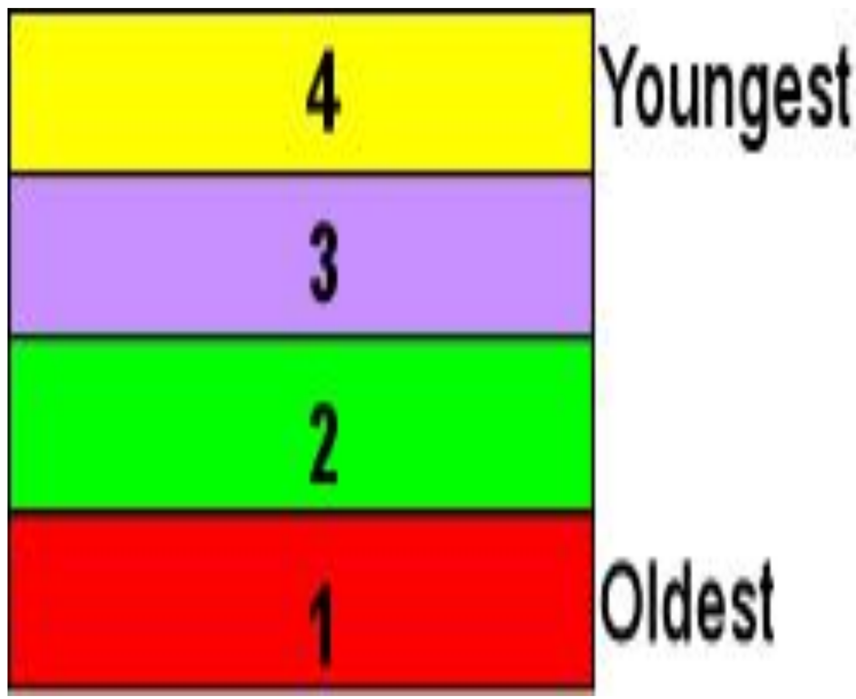
Geologic Time

Relative ordering

- The relative order of events can be determined based on rock layers. Each rock layer represents a period of time in earth history. Applying geologic laws allows sequencing the rock layers relative to one another.
- One such law is the law of superposition. "In any **undisturbed** sequence of rocks deposited in layers, the **youngest layer is on top and the oldest on bottom**, each layer being younger than the one beneath it and older than the one above it".
- Superposition is just one example of relative ordering. There are others such as cross-cutting relationships and lateral continuity.
- The relative age provides information about the order of events. It tells us if one event occurred before or after another event. Relative age does not tell us the actual age.

Principle of Superposition

Sedimentary layers are deposited in a time sequence, with the oldest on the bottom and the youngest on the top.



Geologic Time

Absolute time

- It is important to know the actual or absolute time an event took place.
- Using radiometric dating scientists can analyze the chemistry of the rocks and determine the absolute age within ranges. These techniques take advantage of the radioactivity and other attributes in the rocks.
- Dates can be determined within ranges of statistical accuracy going back billions of years. There are numerous techniques that can be used in series to cross check results and provide higher degrees of accuracy and confidence.
- By combining the techniques of relative and absolute dating scientists have developed the geologic time scale which orders the history of the earth.
- Names are assigned to each time period in the geologic time scale.
- Different time scales have been developed to show different events at different times, such as where continents are located; when and where various plants and animals evolved, where they moved to; where the continents have.
- The Nashoba Woodlands story starts about 500 million years ago. See where that is on the time scale.

Geologic Time

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Geologic Time

Absolute time

- Some atoms of elements that make up rocks are radioactive (unstable) and decay (over a known period of time) to non-radioactive (stable) elements.
- If the ratio of unstable elements to stable elements can be determined the passage of time can also be determined.
- The next few slides show one example of dating using zircon crystals which tends to incorporate radioactive **Uranium** in its structure when it is formed.
- **Carbon dating** is a form of radiometric dating but carbon dating only works for more recent events that incorporate biological material (Carbon- C_{14}), such as within the last 50,000. While the calculations are similar for the various types of radiometric dating the elements being tested for are different.

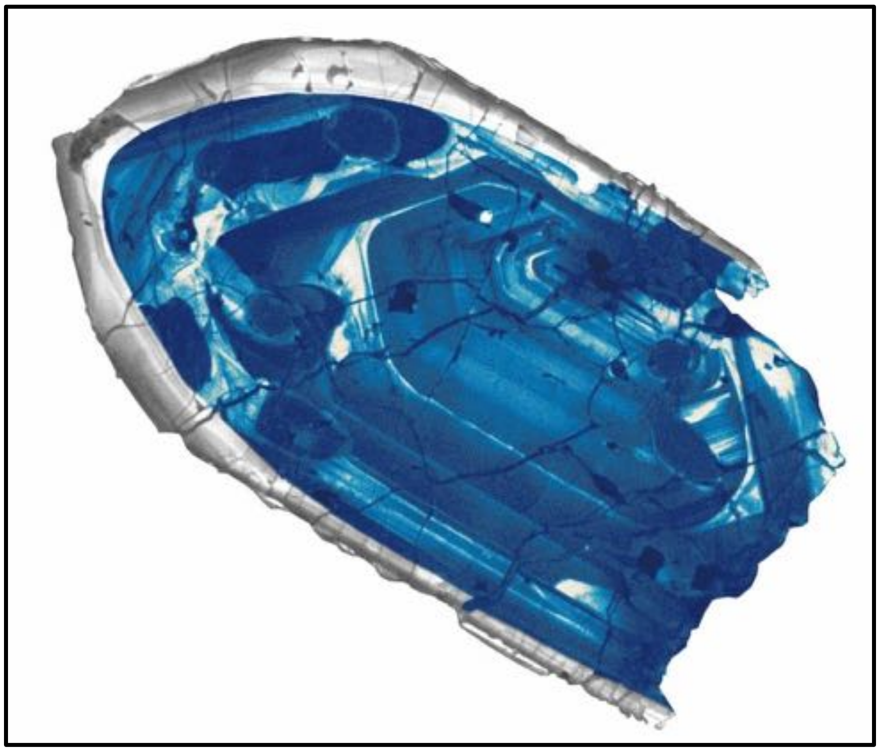
Unstable Isotopes

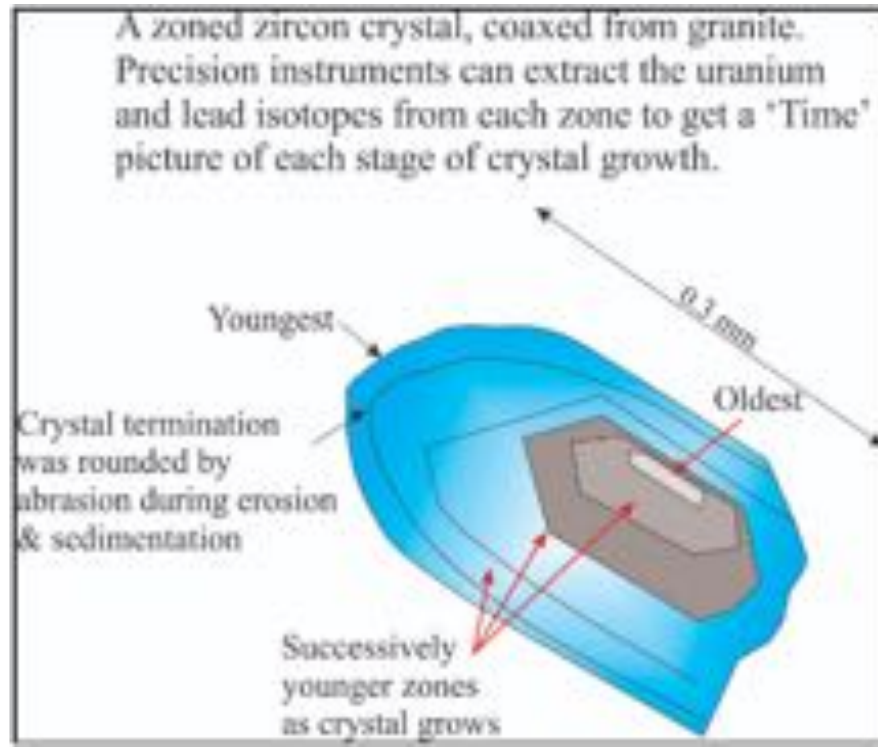
- Unstable isotopes = radioactive
- Nucleus that decays = Parent Isotope
- Product of the decay = Daughter Isotope
- **Amount of time for ½ of the parent isotope to decay is = ½ life of the isotope.**
- Example: Assume you start with 16 parent isotopes (atoms): if the result is 8 atoms 1 half life has passed: if the result is 4 atoms 2 half life's have passed…etc.
- **By calculating ratios between parent and daughter isotopes age can be determined**.
- Numerous elements have radioactive isotopes that possess this behavior and lend itself to radiometric dating.

Zircon

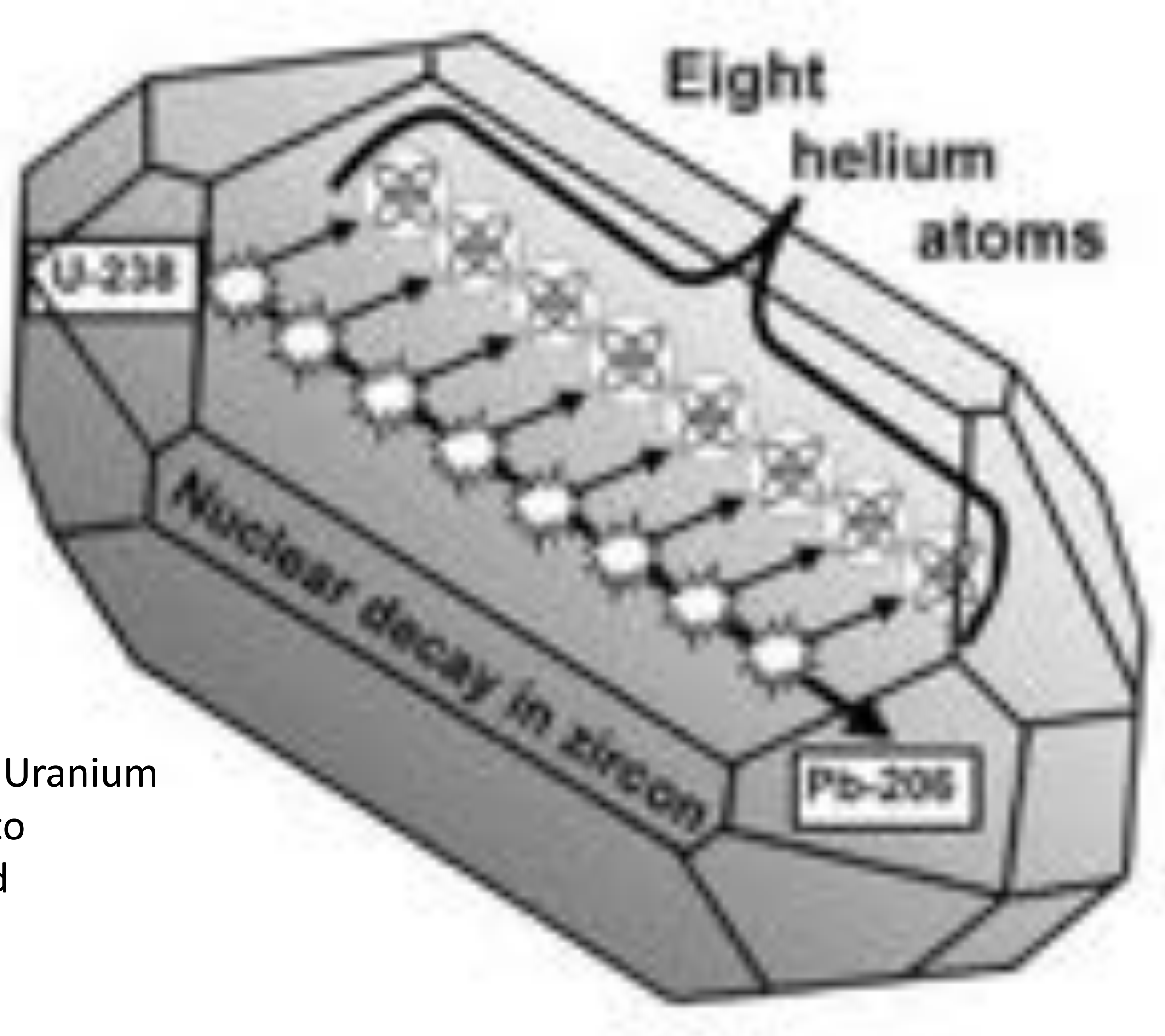
(example of a mineral that lends itself to radiometric dating.)

The zircon mineral incorporates uranium and thorium atoms into its crystalline structure, **but strongly rejects lead**. All isotopes of Uranium are not stable (some decay eventually to lead). When Zircon forms there is no lead present, but there is uranium. Therefore we can assume that the entire lead content of the zircon is **radiogenic** (i.e produced by radioactive decay).



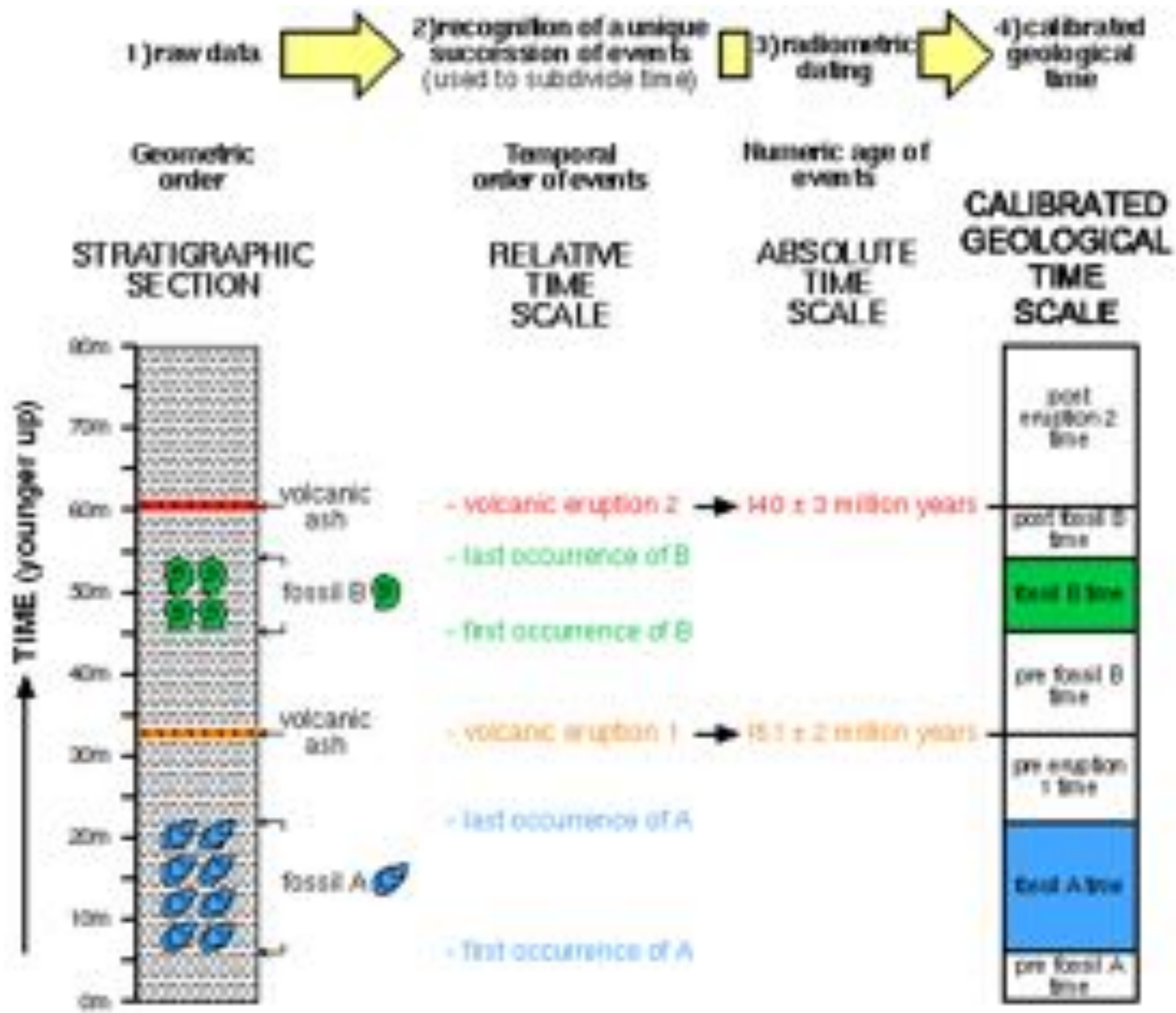


Zircon Decay



U-238 Radioactive Uranium
decays to
Pb-206 Stable Lead

Putting together Relative and Absolute Dating



Figuring out the lay of the land

- Observe attributes and characteristics of the land:
  - Learn the physical characteristics (i.e. Topography), the ups and downs, the grades (steepness). Walk around the land at different times of the year.
  - Bedrock exposures. Look for rock outcrops or bedrock that appears “anchored” to the earth.
  - Surficial geology on the surface. Are there boulders on the surface or gravel? How large are the boulders, with what frequency?
  - Are there man made structures? Stone walls, fence posts, barbed wire, remnants of structures? Does the land appear to be worked by man or machine?
  - Ponds, vernal pools, streams, drainage patterns. How deep is the water, how clear? Is the water moving or stagnant?
  - Floral, fauna, fungi (ferns, grasses, trees, mushrooms).
  - Signs of wildlife? Animal tracks, cavities in trees (birds) or ground. Low bushes eaten? Claw marks in bark (bear, bobcat), rubs on bark (deer), owl pellets at base of tall trees.
  - Talk to local people that are familiar with the area.

Maps, Maps and More Maps.

Numerous map resources support research on surficial geology, bedrock geology, wetlands, historic topography, soil profiles, interactive mapping, lidar imaging. Following are a few of the tools I make use of.

- https://mrdata.usgs.gov/geology/state/ - Bedrock maps of United States
- http://www.geo.umass.edu/stategeologist/Products/Bedrock_Geology/Westford/OMSG_OFR_09-01_WF_sh1.pdf - Westford Quadrangle - Progress Map
- https://pubs.usgs.gov/of/2006/1260/C/OFR2006-1260C_50.pdf - Surficial Geology
- http://maps.massgis.state.ma.us/images/dep/omv/wetviewer.htm - Wetlands viewer map for Massachusetts
- https://ngmdb.usgs.gov/maps/TopoView/ -USGS Historic Topographic maps.
- https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/home/?cid=nrcs142p2_053369 – Soil Profile
- http://about.ugridd.com/product/ufind/layers/lidar-data - lidar maps
- http://www.maine.gov/dacf/mgs/pubs/mapuse/informed/informed.htm - Reading maps with a critical eye - Informed reading of maps
- Google Earth – location finding, distance calculation, elevation comparisons.

The sample maps that follow are screen captures of areas of interest (AOI). These images do not capture the full power of these tools when they are used interactively.

Topography of Nashoba Woodlands

Observations:

- Without maps and the work of others it is challenging to figure out the lay of the land and contours over a large area. I walked the area many times in all seasons. Credit to Art Lazarus – Guide to Littleton Conservation Land for documenting his site work.
- Many small NE-SW trending elongated hills, ~parallel to one another. Numerous bedrock outcrops that tend to be exposed near the tops of the hills.
- NE-SW trending hills and valleys are indicative of an **ancient bedrock fault zone**.
- Large boulders and glacial till distributed randomly throughout the site.
- Valleys had pools of water and wetland plants (e.g. various ferns, skunk cabbage, marsh marigolds). No bedrock exposures found in the valleys, but some boulders.

Seeing the topography:

- By using lidar (**li**ght **d**etection **a**nd **r**anging) pulsed laser light is used to develop maps that show the contours of the land despite the vegetation cover.
- Supplement the Lidar map with USGS quadrangle map that has visited bedrock locations.
- Compare the lidar terrain view with the satellite view.

LIDAR and Satellite Views

Lidar Terrain View

Satellite View

- Can discern topography with shading
- Hills and Valleys ~parallel one another
- Hills and Valleys ~direction trend NNE to SSW

- Satellite view differentiated some vegetation types.
- Could not discern topography.

Bedrock and Surficial Geology

- Much of the landscape we see is influenced by the recent ice age…but first we discuss the underlying bedrock.
- Bedrock is the lithified rock that is under the loose softer material call regolith which is at the surface of the earth.
- Bedrock slabs exposed in field off Newtown Road
- Bedrock exposures throughout Nashoba Woodlands.
- Erratic boulders and glacial till scattered throughout Nashoba Woodlands.
- Glacial deposits and structures in nearby lands.
- Some boulders piled by man/machine during clearing.

Bedrock

Bedrock is the lithified rock that lies under a loose softer material called regolith at the surface of the Earth or other terrestrial planets. Boulders, irrespective of their size is not bedrock; although boulders are derived or eroded from bedrock.

Bedrock in field along Newtown Road.

Bedrock in field along Newtown Road




Bedrock in Nashoba Woodlands (1)

Fort Rock

Massive granite pegmatite unearthed through glacial erosion. Ordovician age

Fort Rock (2)

- Left clockwise. On top of Fort Rock looking south toward Newtown Road. Note Fort Rock on top of symmetric shaped elongated hill.
- On bottom of Fort Rock quartz deposit. Note ski pole for scale.
- Fort Rock pegmatite. Coarse grain quartz, biotite mica (black), muscovite mica (clear) and feldspar. Inferred from USGS Quadrangle map: ANDOVER GRANITE, PEGMATITIC PHASE – Light- to medium-gray, tan and pinkish-gray, AGE: 412 ± 2 Ma (U/Pb) maximum age (Hepburn et al., 1995).

Bedrock along Shaker Lane Trail on Hills

Along Shaker Lane trail.
Left counter clockwise:

- **Bedrock outcrop.** Boulders eroded from source. Located on top of hill.
- **Boulder** eroded from bedrock.
- **Another bedrock outcrop on hill.** Note erosion from freeze/thaw and tree roots.

Locating Bedrock

- Often bedrock is under the surface. Locating bedrock that is not mapped requires using geo-physical techniques; e.g. drilling, coring, excavation or using reflective sound or seismic technology.
- Understanding the plate tectonics setting of the land provides strong clues for the types of bedrock you may find in any area.
- Bedrock erodes leaving varying size fragments from house size boulders to pebbles that are no longer bedrock. Large boulders can sometimes be challenging to determine if it is derived from local bedrock or glacially transported.
- Mapping tools can help you take advantage of existing research to determine the bedrock in a particular area. Following are two mapping tools I use.
    - https://mrdata.usgs.gov/geology/state/ - Bedrock maps of United States – USGS
    - http://www.geo.umass.edu/stategeologist/Products/Bedrock_Geology/Westford/OMSG_OFR_09-01_WF_sh1.pdf - Westford Quadrangle - Progress Map

Determining Bedrock Type

- Bedrock is made up of the 3 major types of rocks: igneous, metamorphic, sedimentary.
- Within each major rock type there are different types of rocks. The particular rock type is based on the minerals that are present when the rock is formed.
- For example: granite is an igneous rock. It is produced from molten magma or lava. Depending on the magma mix different types of granite will result when the magma solidifies.
- Slow cooling of magma results in large crystals. Fast cooling results in small crystals.
- Granites' primary constituents are quartz and feldspar with varying amounts of mica, amphiboles and other minerals. Depending on the % of each mineral you wind up with a different type of "granite".
- Geologists differentiate rock types including granites based on the mineral composition as well color, weight, crystal size, cleavage, radioactivity and other attributes.

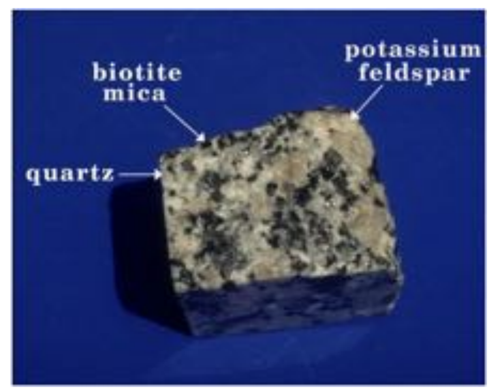
Igneous Rocks

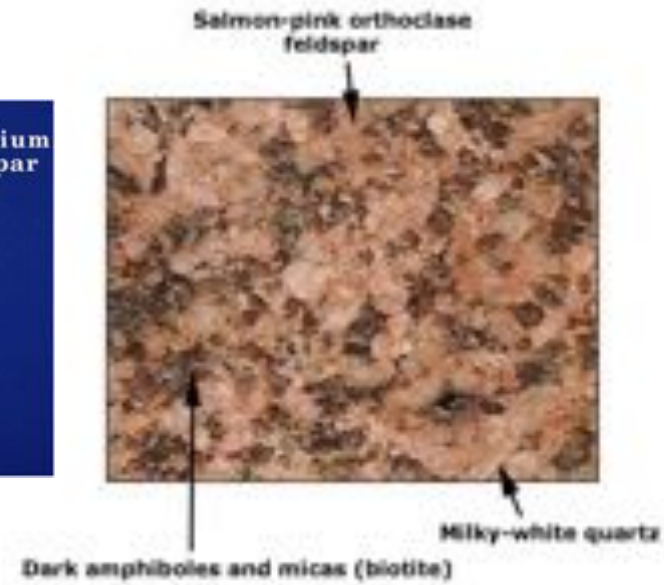
- Igneous rocks are formed through the cooling and solidification of magma or lava.
- The magma can be from partial melts or full melts of existing melts in the earths mantle or crust.
- If the magma reaches the earths surface it is lava. The cooling rocks are termed extrusive igenous.
- If the magma cools underground in place they are termed intrusive igneous.
- If magma cools fast the crystal size of the minerals is small. If magma cools slow the crystals get to grow and are large. Pegmatites are valued by collectors for large crystals.

Igneous Rocks - Granite

Primary materials for granite:

Depending on the magma you get different types:

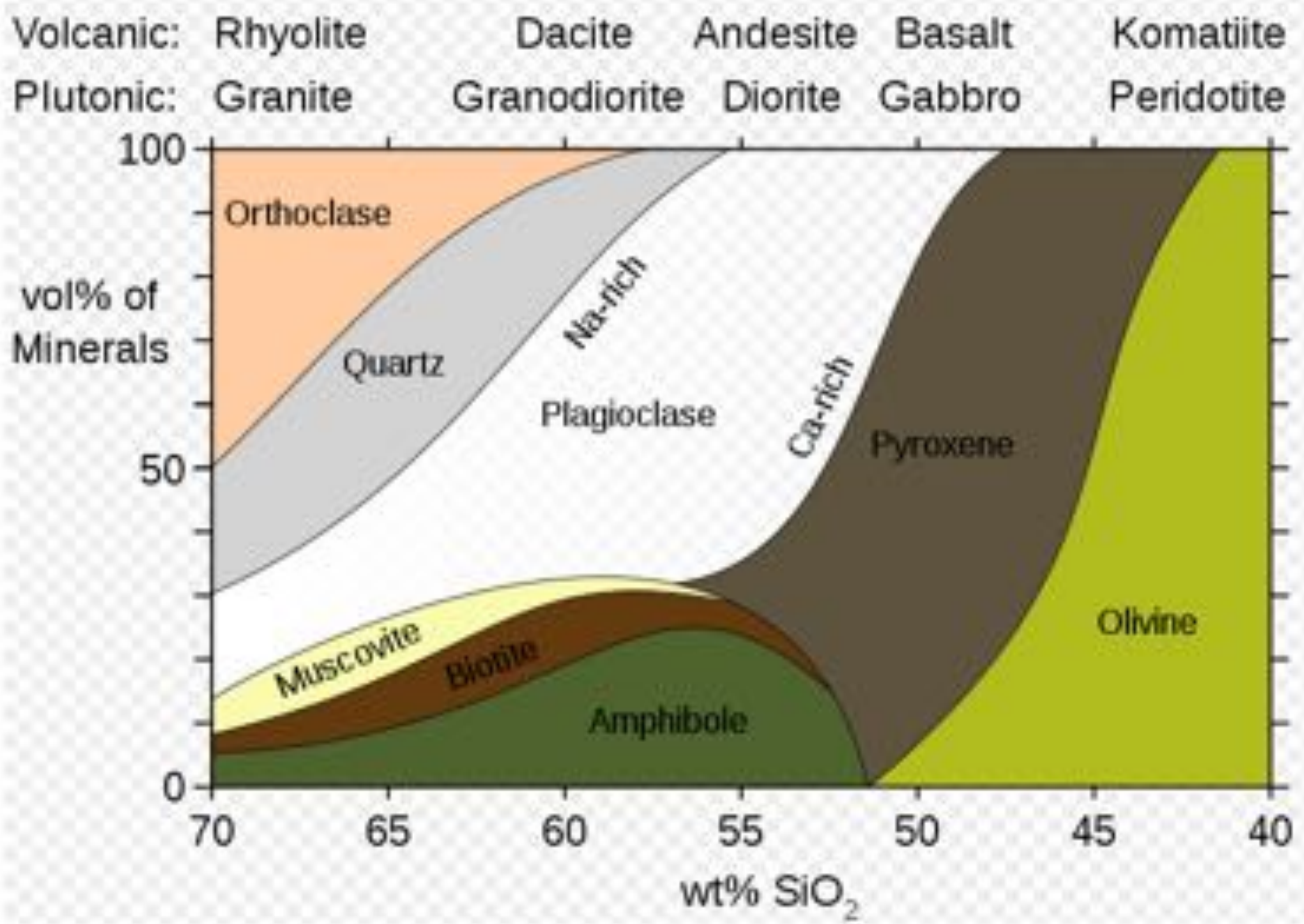




The variation in quantity of contributing minerals is many. For geologists to differentiate between the various granites there are different names assigned to the rocks based on constituent materials.

Mineral Composition of Igneous Rocks

Mineralogical composition of igneous rocks with decreasing silica (SiO_2) content. The rock names for **volcanic/extrusive** and **plutonic/intrusive** rocks are written above. Notice that this is a **rough way to determine a rock name**: the exact difference between the given igneous rocks does not only depend on silica content.



Metamorphic Rocks

- A **metamorphic rock** results from a transformation of a pre-existing **rock**. The original **rock** is subjected to varying degrees of heat and pressure, which result in physical and/or chemical changes. Examples of some metamorphic **rock** types include **marble, slate, schist, gneiss, quartzite**, **phylite.**

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- Where would the heat or pressure come from to transform a rock? If a source of magma was under the surface any rock near the magma would be subjected to the heat. If tectonic plates are colliding or sliding pass one another the resulting pressure can be enormous. If rocks are buried they are subjected to heat and pressure.

- These forces result in the source rock changing at both an microscopic (atomic) and macroscopic (appearance to naked eye) resulting in a new rock type. Depending on the amount of heat and pressure different rocks are formed in a series.

- Start with shale (sedimentary rock) and apply heat and pressure and you get slate; more heat and pressure phylite; then schist; and finally gneiss.

Increasing heat and pressure ➡

Shale ➡ slate ➡ phylite ➡ schist ➡ gneiss

- Start with limestone (sedimentary rock) apply heat and pressure and you get marble.

Limestone ➡ marble

- Start with granite (igneous rock) apply heat and pressure and you get granitic gneiss.

Granite ➡ gneiss

Sedimentary Rocks

- Rock that has formed through the deposition and solidification of sediment, especially sediment transported by water (rivers, lakes, and oceans), ice (glaciers), and wind. Sedimentary rocks are often deposited in layers, and frequently contain **fossils**. **Limestone**, **sandstone**, **chert, coal, conglomerate and shale** are common sedimentary rocks.
- There are few sedimentary rocks in Nashoba Woodlands, however some of the rocks that were metamorphosed started out as sedimentary rocks on the sea floor (limestone->marble) or sedimentary rocks on land (sandstone->quartzite). We see this history in the rocks.

Sedimentary Rocks

Grand Canyon showing various sedimentary layers.

Rocks at Nashoba Woodlands

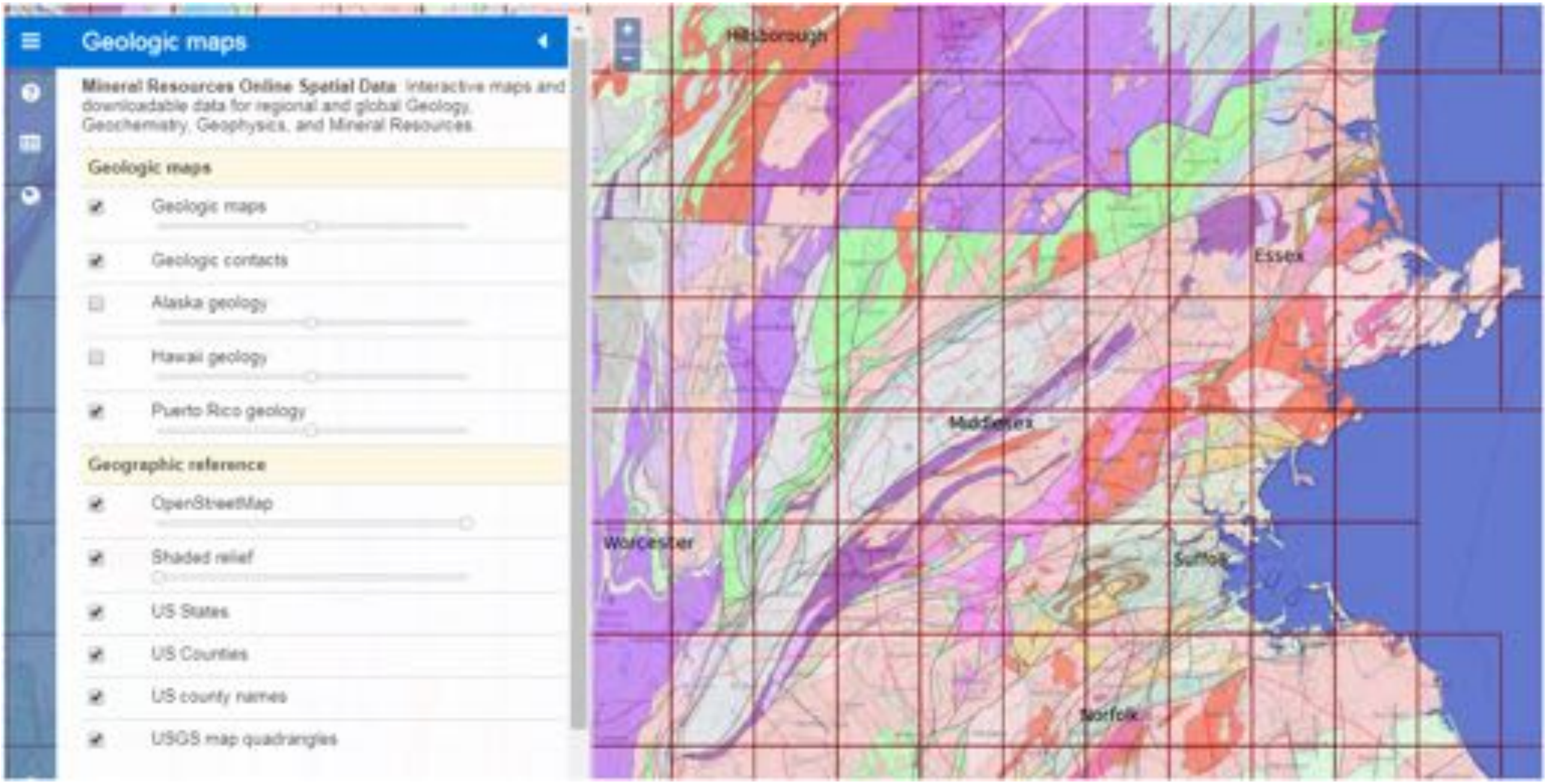
- Understanding the basics on the 3 rock types allow us to look closer at the rocks in Nashoba Woodlands.
- The two mapping tools I use are the USGS Bedrock and USGS Quadrangles. These allow us to understand rock types, where they came from and their age.
- **Nashoba Woodlands is Nashoba Terrane and the rocks are Nashoba Formation.**

Figure 1 - Location of quadrangle with respect to major geologic terranes of eastern Massachusetts

- The terranes in the map were moved into place under the power of plate tectonics. As the terranes collided and sunk under one another the resulting heat and pressure caused the rocks to be metamorphosed into new rocks. In some cases the rocks melted back to become igneous rock.
- Keep the tectonic forces in mind as they are central to the resulting rocks we see.
- Also keep in mind the shaping of the landscape from the ice age we have yet to discuss.

Bedrock Geology Maps - USGS

- https://mrdata.usgs.gov/geology/state/ - Bedrock maps of United States
- Provides good high level detail on bedrock belts, terranes, rock types, mineral composition, age of deposits.
- Navigate and zero in to area of interest. Sample below is eastern Massachusetts.
- The various colors are different bedrock types.



Bedrock Geology

- Zero’d in to Nashoba Woodlands; outlined in blue.
- Shaded areas are different types of bedrock.
- Click on area of interest (AOI) and details display (next slide)

Bedrock Geology High Level

Nashoba Formation

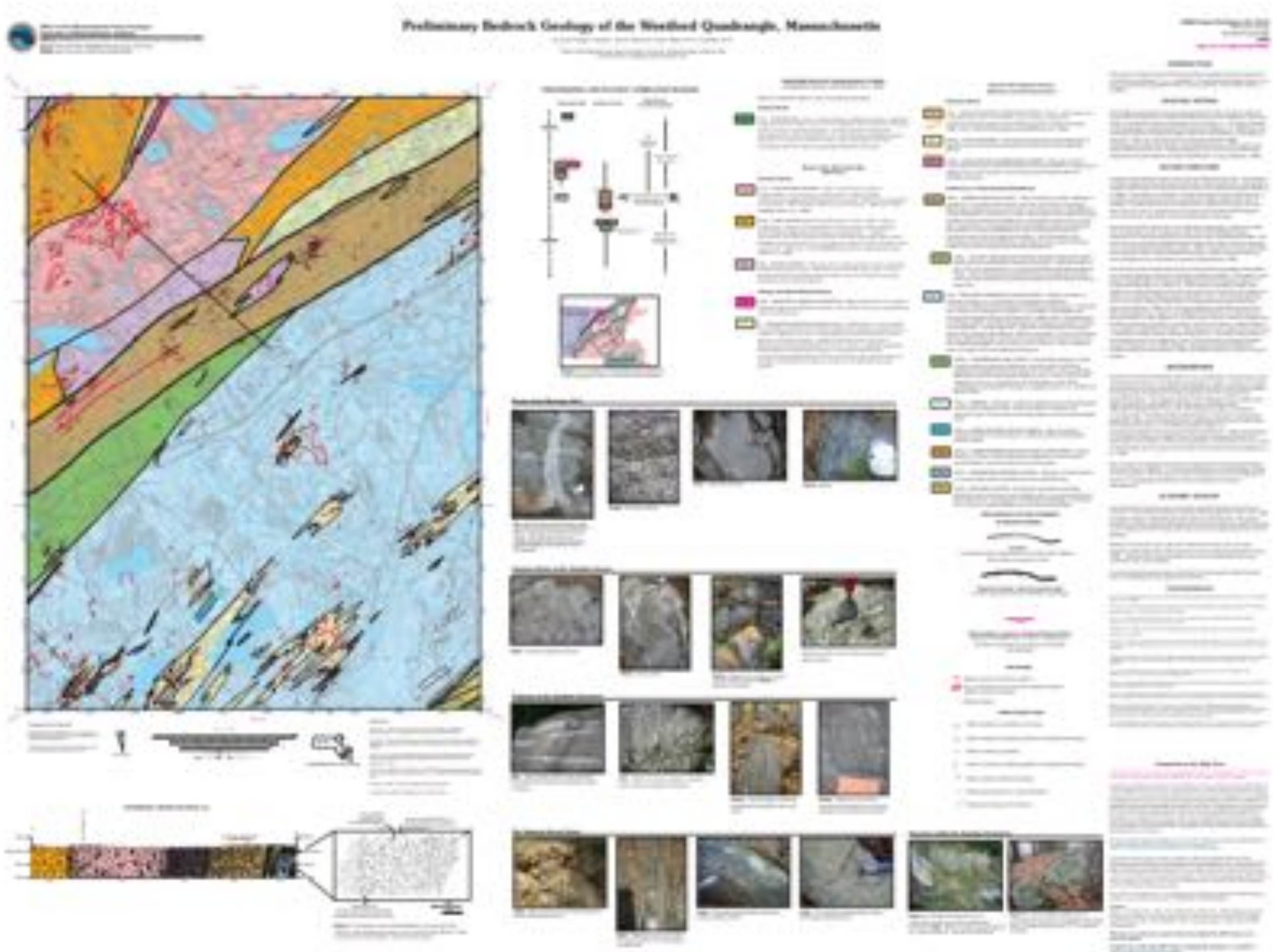
Nashoba Formation - Sillimanite schist and gneiss, partly sulfidic, amphibolite, biotite gneiss, calc-silicate gneiss and marble. Nashoba Formation occurs in Nashoba zone of eastern MA. Consists of interlayered sillimanite-bearing, partly sulfidic schist and gneiss, calc-silicate gneiss, and subordinate quartzite and marble. ***(balance of summary removed for space)***

State	Massachusetts
Name	Nashoba Formation
Geologic age	Ordovician or Proterozoic Z
Comments	Part of Nashoba Zone (Silurian and Older Rocks) Secondary unit description per MA017. Age debated. MA017 = Although age on MA State bedrock map is shown as Proterozoic Z or Ordovician (*balance of comments removed for space)*
Primary rock type	schist
Secondary rock type	gneiss
Other rock types	amphibolite; biotite gneiss; marble
Lithologic constituents	(removed for space)

USGS or State Quadrangle Maps

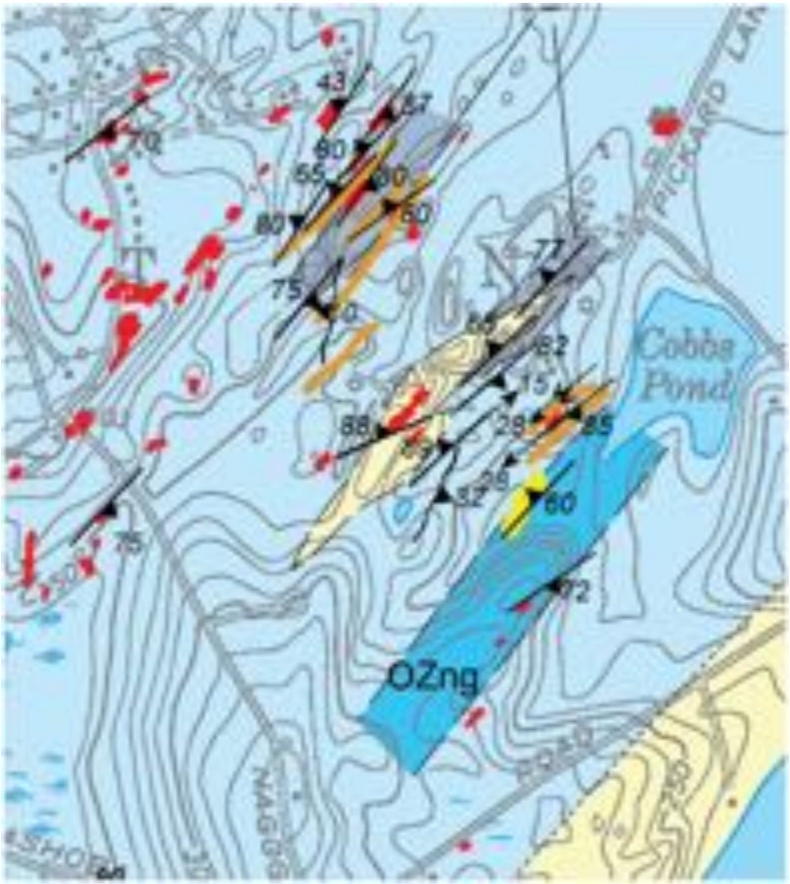
- Scale of 7.5 minute 1:24,000
- Quadrangle ranges from 64 square miles at latitude 30 degrees north to 49 square miles at latitude 49 degrees north.
- Considerable more detail on quadrangle map than USGS Bedrock Tool.
- Notes on map directed towards that quadrangle and are detailed.
- Next slide is example of a quadrangle map that includes the Nashoba Woodlands property. This is provided so you can see the general format of a quadrangle map.

USGS or State Bedrock Quadrangle



USGS Quadrangle Maps – focused on Nashoba Woodlands.

Extracted parts of legend applicable to Nashoba Woodlands. Abbr. (Dsan, OZ… rock type/age.)



EXPOSURE

Bedrock outcrops visited by authors

Area of abundant small outcrops or shallow bedrock (within 3 meters of surface)

Intrusive Rocks

DSan — DSan - ANDOVER GRANITE, PEGMATITIC PHASE

SOag — SOag -- ACTON GRANITE

Ordivician or Older Metastratified Rocks

OZnh — OZnh - HORNBLENDE-BEARING GNEISS

OZng — OZng - GARNET-BEARING BIOTITE GNEISS

OZn — OZn – NASHOBA FORMATION (undifferentiated)

STRUCTURAL DATA

80 Strike and dip of S_2 foliation in all rocks

80 Strike and dip of S_2 foliation parallel to compositional layering

Strike of vertical S_2 foliation

Strike of vertical S_2 foliation parallel to compositional layering

80 Strike and dip of folded S_1 foliation

80 Bearing and plunge of L_2 mineral lineation

80 Bearing and plunge of F_2 fold axis

Bedrock

- Bedrock can be tricky to identify. Sometimes bedrock outcrops on the surface are obvious. Other times large boulders can appear to be bedrock but they are part of the glacial till, detached from the underlying bedrock.
- Bedrock can be 100’s of feet below the surface.
- The boulders we see on the surface may have eroded in place from the bedrock or they may have been transported from distance places by ice.
- Bedrock can be any of the 3 rock types: igneous, metamorphic, sedimentary.
- In Nashoba Woodlands there are igneous and metamorphic bedrock outcrops.
- Following are some of igneous bedrock types found throughout the Nashoba Terrane

Igneous Bedrock in Nashoba Terrane

Metamorphic Bedrock in Nashoba Terrane

- Metamorphic rock has changed or metamorphosed from some other rock. Remember the rock cycle; any rock can become any other kind of rock.
- The metamorphic rock may sometimes maintain clues about the original source rock.
- Metamorphism from compression pressures may result in like material being clustered together in layers.
- (left to right) The biotite gneiss below started as granite and was metamorphosed to layers of pegmatite and biotite.
- Calc-silicate started as seafloor and was folded and compressed.
- Amphibolite appears in igneous and metamorphic rock. Layering is clue of compressional forces.
- Marble starts as limestone.

Subunits of the Nashoba Formation

OZn - Typical biotite gneiss of the Nashoba Formation with boudins of pegmatite parallel to foliation

OZn - Folded calc-silicate (epidote, diopside) layers within the Nashoba Formation

OZnas - Typical flaggy-weathering amphibolite interlayered with rusty schist.

OZnm - Distinctive pock-mark weathering of marble and carbonate gneisses in the Nashoba Formation

Bedrock at Nashoba Woodlands (1)

Bedrock in field off Newtown Road. Surface exposures trend from upper parking lot along Shattuck Trail in a ~NNE direction. Coarse grain pegmatite to right.

Coarse grain pegmatite.

Quartz intrusion.

Along main trail on Yapp. Runs on hill along trail, Coarse grain pegmatite with some intrusions of quartz. Close-up on right.

Bedrock at Nashoba Woodlands (2)

Bedrock exposure (right) showing folding (top right) and pegmatite in contact with gneiss below.

Contact point between 2 rock types (below and bottom right) : finer grain material (?amphibolite ? on top) and pegmatite on bottom. Rock probably eroded from bedrock nearby.

Bedrock at Nashoba Woodlands (3)

Layering of gneiss result of compressional metamorphism. Left shows folding

Overlooking Cobb Pond from ~South

Neat Boulders not far from bedrock source. Nashoba Woodlands (4)

- Clockwise from left. Fine grained gneiss showing layering in contact with granite pegmatite. Pen for scale.
- Coarse grain granite pegmatite (bottom) in contact with fine grain ?hornblende? or ?amphibole? on top.
- Coarse grain granite pegmatite (r) and contact with granite or diorite on (l).

Nashoba Terrane

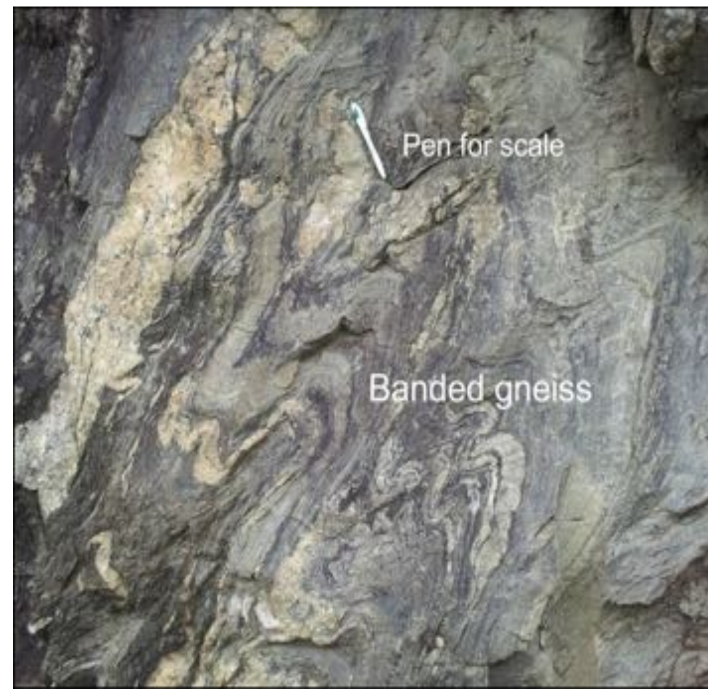
- The primary bedrock member of the Nashoba Woodlands is Nashoba Terrane (NT). Most of Littleton is comprised of NT. NT consists of metamorphic rock which grades from **phylite to schist to gneiss**. Within the NT are **intrusions of granitic rock**.
- NT consists of many different rock members or rock units. By units I mean the rock can vary greatly in mineral composition, color, texture, grain size or structure.
- A small part of western Littleton is Merrimack Terrane.
- NT with parts of what was to become Littleton originated off the coast of Gondwana ~490 million years ago.
- There are some nice bedrock exposures of NT on the Nashoba Woodlands. Much of the area is covered by vegetation and glacial till.
- To see large outcrops of gneiss NT take a ride to the intersection of Route 111 and 495 across from Swanson Road in Boxborough. Observe the schist and gneiss of NT along with granitic intrusions. Smaller outcrops are found throughout Littleton.

Nashoba Terrane – Exit from Route 495-S to 111

Igneous granite intrusion (younger) on top of metamorphic banded gneiss (older).

Close-up of banded gneiss. Gneiss is a high grade metamorphic rock. Metamorphic pressures result in like minerals aggregating into bands.

Banded gneiss near granite intrusions resulting in migmatite formations (partial melting of gneiss recrystallizing to igneous).



Nashoba Woodlands – Part 2

Surficial Geology

Surficial Geology

- **Surficial materials** including unconsolidated alluvial, residual, or glacial **deposits** overlying **bedrock** or occurring on or near the surface of the earth. Includes "young" sedimentary material of various origin and ages, typically Quaternary age and younger (less than about 2 million years). Also known as superficial **deposit**; or surface **deposit**.
- **Surficial materials** include such materials as stream-deposited alluvium, wind-blown sand and dust (including dunes), glacial deposits, landslide deposits, soil and colluvium where such units exist on a scale that can be mapped.
- **Surficial geologic maps** are extremely valuable for many scientific and engineering applications.
- **Surficial maps** are important for many ecological applications, aggregate, hydrogeology, and natural hazard evaluation.
- **Surficial material** maps are often combined with bedrock geology and structural features, such as faults and folds.

Pleistocene Ice Age (1)

- The Pleistocene ice age was a recent event in geological terms. It began ~2.5 million years ago (mya) and ended ~11,700 years ago.
- The Pleistocene ice age consisted of several ice age stages followed by inter-glacial periods of warming. The most recent ice age is called the Wisconsin and ended 11,700 years ago.
- During the ice age, glaciers ~1- 4 kilometers (~1-2.5 miles) high extended from the north pole to the 40th parallel in some areas. Sea level dropped ~120 meters (390 feet).
- Here in Littleton there was ice more than a mile high depressing the land, grinding up rock and transporting glacial till in the path of and to the extent of the glacier.

Pleistocene Ice Age (2)

- The glacier effects the landscape in a two general ways: it erodes the land by its grinding power and it deposits material as it moves along its path.
- Some erosional effects occur when the glacier is advancing and some occur when it is receding.
- Similarly, some depositional effects and structures occur during glacial advance and some during glacial recession.
- The erosional effects we see around here are boulders ground off of bedrock, sheep back structures (stoss-lee) from glaciers plucking rock from bedrock, glacial scratches/striations/gouges on bedrock and boulders. Smoothing of bedrock from the glacial overriding rock during its advance. When the glacier melts (recession) enormous volumes of water are released resulting in erosion.
- The depositional effects are glacial till and erratic boulders distributed throughout the area. Glacial moraine where the glacier stalled and deposited piles of till like a conveyor belt. Kettle ponds, kettle holes, drumlins, eskers, kames are unique features of a glacial landscape.
- All of these features are not on the Nashoba Woodlands but many are. Many more of these features are very close by in Littleton and surrounding areas. We will discuss several of them.

Extent of Pleistocene Glaciation in North America

~locus of Littleton

Pleistocene glaciation in North America

- During the Pleistocene Epoch glaciation occurred throughout parts of the northern hemisphere. This includes the Island of Greenland, parts of Europe, Northern Russia and other northern latitudes.
- In North America there were two ice sheets that formed during the Pleistocene: the Cordilleran and Laurentide.
- Between the two ice sheets it is theorized there may have been ice free corridors that supported early migration of humans from Asia during the later stages of the Pleistocene.

Effects of Ice Age in Littleton

- In Littleton and the surrounding areas the effect of the ice age is **enormous**. Every where we look we see signs of the ice age. There are two general mechanisms to consider: glacial erosion and glacial deposition.
- **Glacial erosion** – A mile high of ice is extremely heavy. It tends to flow from the source in a plastic state (at the bottom) grinding everything in its path. Mountains are ground down, glacial valleys carved, boulders are transported miles from their source and weigh of the glacier depresses the land. Bedrock is scraped, scoured and polished.
- **Glacial deposition** – glacial till is dropped at the terminus of the glacier or when the glacier melts. Till consists of clay, gravel, small rocks to house sized boulders. Till is distributed throughout the landscape. Egg shaped structures called drumlins were deposited that are made of consolidated till. Moraines are deposited along the sides of glaciers and at terminal points when the glacier stalls building up piles like a conveyor belt. Some moraines can be 100’s of feet high.
- The melting of the glacier resulted in **massive volumes of water** to be released and flood the landscape. Glacial lakes were formed dammed by the melting ice. The eventual release of this water led to river valleys and the water sheds we know today. Melting glaciers left **well sorted stratified drift** in forms called eskers, kames and outwash plains.
- From the extreme weight of the glacier the land rebounds or springs back a result of isostatic rebound. This rebound is measureable and alters the height of sea or lake levels which are visible in the form of shelfs. The amount of rebound is based on where the glacier was and how much time has passed since the glacier receded. Land is still rebounding.

Research on Ice Age Causes

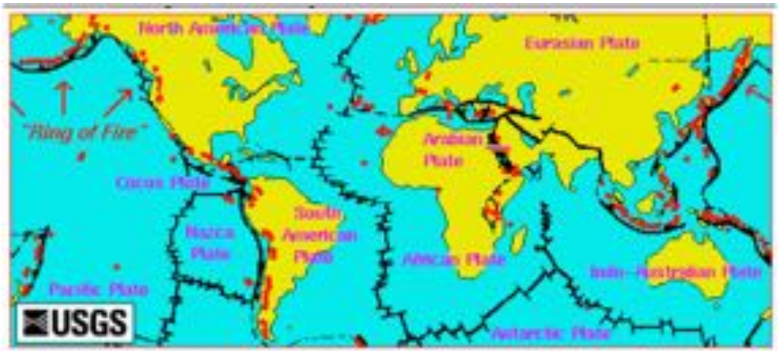
- There are complex relationships between solar output, distance of the earth from the sun, ocean circulation and the positions and geography of the continents.
- These processes combine to provide optimal conditions for the formation or recession of ice.
- Scientific consensus indicates that anthropogenic (man-made) causes contribute to the warming of the ice and melting of the ice.
- Milankovitch cycles (next slide), show that collective changes in the earth movements correlate with climate changes. Note the cycles in years of each celestial event (obliquity, precession, eccentricity) . When event cycles overlap glacial advance increased. Note there are several observations the hypothesis does not explain which continue to be studied.

Ice Age Causes (1)

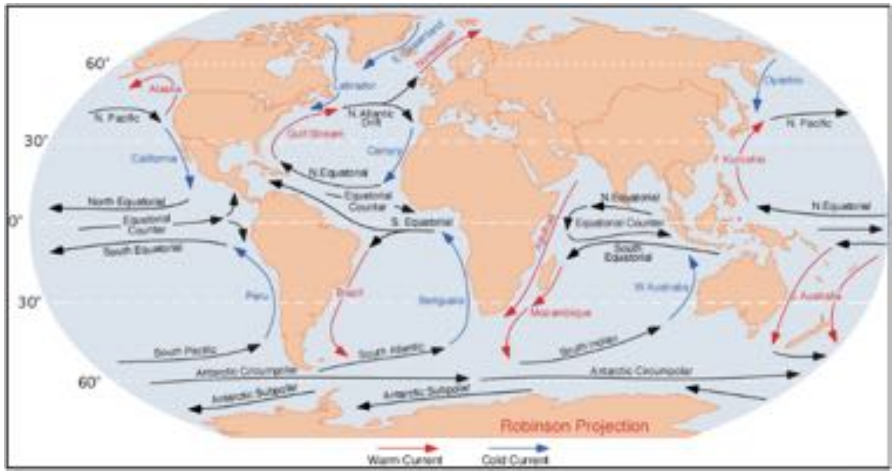
There are complex relationships between solar output, distance of the earth from the sun, ocean circulation and the positions and geography of the continents.

Solar Output; sunspots

Plate tectonics

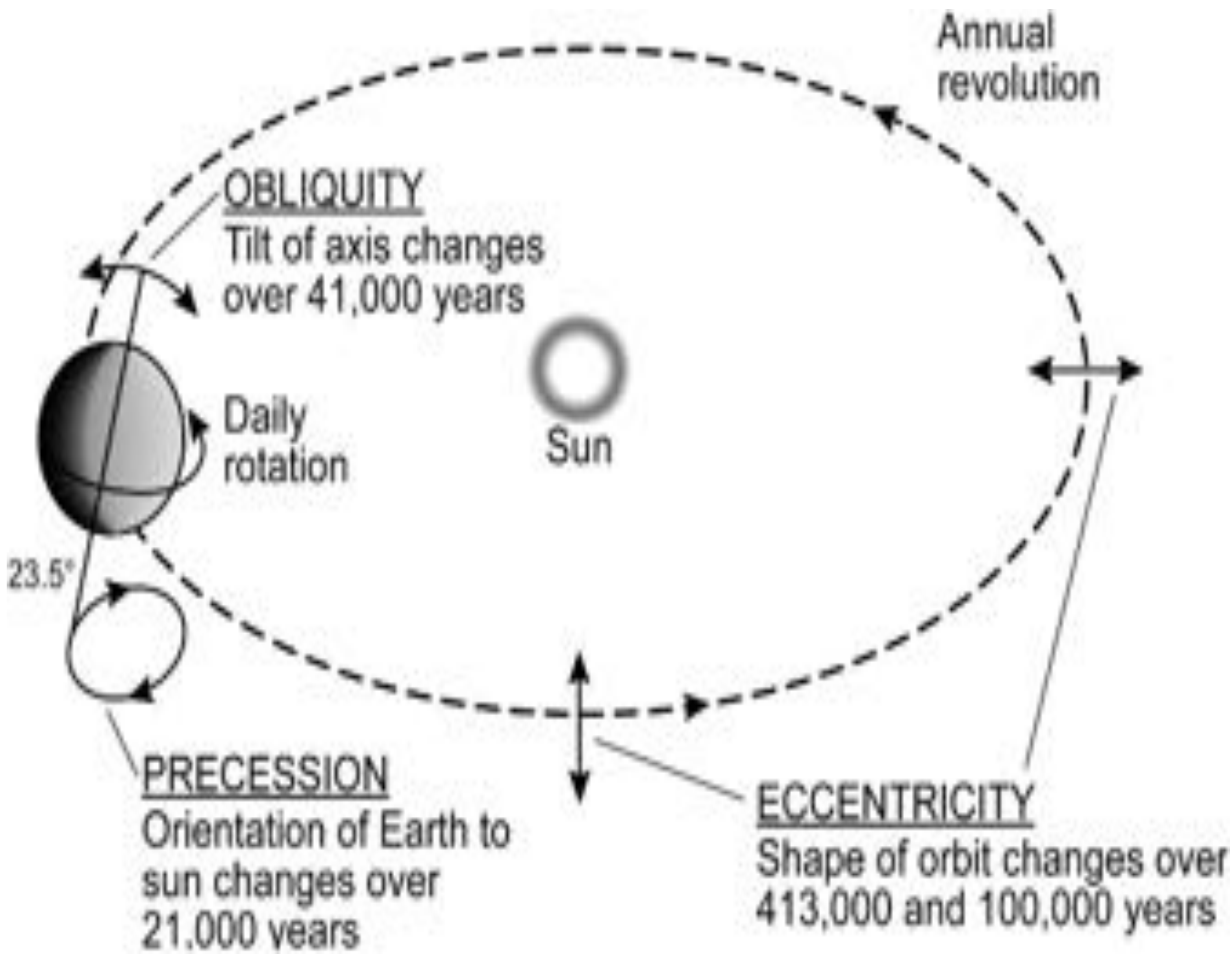


Ocean Currents



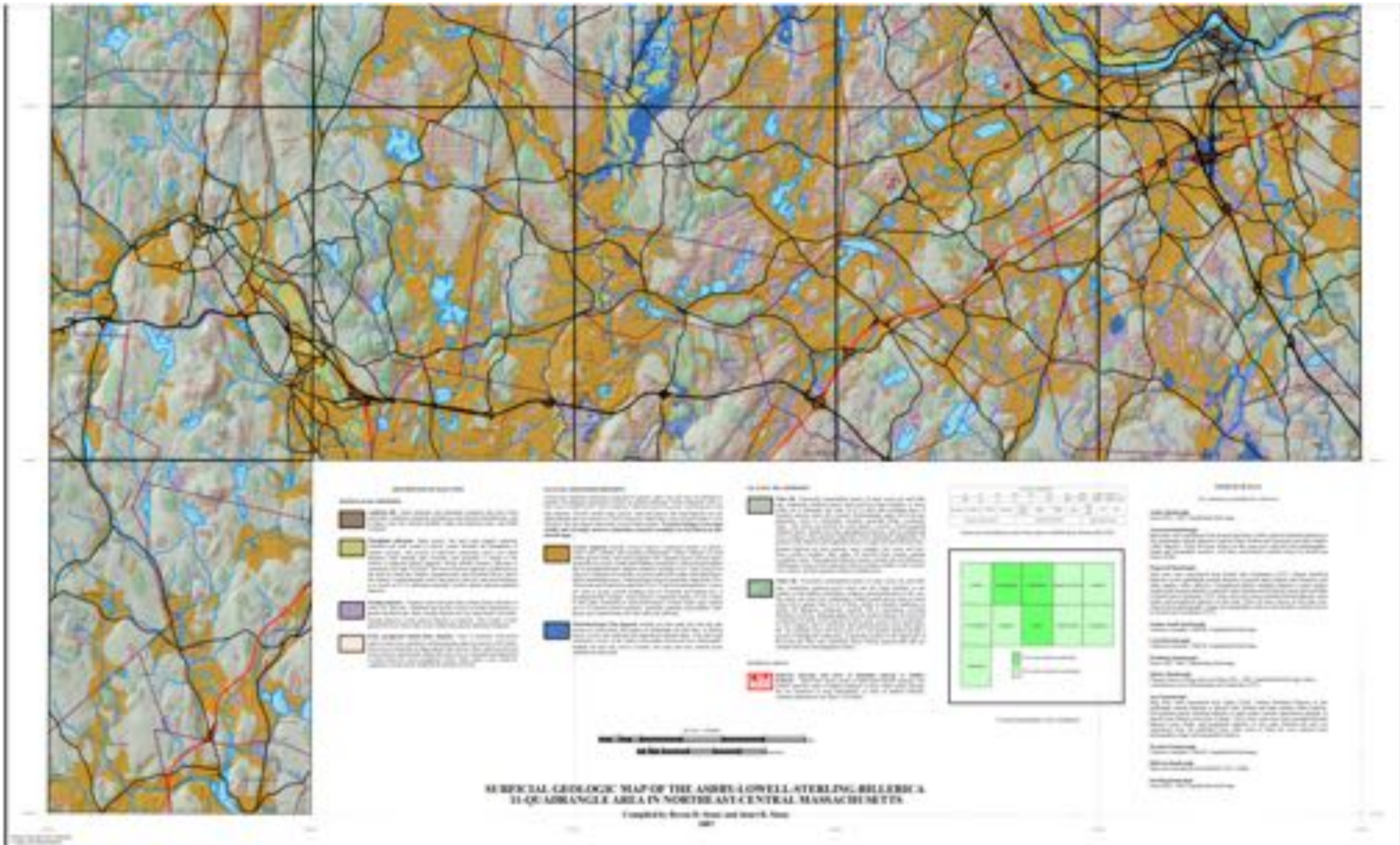
Ice Age Causes (2)

Milankovitch cycles. Note the cycles in years of each celestial event (obliquity, precession, eccentricity). When event cycles overlap distance from earth to sun decreases and glacial advance increased.



USGS or State Surficial Geology Quadrangle Maps

What it looks like for reference



SURFICIAL GEOLOGIC MAP OF THE ASHBY-LOWELL-STERLING-BILLERICA 11-QUADRANGLE AREA IN NORTHEAST-CENTRAL MASSACHUSETTS

Extracted parts of map and legend applicable to Nashoba Woodlands.

Bedrock Outcrops

Thick Till (common >100')

Thin Till (10-15')

Bedrock Outcrops

Swamp deposits

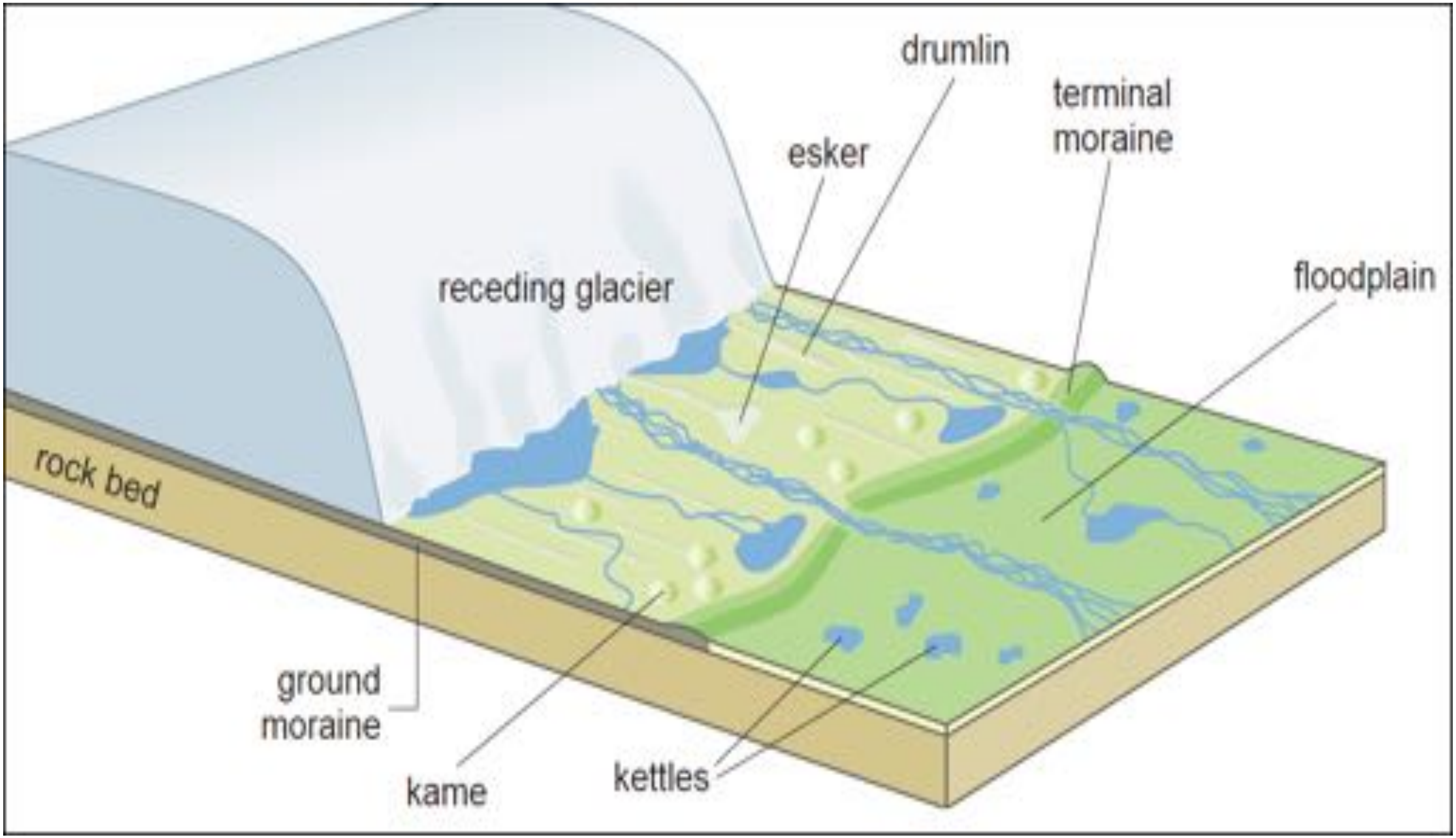
Glacial Landforms

- Glacial landforms can be the result of erosion, deposition or both. The depositional features at Nashoba Woodlands are glacial erratics, glacial till, glacial moraine.

- Erosional features are boulders that have been plucked from bedrock by the advancing glacier. Movement of glacier results in abrasion of underlying bedrock. Freeze/thaw cycles of water getting into bedrock results in erosion.

- The glacial landforms we cover here are those in Littleton and nearby areas. If we were in Northern New Hampshire or Cape Cod there would be more features to consider. New England is a great place to be for studying the effect of glaciation.

A Few Glacial Landforms



Glacial Till

- Nashoba Woodlands surficial geology is made up of a lot of glacial till.
- The till grades to several soil profiles that are defined by particle size, drainage characteristics, color and other factors.
- Till can be clay, sand, gravel and boulders.
- Primary distribution of till is by glacial movement and melting.
- Secondary distribution of till is by fluvial processes or erosion.

Glacial Erratic

- **Glacial erratics** are stones and rocks that were transported by a **glacier**, and then left behind after the **glacier** melted.
- Glacial erratics vary in size from small stones to boulders larger than houses.
- Some erratics are carried great distances by the glacier which is shown by the erratic being of a different material then the underlying bedrock.
- Other erratics are from the local bedrock or glacial till and are carried shorter distances.

Glacial Erratics

Left clockwise: Note smoothing and rounding of boulder to left. May have been carried, tumbled and smoothed by ice longer that top left.
Top left: Several boulders probably eroded from nearby bedrock (not hill) and carried short distance by ice.
Above: Rounded and smoothed boulder. Bottom shows gneissic layering of calc-silicate of NT, or biotite gneiss; but if boulder traveled for a while could be Silurian Berwick Formation from Merrimack Terrane to the west; or more distant points!

Glacial Erratic across trail from Fort Rock

Size range of Very Coarse Soil including Large Boulders, Boulders and Cobbles.

Madison, NH Boulder
Largest Known Glacial Erratic in North America

Note person for scale.

Nashoba Woodlands Stone Walls

- Many of the glacial erratics that have been brought to the surface through freeze and thaw cycles and erosion have been used to build stone walls at Nashoba Woodlands.
- Land needed to be cleared for farming and building. Rocks were moved to the edges of the property.
- The stone walls mark the property boundaries but were also used to delineate fields, contain livestock and create paths to drive livestock from one field to another.

Newtown Road

Key
Black = Walls/Boundaries
Yellow Dashes = Trails
Yellow solid = Yapp Land

Stonewalls in Nashoba Woodlands

Stonewalls throughout the woodlands. Large boulder of gneiss incorporated into wall (below). Note layering from metamorphic compression and mechanic weathering (freeze/thaw) splitting rock.

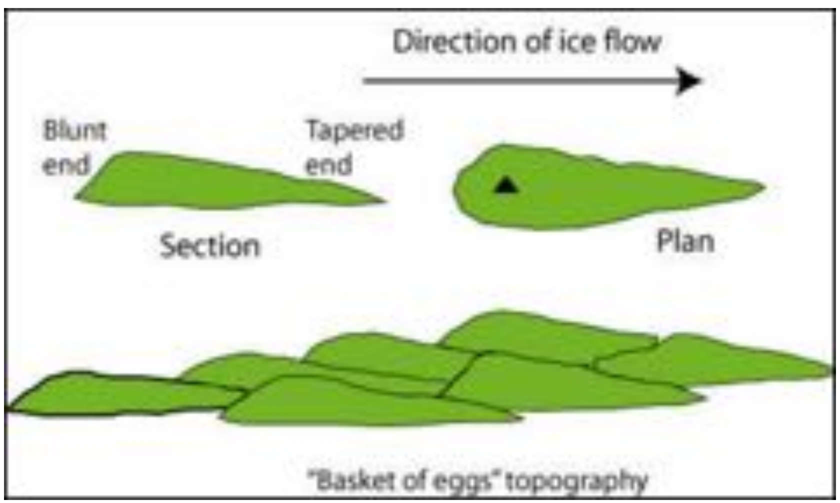
Drumlins

- A ***drumlin*** is an oval-shaped hill that consists of glacial till.
- There are no drumlins on Nashoba Woodlands, but soil profiles of the surficial geology indicate parent structures are drumlins and moraines.
- Each individual hill is generally aligned in a north/south direction which represents the direction of glacial advance.
- There are many drumlins in Littleton and surrounding areas. Proctor Hill, Wilderness Hill and Starr Hill (Prouty).
- Along Route 119 in Groton center and near Groton country club.
- Drumlin Farm in Lincoln, Ma.
- Boston Harbor Islands

Drumlins

- Drumlins are composed of glacial till deposits resulting from the north to south grinding action beneath an advancing continental glacier commonly thought to be about one mile thick.

- The drumlin normally forms when a pinnacle or small hill of bedrock is encountered and the glacial ice was plastered over it. It is not known whether the bedrock is close to the surface or whether it could be over 100 feet deep.



Kettle Ponds

- A kettle pond is a depression in the ground formed when a block of ice breaks off from the retreating glacier and forms a hole in the sediment in the outwash plain.
- If the hole holds water it is a kettle pond. If the hole does not hold water it is a kettle hole.

Kettle Ponds in Littleton and surrounding areas.

- Spectacle Pond
- Long Lake is thought to be a kettle pond that also has a glacial meltwater channel that joins the SuAsCo River drainage.
- Walden Pond; Concord, Ma.
- Sandy Pond; Ayer, Ma.
- Cape Cod is dotted with 100's of kettle ponds and kettle holes.

Kettle Ponds in Littleton

Spectacle Pond

Long Lake note meltwater channel

Esker

An ***esker*** is a long, narrow ridge of sand and gravel deposited by a stream of water that flowed in a tunnel beneath a melting glacier.

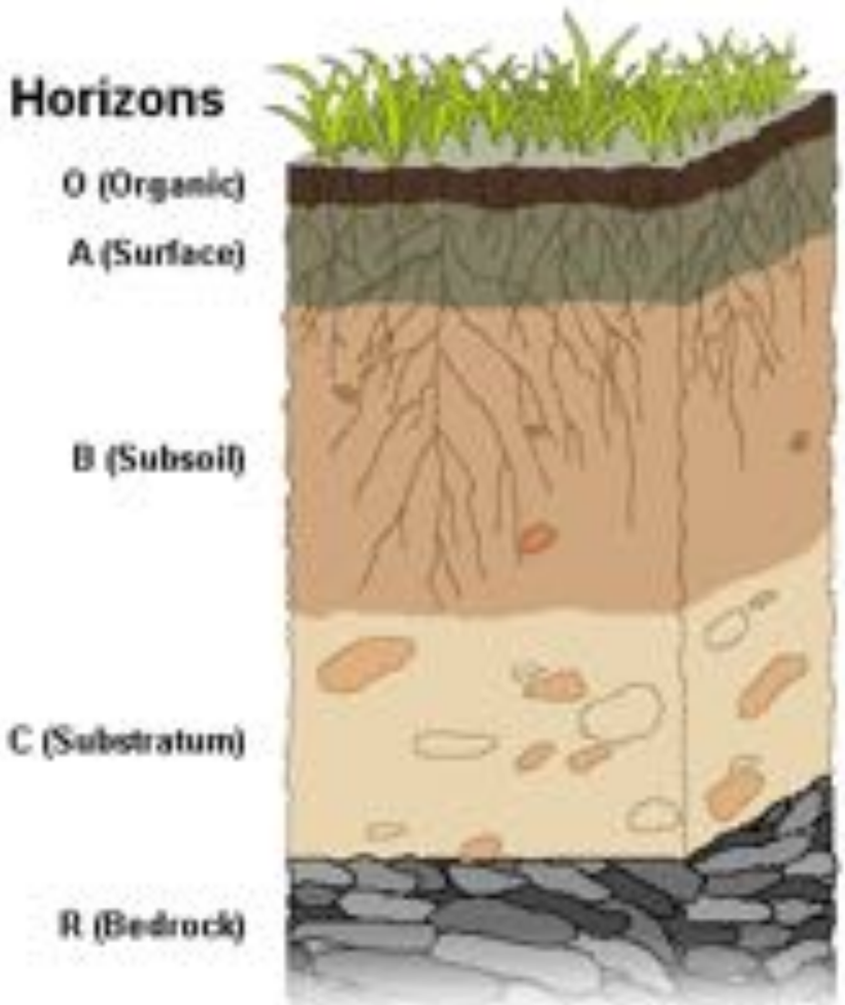
Eskers in Littleton

- Hartwell Hill
- Mary Shepard open space
- Sanderson Esker (below)

Soil Profiles

- Soil profiles are useful for classifying soil types for determining land use.
- Soil types can help determine the suitability of land for:
  - Supporting native species
  - Finding water
  - Specific types of farming
  - Building
  - Determining drainage patterns
  - Understanding geologic setting

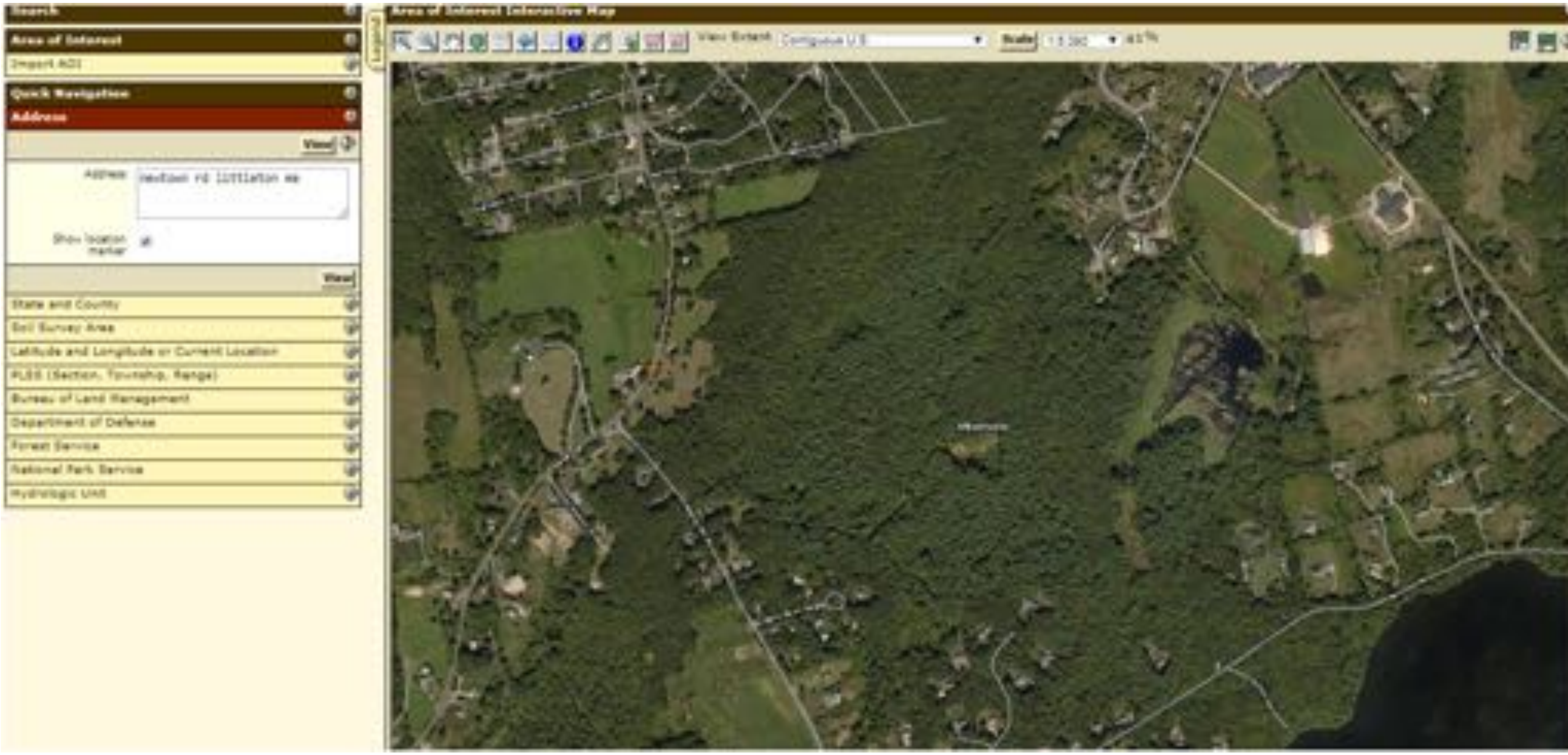
Soil Horizons



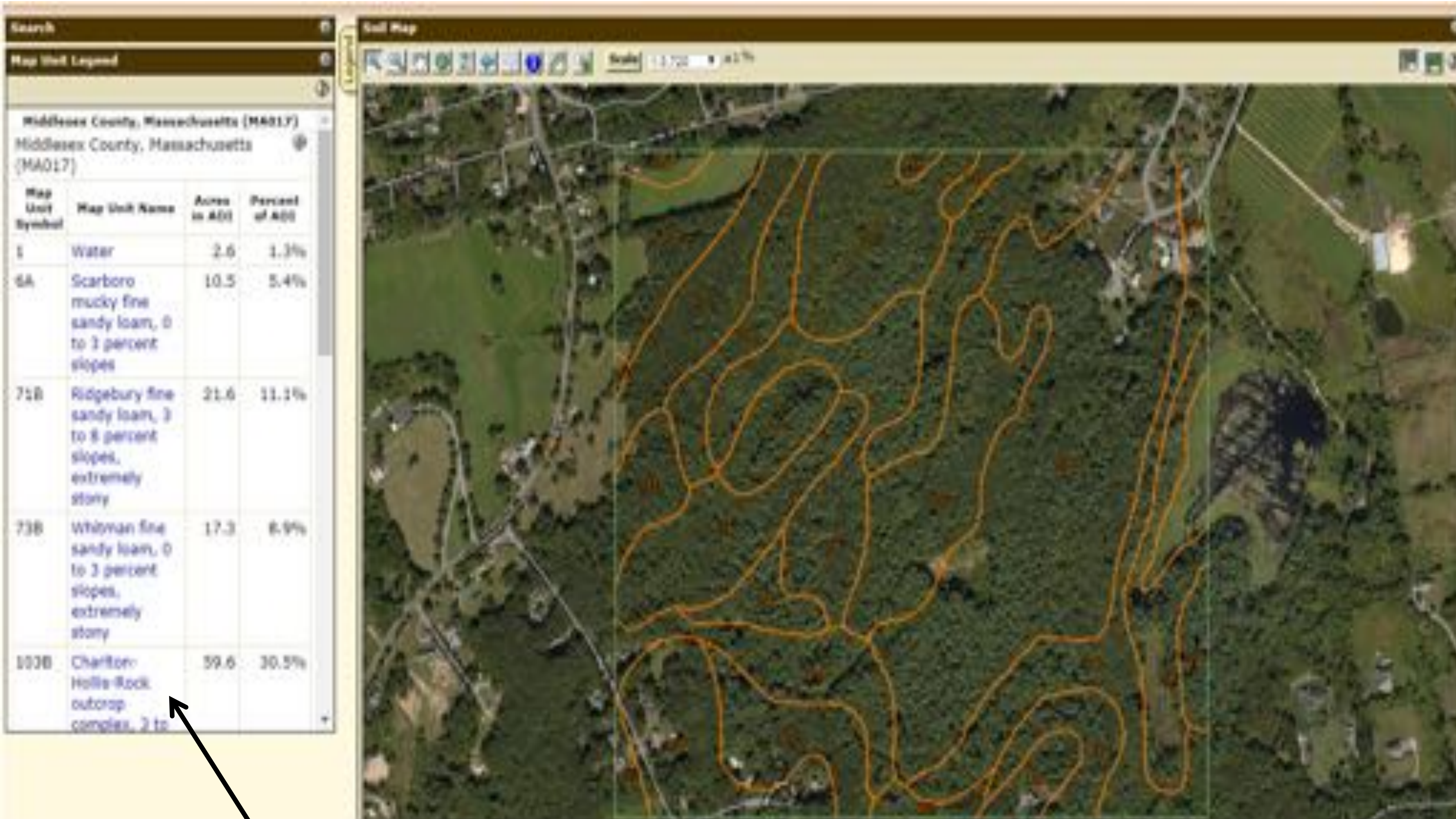
O (Organic) - Surficial organic deposit with litter layer of plant residues in relatively non-decomposed form.
A (Surface) – Organics mixed with mineral layer.
B (Subsoil) Subsurface layer reflecting chemical or physical alteration of parent material. This layer accumulates iron, clay, aluminum and organic compounds, a process referred to as illuviation .
C (Substratum) Parent rock also known as substratum: The parent material in sedimentary deposits. Layer of large unbroken rocks. This layer may accumulate the more soluble compounds .
R (Bedrock) The parent material in bedrock landscapes. This layer denotes the layer of partially weathered bedrock at the base of the soil profile.

Soil Profiles

- https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx - Soil Profile maps of United States
- Navigate to area of interest (AOI). Result is detailed outlines of AOI labeling different soil profiles with descriptions (next slide).



Soil Profiles of Nashoba Woodlands



Press on map unit AOI (Area of Interest) and get detailed profile information (next slide)

Details of 103B – Nashoba Woodlands

Map Unit Description

Printable Version

Report — Map Unit Description

Middlesex County, Massachusetts

103B—Charlton-Hollis-Rock outcrop complex, 3 to 8 percent slopes

Map Unit Setting

National map unit symbol: 9byc
Elevation: 0 to 1,000 feet
Mean annual precipitation: 45 to 54 inches
Mean annual air temperature: 43 to 54 degrees F
Frost-free period: 110 to 240 days
Farmland classification: Not prime farmland

Map Unit Composition

Charlton and similar soils: 50 percent
Hollis and similar soils: 25 percent
Rock outcrop: 15 percent
Minor components: 10 percent

Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Charlton

Setting

Landform: Drumlins, ground moraines
Landform position (two-dimensional): Footslope
Landform position (three-dimensional): Base slope
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Friable loamy eolian deposits over friable loamy basal till derived from granite and gneiss

Typical profile

H1 - 0 to 5 inches: fine sandy loam
H2 - 5 to 22 inches: sandy loam
H3 - 22 to 65 inches: gravelly sandy loam

Properties and qualities

Slope: 3 to 8 percent
Percent of area covered with surface fragments: 9.0 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 6.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 7.3 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6s
Hydrologic Soil Group: A
Hydric soil rating: No

Description of Hollis

Setting

Landform: Ridges, hills
Landform position (two-dimensional): Shoulder, summit
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Friable, shallow loamy basal till over granite and gneiss

Typical profile

H1 - 0 to 2 inches: fine sandy loam
H2 - 2 to 14 inches: fine sandy loam
H3 - 14 to 18 inches: unweathered bedrock

Properties and qualities

Slope: 3 to 8 percent
Percent of area covered with surface fragments: 9.0 percent
Depth to restrictive feature: 8 to 20 inches to lithic bedrock
Natural drainage class: Well drained
Capacity of the most limiting layer to transmit water (Ksat): Very low to moderately low (0.00 to 0.14 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Very low (about 2.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6s
Hydrologic Soil Group: D
Hydric soil rating: No

Description of Rock Outcrop

Setting

Landform: Ledges
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Head slope
Down-slope shape: Concave
Across-slope shape: Concave
Parent material: Granite and gneiss

Properties and qualities

Slope: 3 to 8 percent
Depth to restrictive feature: 0 inches to lithic bedrock

Areas of note in Soil Profile

- Area of Interest (AOI) size in acres
- AOI size in percentage of area
- Map unit setting
- Landforms the soil was derived from
- Suitability of soil for farming

From the Details of 103B previous slide.

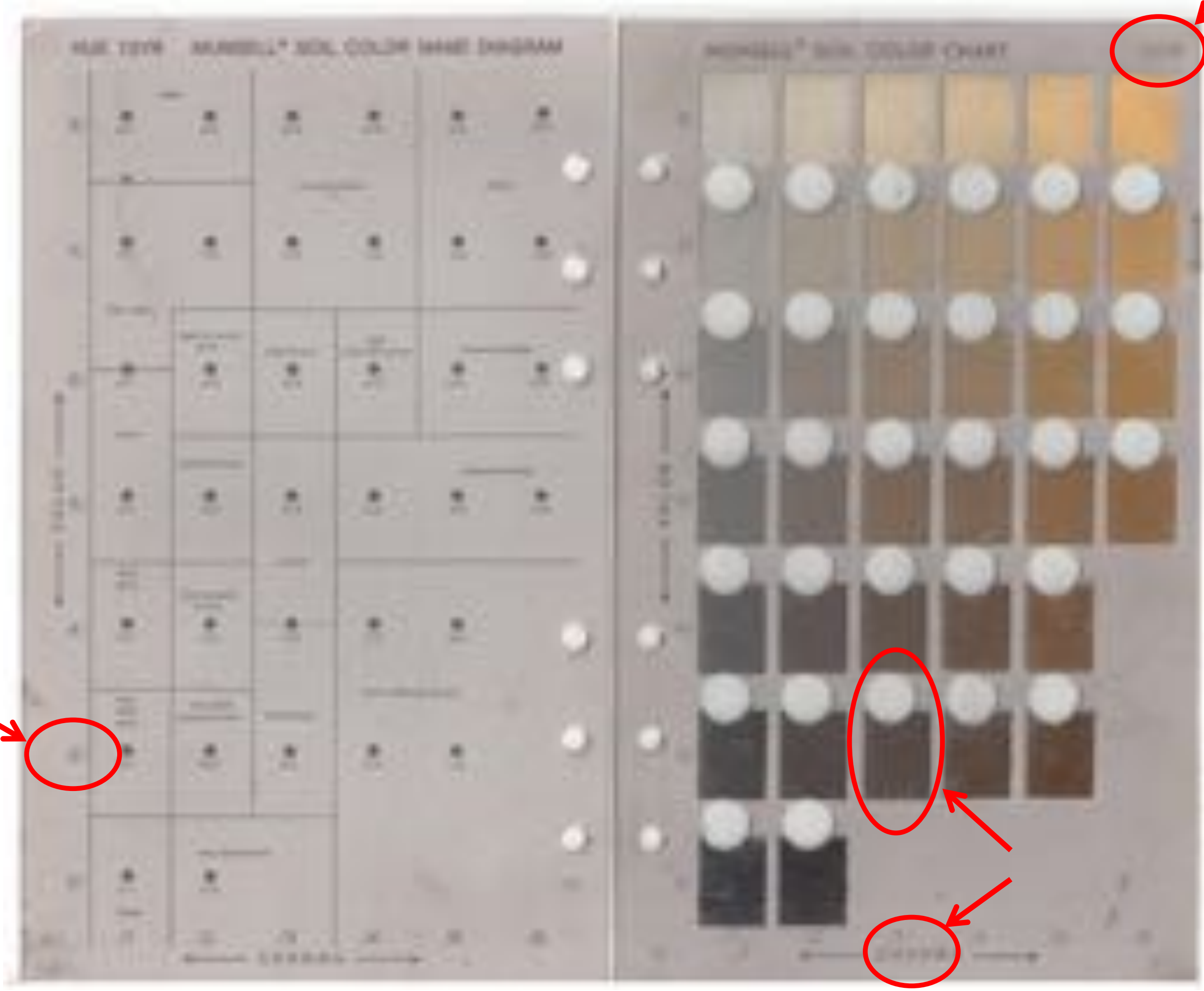
- Consider the minor soil components
- Nashoba Woodlands is made up of soil named **Charlton-Hollis-Rock outcrop** soil **labeled 103B** for **59.6 acres**, it represents **30.5%** of the area.
- The soil is derived from drumlins and ground moraine.
- The parent rocks are granite and gneiss.
- Note considered prime farmland.

Soil Color

- Soil color is an important attribute for soil identification.
- Munsell Soil Color charts are a standard for soil comparisons.
- The system has three components: hue (a specific color), value (lightness and darkness), and chroma (color intensity) that are arranged in books of color chips.
- Soil color is compared against samples from the Munsell color chart.

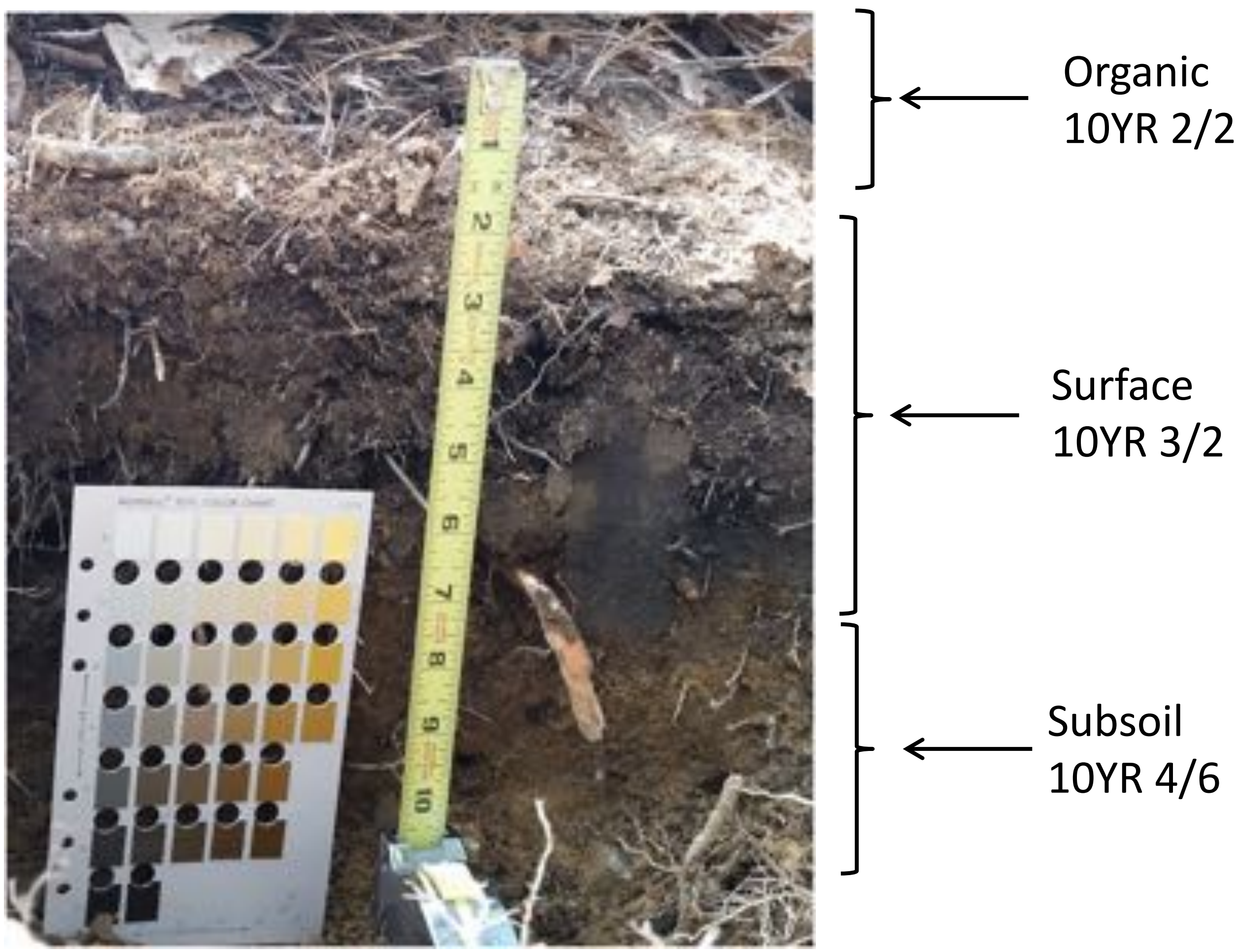
Munsell Soil Color Chart

Munsell designations are hue:value:chroma.
Example: **10YR 3/3 = Hue Yellow/Red :3:Dark Brown**



Evaluating Soil Profiles

- Using a flat shovel cut smooth face in the sample.
- Measured depth of cut. This would also be supplemented with field notes and sketches.
- Note 3 layers. I could have dug deeper given the energy to expose lower horizons.
- Match the sample with hue:value:chroma



Water

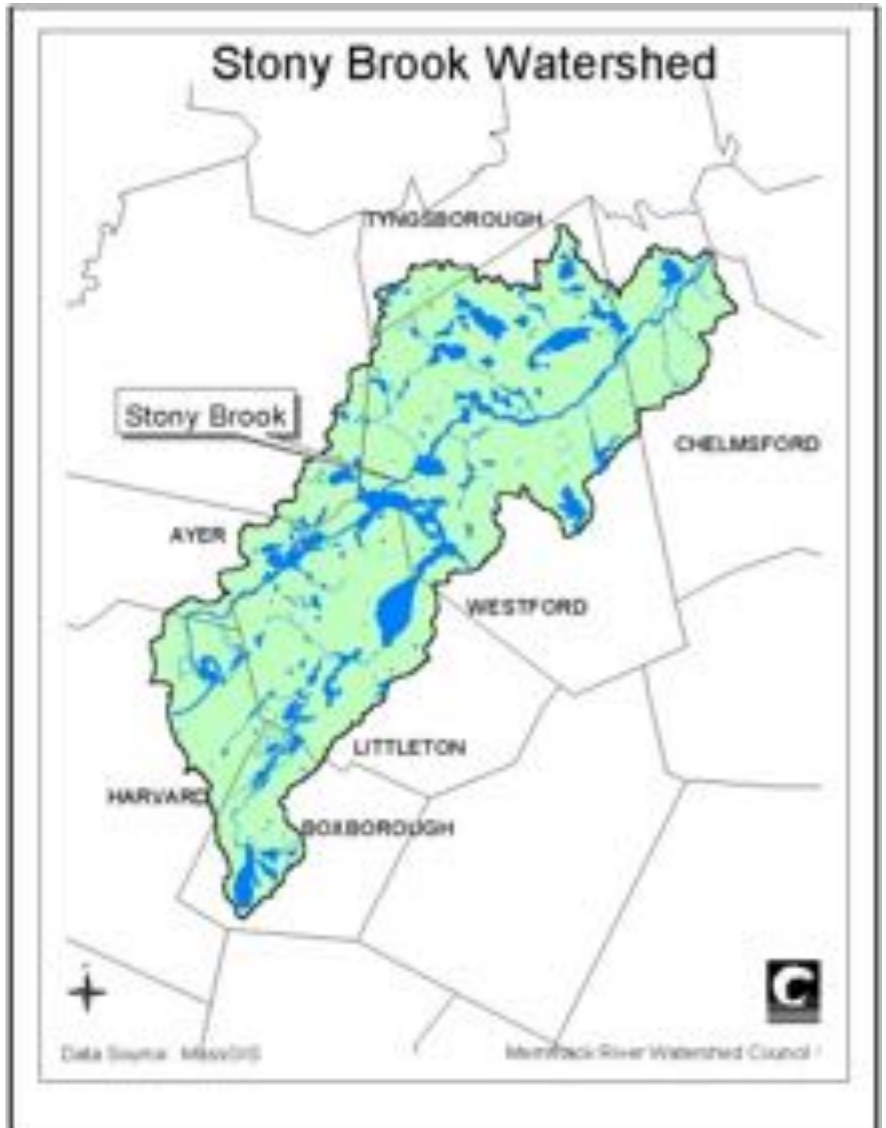
- Nothing lives without water.
- Knowing where the water is helps us manage and maintain:
  - Healthy and safe aquifers for drinking water
  - Maintaining environments for healthy, sustainable, diverse environments.
  - Determining drainage patterns and maintaining flood control landscape.
  - How to monitor for pollution.
  - Understanding geologic setting.

Watersheds

- An area or ridge of land that separates waters flowing to different rivers, basins, or seas.
- Wilderness Hill at Prouty Woods is on the divide between two watersheds.
- Stony Brook (Merrimack River Watershed) to the north.
- SuAsCo (Sudbury, Assabet, Concord Watershed) to the south.
- Nashoba Woodlands is in the SuAsCo watershed.

Watersheds in Massachusetts

Stony Brook sub-drainage to Merrimack



SuAsCo sub-drainage to Merrimack

Wetlands Mapping Tool and Viewer

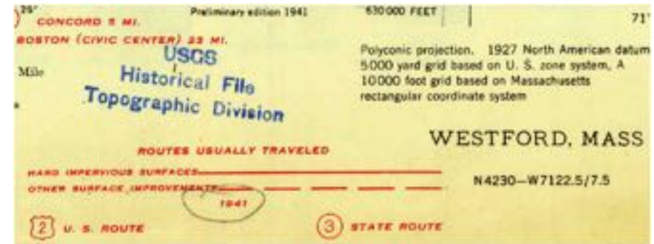
- Mapping tools can help you take advantage of existing research to determine the aquifers and in a particular area. Following is one of the mapping tools I use.
  http://maps.massgis.state.ma.us/images/dep/omv/wetviewer.htm - Wetlands viewer map for Massachusetts

- Interactive tool provided for free. Allows navigation to area in Massachusetts, scaling down to desired detail and displaying labeled maps of wetland habitat, including vernal pools, permitted areas (with permit numbers).

Output from Wetlands viewer for Nashoba Woodlands

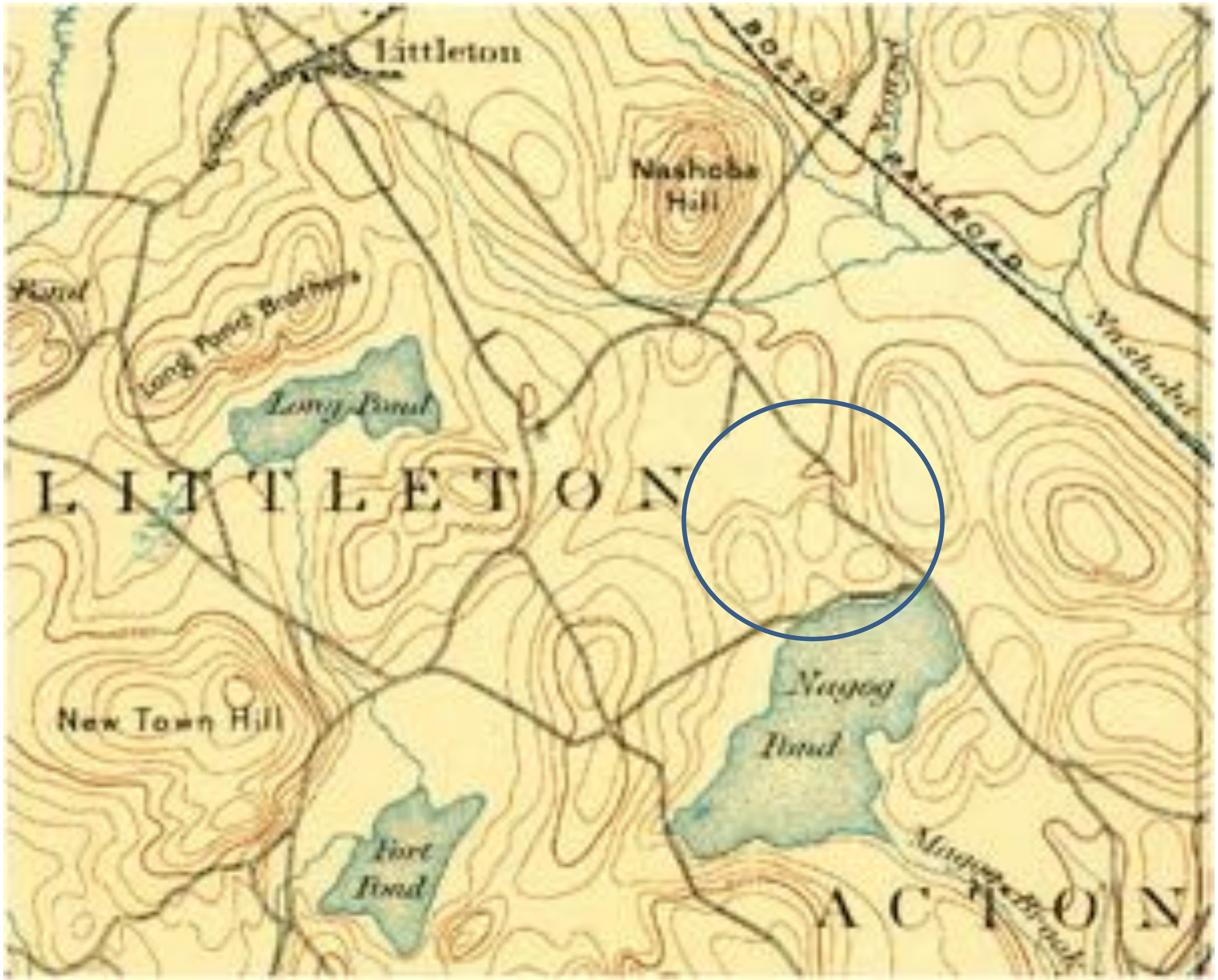
Legend (partial) on left. Map of Nashoba Woodlands below. Various habitats delineated; vernal pools mapped. Note Cobb Pond for reference.

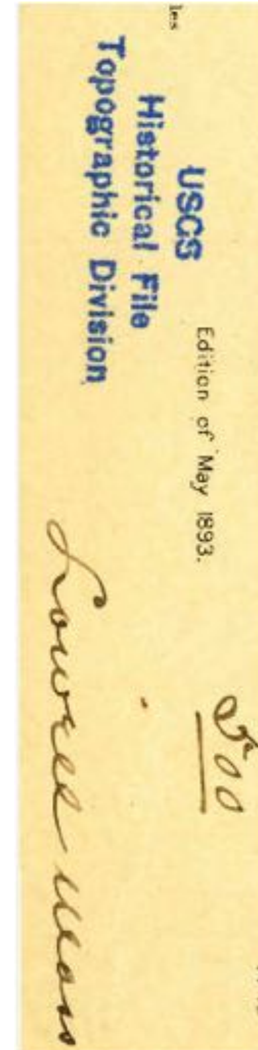
1941 Historic Map



Yapp Property and nearby lands.

1893 Topographic Map





Nashoba Terrane

- Primary bedrock below surficial deposits on Nashoba Woodlands is Nashoba Terrane.
- Nashoba Terrane grades from Phylite to Gneiss: there are granitic intrusions and various mineralization that can be found in all rock types.

Note banding in gneiss of like minerals during metamorphic process.

Gneiss found near intersection of Route 111 and 495 Boxborough.

All Granite is not created equal!

- Granite or granitic rocks are made up of a variety of minerals.
- Granite is made up of: 20-60% Quartz, at least 35% feldspar, darker minerals of biotite mica or amphibole minerals (e.g. hornblende).
- The different contributions of various minerals will result in different types of granite.

Examples of 3 minerals in crystal form that contribute to granite formation

Gneiss

(metamorphic rock)

Banding in gneiss of like minerals during metamorphic process. Sample contains many of original minerals before metamorphism.

Granite

(igneous rock)

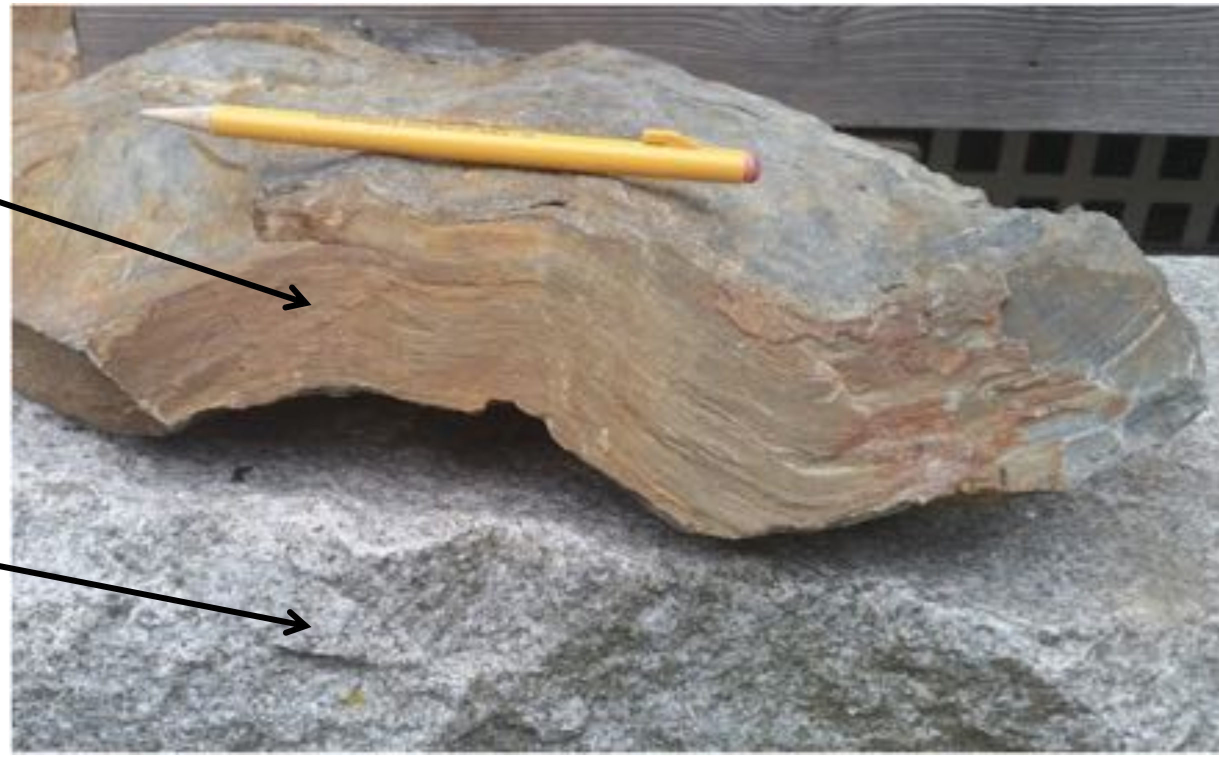
Quartz, feldspar, amphibole, biotite mica. Granite intruded near the gneiss under the surface (intrusive) in molten state.

Specimens found near intersection of Route 111 and 495 Boxborough.

Tadmuck Brook Schist from Oak Hill Area

Folding of schist while at depth under compression forces while in a malleable form.

Granite block: quartz, feldspar, biotite mica and amphibole minerals.



Note: Categories of rock: Igneous, metamorphic, sedimentary will often (not always) have original minerals maintained as the specimen progresses through the rock cycle.

Common Minerals locally found

Garnet, milky quartz, feldspar and mica found in bedrock off Beaver Brook in Littleton.

Muscovite Mica. Found southern NH at Beryl Mountain. Mica is a common accessory mineral we see in rocks usually in small shiny flakes. It can be formed in large sheets or “books”.

Garnets in Crystal Form

Quartz in Crystal Form