Name:_____

Earth Science Field School Field Guide



Spring, 2013

PLEASE CARRY THIS GUIDE WITH YOU AT ALL TIMES.

Field School Exercise Teams

Mt. Tuam		Argonaut	

*** ***Bold face*** *students responsible for GP & FRS radio* ***

Cover: Myra Formation (part of the Paleozoic Sicker Group) exposed at Myra Falls

EARTH SCIENCE FIELD SCHOOL SYLLABUS

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Optional Reference Texts:

- Bevier; 2005. Introduction to Field Geology, McGraw-Hill Ryerson, ISBN-13: 9780070931091
- Coe, A. (ed.); 2010. Geological Field Techniques, Wiley-Blackwell, ISBN 13: 9781444327441
- Lisle, R.J.; 2011. Basic Geological Mapping, Wiley, ISBN-13: 9780470686348
- McClay, K.R.; 1991. The Mapping of Geological Structures, Wiley, ISBN-13: 9780471932437

Course Goals

- To develop the skills necessary to enable you to organize, conduct and successfully complete a field-based geological investigation involving the production of geological maps and cross sections, and the development of geological histories based on these.
- To provide you with the opportunity to apply those geological skills learned in a classroom setting, including mineral and rock identification, and structural and petrological analysis, in the field.
- To enable you to acquire an understanding of the geological evolution of Wrangellia.

Grading

Exercises:

Mt. Tuam	20%	Vesuvius	10%
Argonaut	40%	History of Wrangellia	10%
Sayward Beach	15%	Participation	5%

Grade Assignment:

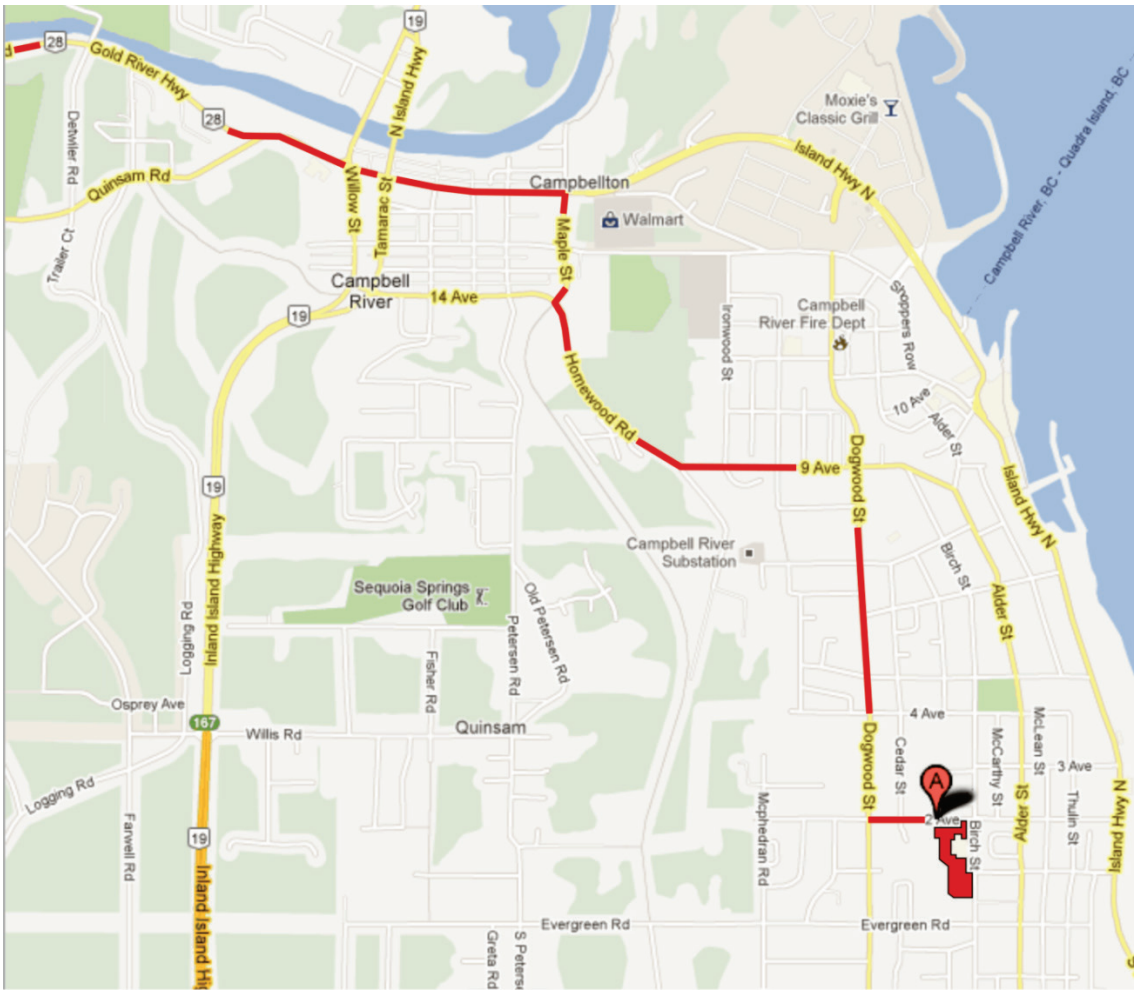
A+	90 – 100%	B–	70 – 72%
A	85 – 89%	C+	65 – 69%
A–	80 – 84%	C	60 – 64%
B+	77 – 79%	D	50 – 59%
B	73 – 76%	F	< 50%

ESFS ITINERARY

Day(s):	Date:	Activity:
1	Tuesday, 23rd April	On-campus tutorial: Meet in SCI B119/121 at 10am.
2-3	Wednesday, 24th - Thursday, 25th April	MT. TUAM EXERCISE: Depart Lot 1 @ 7:45am, both days. Goal – working in pairs (but traversing in groups of four), you will spend two days mapping the summit area of Mt Tuam (Saltspring Island). You will be required to submit a geological (field) map of the area, along with a complete legend, explanatory (marginal) notes describing the geological history of the region, and an appropriately oriented sketch cross section. In particular, you will be asked to note evidence for metamorphism, the relationship between structural elements (*e.g.*, folds and cleavage), the geometry and distribution of igneous rocks and their relationship to deformation of the region. Return to Lot 1 by 7:00pm each day.
4	Friday, 26th April	Geological stops between Victoria and Strathcona Lodge: Depart Lot 1 @ 8am. Goal – working individually, record observations made at road-side stops as we drive up-Island. These observations will, in part, assist you in writing your geological history at the end of the program. Please have your Field Guide, notebook, compass, hammer and hand lens handy at each stop.
5-9	Saturday, 27th April - Wednesday, 1st May	ARGONAUT EXERCISE: Depart the Lodge @ 8:30am each day. Goal – working in pairs (but traversing in groups of four), you will produce a complete geological report on the map area. The report is to include a geological map (both field and compilation) showing the distribution of geological units and annotated with all available structural data; an explanatory legend, a set of marginal notes describing the geological history of the area, and at least one to-scale cross section. In addition, each pair is required to provide nightly reports on their progress, indicate the main questions being addressed by their mapping, and outline a traverse plan for the next day. Structural orientation data are to be collected catalogued and analyzed (stereonet). BUTTLE LAKE EXCURSION: Depart the Lodge @ 8:30am Goal – working individually, record observations made at road-side stops and at Myra Falls Mine, a volcanic-hosted (volcanogenic) massive sulphide deposit at the south end of the lake. These observations will, in part, assist you in writing your geological history at the end of the program.
10	Thursday, 2nd May	VESUVIUS STRATIGRAPHIC SECTION EXERCISE: Depart the Lodge @ 7:30am. Goal – working individually, produce a stratigraphic section through a sedimentary sequence (part of the Nanaimo Group). Your report should include a quantitative measured section detailing lithofacies, sedimentary structures and (trace) fossils, and an assessment of the evolution of the depositional setting through time. Catch 4pm ferry & return to Lot 1 by 6:00pm
11	Friday, 3rd May	SAYWARD BEACH EXERCISE: Meet at Parker Park parking lot (see p. 47) @ 8:30am. Goal – working individually, map an outcrop of complexly interrelated rocks in detail and at large-scale. You will be required to submit a geological (field) map of the beach area containing a legend and all the essential cartographic features, as well as a brief geological history.
12	Saturday, 4th May	GEOLOGICAL HISTORY OF WRANGALLIA: Meet in SCI B119/121 @ 10am. Goal – using all of your observations from the first ten days, as recorded in your field notes, write a detailed geological history of Wrangellia.

Safety in the Field

The safety of all Field School participants is of paramount importance. Those with first aid training will be identified at the beginning of the program and instructors/TA's will carry wilderness first aid kits and monitor GMRS radio channel 21-0 at all times while in the field. A BC Level 1 first aid kit and satellite phone will also be located in the back of one of the vans, the keys to which will always be left in the front passenger wheel-well when parked in the field. In case of an emergency, you will hear three (3) long blasts from an air horn repeated three (3) times at approximately fifteen (15) second intervals. If you hear such a signal, turn on your radio and return to the vans immediately. Radios should otherwise be kept off and should not to be used for non-emergency communications. Should transport to the Campbell River Hospital (see map, below) ever be required, please attempt to contact one of the instructors/TA's *first*. Approved eye protection must be worn at all times when hammering or using acid and safety vests must be worn where there is potential for interaction with traffic (*i.e.*, on/near roads). As a minimum, traverses are to be done in pairs and you should inform your partner or another student pair if you intend to venture off-road for *any* reason. Never discard food or food waste of *any* kind in the field (this includes orange peels & apple cores), as this can attract bears. Cigarette butts are never to be discarded in the field. Finally, always be on the look-out for potential hazards that may influence either your safety or that of one of your colleagues.



Campbell River Hospital
375 2nd Avenue
(250) 287-7111

Equipment

In addition to your personal field notebook and hand lens, students will be issued a rock hammer, compass, clipboard, safety vest and acid bottle. One member of each team will also receive (and should keep for the duration of the course) a handheld GPS, pencil magnet and FRS radio. ***You are responsible for returning all of the equipment originally issued to you.***

While you will be working in pairs on both the Mt. Tuam and Argonaut exercises, individual notes should be taken on all other days. These notes will assist you in completing the Geological History of Wrangellia exercise on the final day.

Compass Measurements

Geological mapping involves collecting and interpreting structural data using a compass. If you are not proficient at taking attitudes with a compass, please familiarize yourself with the techniques described on the following pages.



Suunto MC-2

Magnetic Declination

All measurements shown on geologic maps are shown relative to true north. The compass needle, however, always aligns itself relative to magnetic north and thus an adjustment must be made to compensate for local declination or the angle between magnetic and true north. Declination at any given location changes constantly, as the position of the magnetic north pole changes (Figure 1). Currently, at the summit of Mt. Tuam, it is just shy of **17° E**, while at the Argonaut , it is **17 °35' E** (both decreasing 11-12'/year).

Note: 1 degree = 60' (minutes) = 3600" (seconds). All compasses can be adjusted for declination by turning, using the attached tool, the screw located on either the front or back bezel. (Note: declinations *west* of Ontario are *east* of north.)

This should be among the first steps you take before starting fieldwork any area.

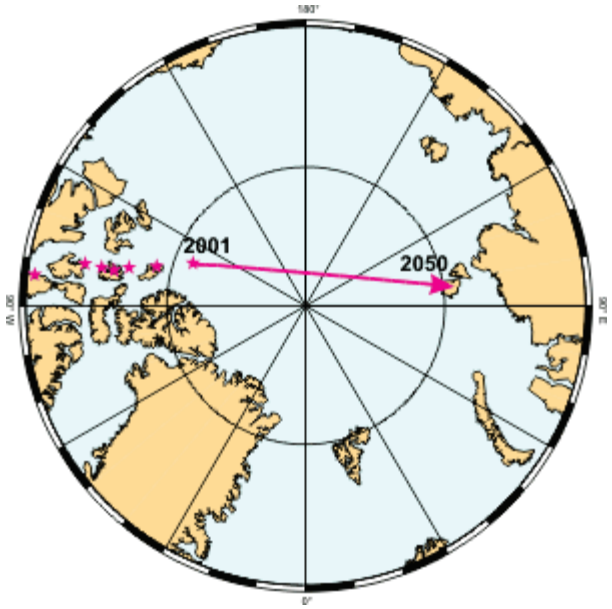
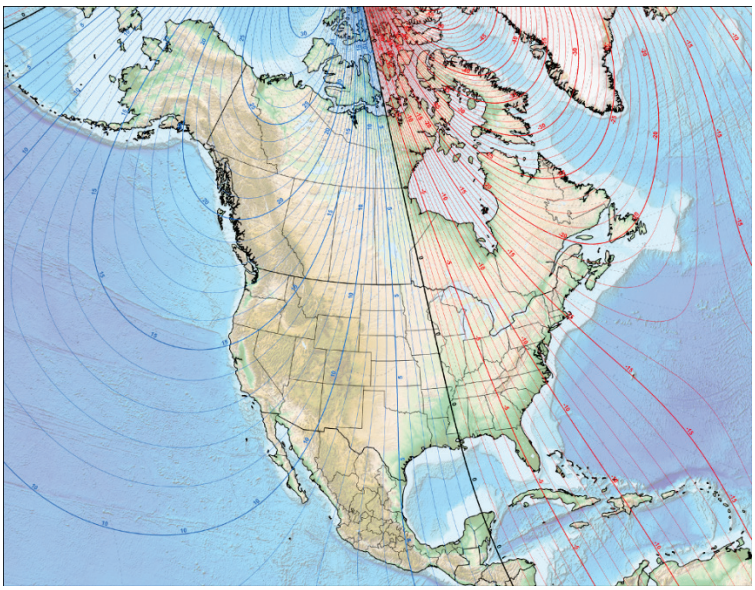


Figure 1 – Magnetic north pole locations 2001-2050



N. American Magnetic Declinations (2010)

Navigation and Location

However good your field observations are, they are next to useless if you don't know where you are when you are making them. Your compass can be used to locate yourself in different ways when you are mapping. Perhaps the most common way is the technique of triangulation, described below.

Triangulation Methods

- Choose prominent landmarks (*e.g.*, mountain peaks, radar towers, *etc.*) that can be both observed from your position and located on your map. Landmarks that are approximately 90° apart will provide the best accuracy.
- Measure the bearing to the first landmark. Be sure to hold the compass at arm's length, sight using the notch in the compass top and use the mirror to view the bezel.
- Without adjusting the bezel, place the compass on your map so that the parallel red lines under the needle are aligned with map (UTM) north and one side of the base-plate intersects the landmark.
- Draw a line on the map along the edge of the base plate through the landmark. *Your position is somewhere along this line*.
- Repeat this procedure for the other landmark(s). Your position is where the lines intersect.
- Where possible, three landmarks at 60° to one another are used because the third provides a check on the first two.

When mapping on a large-scale (small area, large amount of detail), taking a bearing and walking along it, counting your paces as you go, will allow you to produce your own base map. If you know where you are to begin with, and how far you have walked in any given direction, you can then determine your final position.

In addition to navigation, compasses can be used to measure the attitudes of lines and planes (Figure 2). The attitude of a plane is described in terms of its strike and dip (*e.g.*, 040°/45°SE), while that of a line is determined by measuring its plunge and trend (*e.g.*, 20°→060°).

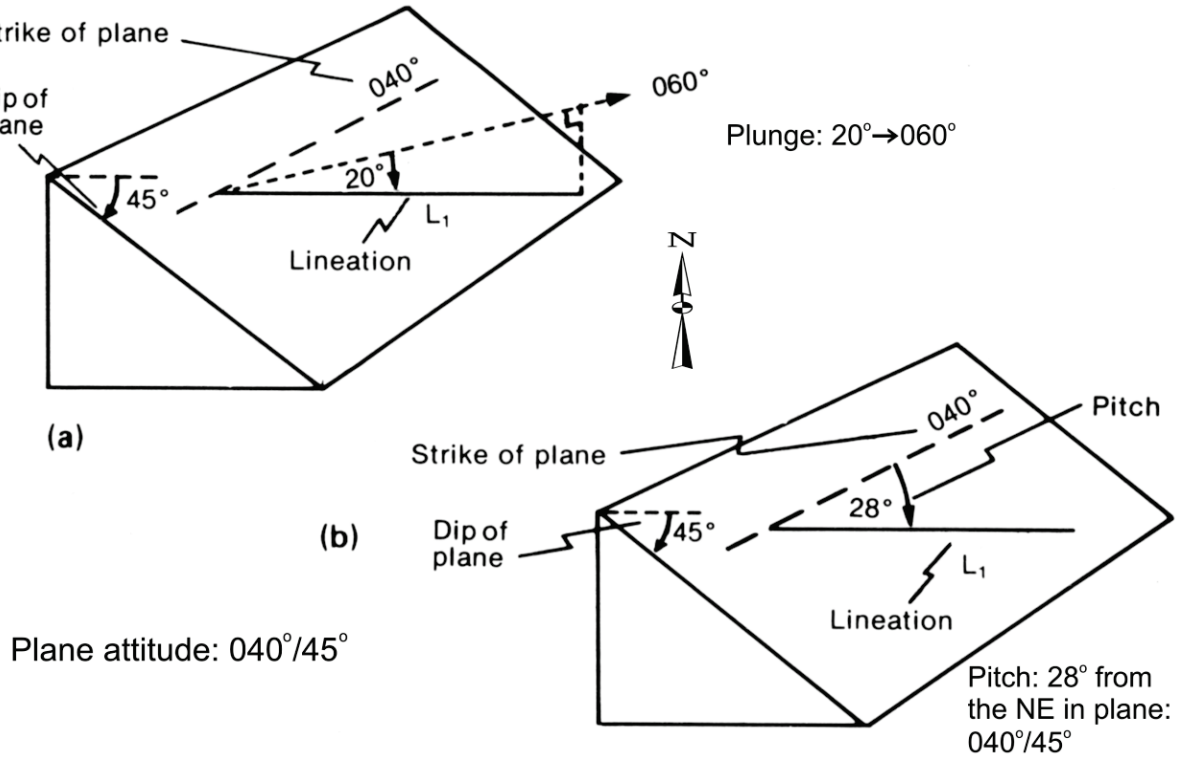


Figure 2

Structural data should be consistently recorded in the following manner:

- angles (dip*, plunge, pitch# – measured from horizontal) with 2 digits (*e.g.*, 06°)
- azimuths (strike, trend – measured from north in a horizontal plane) with 3 digits (*e.g.*, 009°)

* should also include a cardinal/intercardinal dip direction (*e.g.*, 45°*SW*)
# should also include a pitch sense (*e.g.*, 28° from the *NE*)

Planes

The strike of a plane is the compass direction (azimuth) of any horizontal line in that plane. While such lines have two possible orientations (@ 180° to one another), the strike direction is, by convention, the one where the plane dips to the right (right hand rule – commonly used when digitising orientation data). In this way, the dip direction can be deduced from the direction of strike. To measure the strike of a plane, simply line up the edge of your compass with any horizontal line in the plane and rotate the bezel until the red part of the needle lines up with the red arrow below. It may be easier to first draw a horizontal line in the plane while you are becoming familiar with this technique. It is ***critical*** that your compass is horizontal when taking strike measurements (Figure 3).

Dip is the angle of inclination of a plane, from horizontal, measured perpendicular to the direction of strike in a vertical plane (*i.e.*, the maximum angle at which the plane is inclined). This measurement is taken by rotating the compass bezel to either 090° (*E*) or 270° (*W*), lining up the edge of the compass with the plane being measured in the direction of maximum dip (90° to strike) and reading the dip angle using the compass' clinometer (Figure 4). *When recording the strike/dip of a plane or plunge→trend of a line in your notebook, ensure that you indicate what it is that you measured (e.g., bedding or foliation, cleavage/bedding intersection lineations or parasitic fold hinge lines).*

During EOS 300, and most of the geological mapping you will ever undertake, measuring joint orientations will not be particularly useful. Bedding and foliation/cleavage (planar) and their intersections (linear) are the key features which you will generally want to measure.



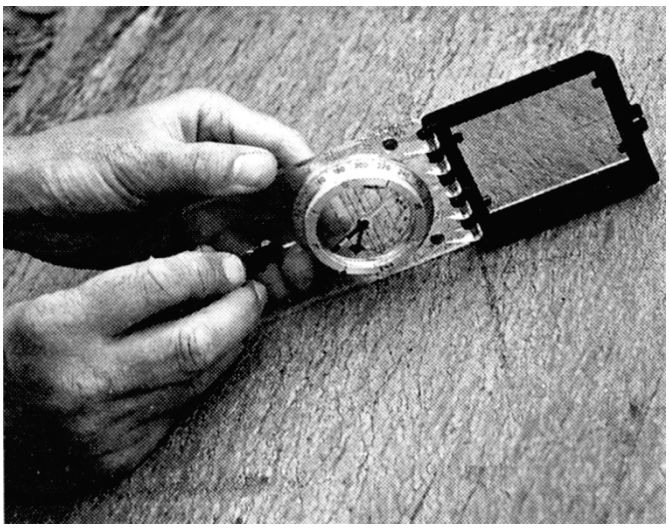
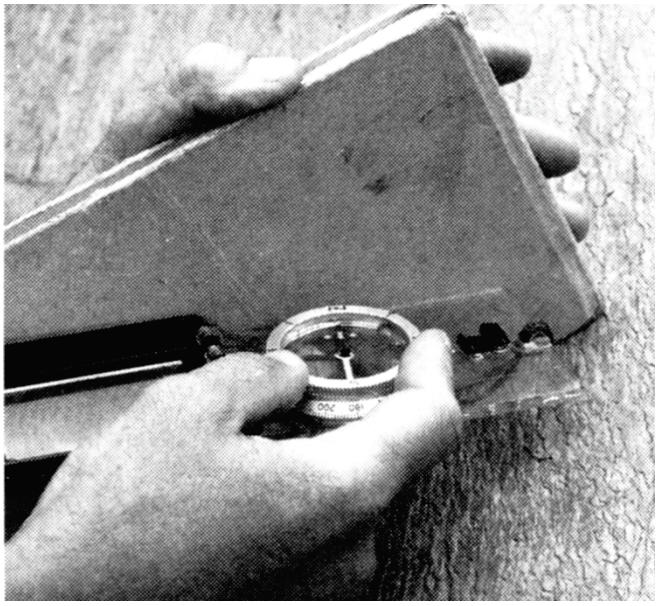


Figure 3 *(from McClay, 1987)* *Figure 4*

Lines

The trend of a line is the azimuth of that line in a horizontal plane measured in degrees from north, in a clockwise direction. The trend of a linear feature is most easily determined by measuring the strike of a vertical plane passing through that line (Figure 5).

The plunge of a line is the angle of inclination, from horizontal, of the line measured in a vertical plane containing that line. This angle is measured similarly to the dip of a plane, except that the compass is oblique to the dip of the plane which contains the line (Figure 6).



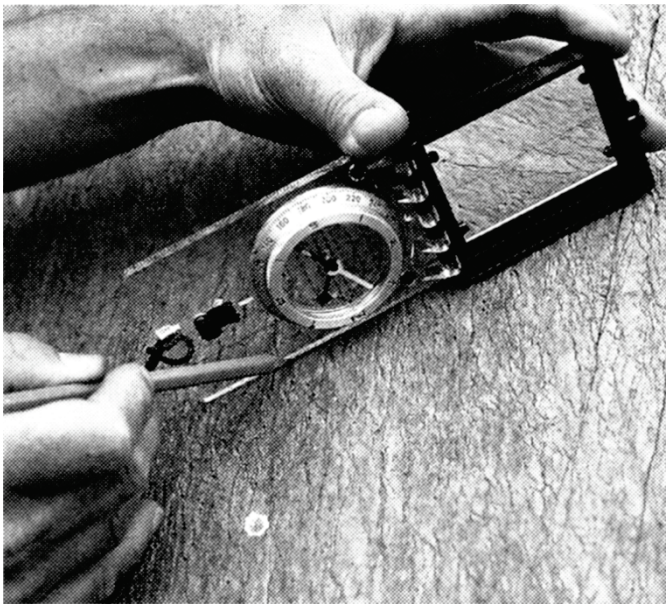


Figure 5 *(from McClay, 1987)* *Figure 6*

Problems may arise when no suitable surface is available on which the compass may be placed to measure orientations. In these situations, a non-magnetic clipboard can be used to make a measurable surface parallel to the plane which you are trying to orient (Figures 7 & 8).



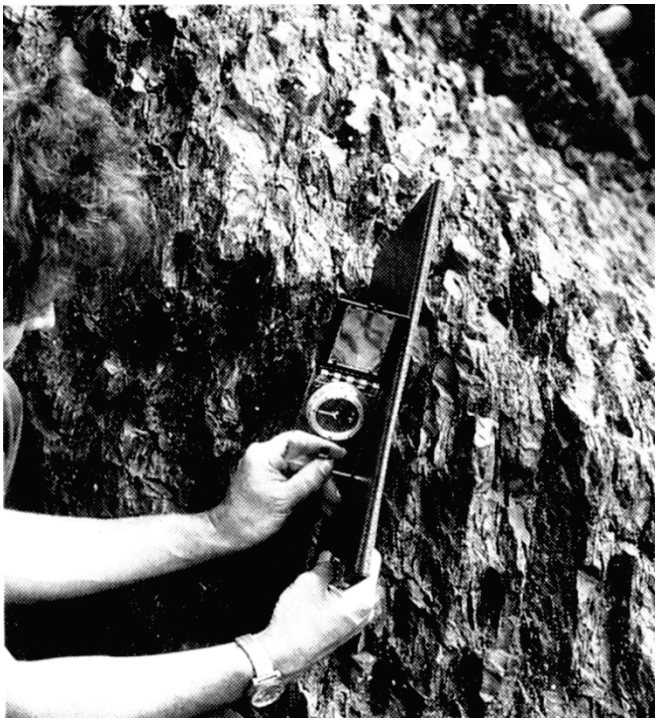


Figure 7 *(from McClay, 1987)* *Figure 8*

Field Notes

Field notes are a critical record of your field observations – without these, your time in the field will generally be wasted. They should be ***neat***, ***organized*** and ***well illustrated***. They must contain appropriate location information so that, together with your field map (see below), they can be interpreted by someone else. The key to producing good field notes is ***careful observation*** and ***systematic recording***. Always ask yourself what information would somebody who has not seen the outcrop need in order to interpret its geological history. Use sub-headings to help keep your notes well organised. Page numbers and a content (index) page can also be helpful.

Each day's notes should begin with the date, location of the area in which you are working (sufficient information for someone to return to the same area), potential safety issues for that day, the weather, and ideally some reference that will help you remember that particular day – such as an animal encounter, *etc.* (Figure 9). Also, it is a good idea to note the aims and objectives for that day. Localities of interest should then be assigned sequential numbers (*e.g.*, **001**, **002**, *etc.*, or **A-001** for traverse **A** – decide the most appropriate system for yourself), which should also be marked on your field map. You do ***not*** need to assign a number to every outcrop you encounter, only the ones of significance where, for example, lithology &/or structure changes or you note something of interest (*e.g.*, mineralization). UTM co-ordinates (as a waypoint) should also be recorded using your GPS.

Next, describe the general characteristics of the outcrop (size, location, *etc.*), the dominant lithologies and their structural characteristics. If warranted, sketch the outcrop in plan &/or section (Figure 10). Field sketches (which should be large enough to be easily comprehended by any reader) are invaluable, but should focus on representing the key geological features rather than being works of art. They should always have a **title, scale, orientation** and **key**. Also, it is a good idea to include a note as to why you are making the sketch. Always separate your observations (which will not change) and interpretations (which may change as you make more observations). For example, use a different colour for interpretation or draw a box around all interpretations. (It is also a good idea to separate what you are told from what you observe). At the end of a day, it is useful to summarise that day's observations.

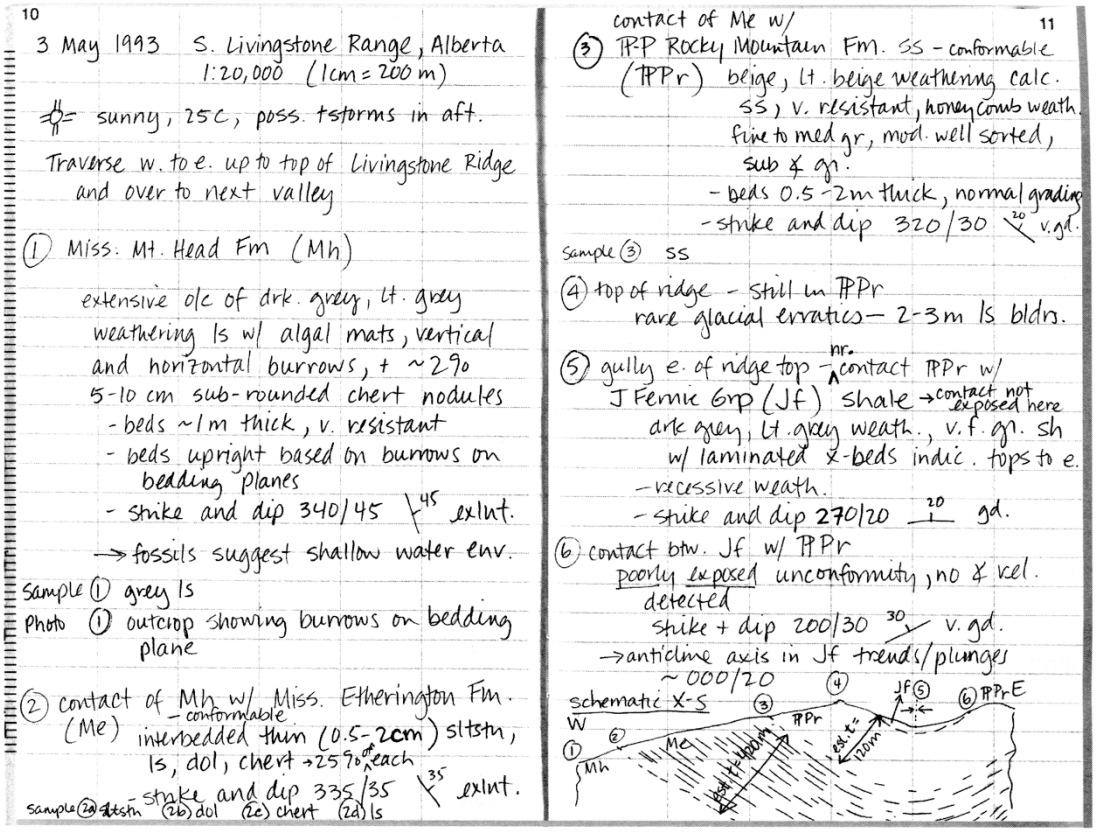


Figure 9 – An example of organized field notes (from Bevier, 2005)

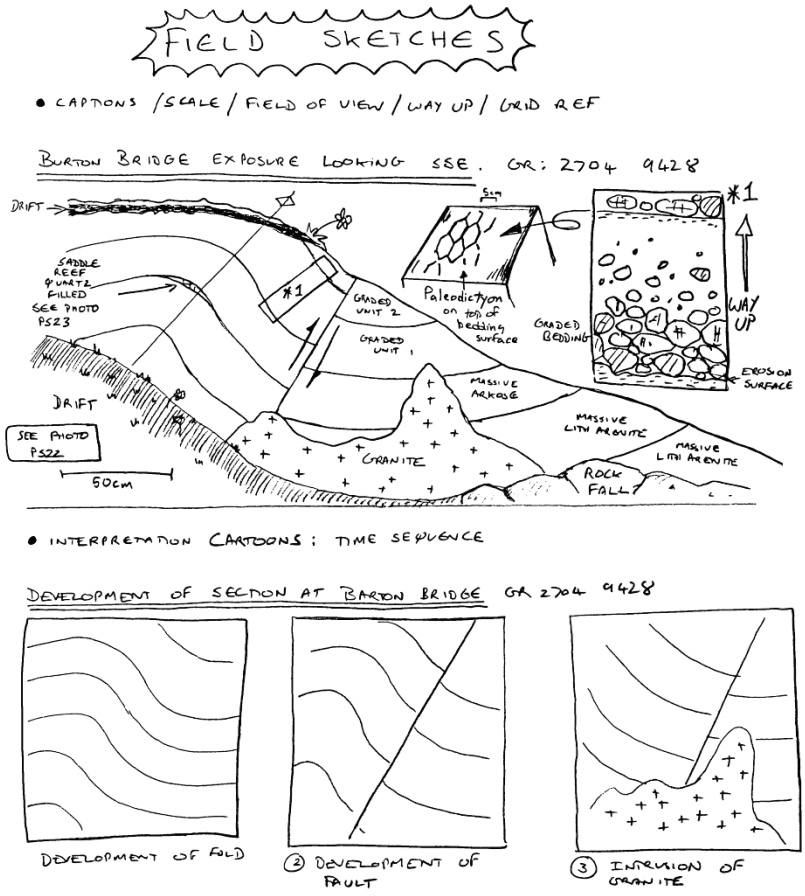


Figure 10 – An example of clear field sketches (from McClay, 1987)

Field Maps

Geological maps provide the basis for most geological studies and are made by careful field studies that determine the distribution of lithologies and structures. Without this knowledge, correct interpretation of other geological data (*e.g.*, petrology or geochemistry of samples) is impossible. Careful interpretation of such observations, and making predictions about what you will observe at the next outcrop, are all key parts of making a good geological map. You will be constantly modifying these interpretations as more ground is covered, so have your eraser close at hand.

Plot all outcrop localities (keyed to lithology) and appropriate structural data (bedding, cleavage, lineations, dyke orientations, *etc.*) right on your map <u>at the time they are taken</u> (Figure 11). Colour your map in as you work using harder shading where you observe a lithology (this will not change) and softer shading (of the same colour) where you interpret the lithology to be but do not observe it (Figure 12). The importance of plotting up your data at the time it is collected (*i.e.*, at <u>each</u> outcrop) cannot be over-emphasized, as this will allow you to make interpretations in the field, when they are most useful and easily verified. Where more than one orientation (such as bedding) is measured at a single location, plot only those that reflect prevalent attitude(s), so as not to clutter your map. Once a pattern emerges (for example a lithological contact exposed in two successive road-cuts), investigate the areas most prospective to finding extensions of that boundary and draw the boundary between lithologies as you go. Always consider the relationship between the attitude of the boundary and topography; for example, a horizontal contact will parallel a contour. <u>Never</u> put off the interpretation of your observations until after you get back from the field, as then you will be unable to verify them! ***Important observations should also be recorded directly onto your map.***

As with all maps, a key, north arrow, scale and title are essential.

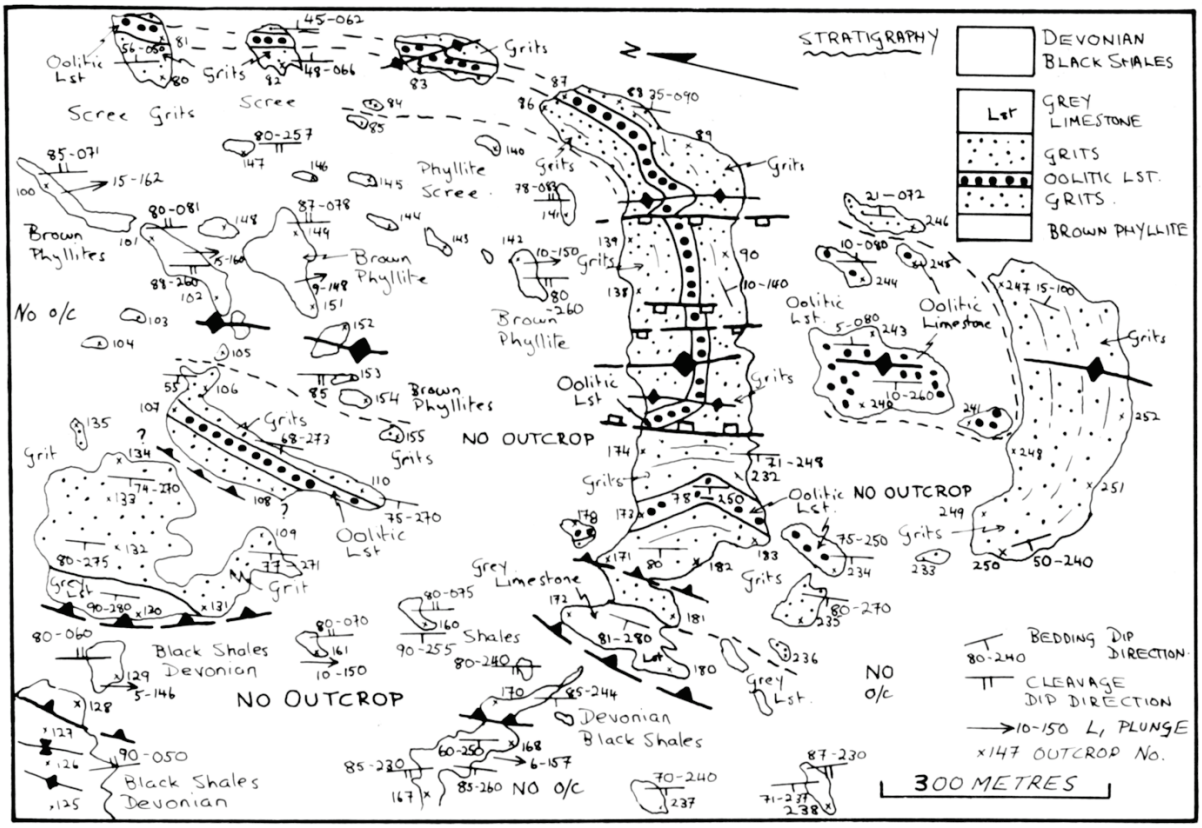


Figure 11 – An example of a field map (note: attitudes displayed here include the azimuth of the feature. Your symbols should be plotted at the appropriate azimuth and include only dip/plunge angles [see Figure 13]). (from McClay, 1987)

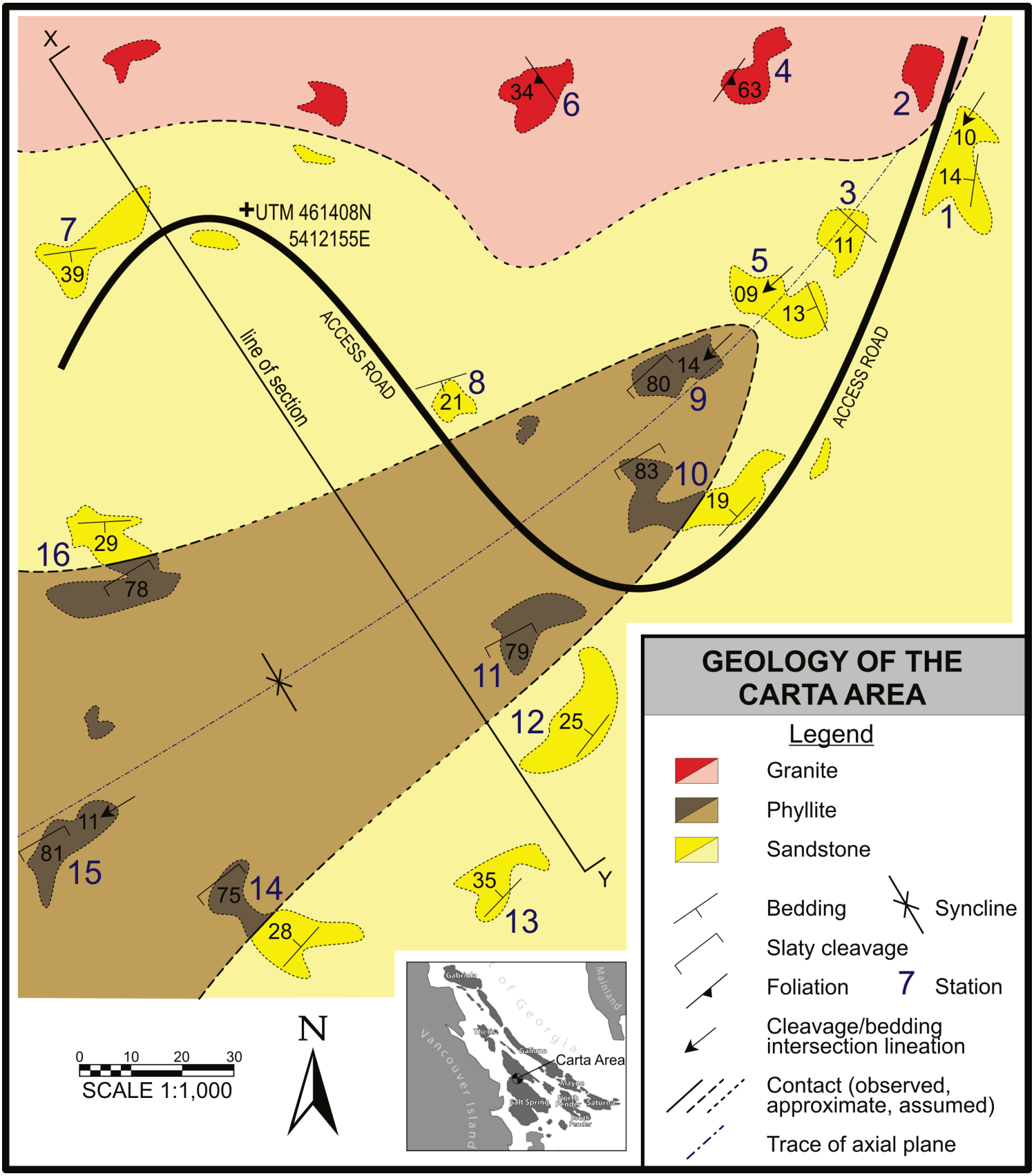


Figure 12 – Field Geology Map of the (fictitious) Carta Area.
Note: lithology descriptions for submitted field maps should provide far more details.

Compilation Maps

As you compile the data you collect in the field each day, a pattern related to the structure of the rock units exposed in the area (and the way they are expressed in the topography) should begin to emerge on your field map. It is this pattern that should form the basis of your final compilation map (Figure 13). This map should be a *summary* of your field investigations and thus will not include individual outcrops or stations. Instead, it will emphasize the major rock units and their overall structure. It should depict any lithological boundaries or structural breaks according to the certainty of their location (solid – observed, dashed – approximate, dotted – assumed). A certain amount of interpolation will be required in areas of poor exposure. Topographic controls such as roads and creeks should be included, but should appear subordinate to the geological features. Be careful not to omit important information (*e.g.*, attitudes, especially where they are representative) from your compilation map simply for the sake of brevity.

A geological map should be a visual representation of the geology and so, as you compile it, think about how to make it easy for someone looking at the map to rapidly understand the geology of the area. For example, if there are many parallel dikes in an area, even if they are too small and abundant to show to scale on the map, show representative ones in the true orientation on your map so the reader can see that they exist.

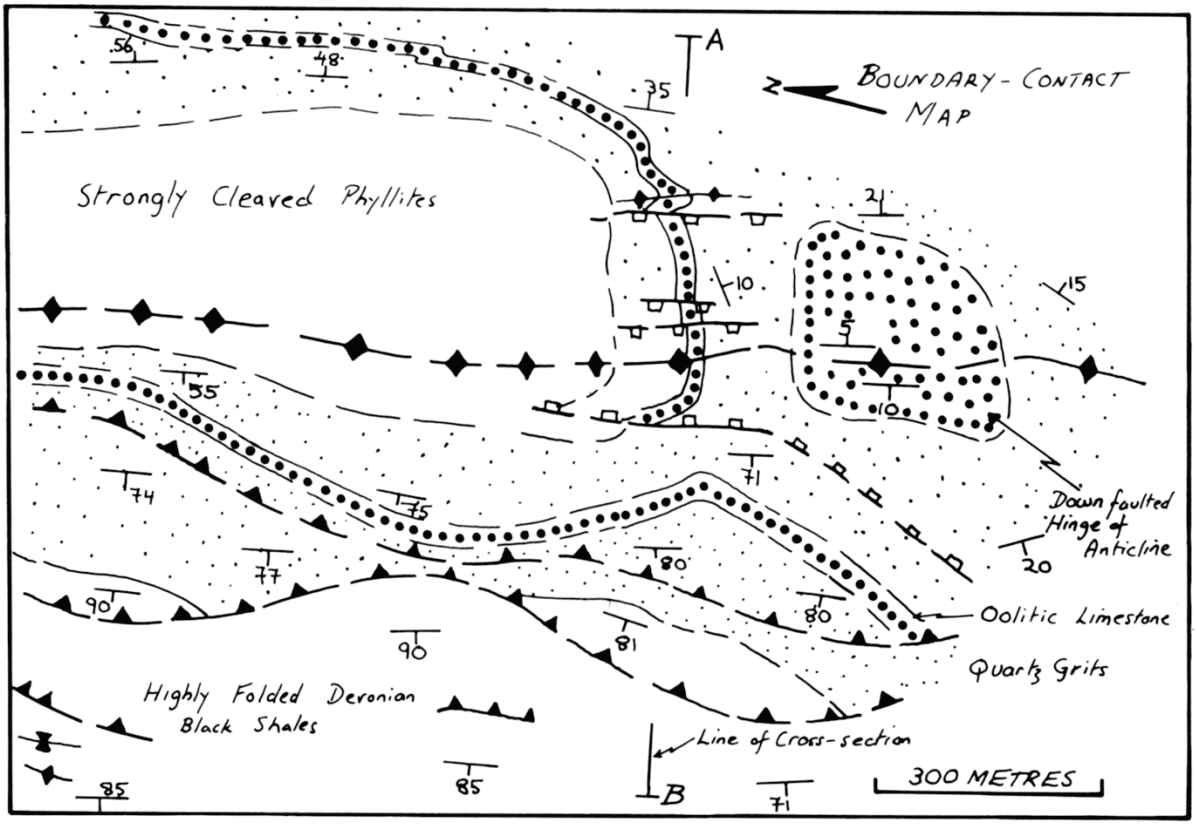


Figure 13 – Compilation map showing stratigraphic contacts and structural features. (from McClay, 1987)

Compare the level of detail of this map to the field map in Fig. 11.

Before submitting your work, make sure your map contains the following essential cartographic elements:

- **Title:** should include a geographic name for the area (*e.g.*, Geology of Mt. Tuam, Saltspring Island, BC)
- **Scale:** ***both*** numerical and graphical, in metric units.
- **North arrow:** showing magnetic, true north and grid (UTM) north (if used). Declination (as of the map date) and the degree to which it is changing should also be indicated.
- **Co-ordinate reference:** labelled lines of latitude & longitude ***or*** a UTM grid should accompany your map.
- **Legend:** should be organized and include the following items:
  - **Stratigraphic column -** this should consist of small rectangular boxes containing the symbols or colours used on the map to identify the various rock units and be arranged from youngest at the top to oldest at the bottom. If colours are used, they should be applied lightly and uniformly, so as ***not*** to impart a fabric. If symbols are used, make sure they do not make the map hard to read or obscure other geological symbols. Accepted lithological conventions appear in Appendix B. The name of the unit and a brief description of its lithology should appear adjacent to its respective box.
  - **Key to symbol usage -** symbols, including structural, lithological and geographical, should be identified (see Appendix B)
- **Index Map:** included to key large-scale maps to regional, more recognizable geographical features (*i.e.*, Vancouver Island or British Columbia).
- **Author's name(s) and date of compilation.**

Cross sections

Cross sections (Figure 14) are an essential part of structural analysis and should be drawn to complement your plan-view representation of geology. The scale (always horizontal = vertical) and direction of any section must be indicated and its orientation should be approximately perpendicular to the structural grain of the area (*i.e.*, normal to the strike of bedding or fold axes). Corrections for apparent dips (always < true dip) and thicknesses (always > true thickness) may be required in cases where attitudes are more than 10° 'off-section' (Figure 15). Your interpretations should project above the current erosional surface (as dashed lines), to give a better sense of overall structure. Make sure that your cross section(s) clearly show the reader the relationships between all lithologies depicted (*e.g.*, conformable/unconformable, gradational, fault, intrusive, *etc*.).

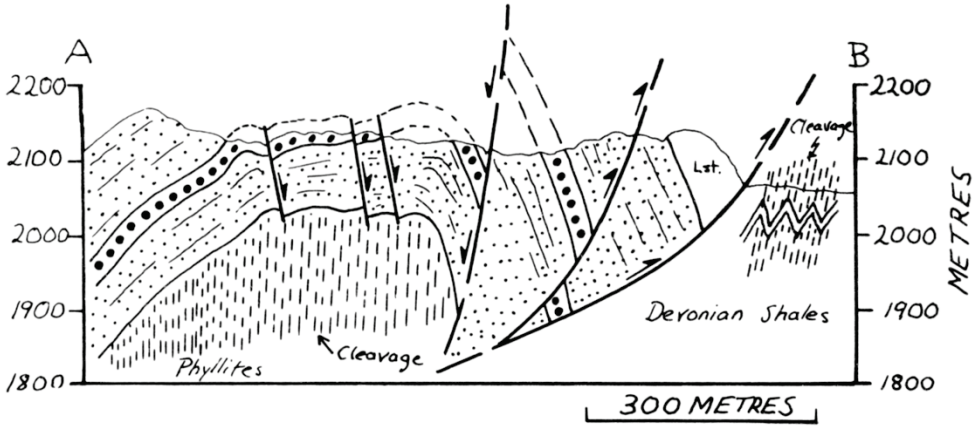


Figure 14 – Cross section along A-B (looking south). See Figure 11 for key. (from McClay, 1987)

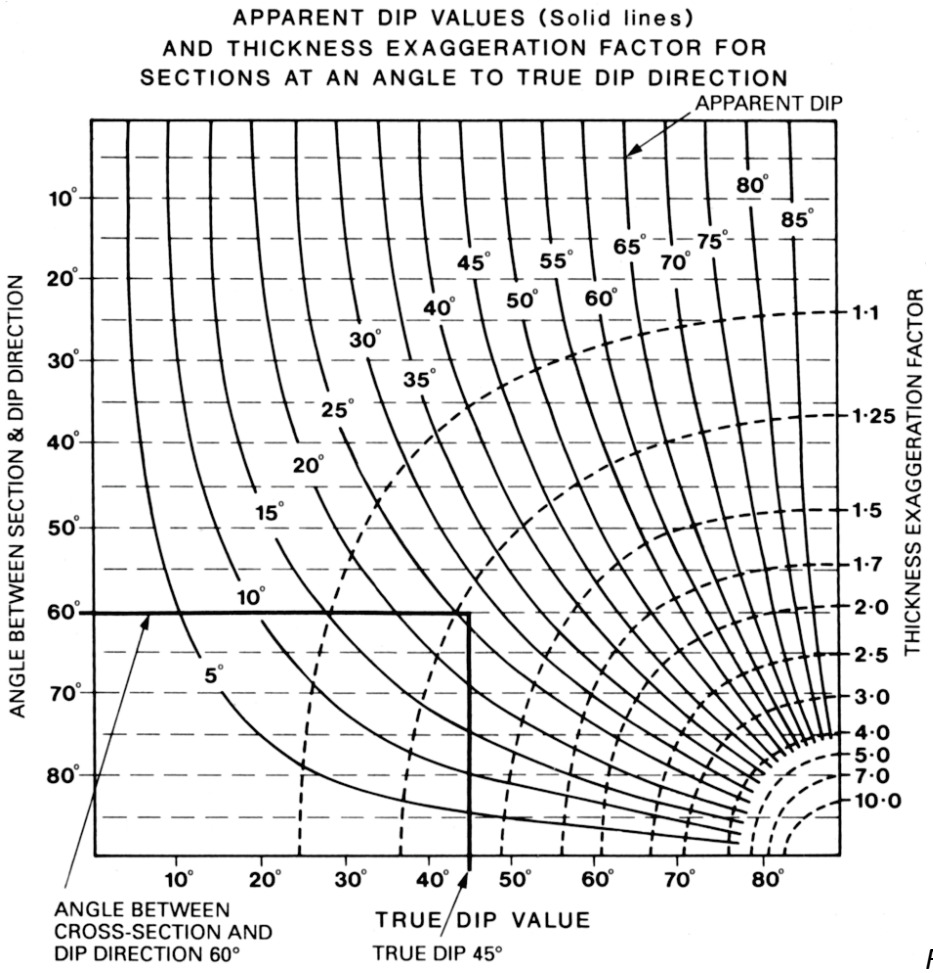


Figure 15

***Sketch* cross sections** made from a remote vantage point (*e.g.*, from across a valley) can also help you to interpret/understand the overall structure of the area (Figure 16).

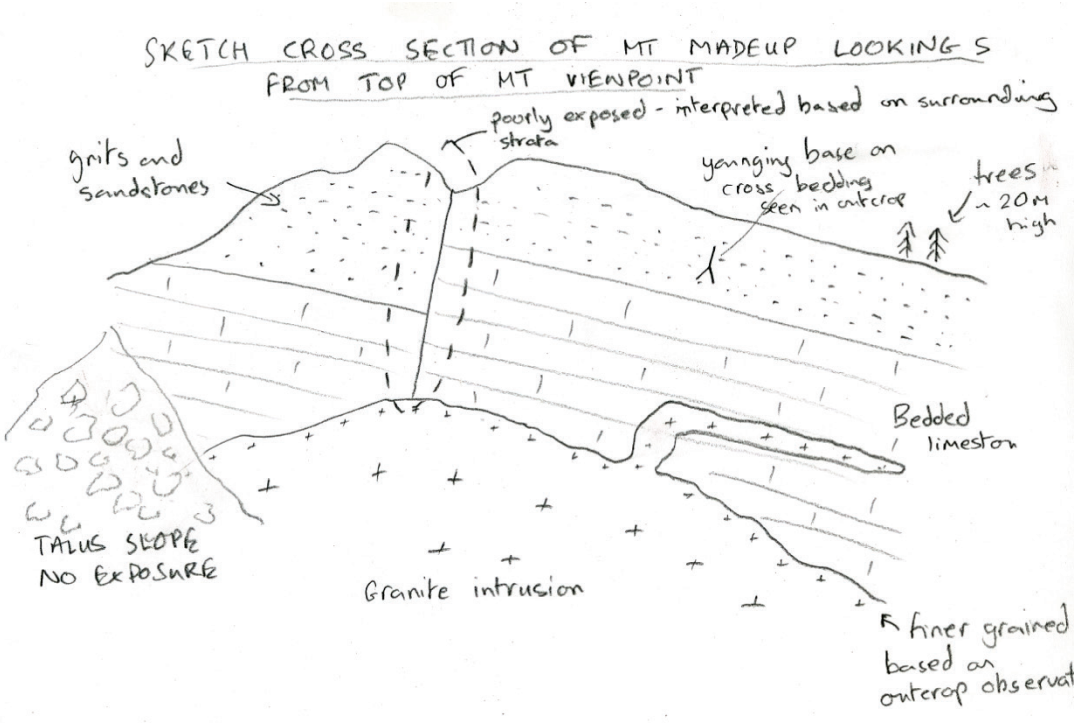


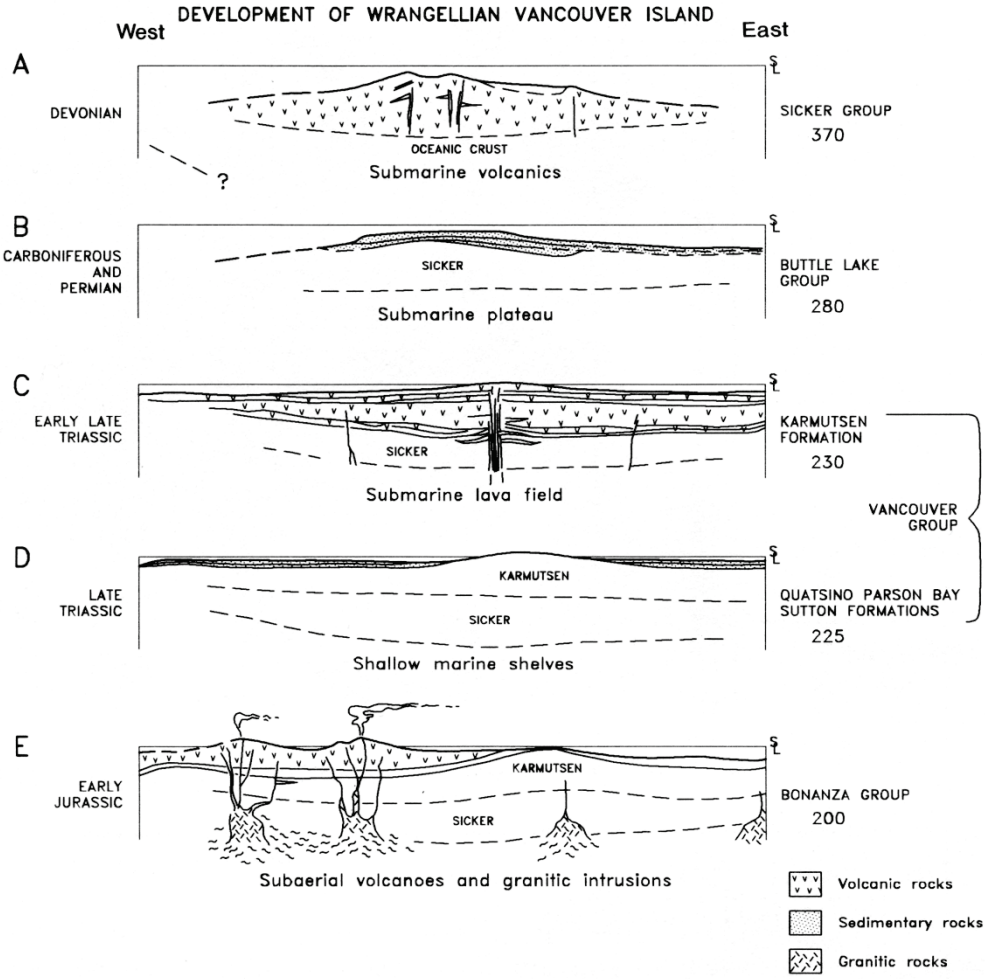
Figure 16 – An example of a sketch cross section

A Brief Geological History of Vancouver Island

Much of British Columbia and the Yukon are thought to have originated as the result of the collision of exotic pieces of the Earth's crust, known as terranes, with the western edge of North America over the past 170 million years (since mid-Jurassic time). With the exception of its extreme southern tip, Vancouver Island (together with the Queen Charlottes and parts of southeastern Alaska) forms part of the ***Wrangellia Terrane***, which accreted to cratonic North America during the mid-Cretaceous, approximately 100 million years ago (Ma). This event, together with subsequent collisions of the ***Pacific Rim*** and ***Crescent*** terranes in the Eocene, are thought to be responsible for much of overall geological character of Vancouver Island.

The island itself has not always existed in the shape and form it has today. Rather, its oldest rocks originated during the Devonian, far removed from their present-day location, as part of a chain of volcanic islands overlying a subduction zone similar to the present-day Aleutians. These chains, known as island arcs, spewed out dense clouds of hot gas and volcanic ash and lavas over a period of approximately 20 million years, resulting in the accumulation of lavas, tuffs and volcaniclastic sediments on the deep ocean floor. These rocks are now assigned to the Paleozoic ***Sicker Group***, and host coeval granodiorite stocks and quartz porphyry dikes collectively known as the ***Saltspring Intrusive Suite***.

By the early Carboniferous (and through the Permian), the arc had been eroded and subsided into a broad smooth submarine plateau supporting abundant colonies of marine invertebrates, including crinoids and brachiopods. The skeletal remains and shells contributed by these animals accumulated in some areas to form limestones and in other areas / at other times clastic sediments were deposited. These sedimentary units make up the ***Buttle Lake Group***.

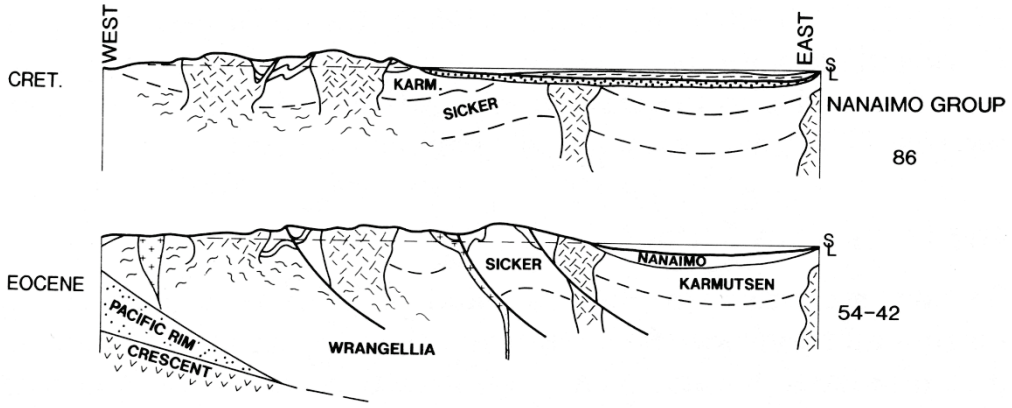


The development of Wrangellian Vancouver Island. Sections from present Barkley Sound on the west to Parksville on the east. (from: Yorath, 1995)

During the Late Triassic basaltic magma, thought to be derived from melting in an upwelling mantle plume, extruded in many thick flows across the remanent volcanic arc. These lavas accumulated over a few million years to form a ~6 km thick unit referred to as the ***Karmutsen Formation***; coeval mafic intrusions are known informally as the ***Mount Hall gabbro***. The underlying mantle eventually cooled and the crust subsided below sea-level. This allowed for the subsequent establishment of aquatic colonies, whose shells and reef-structures were converted to limestone now assigned to the ***Quatsino Formation***. Mixed volcaniclastic-carbonate sediments now assigned to the ***Parson Bay Formation*** were subsequently deposited atop these rocks, which collectively have been assigned to the ***Vancouver Group***.

Arc volcanism returned to Wrangellia in the Jurassic, when both mafic and felsic volcanics were erupted subaerially and their parent magma emplaced at depth. The volcanic rocks form the ***Bonanza Group***, while the relatively shallow plutonic rocks belong to the coeval ***Island Plutonic Suite*** that, through subsequent erosion and uplift, have now been exposed at the surface. Deep in the crust, these magmas metamorphosed and partially melted the already hot country rocks (thought to be Sicker Group). The mixed lithologies of intrusions, migmatites and metamorphosed rocks are collectively termed the ***Westcoast Crystalline Complex*** (formerly known as the ***Wark-Colquitz Gneiss***), which underlie much of Victoria (*e.g.*, Mt. Douglas).

In the middle Cretaceous, the part of Wrangellia that would ultimately become Vancouver Island collided with North America, an event that compressed and buckled the rocks, perhaps resulting in the formation of two areas of uplift known as the ***Cowichan*** and ***Buttle Lake anticlinoriums***. Subsequent erosion of the uplifted rocks resulted in the accumulation of sediments in a broad basin formed between Wrangellia and western North America, in the present-day Strait of Georgia region. These sediments, which now incorporate coal formed in the low swampy regions adjacent to the basin, belong to the ***Nanaimo Group*** which underlies much of the Island's eastern coastal plain, south of Campbell River, as well as the Gulf Islands and the western-most part of the lower mainland (*e.g.*, Stanley Park).



As a consequence of the accretion of Wrangellia to North America, the core of Vancouver Island was uplifted. During the Eocene, the Pacific Rim and Crescent terranes were added to the Island. Forces resulting from these collisions caused further uplift and faulting. (from Yorath, 1995)

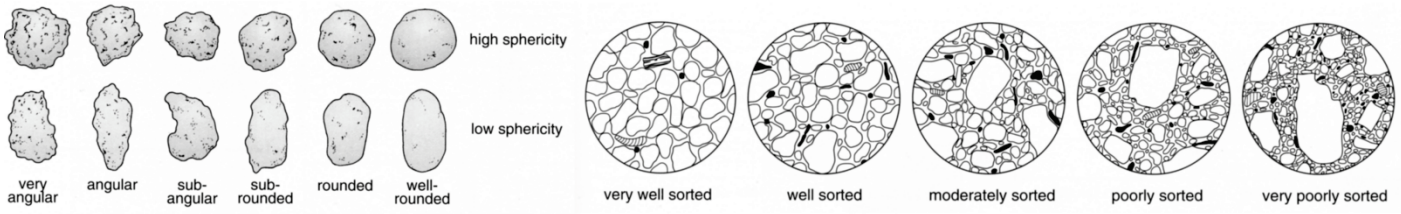
During the Tertiary, some small intrusions were emplaced (*e.g.*, on Flores island) and two small terranes were accreted to the southern end of Vancouver island. Approximately 55 Ma, continental slope sediments belonging to the ***Pacific Rim*** and ***Leech River complexes***, which together form the ***Pacific Rim Terrane***, accreted to Wrangellia from the southeast along the ***Westcoast*** and ***San Juan-Survey Mountain fault systems***. Then, around 42 Ma, a piece of oceanic crust was emplaced beneath the Pacific Rim Terrane along the ***Leech River Fault***. Called the ***Metchosin Igneous Complex*** on Vancouver Island, these rocks form part of a larger province of ophiolites known as the ***Crescent Terrane***, which stretch south through Washington and into Oregon. These accretionary events resulted in the folding and faulting of the Nanaimo Group sediments and the eventual exposure of Westcoast Crystalline Complex rocks.

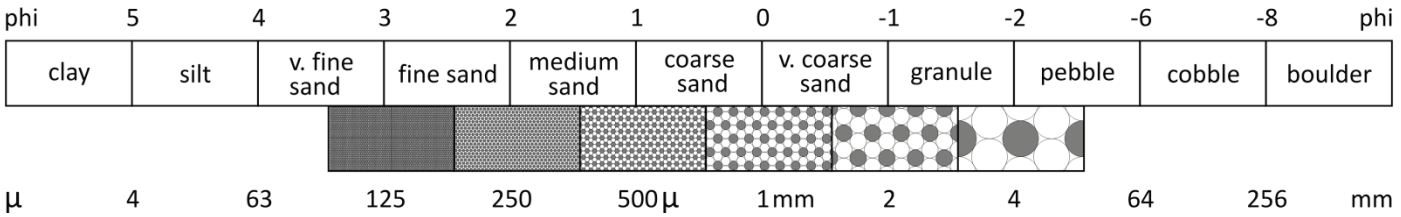
The youngest rocks exposed on Vancouver Island are the Oligocene-aged ***Sooke Formation*** of the ***Carmanah Group***, which comprises shallow marine sediments deposited, for the most part, off the coast south & west of the Island.

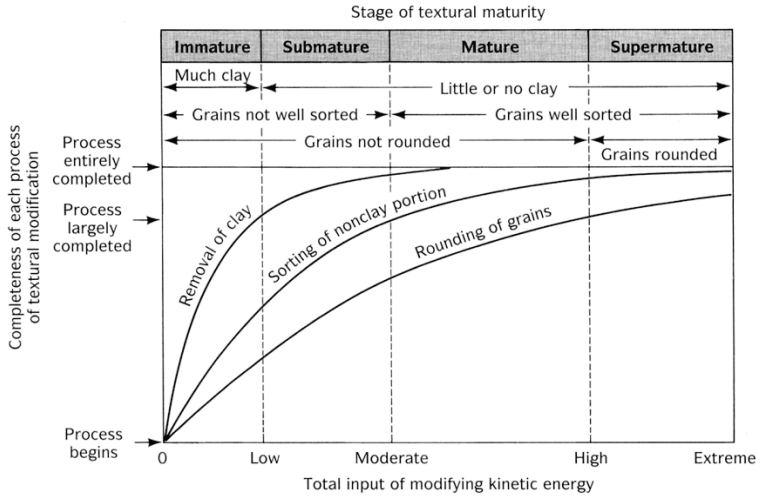
Appendix A

Siliciclastic Rock Classification

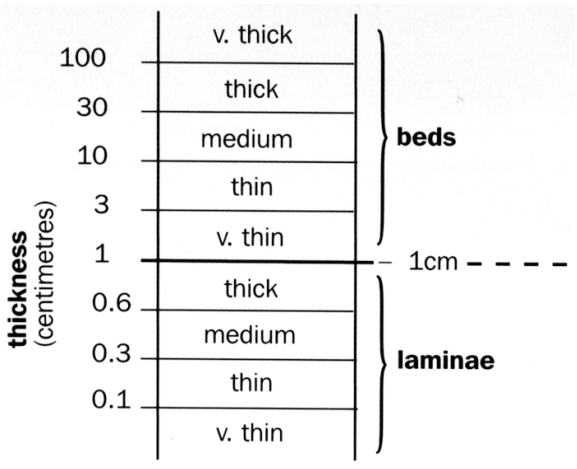
UDDEN-WENTWORTH SIZE SCALE		
PARTICLE NAME	DIAMETER (mm)	ROCK NAME
Boulder	>256	Conglomerate
Cobble	64 – 256	
Pebble	4 – 64	
Granule	2 – 4	
Coarse sand	0.5 – 2	Sandstone
Medium sand	0.25 – 0.5	
Fine sand	$^1/_{16}$ – 0.25	
Silt	$^1/_{256}$ – $^1/_{16}$	Siltstone
Clay	< $^1/_{256}$	Claystone





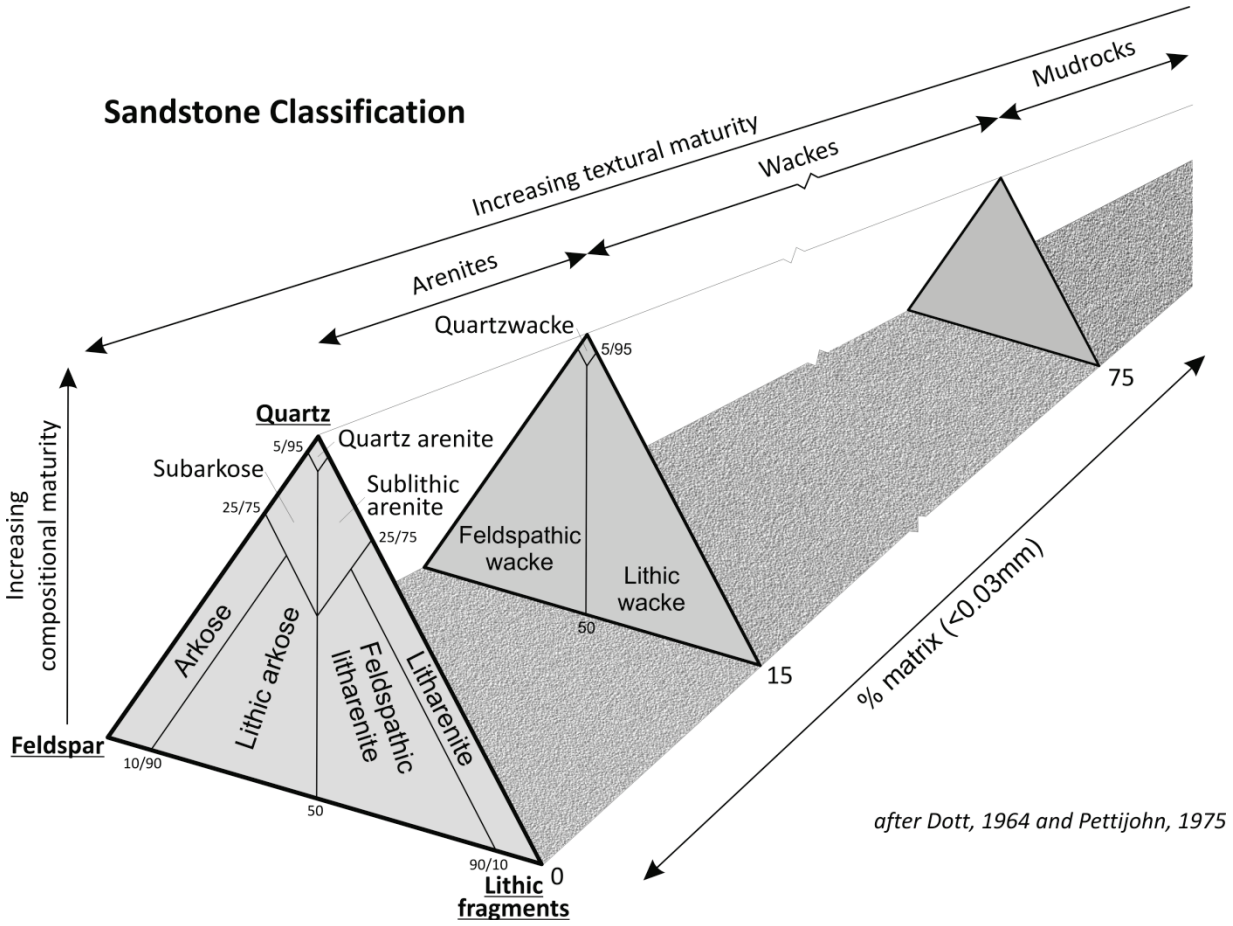


Sandstone Maturity



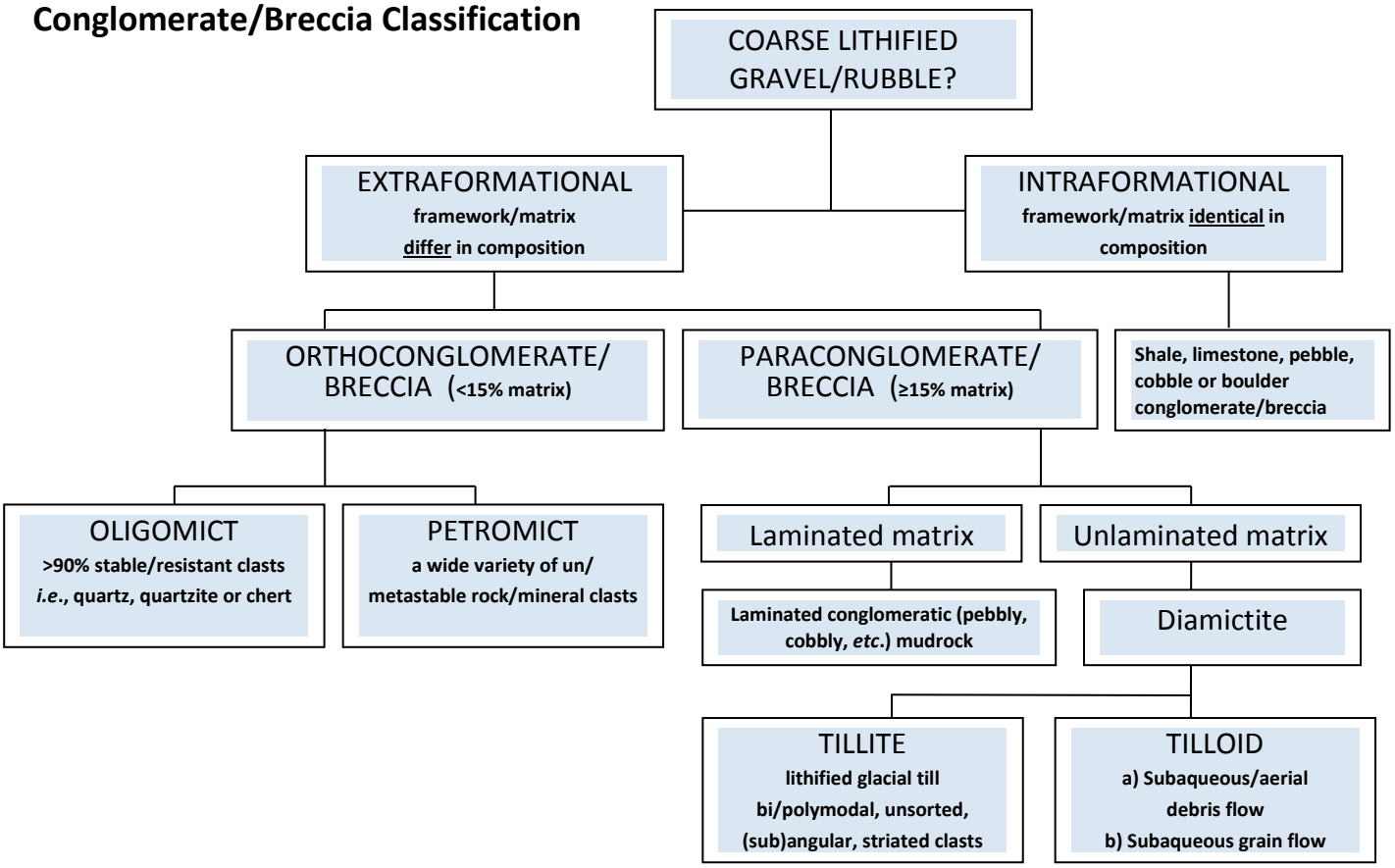
Layer Terminology

Sandstone Classification



after Dott, 1964 and Pettijohn, 1975

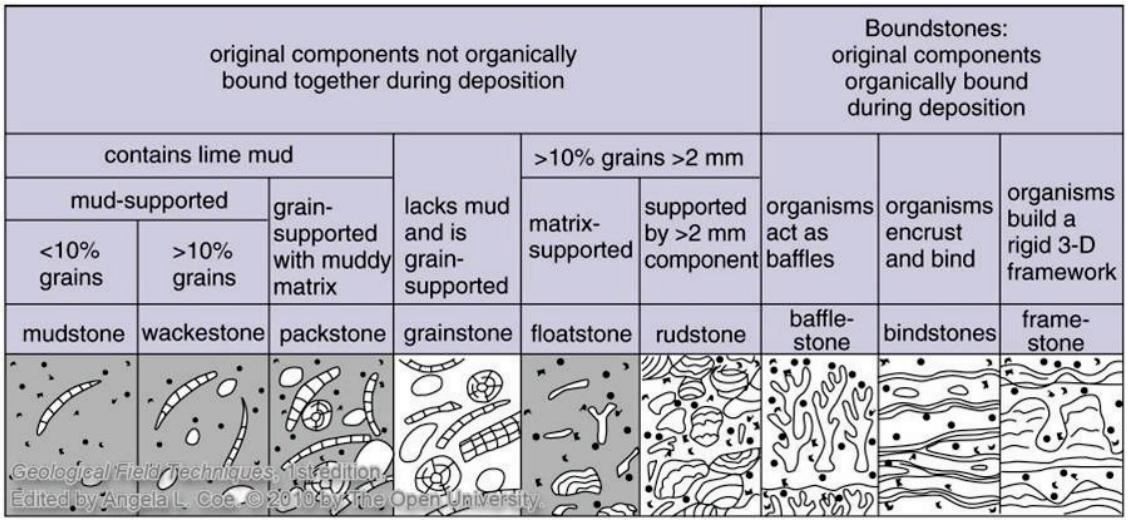
Conglomerate/Breccia Classification



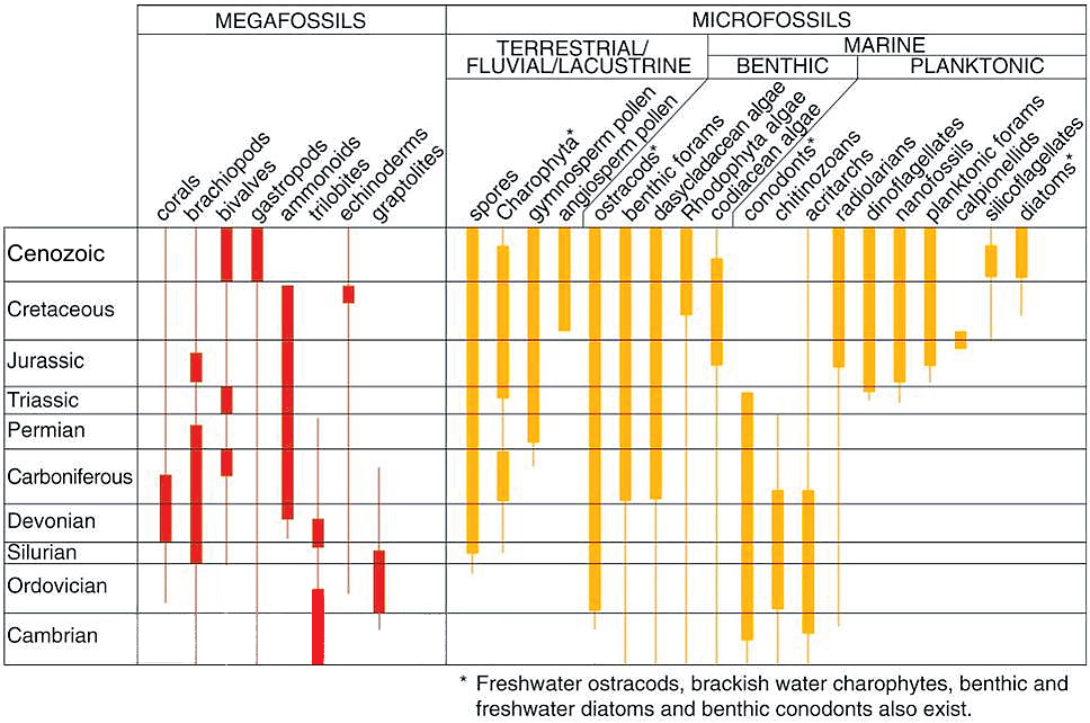
TEPHRA NAME	CLASS SIZE RANGE	SILICICLASTIC EQUIVALENT	PYROCLASTIC ROCK
Blocks (angular)	>64 mm	Cobbles & boulders	Volcanic breccia
Bombs (rounded)			Agglomerate
Lapilli	2 – 64 mm	Granules & pebbles	Lapilli stone
Coarse ash	$^{1}/_{16}$ – 1 mm	Sand	Coarse tuff
Fine ash	$<^{1}/_{16}$ mm	Silt & clay	Fine tuff

Pyroclastic Rock Terminology

Carbonate Rock Classification

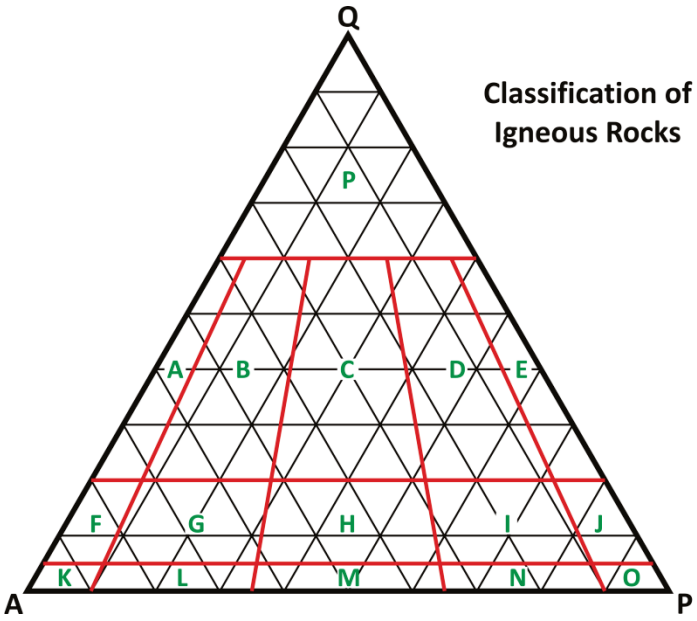


Field classification scheme for limestone (after Dunham, 1962)



Biostratigraphically important organisms. Thick part of the line indicates interval of greatest diversity. (after Nichols, 1999 and Emery & Myers, 1996)

Igneous Rock Classification



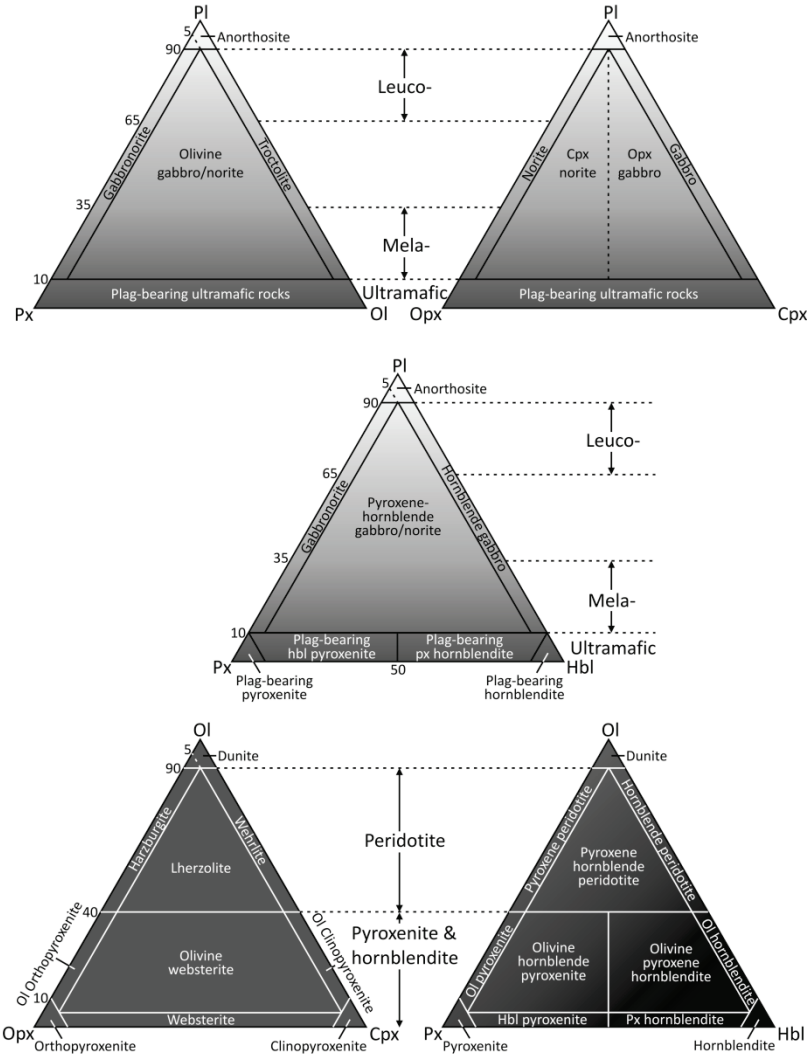
Classification of Igneous Rocks

	Plutonic	Volcanic
A	Alkali feldspar granite	Alkali feldspar rhyolite
B	Syeno-Granite	Rhyolite
C	Monzo-Granite	Rhyodacite
D	Granodiorite	Dacite
E	Tonalite	Quartz andesite
F	Quartz alkali feldspar granite	Quartz alkali feldspar trachyte
G	Quartz syenite	Quartz trachyte
H	Quartz monzonite	Quartz latite
I	Quartz monzodiorite[1]	Quartz latite andesite
	Quartz monzogabbro[2]	
J	Quartz diorite[1, 4]	Andesite
	Quartz gabbro[2, 4]	
	Quartz anothosite[3]	
K	Alkali feldspar syenite	Alkali feldspar trachyte
L	Syenite	Trachyte
M	Monzonite	Latite
N	Monzodiorite[1]	Latite basalt
	Monzogabbro[2]	
O	Diorite[1, 4]	Basalt
	Gabbro[2, 4]	
	Anorthosite[3]	
P	Quartz-rich granite	Quartzolite

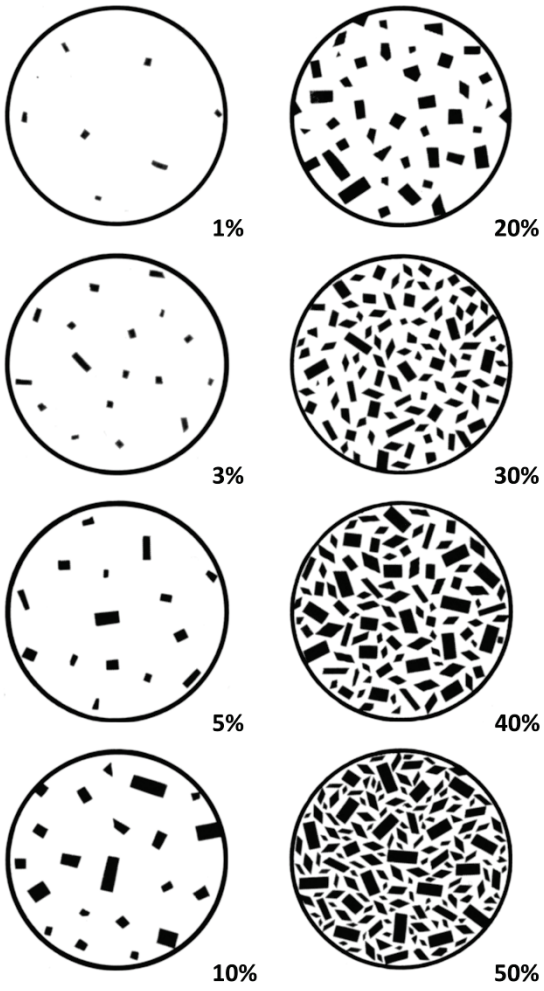
[1] plagioclase: An_{0-50} hornblende chief mafic
[2] plagioclase: An_{50-100} pyroxene chief mafic
[3] mafics <10%
[4] mafics >10%

IUGS Classification of Gabbroic and Ultramafic Rocks

(shading represents approximate colour index)



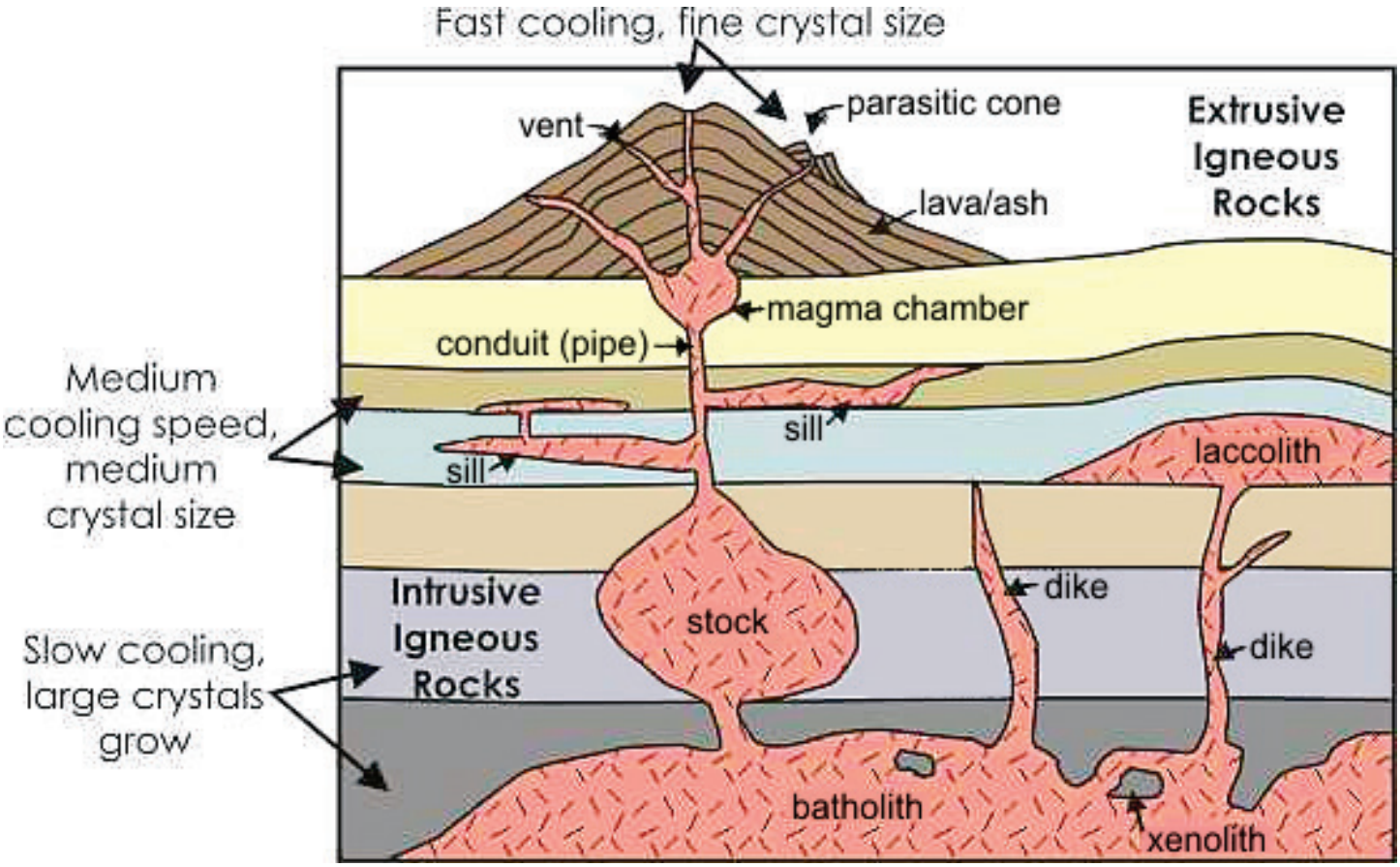
(after Winter, 2010)



Estimate Percentage Composition

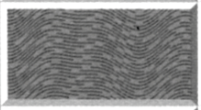
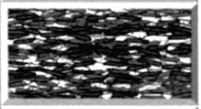
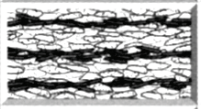
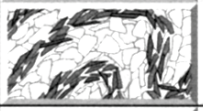
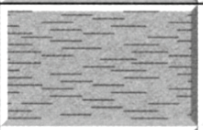
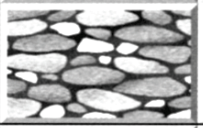
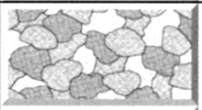
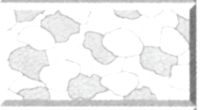
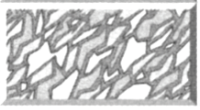
(after Philpotts, 1989)

Grain size in igneous rocks is closely allied to the degree of crystallinity (proportion of crystals vs. glass) and is a function of cooling rate. A rock whose constituent grains are too fine to be discerned with the naked eye is termed **aphanitic**. All coarser grained rocks are referred to as **phaneritic**. As a rough guide, an average grain size of ≤1 mm is termed fine-grained, 1-5 mm is termed medium-grained, 5-50 mm is termed coarse-grained and ≥50 mm is termed very coarse-grained. The term **pegmatitic** is applied to very coarse-grained igneous rocks resulting from late-stage crystallization of granitic magmas.



Common Igneous structures

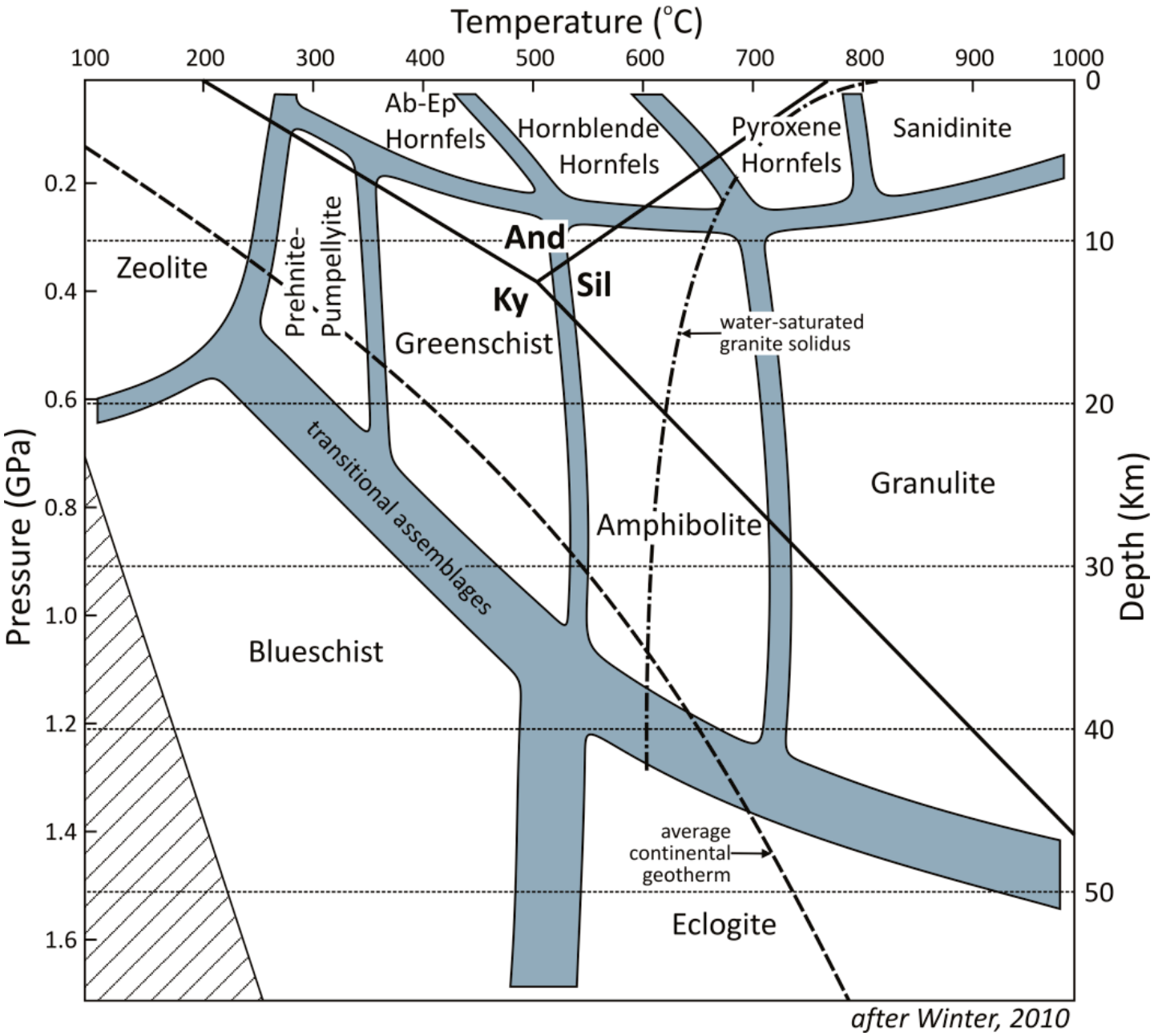
Metamorphic Rock Classification

Rock Name	Texture		Grain Size	Comments	Parent Rock
Slate	Foliated (Increasing Metamorphism)		Very fine	Excellent rock cleavage, smooth dull surfaces	Shale, mudstone, or siltstone
Phyllite			Fine	Breaks along wavey surfaces, glossy sheen	Slate
Schist			Medium to Coarse	Micaceous minerals dominate, scaly foliation	Phyllite
Gneiss			Medium to Coarse	Compositional banding due to segregation of minerals	Schist, granite, or volcanic rocks
Migmatite			Medium to Coarse	Banded rock with zones of light-colored crystalline minerals	Gneiss
Mylonite	Weakly Foliated		Fine	When very fine-grained, resembles chert, often breaks into slabs	Any rock type
Metaconglomerate			Coarse-grained	Stretched pebbles with preferred orientation	Quartz-rich conglomerate
Marble	Nonfoliated		Medium to coarse	Interlocking calcite or dolomite grains	Limestone, dolostone
Quartzite			Medium to coarse	Fused quartz grains, massive, very hard	Quartz sandstone
Hornfels			Fine	Usually, dark massive rock with dull luster	Any rock type
Anthracite			Fine	Shiny black rock that may exhibit conchoidal fracture	Bituminous coal
Fault breccia			Medium to very coarse	Broken fragments in a haphazard arrangement	Any rock type

Classification of common metamorphic rocks
(from Foundations of Earth Science, Lutgens et al., 2005)

Temperature-Pressure Diagram

showing associated metamorphic facies



Metamorphic facies and corresponding temperature and pressure conditions

	Pelite	Calcareous	Mafic	Ultramafic
Zeolite	illite/phengite + chlorite +quartz	calcite and/ or dolomite	Ca-zeolite + chlorite + albite + quartz	lizardite/ chrysotile + brucite + magnetite
+/-	kaolinite, paragonite	quartz	prehnite, analcime, pumpellyite	chlorite, carbonate
Prehnite-pumpellyite	phengite + chlorite + quartz	calcite and/ or dolomite	prehnite + pumpellyite + chlorite + albite + quartz	lizardite/ chrysotile + brucite + magnetite
+/-	pyrophyllite, paragonite, K-feldspar, stilpnomelane, lawsonite	quartz	actinolite, stilp-nomelane, lawsonite	antigorite, chlorite, carbonate, talc, diopside
Greenschist	muscovite + chlorite + quartz	calcite and/ or dolomite	chlorite + epidote + albite	antigorite + diopside + magnetite
+/-	biotite, K-feldspar, chloritoid, para-gonite, albite, Mn-rich garnet	quartz, talc, actinolite	actinolite, biotite	chlorite, brucite, olivine, talc, carbonate
Amphibolite	muscovite + biotite + quartz	calcite and/ or dolomite	plagioclase + hornblende	olivine + tremolite
+/-	garnet, staurolite, kyanite, sillimanite, andalusite, cor-dierite, chlorite, plagioclase, K-feldspar	quartz, tremolite, diopside, forsterite, phlogopite, epidote, grossular, scapolite, vesuvianite	epidote, garnet, orthoamphi-bole, cumming-tonite	antigorite, talc, antho-phylite, cum-mingtonite, enstatite
Granulite	K-feldspar + plagioclase + sillimanite + quartz	calcite and/ or dolomite	orthopyrox-ene + plagio-clase	olivine + diopside + enstatite
+/-	biotite, garnet, kyanite, cordierite, orthopyr oxene, spinel, corundum, sappharine	diopside, forsterite, wollastonite, scapolite, spinel monticellite, periclase, grossular	clinopy-roxene, hornblende, garnet	spinel, plagioclase
Blueschist	phengite + chlorite + quartz	calcite and/ or dolomite	glaucophane/ crossite + lawsonite/ epidote	antigorite + olivine + magnetite
+/-	albite, jadeite, lawsonite, garnet, chloritoid, paragonite	quartz, aragonite, phengite	pumpellyite, chlorite, garnet, albite, aragonite, phengite, paragonite, chloritoid	chlorite, brucite, talc, diopside
Eclogite	phengite + gar-net +quartz	calcite and/ or dolomite	omphacite + garnet + rutile	olivine

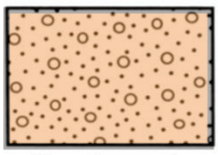
Metamorphic Facies Table
(from The Geoscience Handbook, AGI Data Sheets, 2006)

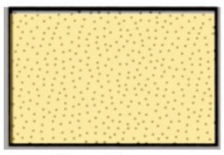
Appendix B

Lithological Symbols

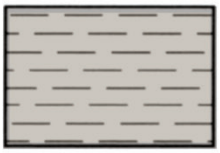
Sedimentary Lithologies

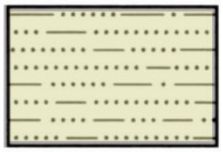

Breccia

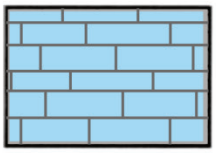

Conglomerate

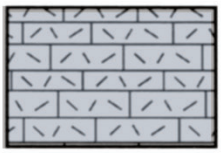

Sandstone

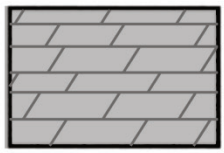

Siltstone


Shale

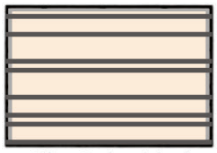

Greywacke

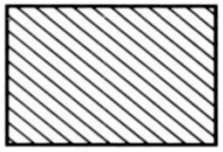

Limestone

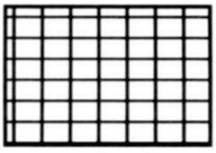

Clastic Limestone


Dolomite

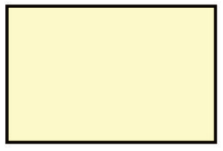

Chalk


Chert, bedded

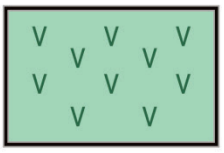

Gypsum

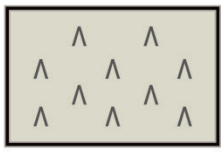

Rock Salt

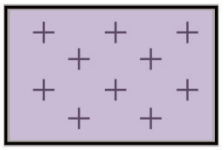

Coal beds

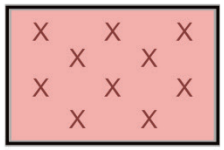

Colluvium

Igneous Lithologies

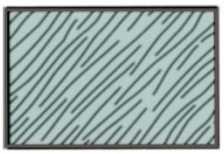

Mafic Volcanic

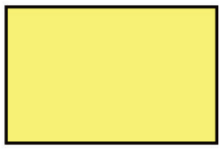

Felsic Volcanic


Mafic Plutonic


Felsic Plutonic

Metamorphic Lithologies


Schist


Quartzite


Gneiss

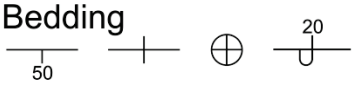

Slate/Phyllite

Note: it is <u>not</u> necessary to use both colour and stippling to identify lithologies.

Structural Symbols

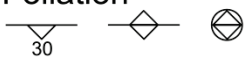
(modified after U.S. Geological Survey Digital Cartographic Standard for Geologic Map Symbolization)

Bedding



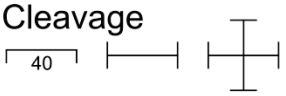
inclined (showing dip), vertical, horizontal, overturned

Foliation



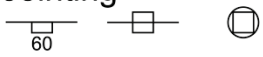
inclined (showing dip), vertical, horizontal

Cleavage



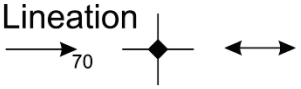
inclined (showing dip), vertical, horizontal

Jointing



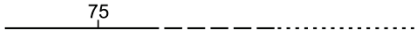
inclined (showing dip), vertical, horizontal

Lineation



inclined (showing plunge), vertical, horizontal

Lithological contact



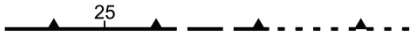
observed, approximate, assumed; showing dip

Unconformable contact



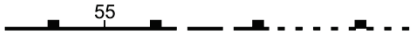
observed, approximate, assumed, showing dip

Thrust fault



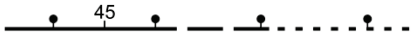
showing dip; teeth on up-thrown block

Reverse fault



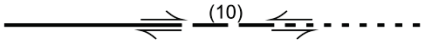
showing dip; rectangles on up-thrown block

Normal fault



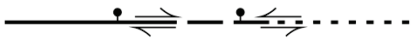
showing dip; ball/stick on down-dropped block

Strike-slip fault



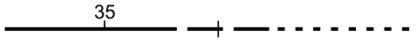
dextral, sinistral; offset in metres

Oblique-slip fault



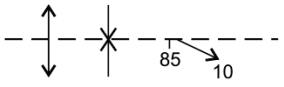
dextral, sinistral; ball/stick on down-dropped block

Inclined fault

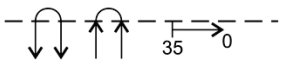


sense of motion unknown; showing dip, vertical

Fold geometry



trace (approximate) of axial surface (anticline, syncline) showing dip, plunge/trend of fold axis



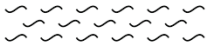
trace (approximate) of axial surface (o/t anticline, o/t syncline) showing dip, plunge/trend of fold axis

Dike, sill



showing dip, width (m); colour indicative of lithology

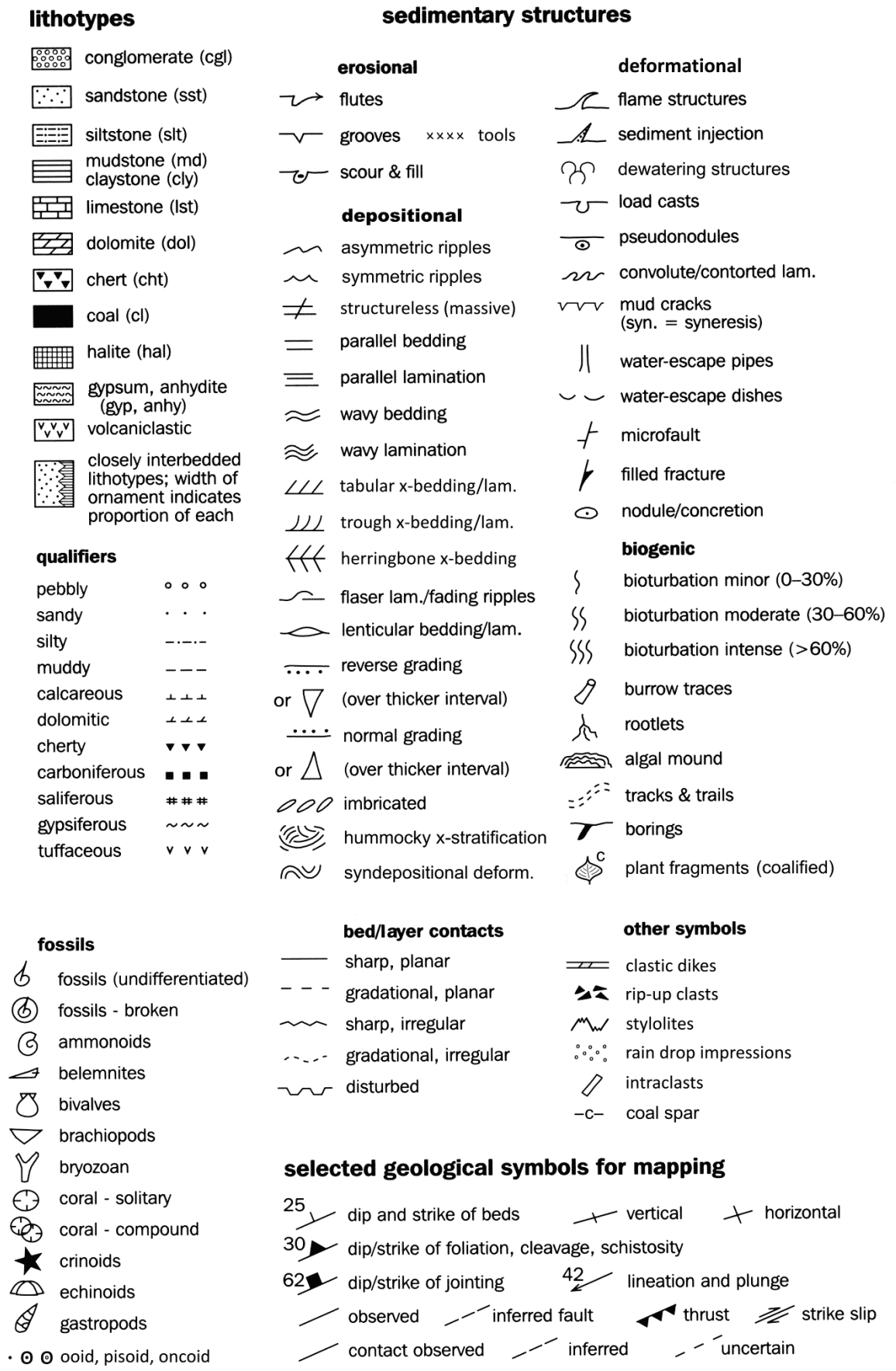
Ductile shear zone



Breccia zone



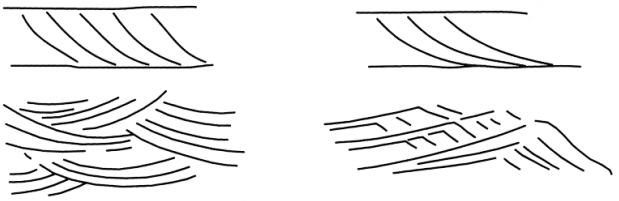
Graphic Log Symbols



Appendix C

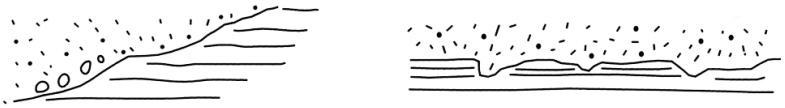
Sedimentary Geopetal (Way Up) Indicators

cross-stratification (all scales: cross bedding, cross lamination, etc)

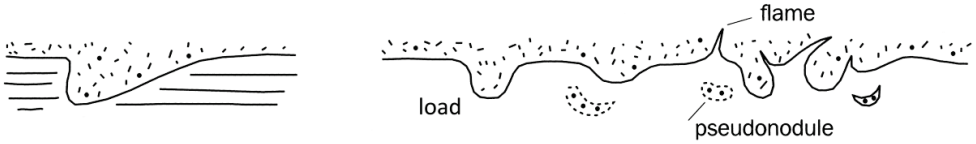


truncated tops, curved bases

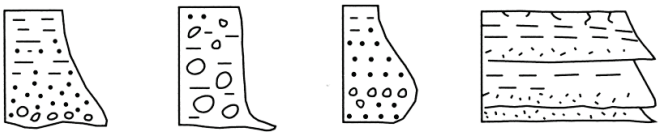
erosional structures (all scales: channel scours, micro scours, etc)



sole marks (grooves, tools, flutes) and other **secondary structures** (loads, flames)



grading (graded beds/laminae) and structural sequences (Bouma, Stow, etc)



normal grading common but
reverse / symmetrical grading also occurs

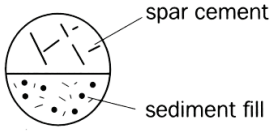
surface marks (ripples, desiccation cracks, rain drops, lineation, footprints, etc)



water-escape structures (dishes, burst-throughs, sand volcanoes)



geopetals



grazing trails (bed surface)



fossils in growth position eg.stromatolite



volcanic pillows

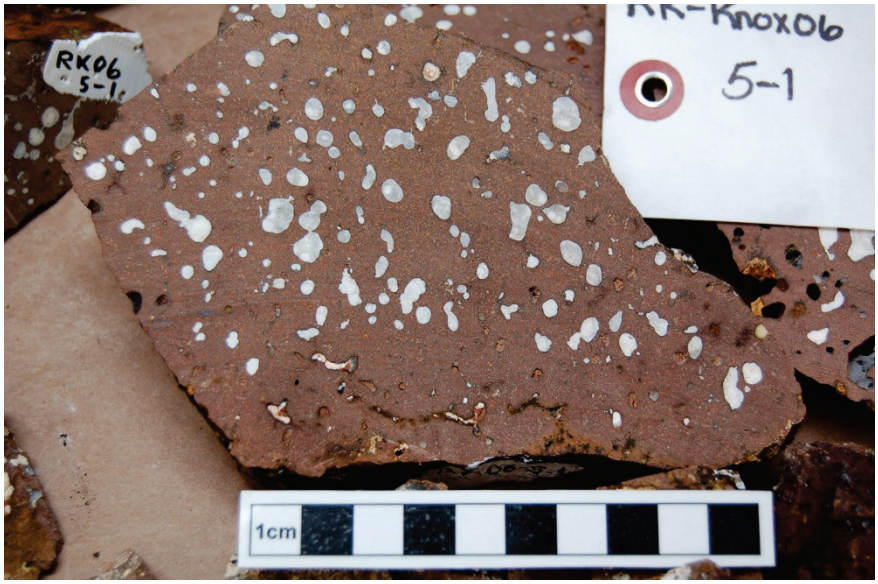


Appendix D

Amygdules vs. Phenocrysts

Amygdules (or amygdales – from the Greek word *amygdalos* meaning 'almond') form when vesicles in extrusive or shallowly emplaced igneous rocks are in-filled with a secondary mineral such as calcite, quartz, chlorite or one of the zeolites as the result of circulating groundwater or late magmatic solutions. Amygdules are typically sub-spheroidal and are often concentrically zoned. Rocks containing amygdules are described as amygdaloidal.





Phenocrysts (from the Greek words *phainein* meaning 'to show' and *krustallos* meaning 'crystal') are relatively large and usually conspicuous crystals distinct from the fine groundmass in a porphyritic igneous rock. Phenocrysts often have euhedral forms due to their early growth within a magma. Note: large crystals set in a medium or coarse-grained groundmass (*e.g.*, below, right) are more correctly termed **megacrysts**.





eTrex LEGEND

QUICK START GUIDE



GARMIN

Step-by-Step Instructions to Get You Started

(Turn this page and begin with Step 1)

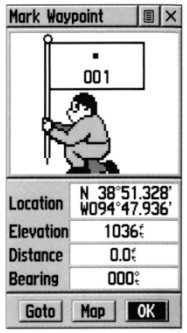
Basic Navigation

Starting to Navigate

Basic navigation with your eTrex Legend requires only three steps: mark, move, and return. Mark your location as a waypoint, move a distance away, and then return after choosing one of several methods to help you find your way.

To mark a waypoint:

1. Press in and hold the **THUMB STICK** for two seconds to display the Mark Waypoint Page. Your current location is marked as a waypoint and automatically assigned a three digit number.
2. The 'OK' button is highlighted so press the **THUMB STICK** to save the

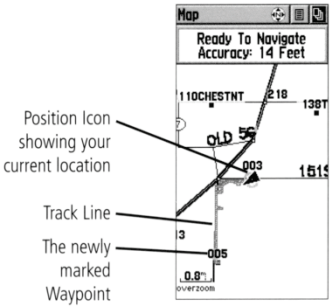


To move about with the Map Page:

1. Use the **PAGE** button to access the Map Page and view the new waypoint.

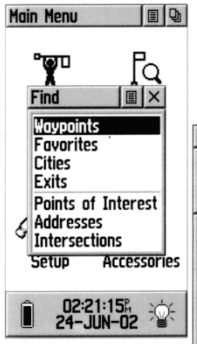
   Press the **ZOOM IN** button to get a more detailed view of the map.
2. Walk or drive around for a few minutes, make a right or left turn, then continue for a few more minutes and then stop.

   The 'position icon' shows your location and the dotted line shows your path of travel (a Track).

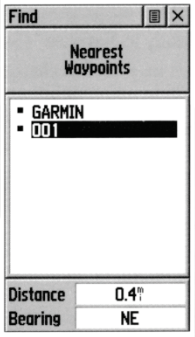


To return to a waypoint using Goto:

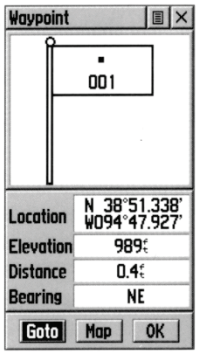
1. Press the **FIND** button to display the Find Menu.
2. Use the **THUMB STICK** to highlight 'Waypoints' and then press it in.
3. Use the **THUMB STICK** to highlight 'Nearest' and then press it in.
4. Use the **THUMB STICK** to highlight the waypoint and then press it in to display the Information Page.
5. With the on-screen 'Goto' button highlighted, press the **THUMB STICK** to activate the Goto navigation feature.



Find Menu



Waypoints List



Waypoint Information Page

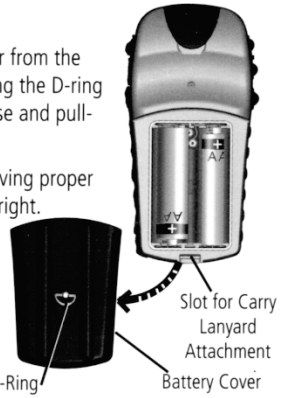
1 Installing the Batteries

The eTrex Legend operates on two AA batteries (not included), which are placed in the back of the unit. Rechargeable Alkaline, NiMH, NiCad or Lithium batteries may be used, but cannot be charged in the unit.

Stored data will not be lost when changing the batteries.

To install the batteries:

1. Remove the battery cover from the back of the unit by turning the D-ring 1/4 turn counter-clockwise and pulling out.
2. Insert the batteries observing proper polarity as shown at the right.
3. Reinstall the battery cover by turning the D-ring 1/4 turn clockwise.



2 Using the Button Functions

The ZOOM IN and OUT buttons:

- When on the Map Page, press to Zoom in and out.
- When on the Satellite Page, press to adjust the screen contrast.

The FIND button:

- Press to access the Find Menu.

The THUMB STICK:
(When moved or pressed in, button 'clicks')

- Press to enter highlighted options or confirm messages.
- Move Up/Down or Right/Left to move through lists, highlight fields, on-screen buttons, icons, enter data or move the map panning arrow.
- Press in and hold for two seconds to mark your current location as a waypoint.

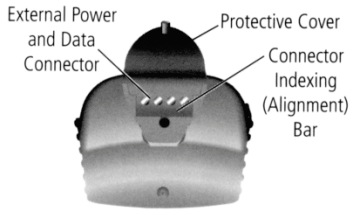


The PAGE button:

- Press to cycle through main pages.

The POWER button:

- Press and hold to turn the unit On/Off.
- Press to toggle the backlighting On/Off.



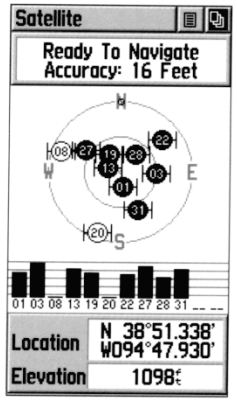
NOTE: While designed to be held and operated in the left hand, the unit can be used with the right hand, if preferred.

3 Start Up Sequence

To turn the unit On:

1. Press and hold the **POWER** button.
2. Press the **PAGE** button to acknowledge the copyright.
3. Carefully read the warning message and press the **PAGE** button to acknowledge and proceed to the Satellite Page.

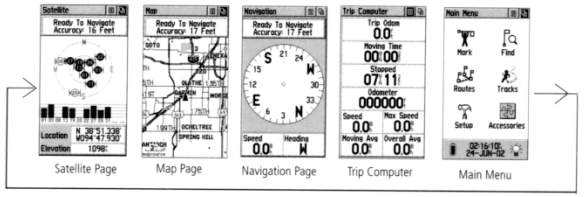
The unit may take up to 5 minutes to establish a position the first time you use it outside with a clear view of the sky. After that, it should take only 15 to 45 seconds. When the Legend has acquired enough satellite signals to determine your location, a "Ready To Navigate" message and your location coordinates and elevation are shown.



Satellite Page: displaying Satellite Position, Signal Strength, Location, and Elevation

4 Previewing the Main Pages

All of the information you need to operate the eTrex Legend is found on the five Main Pages (or display screens). To preview these pages, press the PAGE button to cycle from one page to the next. The five pages are shown in order below.



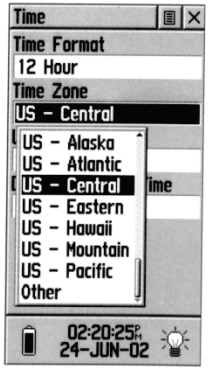
Satellite Page - Provides a visual reference of satellites being tracked.
Map Page - Displays your movements and nearby map features.
Navigation Page - Provides guidance to your destination.
Trip Computer - Provides a variety of trip and navigation data.
Main Menu - A directory of advanced features and settings.

5 Setting the Time Zone

If the Legend is "Ready to Navigate" (Step 3) but the time shown is not correct, you may need to change the Time Zone selection.

To change the Time Zone:

1. Use the **PAGE** button to access the Main Menu.
2. Use the **THUMB STICK** to highlight the SetUp icon and then press it in to display the SetUp Menu.
3. Use the **THUMB STICK** to highlight the Time icon and then press it in to display the Time Page.
4. Use the **THUMB STICK** to highlight the 'Time Zone' field then press it in to display the list of time
5. Highlight a time zone and then press the **THUMB STICK**.
6. The correct time is displayed at the bottom of the page.



Appendix F

Subdivisions of the global geologic record are formally defined by their lower boundary. Each unit of the Phanerozoic and the base of the Ediacaran are defined by a basal Global Boundary Stratotype Section and Point (GSSP - http://www.stratigraphy.org/index.php) whereas Precambrian units are formally subdivided by absolute age. Numerical Ages are from 'A Geologic Time Scale 2004', by Gradstein, F.M., Ogg, J.G., Smith, A.G., et Al. (Cambridge University Press) and 'The Concise Geologic Time Scale' by Ogg, J.G., Ogg, G. and Gradstein, F.M. (2008), and are subject to revision. Most sub-Series boundaries (e.g., Middle and Upper Aptian) are not formally defined.

Intra-Cambrian unit ages with * are informal
Copyright © 2010 International Commission on Stratigraphy

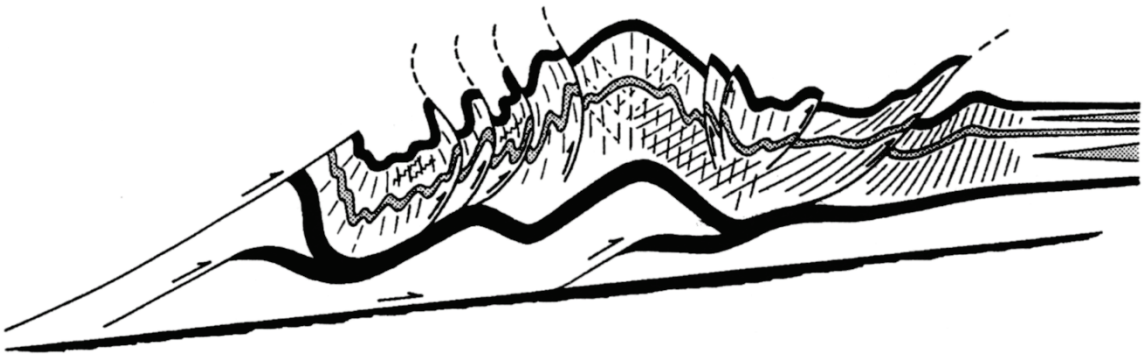
Glossary

Agglomerate – a coarse-grained volcaniclastic rock comprising angular to sub-angular lava fragments (bombs, blocks), commonly set in a fine-grained matrix. Some agglomerates are pyroclastic, being associated with explosive volcanic activity; others are associated with volcanic mud flows or lahars. Cf: ***volcanic breccia***

Amygdule – a gas cavity (see ***vesicle***) in an igneous rock which is filled with secondary minerals such as calcite, quartz, zeolites &/or epidote during later metamorphism. The mineralogy of an amygdale will be an indicator of the host rock's condition(s) of metamorphism.

Andesite – a fine grained, intermediate extrusive rock. The extrusive equivalent of a diorite.

Anticlinorium – a composite anticlinal structure of regional extent composed of lesser folds. Cf: ***synclinorium***



Anticlinorium

Basalt – a fine-grained, mafic igneous rock, commonly extrusive, composed primarily of plagioclase and pyroxene. The extrusive equivalent of a gabbro.

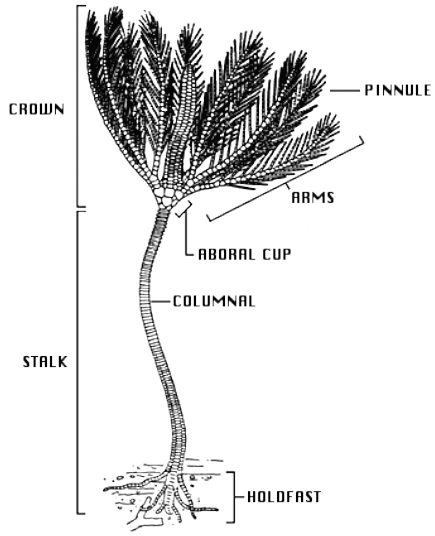
Batholith – a generally discordant igneous intrusion more than 100 km^2 in surface exposure. Cf: ***stock***

Chilled margin – a shallow intrusive or volcanic rock texture characterized by a glassy or fine grained zone caused by rapid crystallization along the margin where the magma or lava was in contact with a much cooler surface (usually water, ice or existing rock). The feature is often seen in dikes and sills, and especially in sheeted dyke complexes, where multiple chilled margins are a distinctive feature.

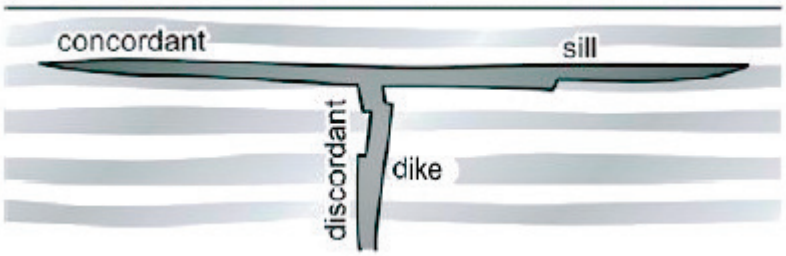
Coeval – of or belonging to the same age or generation.

Craton – a stable part of the earth's crust or lithosphere that has not been deformed significantly for many millions, even hundreds of millions of years. Its use is restricted to continents.

Crinoid –an abundant group of shallow marine filter feeding organisms common in the Paleozoic that exist in much reduced numbers today, having suffered an almost complete extinction at the Permian-Triassic boundary. They are characterized by a columnal stalk that attaches to the seafloor and a crown made up of multiple arms that can move in any direction to gather food. The stalk is made up of many carbonate plates (similar to vertebrae) called ***ossicles***.



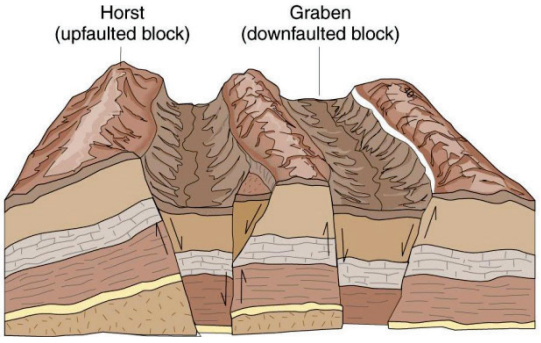
Dike – a discordant (cross-cutting) igneous intrusion, generally with parallel boundaries. Cf: ***sill***



Dike / sill

Epigenetic – said of a mineral deposit of origin later than that of the enclosing rocks. Cf: ***syngenetic***

Graben – a valley formed by the down-dropping of a fault block during extension bound by normal faults on either side. Where multiple grabens are separated by elevated regions the high areas are termed ***horsts***.



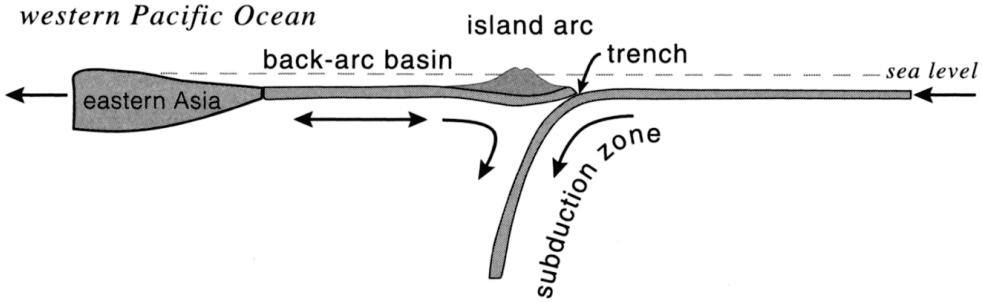
Horst / graben

Greenschist facies – metamorphic facies (= pressure-temperature conditions) in which the characteristic minerals that form in basaltic rocks are chlorite, epidote, amphibole and albitic plagioclase. Basaltic rocks metamorphosed under these conditions thus have a characteristic greenish colour. If the rock is not basaltic in bulk composition, the minerals that form at these PT conditions will be different. The approximate pressure-temperature range of greenschist facies rocks is <7 kbars and 250-500°C.

– the iron-rich end-member of the diopside-augite-hedenbergite (calcic clinopyroxene) solid solution series which crystallizes in the Monoclinic crystal system. A dark coloured contact metamorphic mineral often found in skarn deposits.

Hornfels – a name applied to non-foliated metamorphic rocks of uniform fine grain size, formed by high-temperature contact metamorphism around igneous intrusions. They are commonly fine-grained, light-coloured and very hard/brittle.

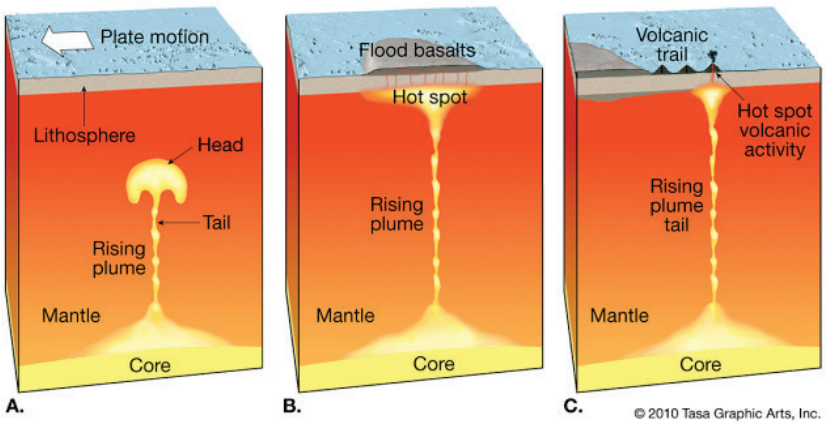
Island arc – a curved chain of volcanic islands (*e.g.*, the Aleutian Islands) rising from the deep-sea floor within a few hundred kilometres of a trench where there is active subduction of one oceanic plate beneath another. Its curve is generally convex toward the open ocean.



Island arc

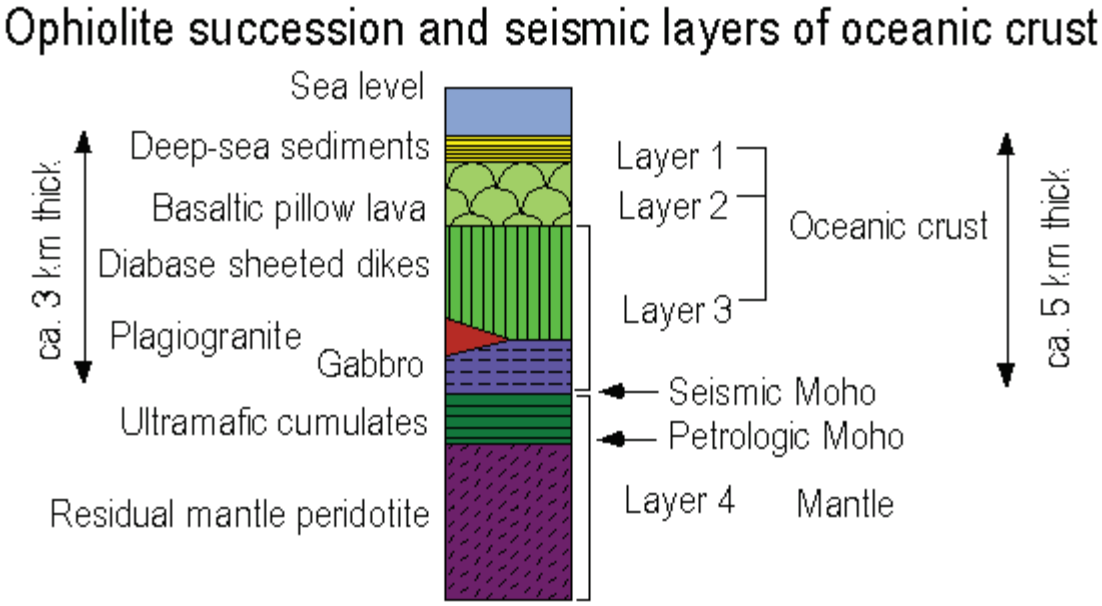
Joint – planar fractures, produced by brittle failure, on a centimetre- to hundreds of metre-scale along which there has been imperceptible 'pull-apart' movement. Joints form regionally when the rock body in which they are found responds to actions such as burial or cooling (contraction) and uplift or heating (expansion).

Mantle plume – an upwelling of abnormally *hot* rock within the Earth's mantle. Mantle plumes can partially melt when they reach shallow depths and are thought to be the cause of volcanic centers known as hotspots from which thick successions of flood basalts are known to effuse (*e.g.*, Hawaii, Iceland).



Migmatite – literally: 'mixed rock'. A composite silicate rock, pervasively heterogeneous on a meso-megascopic scale. Typically consists of darker (exhibiting features of metamorphic rocks) and lighter (looking more plutonic) parts.

Ophiolite – a section of oceanic crust and underlying upper mantle that have been uplifted or thrust onto continental crust and hence are exposed at the surface.



Phenocryst – a large crystal in a fine grained igneous matrix that grew during an initial slow cooling event prior to the rapid cooling that led to formation of the fine grained matrix. Fine grained igneous rocks that have a phenocrysts phase are referred to as being -phyric; *e.g.*, a plagioclase-phyric basalt is a basalt with plagioclase phenocrysts.

Porphyry – an igneous rock of any composition that contains conspicuous phenocrysts in a fine-grained groundmass. When using this term, always define what the phenocrysts are and estimate the composition of the rock based on the colour index of the matrix. ***Glomeroporphyritic*** refers to the grouping of phenocrysts into distinct clusters within porphyritic igneous rocks.

Sill – a concordant (parallel) igneous intrusion, generally with parallel boundaries. Cf: ***dike***

Skarn – Skarn is the general term used to describe rocks composed of calc-silicates derived from carbonates into which large amounts of Si, Al, Fe and Mg have been introduced. Economic mineral deposits containing skarn can form at or near the contact between predominantly carbonate-rich rocks (limestone or dolomite) and a generally large igneous intrusive body, or in veins along faults or fractures.

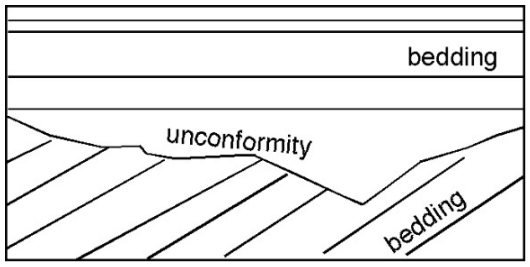
They form when hot magmatic fluids from the intrusion react with the host carbonate-rich rock, producing calcium, iron, manganese and magnesium silicates (also known as calc-silicates). This process is called metasomatism, meaning that new minerals grow in the host rocks when chemically active pore fluids are introduced into it from an external source. The calc-silicate minerals include garnet (calcium-rich grossular and andradite to magnesium-rich pyrope), pyroxene (diopside to hedenbergite), epidote, olivine (forsterite to fayalite), wollastonite, amphibole (actinolite-tremolite to hornblende), goethite (hydrated iron oxide) and scapolite (a hydrous Ca-Al-K-Na silicate). Skarns can also be enriched in many trace metals of economic importance (*e.g.*, Fe, Cu, Au, W, Zn, Mo, Sn, Pb).

Stock – a generally discordant igneous intrusion less than 100 km^2 in surface exposure. Cf: ***batholith***

Syngenetic – said of a mineral deposit formed at the same time, and by the same processes, as the enclosing rocks. Cf: ***epigenetic***

Terrane – an area with a common geological history that differs to that of adjacent regions (*e.g.*, lithostratigraphic units representing a specific depositional or volcanic setting responding to a tectonic event), which differs from adjacent terranes and is bounded by faults. The term does not have any genetic significance, nor does it imply an origin far removed from adjacent terranes or its present position relative to a craton. Terranes are only defined by their internal assemblage composition. An 'accreted terrane' refers to a terrane that has become attached to a continental margin in the later stage of its tectonic history.

Unconformity – a surface of erosion or non-deposition, representing a break or time gap in the geologic record, that separates younger strata from older rocks.



- An angular unconformity

Vesicle – an often spheroidal cavity found in extrusive igneous rocks, formed by the expansion of a bubble of gas in magma as it rises and volatile components (generally CO_2 and H_2O) become less soluble. During metamorphism, especially if large volumes of fluid flows through the rock, low-temperature secondary minerals (*e.g.*, chlorite, calcite, epidote, zeolites, quartz) commonly fill the vesicles (see ***amygdule***).

Vein – a tabular or sheet-like, epigenetic mineral filling of a fault or fracture commonly formed as the result of the movement of hot fluids often with associated replacement of the host rock.

Volcanic-hosted massive sulphide (VHMS) deposit – a type of metal-sulfide ore deposit, mainly Cu-Zn which are associated with and created by volcanic-associated hydrothermal events in submarine environments. They are predominantly stratiform accumulations of sulfide minerals that precipitate from hydrothermal fluids on or below the seafloor in a wide range of ancient and modern geological settings. In modern oceans they are synonymous with sulfurous plumes called black smokers. Massive refers to structure-less, not to large in size.

Xenolith – a foreign inclusion in an igneous rock entrained during magma emplacement or eruption. Xenoliths may be engulfed along the margins of a magma chamber, torn loose from the walls of an erupting lava conduit or explosive diatreme or picked up along the base of flowing lava.

ASSIGNMENTS

The following pages lay out the assignments that you will complete during field school. A few general comments will help you through these:

- If you are unsure about anything please ask. This field course is entirely 'hands-on'. You learn by 'doing' and we are here to help you with this.
- Recording field data (*i.e.*, your observations) accurately and neatly so that they can readily be used is an essential skill of a field geologist. You must constantly be thinking about whether the notes you are producing are recorded in a ready-to-use way and whether your map is clear. And yes, neatness counts!
- Colour your field map as you progress (*i.e.*, as you map) and continually use your map to predict the geology that you are going to see. Don't leave the interpretation of your data until the last minute.
- Finally, include your name on everything you hand in.

Mt. Tuam Mapping Exercise (Days 2 & 3)

A. Equipment

- field notebook, protractor, pencil, eraser, colouring pencils, clipboard
- air photo w/ Mylar overlay
- day pack, compass, rock hammer, hand lens, magnet, safety glasses, acid bottle, *etc.*

B. Objectives

The purpose of this two-day exercise, to be done in pairs, is to introduce you to some of the basic mapping skills used by geologists when mapping relatively small, well-exposed areas. To accomplish this, we will be looking at rocks exposed on the top and southwest flank of Mt. Tuam. You will map onto a Mylar overlay using a ~1:5,000-scale colour aerial photograph as the base. The area to be mapped is outlined in white on the photo. Take special effort in accurately locating yourself on this photo using obvious features such as roads, buildings, fences and large trees/snags. Be sure to record essential outcrop information such as lithology and the attitudes of any primary/secondary structural features ***right on your map as you go***. Any additional important information that cannot fit on your map can go in your notebook (referenced by a station number that should be shown clearly on your map). Field notes are greatly improved by neat sketches with titles, scales and labels. Do not assume that the person looking at your work will be familiar with the area or its geology, so be explicit in your descriptions. Also, be as quantitative as possible in your descriptions of geological features (*e.g.*, 10 metres wide, rather than 'big').

C. Tips for Success

- ♦ We'll start, as a group, by identifying and applying field names to the various geological units exposed north of the radar platform. We'll also discuss some of the important structural features exposed in these outcrops.
- ♦ Once you have a handle on the various lithologies, seek out and follow the contacts separating them. This may require that you 'lose some elevation' in the process. It is *not* necessary, however, to stray outside the white mapping boundaries. Record the exact position of lithological contacts on your map as you go.
- ♦ Each pair should produce a single map, but notes (mainly lithological descriptions and attitudes) should be recorded individually.
- ♦ Note that the timber northeast of the radar platform has been felled but not cleared. While it is important that you investigate this area, tread carefully and stay off of downed trees.
- ♦ Be sure to plot ***all*** of your geological data (measured attitudes, contacts, structural features, *etc.*) ***directly*** on your map (and colour it as you go), so that you see the 'geological picture' as it emerges.
- ♦ At some point on the second day, pick a vantage point in the field area from which you can observe the main geological structures that you have been mapping. From this location, make an accurate sketch cross section in your notes, depicting your ***geological*** observations. Don't forget to indicate the direction of the section (*e.g.*, 'looking northeast') and give some sense of scale (*e.g.*, an object of known height depicted in the section).
- ♦ Ask the instructors or TA's if you are unsure of what you are looking at or how it should be depicted on your map. Be sure to show one of the instructors/TA's your map on the ferry ride back to Swartz Bay the first day so that feedback can be provided.

D. Assignment

Before disembarking the ferry the second day, you will be required to hand in: your field map, a sketch cross section and a point-form geological history of the area. Your map mark **(70%)** will reflect: (i) how accurately you have mapped the geological boundaries, (ii) the quality and quantity of useful structural data you have collected, and (iii) the ease with which your map can be read (*i.e.*, neatness counts!). Your cross section mark **(10%)** will depend on (i) the degree to which it depicts structural elements, (ii) correspondence between it and your map, and (iii) the ease with which it can be read. Your history mark **(20%)** will reflect how well you describe the sequence of events that resulted in the observed geology.

Don't forget to include the following essential elements on your field map:

- ✓ a title, date and your names
- ✓ index map and the location of your cross section
- ✓ a geological legend (youngest to oldest units from top to bottom) with keyed symbols
- ✓ a north arrow, both numerical and graphical scales and a UTM reference point (obtained using your GPS)

Argonaut Mapping Exercise (Days 5 – 9)

A. Equipment

- field notebook, protractor, pencil, eraser, colouring pencils & clipboard
- air photo w/ Mylar overlay, topographic map
- GPS & FRS radio
- day pack, compass, rock hammer, hand lens, magnet, safety glasses, acid bottle, *etc.*

B. Objectives

The purpose of this four-day exercise, done in pairs, is to further enhance your mapping skills by getting you to investigate an area considered favourable to the location of skarn mineralization similar to that exploited at the former Argonaut Mine. To facilitate this, you will map onto a Mylar overlay using either a 1:20,000-scale aerial photograph or corresponding topographic map as the base. Instructors will be checking both your field notes and map each evening, and making suggestions for improvement. ***For safety reasons, do not enter the pit area cross-hatched in red on the photo.***

C. Tips for Success

- Look over all the pertinent background information on the area *before* you head out into the field, so that you are familiar with what others have found before you. This includes the regional (Strathcona) geology.
- Be aware that the aerial photograph you will be using is four times the scale of the one you used on Mt. Tuam and so corresponding distances will be approximately four times greater on the ground. You can choose to map on either the air photo or topographic map, but note that roads on the latter are not as up to date.
- As the area to be covered is relatively large (~8km^2), it is recommended that you focus on mapping outcrops exposed by or near the numerous logging roads traversing the area. Once you have a broad understanding of the local geological setting, you may want to seek out additional outcrop exposures in other sources, such as along creek bottoms. Do *not* venture past the mapping boundaries clearly shown on the air photo (||x).
- Be sure to record *all* your observations: plot lithology, structural data and geological boundaries directly on your map so that you see the 'geological picture' as it emerges. Use your notebook for recording observations that you do not have space to depict on your map (*e.g.*, road-cut sketches). Be sure to accurately describe (mineralogy, texture[s], *etc.*) each lithological unit encountered within the map area.
- Depict dykes in their true orientation on your maps using the appropriate symbol (see p. 26).
- Produce one field map, and one set of field notes (add your initials to the pages you write) per pair.
- Don't leave the preparation of your final map until the last evening or you will be working late into the night. Plot up each day's observations that evening and you will have a much better idea as to where to focus your efforts the next day. ***After the third day of mapping, pairs will be expected to produce a sketch cross section through the mapping area.***

D. Assignment

Your mark will be based on the following, which must be handed in before leaving Strathcona Lodge on the last morning:

- Your field map (which should have a legend/key, *etc.*). **(*40%*)**
- A coloured/keyed final geological compilation map on Mylar showing the distribution of lithologies, contacts (both inferred and observed) and dominant structural features within the map area. Do not show individual outcrops or your individual stations and make sure that non-geological features (roads, creeks, *etc.*) are shown ***subordinate*** to the geological ones. Do not forget to include an inset index map, legend, numerical/graphical scale, UTM grid reference, section location(s) and north arrow. **(*15%*)**
- One (or more if this helps to clarify the geology) cross section(s) showing the subsurface geology of the mapped area drawn at the same scale as your plan maps. You will need the topographic map to accomplish this. **(*25%*)**
- *All* of your field notes (one set between two) in chronological order. Be sure to retain your *individual* notes (*e.g.*, those taken on the Buttle Lake excursion day) to assist you in writing your Geological History of Wrangellia. **(*10%*)**
- A <2 side 'report' on the mapped area, which should include descriptions of the lithologies, stratigraphy, structure *and* a brief geological history (pertaining only to what you have observed in the map area). This can be in point form but should be logically ordered so that the age relationships are clear to the reader. **(*10%*)**

Vesuvius Stratigraphic Section Exercise (Day 10)

A. Equipment

- field notebook, protractor, pencil, coloring pencils, eraser & clipboard
- blank graphic logs (w/ Mylar overlay, if wet)
- measuring tapes (to be provided)
- compass, hand lens, safety glasses, acid bottle, *etc.*

B. Objectives

The purpose of this four-hour exercise, done ***individually***, is to observe, describe and graphically depict a section of sediments assigned to the upper part of the Cedar District Formation of the Upper Cretaceous Nanaimo Group exposed on the northwest side of the Vesuvius ferry dock. Most of you saw these same rocks exposed along Medicine Beach (Stop 3) on the EOS 201 field trip to Pender Island. Regionally, the formation comprises a 300-500 metre thick succession of interbedded mudstones and sandstones (arkosic wackes) which is overlain by thick-bedded sandstones of the De Courcy Formation. The contact between the two formations is gradational and complexly interfingering. Various sedimentary structures indicating paleocurrent direction should be measured and recorded. Numerous other sedimentary structures (including graded bedding, flame structures, soft sediment deformation and bioturbation) can also be seen throughout Cedar District rocks (you will want to note these in your log). Ensure that your log graphically depicts the sequence. Someone looking briefly at your log should get an immediate impression of the sequence. Based on your observations, write a ***brief*** (<10 lines) interpretation of the depositional setting (*i.e.*, in what environment were these sediments likely deposited and on what evidence did you base this interpretation).

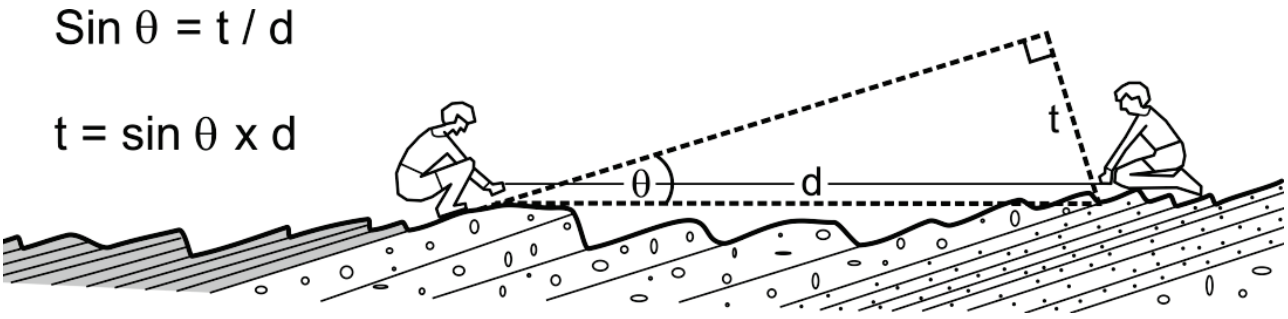
C. Procedure

1. Start by walking out the *entire* section. While doing so, you will need to:

   a) Determine stratigraphic 'up' (*i.e.*, in what direction do the sediments become younger?). This can be done by finding geopetal features (Appendix C) such as graded bedding, load casts, *etc*.

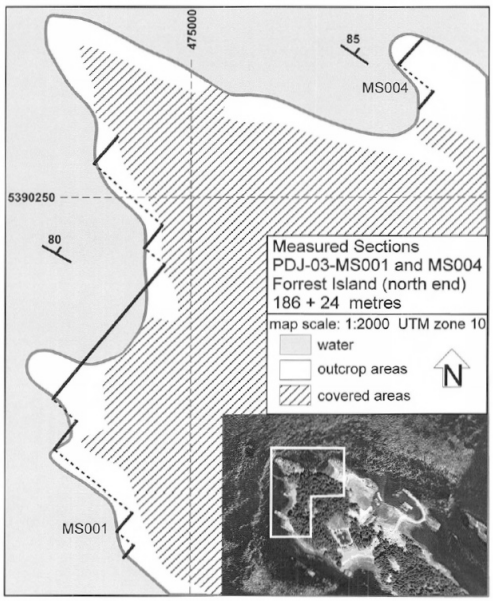
   b) Measure the attitude of the sediments and note when/if it changes over the length of the section. This is important, as such changes will affect thickness calculations and the direction the tape should be laid out.

   c) Estimate the total thickness of the section so that an appropriate scale for your stratigraphic column can be determined. Your final log should fit onto no more than two (2) pages (*i.e.*, 100 vertical increments). To accomplish this, you will need to measure the orthogonal (at right angles to strike) distance from the bottom to top of the section and then use trigonometry to calculate its true thickness (t, figure below). Where dips are within 10° of vertical (*i.e.*, $\geq 80^{o}$), the orthogonal horizontal distance can be taken as the true thickness, without the need for correction.



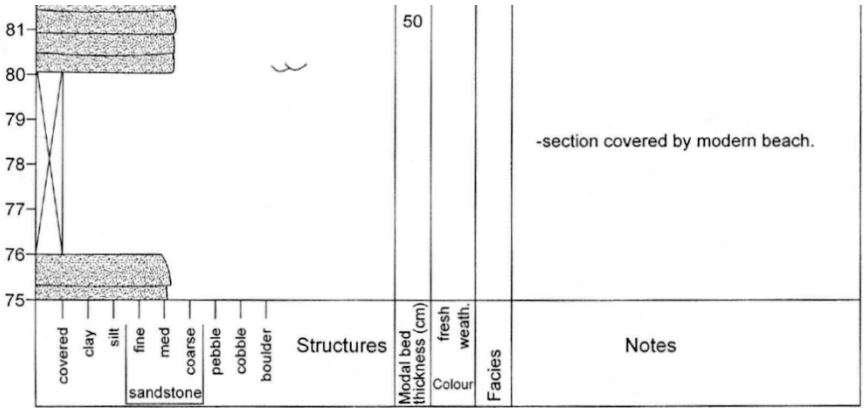
Due to time constraints, and as the dip of this section is nearly vertical, you can assume measured horizontal distances are representative of true thicknesses for this exercise. For the purposes of scale determination, assume the section to be ≤100 metres in true thickness.

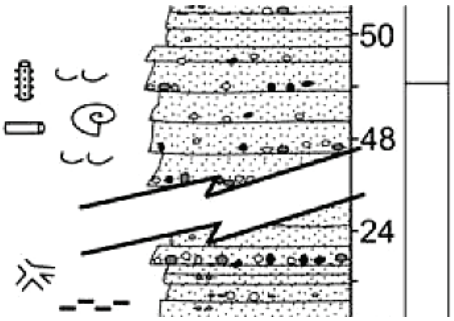
As this is a beach exposure, you may have to 'jog' along strike (dashed lines in the figure, below) to either the left or right if you run out of outcrop. To do this, simply follow a single bed or use your compass to sight in a point along strike where you can continue your measurements up (down) section.



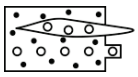
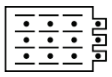
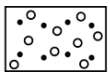
Measuring a beach exposure.

Be sure to account for covered sections (*i.e.*, intervals where there is no outcrop) on your log. For the purposes of this exercise, covered sections should be depicted, to scale, as shown below (left). An alternative (and space saving) method is shown to the right.





d) Decide how many lithologies are required to differentiate the section strata with sufficient detail and graphically depict each in the legend (examples below). Each should be fully described according to the dominant lithotype(s), textural maturity, sedimentary structures, fabrics and the presence of fossils or/or trace fossils. Be sure that the width you use to depict each lithotype on the log is representative of grain size (wider = coarser).

 Pebbly sandstone  Interbedded sand & siltstone  Sandy pebble conglomerate

Geologists tend to fall between two end members when it comes to assigning lithologies: 'groupers', who tend to overlook the finer details and 'splitters' who tend to obsess over them. A balanced approach is recommended in most circumstances. Be sure to take the chosen scale into account when deciding whether or not to split out an individual unit or include it as part of another lithofacies.

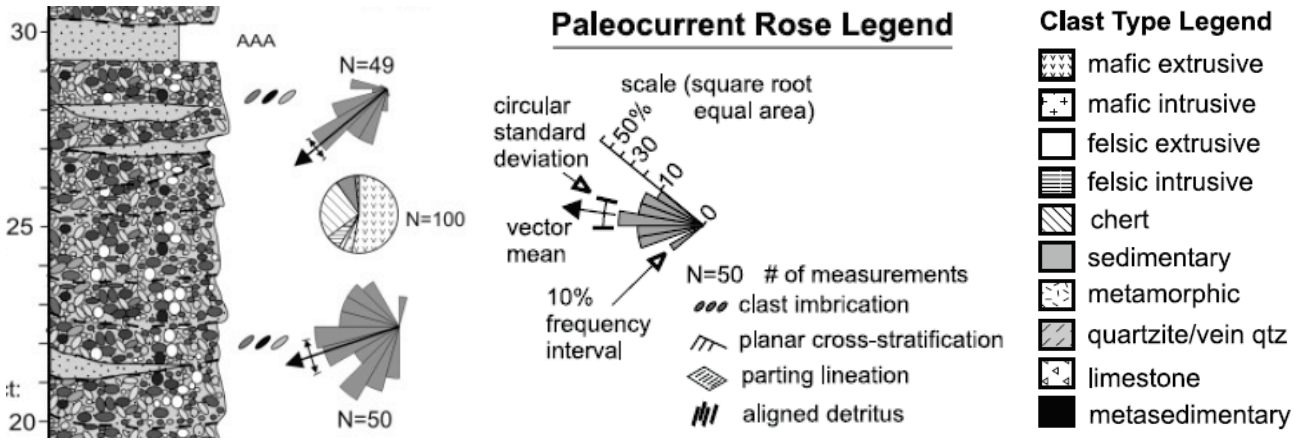
e) Come up with a method for differentiating the finer lithologies (*e.g.*, fine sandstones from siltstones or siltstones from mudstones). The grain size of siltstone is generally too small to see, even with a hand lens, but it is somewhat 'gritty' when rubbed between your fingers or against a front tooth. Mudstones, on the other hand, feel smooth when similarly tested.

f) Finally, fill in the section details (location, formation name, *etc*.) in the log header.

2. Once you have accomplished these important preliminary steps, go to one end of the section or the other and begin your measurements. Some prefer to measure in lithological boundaries first. This method gives you a template into which your other observations (*e.g.*, sedimentary structures) can be later added. Others will prefer to record every detail as they work up (or down) section, so as to avoid having to walk it again. You will have to take the latter approach for this exercise, as there will only be one set of tapes per group. Remember that your log is supposed to be graphical and that symbols are preferred to words, where possible. As new features (*e.g.*, sedimentary structures) are observed and added to the log, the symbols chosen to represent them should be keyed in the legend.

Other considerations:

- Structural features (*e.g.*, fractures) do not, generally, appear in stratigraphic sections, unless they are regional scale. Small-scale faults must, however, be accounted for in the section if they repeat/remove strata.
- Lenticular beds, or those that pinch out in one direction (facies change) should be depicted/described as such on your section/in the legend.
- Sharp contacts *between* lithologies should be depicted with horizontal lines, while more gradational contacts typically slope in one direction or the other (depending on whether the sediment is getting finer or coarser). The latter also applies to changes in grain size *within* a particular unit.
- Paleocurrent indicators (if present), can be depicted, in the 'Notes' column, using a simplified rose diagram (N = # of measurements, north to the top of the page), while clast composition distributions (in the case of conglomerates) are generally shown using a standard pie chart (N = # of clasts counted). The symbols used for both should be keyed in the legend (figure, below).



- While it's a good idea to provide a plan map showing the location of the section (*e.g.*, figure top of p. 41), with at least one geographic reference point, one will <u>not</u> be required for this exercise.

As you work, continually evaluate your progress, keeping your eye on the larger picture and think about what depositional setting these rocks might have formed in. Some things to ask yourself might include:

- Is there a lot of repetition? How can you account for this on your log?
- Are you grouping things at an appropriate scale? If you group too much, then you might miss important details. If too little, you will not have time to complete the section.
- How will you deal with strata missing or repeated as the result of local faulting?
- Are your notes/logs legible? Do you understand your own abbreviations? Have you included everything that you should? Is your key inclusive of all symbols used?
- Does your log look something like the example shown on p. 45?

D. Tips for Success

- Make sure you choose a scale which will allow you to depict the entire section on the blank logs provided.
- Keep your eye on the time (we'll be catching the 4pm ferry back to Crofton) – determine how much ground you have to cover and the time you have to do it.
- Review and become familiar with appropriate symbols and abbreviations (see the section on graphic logs in Appendix B) – this will save you a lot of time at the beginning as you try to orient yourself.
- Remember that a picture is worth a thousand words – one glance at your log should give someone who has never seen this section of rocks an ***immediate*** sense of what is there.

E. Assignment

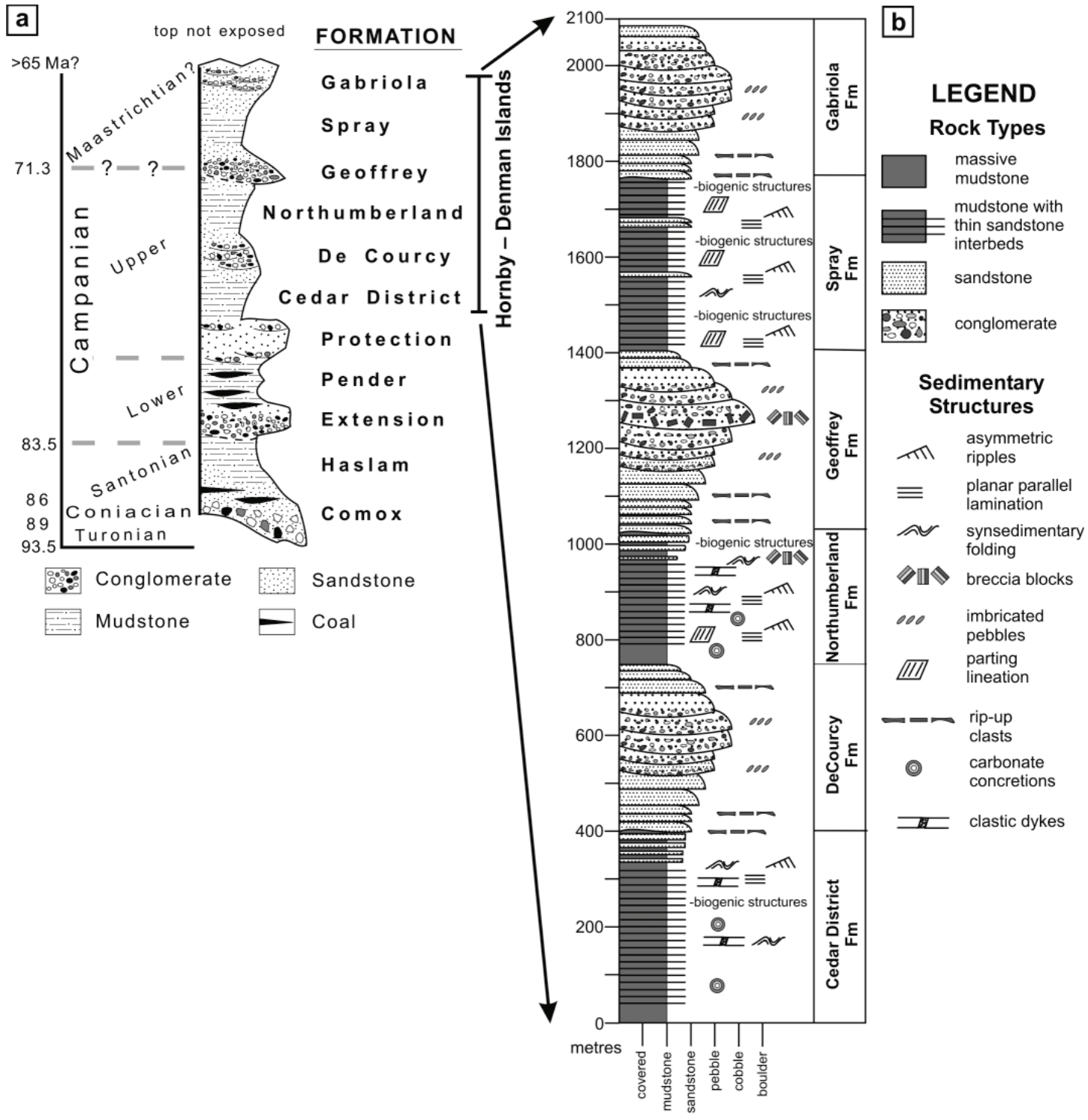
Your mark for this exercise will be based on the following, which must be handed in *before* the ferry docks in Crofton:

1. Your stratigraphic section along with a complete legend including all lithologies observed and a key to the symbols you used.
2. A brief (<10 line) interpretation of a depositional setting in which these sediments might have formed.

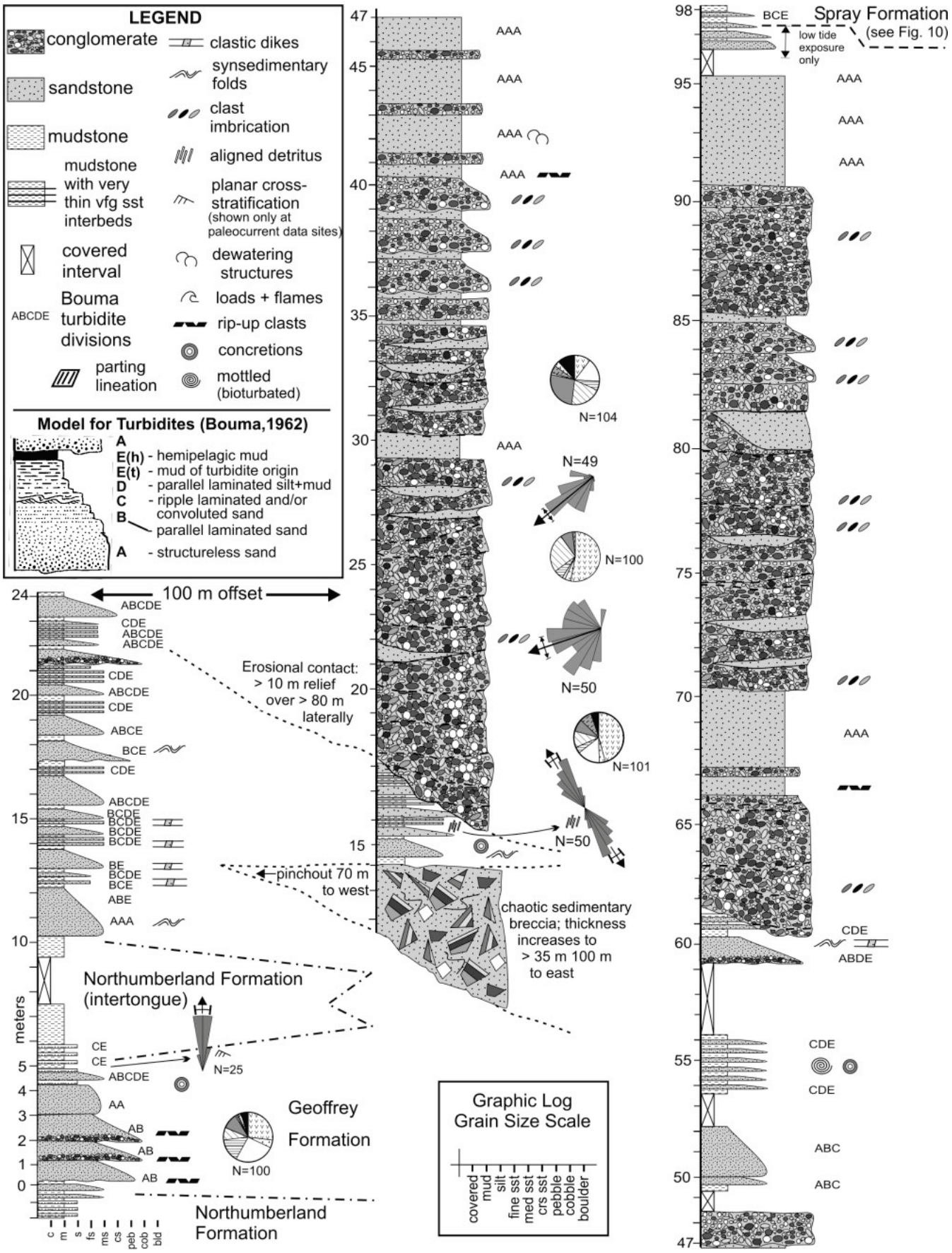
Don't forget to:

- ✓ indicate the location of the section, the formation(s) mapped and the date
- ✓ clearly indicate your vertical scale and the orientation of the strata
- ✓ represent dominant lithofacies with symbols &/or colours
- ✓ clearly identify and describe fossils, sedimentary structures and any distinct beds
- ✓ denote any 'covered' areas, where outcrop was covered and not observed

Last but not least, remember that you are trying to communicate, in a clear and readable fashion, what you have observed and measured. Good communication depends on neatness, accuracy, and clarity. How well you succeed in all three will be reflected in your mark for this exercise.



(a) Generalised stratigraphy of the Nanaimo group and (b) Detailed stratigraphy of the Upper Nanaimo Group (including the Cedar District) formations, Denman & Hornby islands (from Katnick and Mustard, 2003)



An example of a sedimentary log (Geoffrey Fm., Nanaimo group) from Katnick and Mustard (2003)

Sayward Beach Mapping Exercise (Day 11)

A. Equipment

- field notebook, protractor, pencil, eraser, colouring pencils, clipboard & compass
- day pack, hand lens, safety glasses, magnet, acid bottle, *etc.*
- a single GPS will be provided to the group for the purposes of tying in the outcrop to the UTM grid.

Beware – the rocks are very slippery when wet.

B. Objectives

The purpose of this full-day exercise, done ***individually***, is to give you practice producing a detailed geological map of a small (and complex) area. The outcrop is immediately south of Sayward Beach, which is accessed from Parker Park (map, next page). Note that the tides will be slowly falling throughout the day.

The regional geology in this area is poorly understood, in part because of the scattered nature of the outcrops and in part because of poor age constraints. The limited regional exposure increases the need for detailed, large-scale mapping to extract as much information as possible out of the local geological relationships that we can observe where there is exposure – such as this beach outcrop.

In considering the individual rock bodies, determine:

- their orientations and dimensions and if they are tabular, lenticular, or irregular in shape
- if they are internally layered and if these layers are parallel to any of the bounding surfaces
- if any unit contains fragments of another

In considering the boundaries between the bodies, determine:

- the orientations of the boundaries
- if the contacts are sharp, gradational, unconformable, fault-related or intrusive
- if the rocks vary in colour, texture or mineralogy at these contacts

Examine the rocks closely and describe any primary characteristics (mineralogy, texture, grain size, fabrics, structures, alteration/mineralization, *etc*.). Look especially for structures that may establish tops and bottoms of deposited layers that are (or were once) sediments or flows and determine if relations at contacts support these indications of sequence.

C. Tips for Success

- Start by determining the dimensions of your map area & selecting a scale that will fit on your page(s).
- Placing a piece of graph paper beneath your Mylar will assist you with scale.
- Spend some time examining the outcrops and determining lithologies and age/contact relationships *before* diving into making your map (*i.e.*, do a reconnaissance of the area *first*).
- Map out the distribution of lithologies and record structural and lithologic data on your map. Record all observations as notes on your map – *you should not need to use your field notebook*. Do not map sand.
- Don't forget to examine both weathered and fresh surfaces with your hand lens and to use your other tools (probe, acid, magnet, *etc.*) where useful. Wetting down some outcrops can also 'bring out the geology'!
- Accurately depict all structural features (faults/fractures, *etc.*) on your map. Indicate the type of contact (intrusive, fault, unconformable, etc) where it can be determined.
- Be sure to consider contact relationships and indicate chilled margins (including the way the chill faces), where observed.

D. Assignment

Your mark will be based on the accuracy and neatness of your map, which must be handed in before we leave the outcrop (by ~3pm), as well as a brief (point-form) geological history. As always, don't forget to include the essential cartographic elements on your map.



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Geological History of Wrangellia (Day 12)

A. Equipment

- field notes and maps from the first 11 days of the course.

B. Objectives

The first aim of this exercise is for you to use the observations you made during field school to interpret the geological history of Wrangellia. The history should be as detailed as possible and based on the observations and interpretations you made.

All the interpretations should be in reference to specific observations that you made. For example, 'On day 3 at the junction between the Argonaut and Mine mainlines south of Upper Quinsam Lake, I observed an angular unconformity between folded arenites and micritic limestone. The underlying siliciclastics contain fossilized dinosaur bones of Jurassic age, while the overlying carbonates contain Tertiary-aged brachiopod shells. These observations suggest a major transgression between the Jurassic and Tertiary.' If you use information that is not based on your personal observations (*e.g.*, from the field guide or regional map), cite these as your source (*e.g.*, 'based on the regional distribution of the Nanaimo Group sediments [field guide], …'

Start by summarizing your observations about the oldest rocks. Include the range of lithologies and structures observed, and interpret the geological setting of formation as best you can from your observations. Then proceed to describe the successively younger units in the same fashion, all the time thinking about the relationships between adjacent units.

The second aim of this exercise is for you to think about how you could take notes in future that would be more useful to you (or somebody else) when back from the field. Most of us truly learn how to record field observations systematically the hard way – by our mistakes. As you use your notebook to try to recall your observations, record (in point form) ways that your notes could be improved next time.

C. Tips for Success

Start by going through your field notes, extracting the key observations made at the outcrops visited.

Use these observations as the basis for developing your geological history. Ensure that your history discusses the events in chronological order.

D. Assignment

Your mark will be based on the following, both to be submitted before 3 pm:

1. Your geological history (which can be in point form and should be 'three sides' or less, exclusive of diagrams).
2. A list of ways in which your notes could be improved.

Please be sure that you have returned all your equipment and completed an instructor evaluation before departing.





Myra Falls Mine

Resources for a changing world



Operation at a glance

The Myra Falls mine is located in a provincial park in central Vancouver Island and linked by a 90 kilometre asphalt road to the port of Campbell River. The Myra Falls mine has been in operation since 1966 and has a long history of reserve replacement and promising exploration potential.

Fast facts...

Location

— British Columbia, Canada

Mine Type

— underground multi-metal mine

Products

—zinc concentrate, copper concentrate, lead concentrate, silver and gold as by-products

Employees

— 315

Production 2012*

— 32,000 tonnes of zinc in concentrate
3,800 tonnes of copper in concentrate
1.1,000 tonnes of lead in concentrate
13,600 troy ounces of gold in concentrate
580,000 troy ounces of silver in concentrate

OVERVIEW

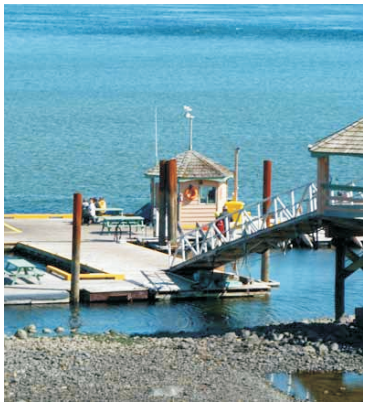
In August 2011, Nyrstar successfully completed its acquisition of Breakwater Resources, the owner of the Myra Falls mine in Canada. There have been over 100 years of mineral exploration activity in central Vancouver Island and over four decades of active mining at Myra Falls.

Active mining has been carried out at Myra Falls since 1966 starting with the Lynx open pit and underground operations, followed in 1969 with the Myra mine. In 1979, the H-W massive sulphide deposit was discovered prompting the installation of new infrastructure and an expansion of the milling facilities to 2,700 tonnes per day. This was later increased to 3,650 tonnes per day. In 1991, the Battle and Gap deposits were discovered. The Lynx underground mine closed in 1993. In 1995, the Marshall deposit was discovered. In 1996, mining in the Battle-Gap zone commenced.

The mineral deposits comprise complex metal-zoned volcanogenic massive sulphides contained in the 450 metre thick Myra Formation of the Sicker Group volcanic assemblage. The Myra Formation hosts a geologically diverse collection of mineralised bodies including poly-metallic massive sulphides, poly-metallic disseminated sulphides, zoned pyritic massive sulphides and stringer sulphide zones. The principal minerals are sphalerite, pyrite and chalcopyrite with minor galena, bornite, tennantite and locally signifcant secondary copper.

In 2009 the mine reacted to the worldwide decline in the metals market by restructuring the operation. Mine planning and execution focused on recently discovered higher grade ore deposits enabling a reduction in costs while achieving favourable concentrate production. Through the ensuing period, Myra Falls has continued a focus on identifying and implementing opportunities that provide continuous improvement to the operation. Included in these initiatives are site water management that ensures environmental compliance, a power strategy that maximises the use of hydro power (nearly eliminating the need for diesel generated power), and Mill upgrades that provide improved recoveries of primary products and also the production of a new lead concentrate product.

*[1] Under Nyrstar ownership in 2012, Myra Falls produced approximately 32,000 tonnes of zinc in concentrate, 1.1,000 tonnes of lead in concentrate, 3,800 tonnes of copper in concentrate, 13,600 troy ounces of gold in concentrate and 580,000 troy ounces of silver in concentrate.



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Myra Falls Operation

Overview

Myra Falls Operation is an underground zinc-copper mine located in Strathcona - Westmin Provincial Park on Vancouver Island, British Columbia, Canada. The property consists of mineral claims, mining leases, and 23 crown granted claims, covering 3,629 hectares (although surface operations only impact approximately 170 ha). Operations consist of two underground mines: the H-W mine and the Battle mines, which are serviced by more than 240 kilometres of drifts, shafts and stopes.

Mining operations are carried out using bulk-mining methods. A single production shaft at the 700 metre level services both mines. Ore is processed through a modern 3,625 tonne/day mill facility. Zinc and copper/precious metals concentrates are transported on a daily basis to the company's Discovery Terminal, a deep-sea port in Campbell River. The terminal has a storage capacity of 33,000 million tonnes (mT) and ship loading capacity of 450 mT/hour. Once a month, concentrate is shipped overseas to smelters in Japan and Korea.

Geology & Mineralization

The volcanic-hosted massive sulfide (VHMS) deposits at Myra Falls are hosted by ancient island arc systems of the Paleozoic Sicker Group. The Sicker Group is exposed on Vancouver Island in several fault-bounded uplifts. At Myra Falls, the Devonian to Mississippian-aged Sicker Group volcanic rocks are conformably overlain by limestone of the Permian- aged Buttle Lake Formation. Sulfide mineralogy at Myra Falls is typical of most VHMS deposits. The common sulfide minerals present in order of decreasing abundance are pyrite, sphalerite, chalcopyrite, and galena. Less common sulfides are pyrrhotite, arsenopyrite and the copper-rich sulfides bornite, renierite, and anilite. The VHMS deposits are hosted by the Myra Formation and are associated with two rhyolite horizons, the at-depth H-W Horizon and the near-surface Lynx-Myra-Price (L-M-P) Horizon.

Mining & Operation

Electric-hydraulic jumbos bore holes into the rock for blasting, which is done every day, producing 360 tonnes of ore. Muck is removed by diesel powered scoop trams and hauled to an underground crusher. After crushing, the ore is hoisted to the surface. There, it is moved via a 1 kilometre long conveyor belt to the mill.

The mine does not have a waste rock dump, as the mined waste rock is left in the underground.

Processing

After arriving at the mill, the crushed ore enters one of several ball and rod mills that grind it with water into sand-size particles. The slurry is piped to froth flotation cells which produce separate copper and zinc concentrates. The mill, which was built in 1985, processes 1.27 million tonnes of ore every year. In 1992 a gravity circuit using a Knelson concentrator was added to the mill to better recover gold.

Coarser tailings are mixed with cement and pumped back into the mine to back-fill the workings. In 2012, the company developed a formal tailings storage facility closure plan, as it had reached capacity.

Myra Falls uses a series of six special settling ponds, called polishing ponds, to clarify and purify the water that comes from the mine, mill, and the tailings pond. These waters contain dissolved metals and mill reagents, and are acidic. Lime and flocculating agents are added to produce clear, clean and neutral water, which is tested daily for toxicity to ensure it is safe for fish and fish habitat before it is released into the environment. Most of the water, however, is pumped back into the mill to be used again.

Environment & Community

Being surrounded by Class A park, all mining activities at Myra Falls, and the eventual reclamation and rehabilitation of the site, fall under a park-use permit. Constant monitoring ensures that environmental concerns and public safety are an integral part of the continuing mine program.

LEGEND

Intrusive Rocks

- **ET** — **Tertiary Intrusives (including Mt. Washington and Clayoquot Plutonic suites):** gabbro (gb), granodiorite (gd), quartz diorite (qd), undifferentiated intrusive rocks (g)
- **LKgr** — **Late Cretaceous Jordan River Metagranodiorite:** mesocratic biotite (hornblende) granodiorite
- **Kgd** — **Cretaceous Intrusives:** granodioritic intrusive rocks
- **EMJgd** — **Early - Middle Jurassic Island Plutonic Suite:** hornblende diorite to quartz diorite and granodiorite; gabbro, tonalite & granite; co-eval with Bonanza Group volcanics
- **Tgb** — **Late Triassic Mt. Hall Gabbro:** diabase, gabbro and leucogabbro with minor diorite; co-eval with basalts of the Vancouver Group (Karmutsen Formation)
- **Dgd** — **Late Devonian Saltspring Intrusive Suite:** granodiorite, quartz-feldspar porphyry

Volcanic and Sedimentary Rocks

- **Qal** — **Quaternary Cover:** alluvium, glaciofluvial gravels & sand, till
- **EOCa** — **Upper Eocene - Oligocene Carmanah Group (incl. Sooke Formation):** undivided sedimentary rocks
- **PEFl** — **Paleogene Flores Volcanics:** subaerial andesite to rhyolite welded tuff, ash-flow tuff, tuff breccia, dacite to rhyolite sills, minor basalt dikes
- **PEMe** — **Paleocene Metchosin Igneous Complex (Metchosin Formation):** massive to pillowed, locally amygdaloidal basalt flows, hyaloclastite breccia, chert, volcaniclastics; sheeted dikes, gabbro
- **uKNa** — **Upper Cretaceous Nanaimo Group:** boulder, cobble & pebble conglomerate, coarse - fine sandstone, siltstone, shale, coal
- **JKLe** — **Jurassic - Cretaceous Leech River Complex (incl. Pandora Peak unit):** slate, phyllite, quartz-biotite schist, quartz-feldspar-garnet-biotite schist, metagreywacke, metabasalt, chlorite schist, ribbon chert, cherty argillite
- **TKPa** — **Triassic - Cretaceous Pacific Rim Complex:** mudstone-rich melange; pillow lava, tuff & chert; green, aphanitic volcanic breccia & massive flows, small diorite intrusions, limestone
- **IJBn** — **Lower Jurassic Bonanza Group:** massive amygdaloidal & pillowed basalt to andesite flows, massive dacite to rhyolite flows, green & maroon tuff
- **muTVa** — **Middle - Upper Triassic Vancouver Group (Karmutsen, Quatsino, Parson Bay & Sutton formations):** massive, locally amygdaloidal &/or pillowed basalt flows, pillow breccia, tuff, interflow sediment & limestone lenses; massive limestone; argillite, graywacke & shaly limestone; bedded limestone
- **CPBt** — **Carboniferous - Permian Buttle Lake Group:** ribbon chert, cherty tuff, graphitic argillite, intercalated sandstone-siltstone-argillite, volcanic sandstone & conglomerate, massive crinoidal limestone
- **DSi** — **Devonian Sicker Group:** pillowed & massive basalt flows, monolithic basalt breccia & pillow breccia; pyroxene-feldspar-phyric agglomerate, breccia, lapilli tuff

Metamorphic Rocks

- **PJg** — **Paleozoic to Jurassic Westcoast Crystalline Complex:** gneiss, amphibolite, migmatite, metasedimentary rocks, & gabbroic to granodioritic plutonic rocks; grades into rocks of the Island Plutonic Suite
- **PJml** — undifferentiated lower-amphibolite/kyanite grade metamorphic rocks

Fault

Thrust fault

Normal fault

Ice field, glacier

ESFS Stop/Exercise

STRAIT OF GEORGIA

JUAN DE FUCA STRAIT

50° 00' E

49° 00' E

124° 00' E

Campbell River

Courtenay

Comox

Cumberland

Denman & Hornby Islands

Qualicum Beach

Parksville

Port Alberni

Nanaimo

Ladysmith

Chemainus

Duncan

Sidney

Victoria

Sooke

Port Renfrew

Ucluelet

Geology of Southern Vancouver Island

(modified after Geoscience Map 2005-3)

Projection: BC Albers Scale 1:1,000,000 Datum: NAD83

0 25 50 75

Kilometres

DMN '13