GY202: Introduction to Petrology – Block 5

THE ISLAND ARC PROJECT

THE PROJECT:

You will investigate the igneous, sedimentary, and metamorphic systems in an island arc setting (Figures A & B) by following the mass incorporated in a parcel of oceanic crust through an island arc system. The parcel will be subducted; some of its mass will be transferred to the mantle wedge overlying the down-going slab; that mass will be incorporated into magma which will rise into the crust; some of the magma will erupt, be eroded, reworked as sediment and deposited in a forearc basin; and some of the sedimentary rocks will get deformed and incorporated into the accretionary prism. Your investigation of this island arc system will involve geological relationships, hand sample observations, petrographic observations, simple theoretical calculations (based on fundamental principles of chemistry and physics), phase diagrams and analysis of geochemical data.

PURPOSES:

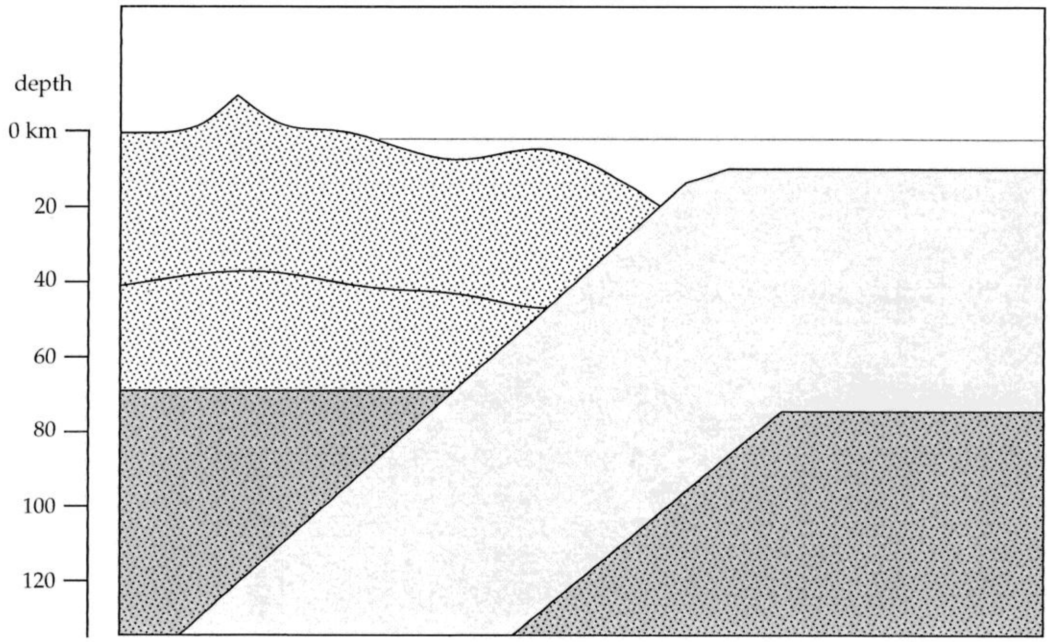
1) To illustrate and apply petrologic techniques and approaches to natural rock systems.
2) To become familiar with the anatomy and physiology of island arcs.
3) To recognize the seamless connections between igneous, metamorphic and sedimentary systems and processes.
4) To hone your ability to integrate large amounts of information and present a synopsis in a clear and organized fashion.

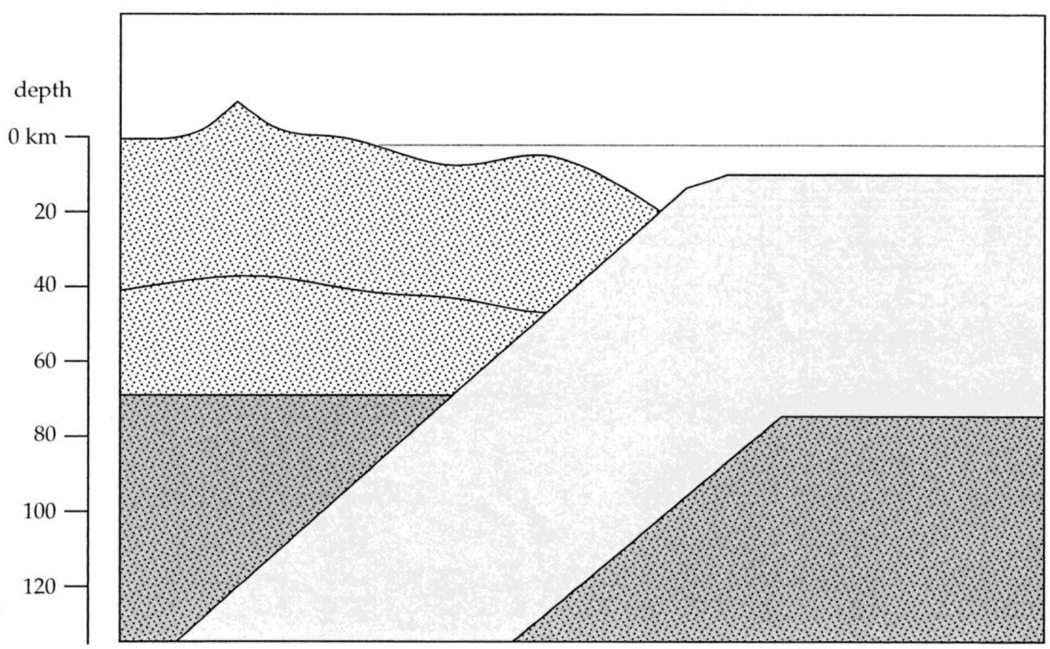
FORMAT:

The project will be completed in the ten steps shown on the following page in Figure B. The steps will be divided into related segments as follows:

IGNEOUS SEGMENT:	*steps 4-7*	*week 1 & 2*
SEDIMENTARY & VOLCANIC SECTION:	*steps 8 & 9*	*week 2 & 3*
METAMORPHIC SEGMENT:	*steps 1-3 & 10*	*week 3*

Each step is a discrete set of exercises, focusing on the processes operating in a limited part of the island arc system, that is designed to be completed separately. However, because we are dealing with a system, each discrete step is related to the preceding steps, as well as the steps that follow.


depth
0 km
20
40
60
80
100
120


depth
0 km
20
40
60
80
100
120

CROSS - SECTIONS FOR THE ISLAND ARC PROJECT

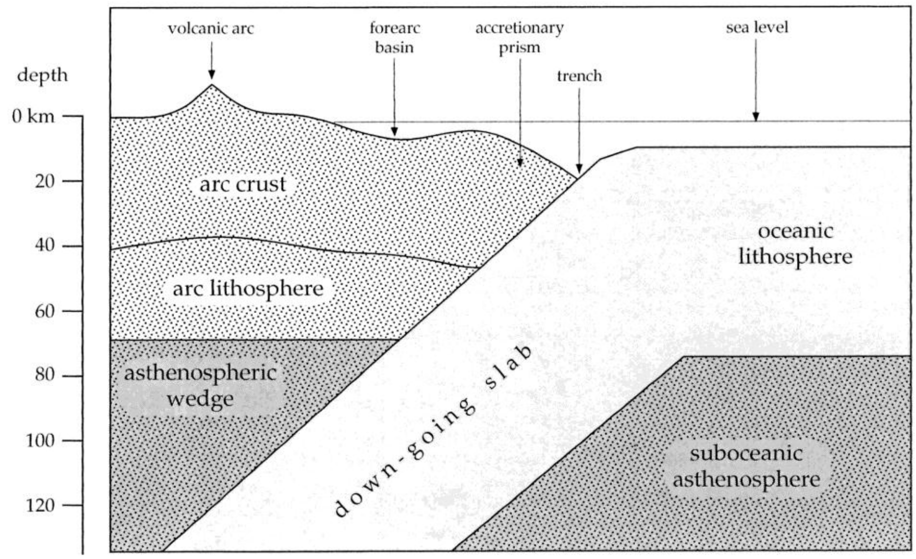


Figure A: This cross-section shows the architecture of the arc as well as the depth to important boundaries

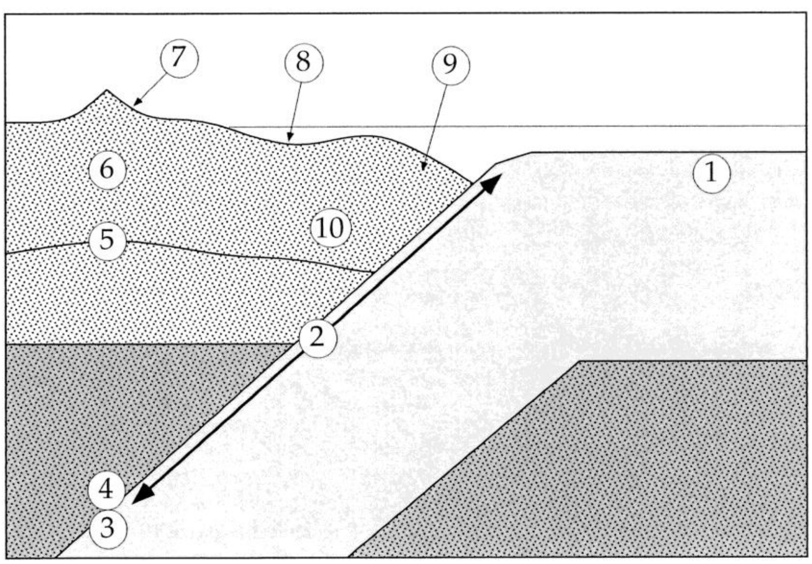


Figure B: This cross-section is the key to 10 segments of the project

GY202: Introduction to Petrology – Block 5
IGNEOUS SEGMENT OF THE ISLAND ARC PROJECT

INSTRUCTIONS: be sure to show ALL OF YOUR WORK as neatly as possible. Include units in every step (a unit analysis) where appropriate. Please circle your final results.

STEP 4: Melting the Mantle above the Down-Going Slab

INTRODUCTION

Previously we considered two ways for the temperature of mantle rocks to exceed the temperature of the mantle solidus, decompression and isobaric heating. We concluded that adiabatic decompression is most consistent with the geological relationships beneath mid-ocean ridges and you did a series of calculations to better understand the complexity of the mantle – melt system. There is a third way to initiate melting: to lower the temperature of the mantle solidus. The most effective way to lower the melting point of any rock is to add water. This is the mechanism by which the mantle above a subduction zone melts.

Consider a 10 km^3 parcel of mantle in contact with the down-going slab at about 120 km depth. Study figures IGN.1 & IGN.2 and review the list of starting parameters and assumptions before attacking the problems. These questions require you to explore the response of the asthenospheric mantle wedge to the transfer of H_2O from the top of the down-going slab.

STARTING PARAMETERS AND ASSUMPTIONS

---

volume of mantle: 10 km^3
initial mantle density: $3.40*10^3$ kg/m^3 = 3.40g/cm^3
initial mantle solidus: T = 10P(kbars) + 1150°C
geothermal gradient: $T = 10 + 0.020892z – 8*10^{-8}z^2$ where z = depth in meters
geobarometric gradient: P = 4.0 km/kbar to 40 km depth and P = 3.2 Km/kbar below 40 km depth
melting depth: 120 km
mantle C_p = 0.25 cal/°C g and does not change as a function of melt production
heat required to melt 100% of the mantle = 100 cal/g
assume that all melt is removed as soon as it forms

starting mineralogy:

mineral	vol%	density (g/cm^3)	melting pt (°C)*
ol	50%	3.40	1700
opx	35%	3.40	1550
cpx	9%	3.28	1340
gnt	6%	3.58	1360

*note that the melting point is for minerals in the presence of H_2O

A. DEGREE OF MANTLE MELTING

Assuming that the slope of the solidus curve decreases by -1.0°C/kbar for every 0.1 wgt% H_2O added to our block of mantle, calculate the weight percentage of the mantle that melts when 1.7×10^{14} g of H_2O is added evenly throughout the 10 km^3 block of mantle.

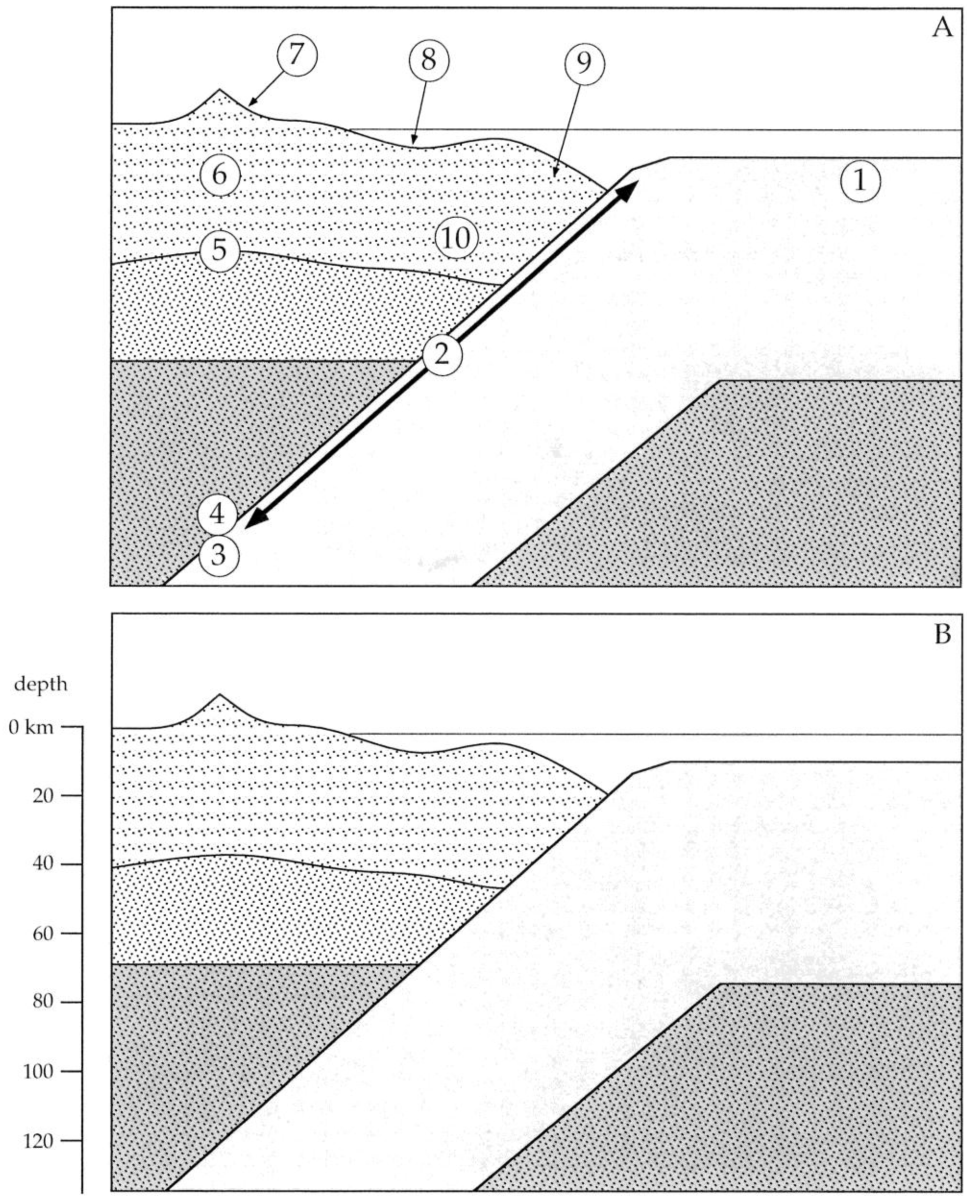


Figure MET.1A&B: Cross-sections of the island arc project

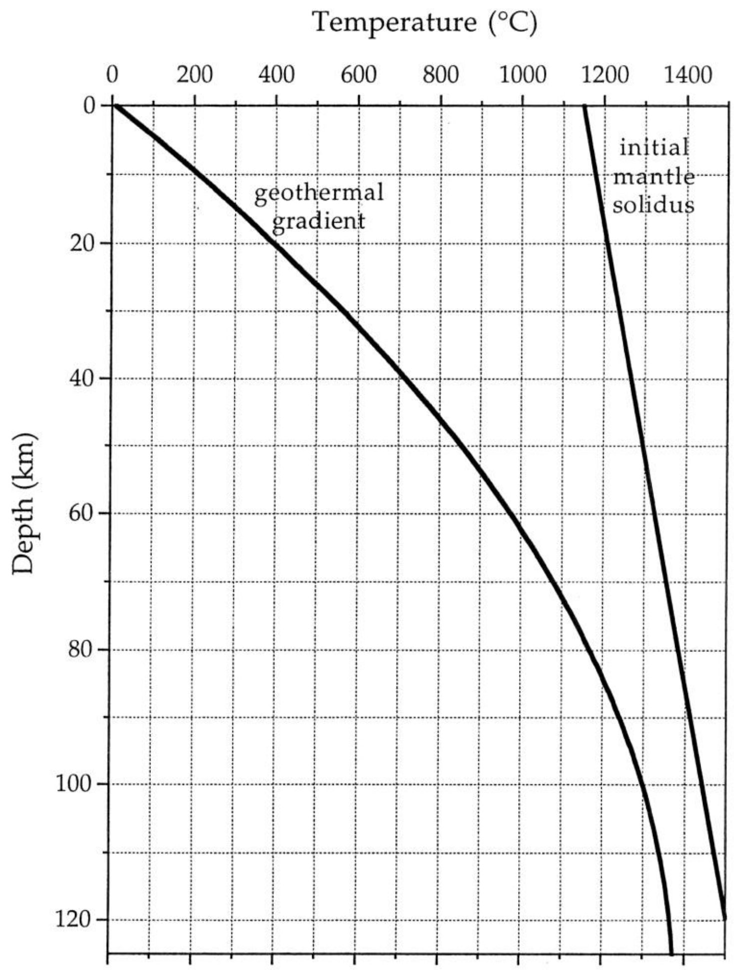


Figure IGN.2: The thermal structure of the mantle above the down-going slab at 120 km depth. Use this plot to set-up the calculations in Step 4 problem A.

B. <u>COMPOSITION OF THE RESULTING MELT</u>

Let's assume that the melt produced in problem A formed by melting the two lowest melting point mineral constituents of the mantle in their given proportions. Using the chemical compositions listed in Table IGN.1, calculate the composition of the melt produced. Note that the chemical analyses are listed in wgt% so that you can directly compare your calculated melt composition to the melt compositions listed in the table. Compare your result to the chemical compositions listed in Table IGN.2 and choose the composition that most closely matches your calculated melt composition. What type of rock did our mantle produce?

Table IGN.1: Mineral Comps			**Table IGN.2: Typical Melt Compositions**					
	cpx	**gnt**	**komatiite**	**basalt**	**basalt**	**basalt**	**andesite**	**dacite**
SiO2	51.90	42.80	45.50	48.30	48.80	50.50	59.65	69.25
Al2O3	10.50	21.70	3.40	9.50	14.41	18.55	18.50	17.80
MgO	14.40	17.50	33.70	22.00	13.90	7.80	4.50	1.50
FeO	3.00	11.30	13.60	11.70	7.60	10.50	7.75	7.65
Cao	20.20	6.70	3.80	8.50	15.30	12.65	9.60	3.80
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

C. <u>CONCENTRATION OF WATER IN THE MELT</u>

Assuming that 50% of the water added to the mantle became dissolved in the melt, calculate the concentration, in wgt%, of the water in the melt.

D. <u>CONCENTRATION OF NICKEL IN THE MELT</u>

Consider the distribution coefficients and concentrations listed below. Using these values calculate the concentration of Ni in the original partial melt.

initial [Ni] in olivine = 4600 ppm $D^{Ni}_{ol} = 20$

STEP 5: Crystallization of the Melt

INTRODUCTION

The melt generated in step 5 rises through the mantle until it encounters the base of the crust where some portion of it pools and crystallizes. On the way, the melt begins to crystallize and undergoes perfect fractional crystallization – that is the crystals separate completely from the melt as they form. Your task in step 5, is to characterize the processes that operate on such a melt. The characteristics you determined in step 4 should be used in the problems below.

A. CRYSTALLIZATION IN THE MANTLE

1) The melt generated in Step 4 rises through asthenosphere without crystallizing until it encounters mantle beneath the arc represented by sample number KH90-1. When the melt encounters this rock type it begins to crystallize. Examine this rock in thin section and complete the accompanying petrographic report.

2) Consider your petrography of KH90-1 as well as the H_2O content of the melt (which you calculated in Step 4). Study the phase diagrams in Figs. IGN.3 and IGN.4. At what approximate pressure and temperature will crystallization begin? To what depth does that pressure correspond? What is the geologic significance of this change in mantle mineralogy? What phase will crystallize? Justify your answers.

B. CRUSTAL UNDERPLATING

1) DEGREE OF MANTLE FRACTIONATION

Some component of the melt reaches the base of the crust at 40 km depth, pools and crystallizes to a plutonic rock. The melt contained 10.49 ppm Ni when the magma chamber formed. Use the equation below to determine how much of the fractionating phase was removed from the melt as it rose through the mantle. Use your results from step 4 and the insights you gained in Step 5 problem A2. NOTE: You must choose the D for the one phase that crystallized in the mantle.

$$\frac{C^{Ni}_{liq}}{C^{Ni}_{o}} = F^{(D-1)}$$

Where C^{Ni}_{liq} = concentration of Ni in the melt when it formed the magma chamber, C^{Ni}_{o} = concentration of Ni in the melt when it began to crystallize in the mantle, F = fraction of melt remaining after the crystals have been removed, and D = the distribution (partition) coefficient for the crystallizing phase. Use the one of the D values listed below – the appropriate D value.

	olivine	opx	cpx	garnet
D for Ni	20	4	3	0.8

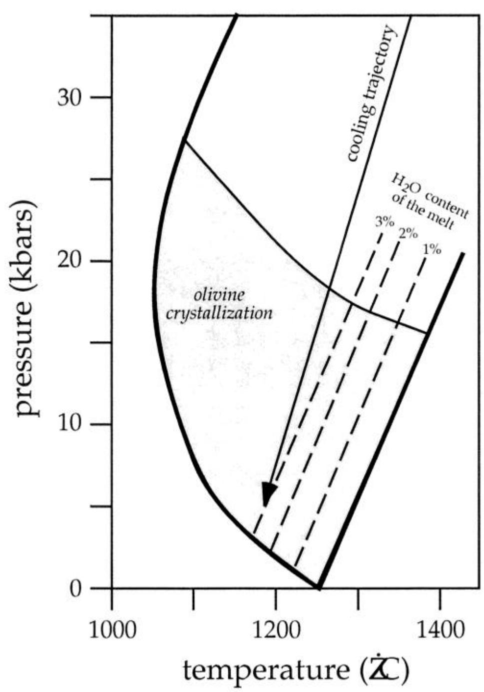


Figure IGN.3: Phase diagram for hydrous mafic magma. The dark curves are the anhydrous (line) and H2O-saturated (lower curve) liquidi. The dashed lines represent the liquidi curves for mafic magma containing varying amounts of H2O. The shaded region correponds to olivine crystallization at temperatures below the appropriate (proper H2O concentration in wgt%) liquidus. The cooling trajectory shows the cooling path of the melt.

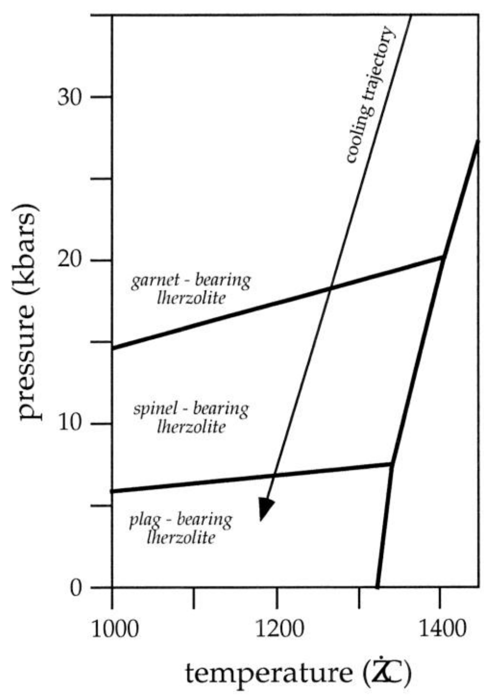


Figure IGN.4: Phase diagram for mantle lherzolite showing the pressure-dependence on the stable aluminum-bearing varietal phase. Notice that plagioclase-bearing lherzolite occurs at crustal pressures and is therefore not observed in the mantle in most parts of the earth. The cooling trajectory shows the cooling path of the melt.

Petrographic Report

Name: ______________________ Sample #: KH90-1

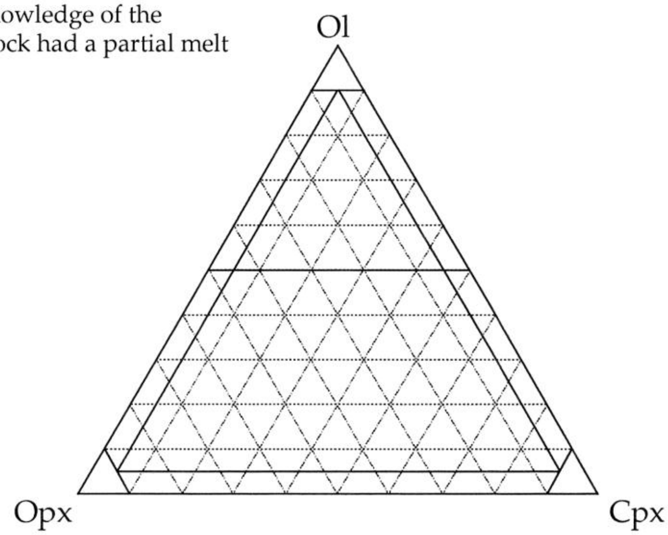
Hand Sample Description (complete rock name):

Color Index:

Mineralogy	mode	composition (if possible)
olivine		
orthopyroxene		
clinopyroxene		
*		

**critical new mineral; identify and list key properties under comp.*

Based on the mode and your knowledge of the mantle, do you think that this rock had a partial melt removed? Explain



Abbreviated Rock Name:

Petrographic Report

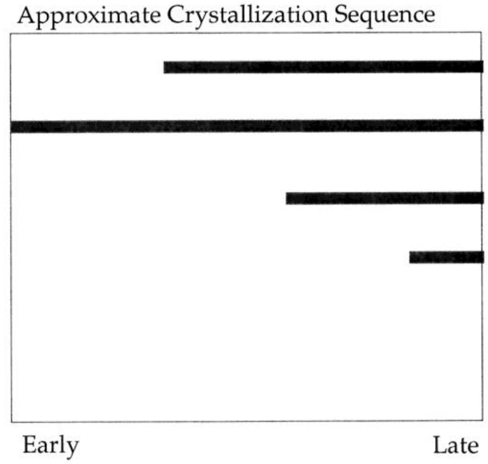
Name: ______________________ Sample #: 3304

Hand Sample Description (complete rock name):

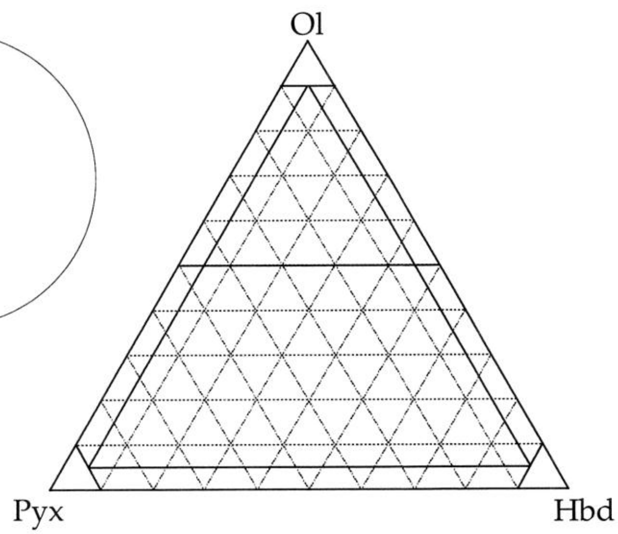
Color Index:

Essential & Varietal Mineralogy	mode
plagioclase	
orthopyroxene	
hornblende	
opaques	
biotite	

Approximate Crystallization Sequence



describe and sketch the prominent reaction relationships between orthopyroxene and hornblende



When did the biotite form in the sequence?________
Where did it get the Fe it needed?________________

Abbreviated Rock Name:

2) <u>CRYSTALLIZATION AT THE BASE OF THE CRUST</u>
Once in the magma chamber, the melt crystallizes to form the plutonic rock represented by sample 3304. During the crystallization, only the one phase (from A.2) sank to the bottom of the chamber. What type of rock would occur as a cumulate layer? The other crystallizing phases remained suspended and make up the rock that eventually formed. Complete the petrographic report for sample 3304.

3) <u>INTERPRETATION OF THE INITIAL MELT COMPOSITION</u>
Consider the entire crystallization history of the magma from initial crystallization in the mantle to final solidification in the magma chamber. Based on that crystallization history and your calculations in Stage 5 B1, plot on the Fo-An-Di ternary system the position, as precisely as possible, of the bulk composition of the melt produced in the source region. Use the ternary diagram in Fig IGN.5.

4) PETROENESIS OF THE RESULTING PLUTONIC ROCK
Consider the textures, mineralogy and crystallization sequence of sample 3304. Explain in some detail the petrogenesis of this sample. In particular, discuss the implications of the reaction relationship between the two prominent mafic minerals (the reaction relationship you sketched on your petrographic report).

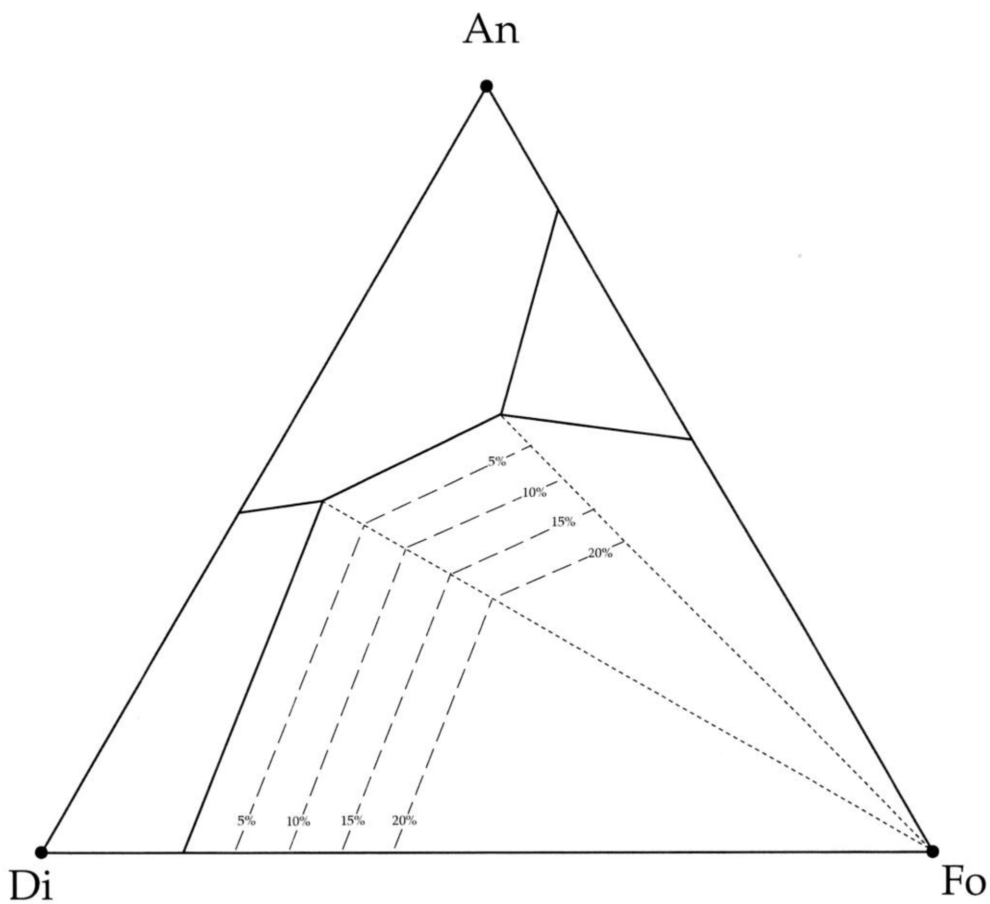


Figure IGN.5: ternary diagram with two fields within the Fo-field contoured for the percent olivine removed by fractional crystallization

STEP 6: Magmatic Processes in the Middle and Upper Crust

INTRODUCTION

The melt that pooled at the base of the crust released enough heat to melt the crust whereas the melt that didn't pool at the base of the crust continued upward where it interacted with the crustal melts. This step examines the rock types produced by the interaction between magmas generated in very different environments.

A. HAND SAMPLES OF MINGLING MAGMAS

Study the hand samples and describe the evidence for magma mingling in some detail.

B. MAGMA MIXING CALCULATION

Two magmas mixed in the sub-arc region, producing a composite mixed rock composition. Workers who stress differentiation, might initially believe that the basaltic melt fractionated to a diorite that in turn fractionated to the final granite. Geologists who paid careful attention to field observations such as you just did in the hand samples, might have found convincing evidence that two magmas commingled in the plutonic environment producing a hybrid third composition.

Using the compositions of the three samples below, plot simple Harker diagrams (SiO2 x each of the other elements). Does this plot favor fractionation or mixing? _________________________. Briefly explain why.

Calculate the proportion of basaltic and granitic end-members necessary to produce a hybrid of this composition.

_____________% Basalt

_____________% Granite

Which oxides give the poorest fit?____

Why might these fit so poorly?

OXIDE	BASALT	GRANITE	HYBRID/DIORITE
SiO2	54.73	75.54	56.62
TiO2	2.04	0.24	1.80
Al2O3	14.38	13.43	14.75
FeO	11.08	1.31	9.80
MnO	0.19	0.05	0.15
Mgo	4.24	0.33	4.01
CaO	7.24	1.12	6.94
Na2O	2.90	3.64	3.29
K2O	2.11	4.25	1.95
P2O5	1.10	0.08	0.69

Does the chemistry support or argue against mixing of these samples?

C. THE ORIGIN OF SAMPLE #2679

1) Complete the petrographic report for sample 2679.

2) Plot the mode of sample 2679 on the granitoid ternary in Figure IGN.6. Study this diagram and then consider the following question. Could this rock be produced by mixing the magmas preserved in the hand samples? On Fig. IGN.6, plot two reasonable end member magmas based on the hand samples from problem 6A. Explain your answer with regards to Fig. IGN.6.

3) Let's assume that the lower crust was composed of mafic rocks. When the melt that eventually became sample #3304 came into contact with the mafic lower crust, the crust partially melted to form the magma that eventually pooled in the upper crust and crystallized to form sample #2679. Given this scenario and the phase diagram in Fig. IGN.7, determine the temperature at which this magma formed in the lower crust.

D. THE ORIGIN OF SAMPLE #2694

1) Complete the petrographic report for sample 2694.

2) Plot the mode of sample 2694 on the granitoid ternary in Figure IGN.6. Study diagram and then consider the following question. Could this rock have been produced by mixing the magmas preserved in the hand samples from problem 6A? On Fig. IGN.6, plot two reasonable end member magmas based on the hand samples from problem 6A. Now show where sample #2694 would fall along the line connecting the two end members represented by the hand samples from 6A. Use the Lever Rule to determine the relative proportions of the two end members that could be mixed to produce sample #2694.

3) What kind of geologic evidence would you look for in the field to demonstrate that sample #2694 formed by magma mixing?

Petrographic Report

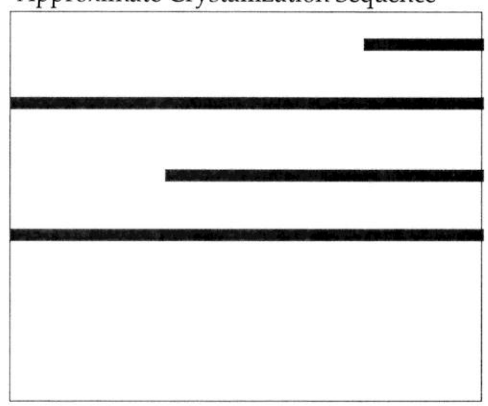
Name: ______________________ Sample #: 2679

Hand Sample Description (complete rock name):

Color Index:

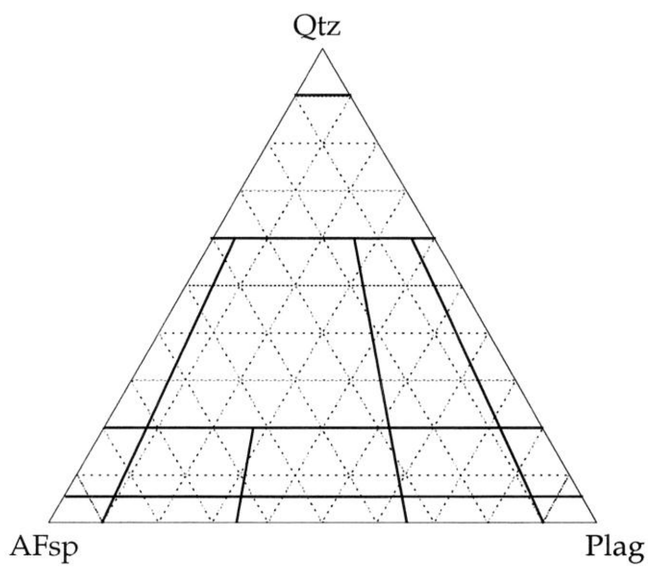
Essential & Varietal Mineralogy	mode
quartz	
plagioclase	
biotite	
hornblende	

Approximate Crystallization Sequence



Early Late

Abbreviated Rock Name:



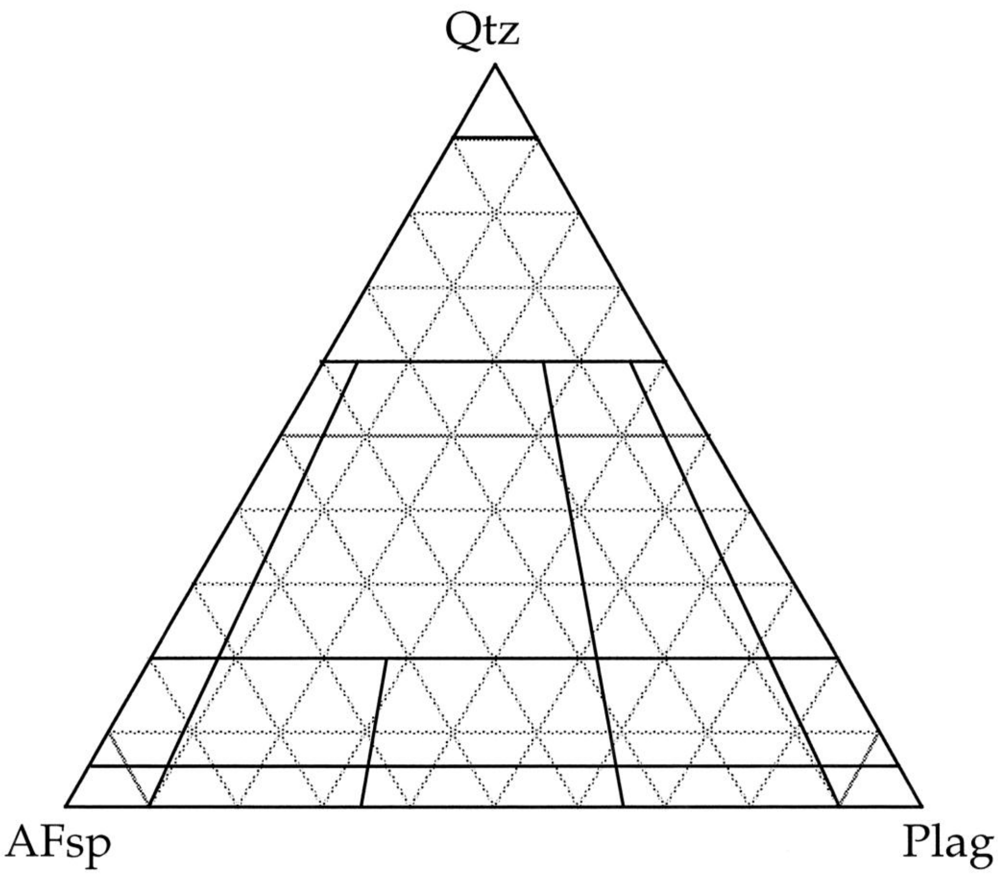


Figure IGN.6: Ternary diagram for granitoids.

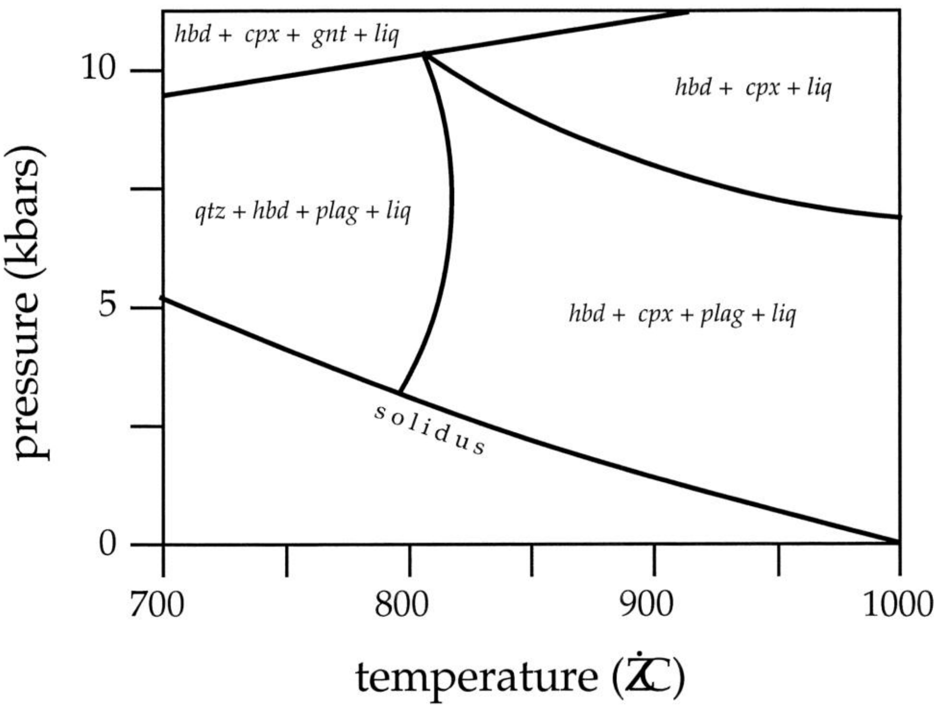


Figure IGN.7: Phase diagram for the melting of mafic rocks containing < 5% H2O. The phenocryst assemblages at different temperatures and pressures are shown.

Petrographic Report

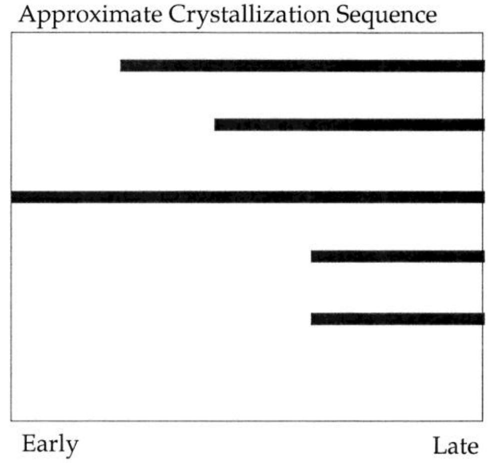
Name: ______________________ Sample #: 2694

Hand Sample Description (complete rock name):

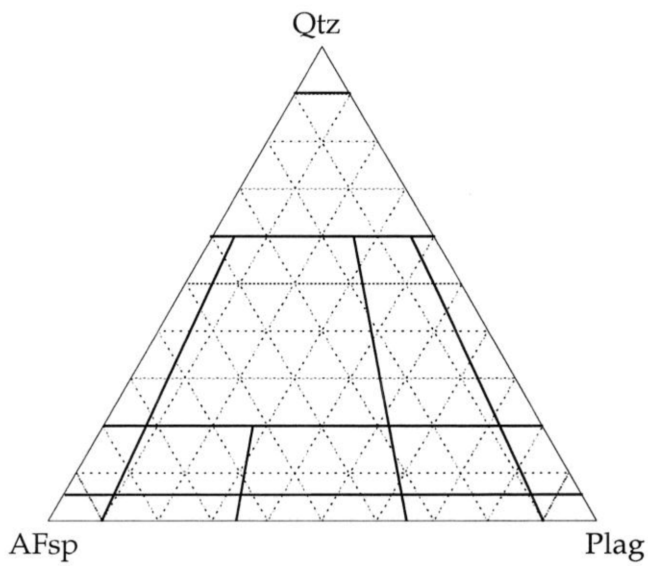
Color Index:

Essential & Varietal Mineralogy	mode
plagioclase	
biotite	
hornblende	
quartz	
orthoclase	

Approximate Crystallization Sequence



Abbreviated Rock Name:



STEP 7: Volcanism on the Island Arc

INTRODUCTION

Based on the compositional variation we've seen so far beneath our island arc, we shouldn't be surprised to find a variety of volcanic rocks as well. In this step you will examine five rocks that crystallized from lavas that flowed over the flanks of the volcano. Study the stratigraphy shown in Figure IGN.8 before proceeding. We'll see some pyroclastic volcanic rocks when we examine the forearc basin in Step 8.

In this step you will examine thin sections and hand samples of six samples, in order of decreasing age, from the volcanic sequence. Your petrography will form the basis for interpreting the petrogenesis of the lavas.

Complete the petrographic reports provided for each of the samples listed below.

A. SAMPLE 58-k-91

B. SAMPLE 2524

C. SAMPLE 0509

D. SAMPLE 66-K-91

E. SAMPLE 0039

SUMMARY PAPER: Prepare a one-page summary of the major igneous processes which effected the block of melted material in these 4 steps!

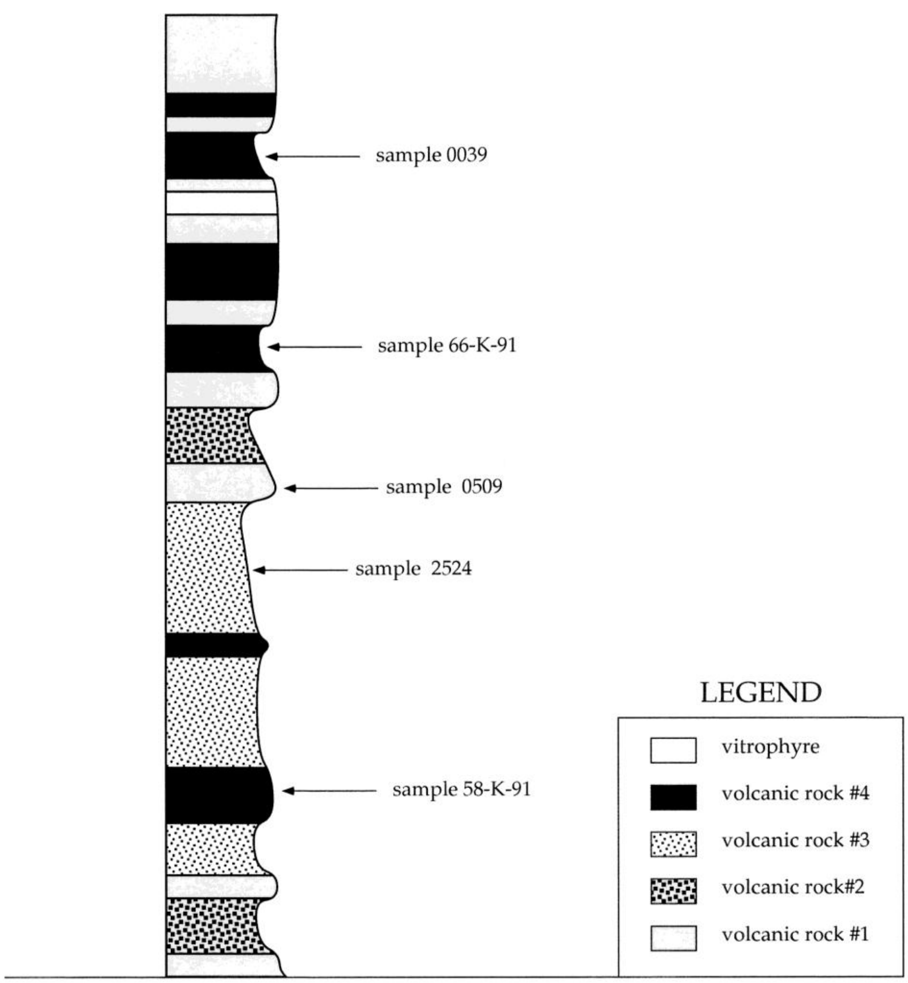


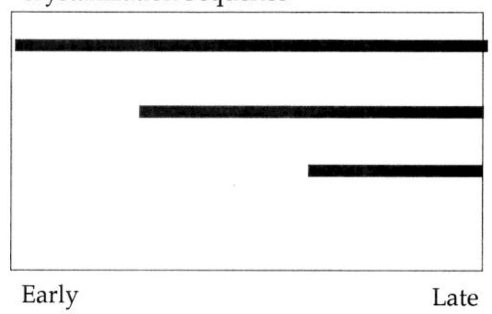
Figure IGN.8: stratigaphic column for the volcanic sequence on the flank of the volcano

Petrographic Report

Name: ____________________ Sample #: 58-K-91

Phenocryst Assemblage		mode
plagioclase		
olivine Ňcomposition =		
orthopyroxene		

Crystallization Sequence



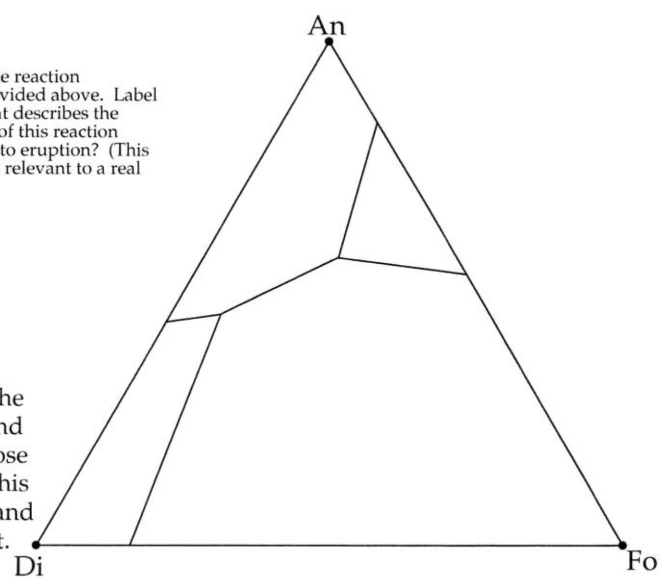
Give an abbreviated rock name:

Estimate the modal abundance of glass in the groundmass. The glass is isotropic in crossed polars and brown in plane polarized light. It contains tiny bubbles that might look like opaque grains.

Ňmode

Go to the circled area of the thin section. Sketch the reaction relationship at high magnification in the space provided above. Label the phases involved. Write a chemical reaction that describes the textural relationship. What does the preservation of this reaction imply about the temperature of the melt just prior to eruption? (This question assumes that the binary phase diagram is relevant to a real rock).

Considering *the relative proportion* of the phenocrysts, groundmass and glass and note the crystallization sequence, choose an appropriate bulk composition for this rock on the Fo-An-Di ternary system and sketch a possible line of liquid descent.



Petrographic Report

Name: ______________________ Sample #: 2524

Phenocryst Assemblage

plagioclase
alkali feldspar which one?
biotite
hornblende
quartz

Give an abbreviated rock name:

In the space provided below, sketch the shape of two *representative* crystals of quartz and plagioclase phenocrysts. Suggest three different magmatic processes that could produce the contrasting textures exhibited by these two minerals. Be sure to label your sketches.

plagioclase

quartz

Did this rock crystallize from an anhydrous magma? Explain.

Petrographic Report

Name: ____________________ Sample #: 0509

Phenocryst Assemblage (identify the two phases)	Groundmass Phases
	plagioclase
	glass
Give an abbreviated rock name:	opaque phase

Examine the the phenocrysts on the thin section. These grains exhibit a sharp change in both color and retardation from core to rim. What does this abrupt change in optical properties represent with regards to the mineral grains?

What change in the magma could have caused such a change in the mineral? Justify your answer in some detail and give at least two potential causes.

Did this rock crystallize from an anhydrous magma? Explain.

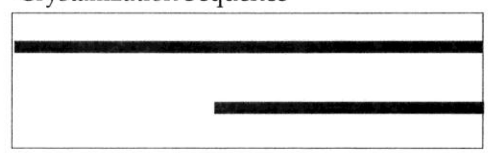
Petrographic Report

Name: ______________________ Sample #: 66-K-91

Phenocryst Assemblage	Ňmode
plagioclase	
*pyroxene:________ **	

** ortho or clino?*

Crystallization Sequence



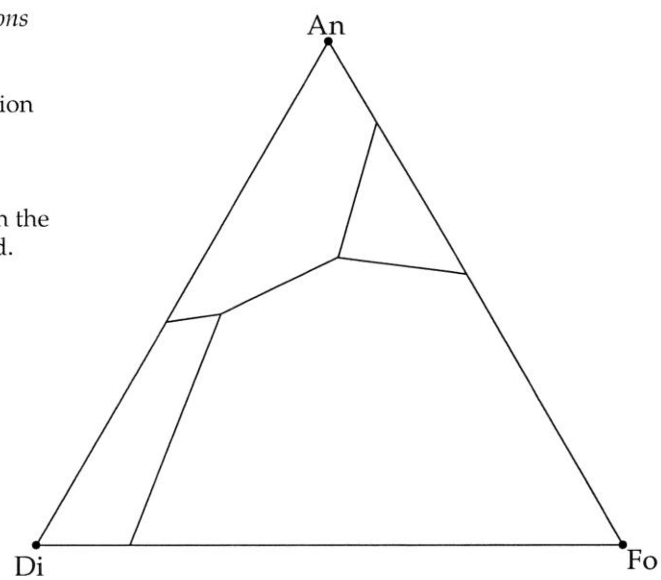
Early — Late

give an abbreviated rock name:

Estimate the modal abundance of glass in the groundmass. The glass is isotropic in crossed polars and brown in plane polarized light. It contains tiny bubbles that might look like opaque grains.

[ ] Ňmode

Considering both *the relative proportions* and the textural relationships of the phenocrysts, groundmass and glass, choose an appropriate bulk composition for this rock on the Fo-An-Di ternary system. Show an appropriate crystallization path from the bulk composition and indicate the point on the diagram at which the magma erupted. Assume the pyroxene in the rock is diopside rather than opx.



Petrographic Report

Name: ______________________ Sample #: 0039

Phenocryst Assemblage

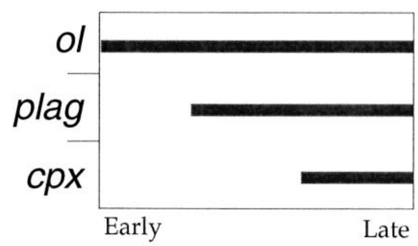
Phenocryst Assemblage		mode
olivine		
plagioclase composition =		
clinopyroxene which one? ________		

give an abbreviated rock name:

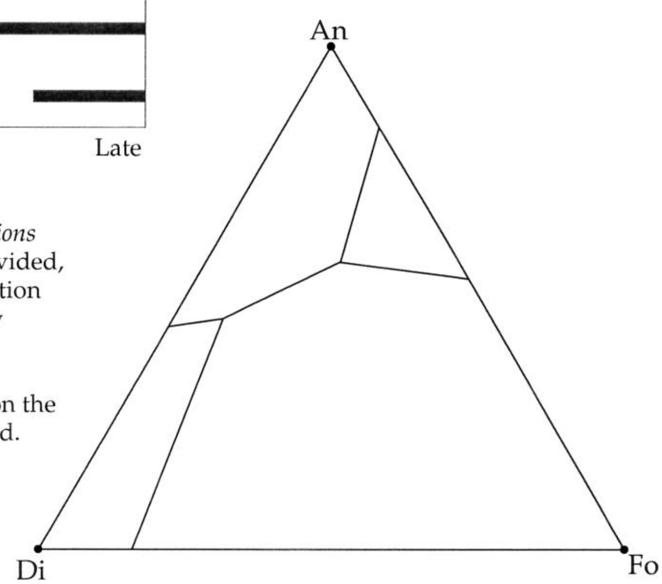
Estimate the modal abundance of glass in the groundmass. The glass is isotropic in crossed polars and brown in plane polarized light. It contains tiny bubbles that might look like tiny opaque grains.

Ňmode

The crystallization sequence is based on the textural relationships in the circled areas of the thin section. Be sure you can derive the sequence.



Considering both *the relative proportions* and the crystallization sequence provided, choose an appropriate bulk composition for this rock on the Fo-An-Di ternary system. Show an appropriate crystallization path from the bulk composition and indicate the point on the diagram at which the magma erupted.



GY202: Introduction to Petrology – Block 5
SEDIMENTARY SEGMENT OF THE ISLAND ARC PROJECT

STEP 8: Geologic Record of the Forearc Basin

INTRODUCTION
In the previous step you examined volcanic rocks on the flank of an arc volcano. In this step you will observe a realistic stratigraphic sequence from a portion of a typical forearc basin (Figs. SED.1a & SED.1b). The main goal is to observe and interpret the lithologic variability of rocks deposited in a relatively underformed basin. As such, you will be looking at hand samples and thin sections rather than performing calculations. Ultimately you will use your petrographic observations to reconstruct the geologic history as preserved in the sequence of rocks deposited in the forearc basin.

INSTRUCTIONS
Study the stratigraphic column in figure SED.2. Pay particular attention to changes in lithology as a function of time. Examine the hand samples and thin sections of each sample indicated on the stratigraphic column. Complete the accompanying petrographic reports and use this information to interpret the geologic history of the forearc basin.

STEP 9: The Accretionary Prism: Scrapings from the Down-Going Slab

INTRODUCTION
As the oceanic lithosphere travels down the subduction zone, deep sea sediments, chunks of oceanic crust and even pieces of mantle get scraped off the slab and accreted to the forearc. The resulting prism of accreted material forms the inner wall of the trench and the continual addition of material results in extensive deformation in the form of folds and thrust faults. This process has been modeled after the behavior of wet snow in from of a slow-moving snow ploy – the so-called “critical taper” or “critical wedge” model. Anyway, the rocks that comprise the accretionary prism are lithologically diverse and structurally complex (see Figs. SED.3-SED.5). The goal of this exercise is to give you a taste of this diversity and complexity. Study the figures mentioned above before proceeding.

INSTRUCTIONS
Study the cross-sections in figures SED.3-SED.5. The five samples you will examine come from the small area shown on figure SED.5. They come from semi-continuous layers (e.g. 56) as well as large isolated blocks (ranging in size from a car to many city blocks in NYC) called olistoliths (1059, PS3cd, PS3aoc, and BR-5). Olistoliths are blocks that form at the toe of emergent thrust sheets. For each sample complete the accompanying petrographic report. Interpret the possible origin of the rock. Use your observations, in concert with information derived from your extensive research, as a basis for a discussion of the geology of the accretionary prism.

CROSS - SECTIONS FOR THE ISLAND ARC PROJECT

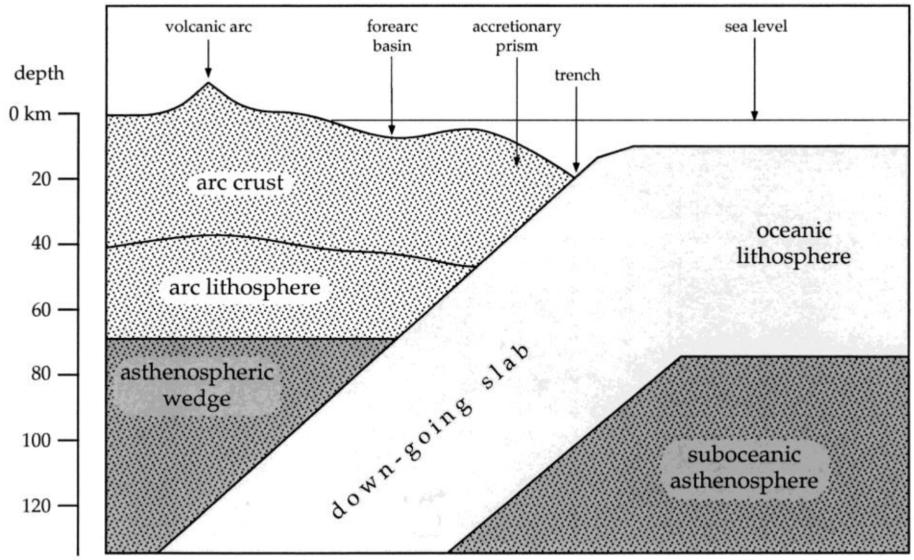


Figure SED.1a: This cross-section shows the architecture of the arc as well as the depth to important boundaries

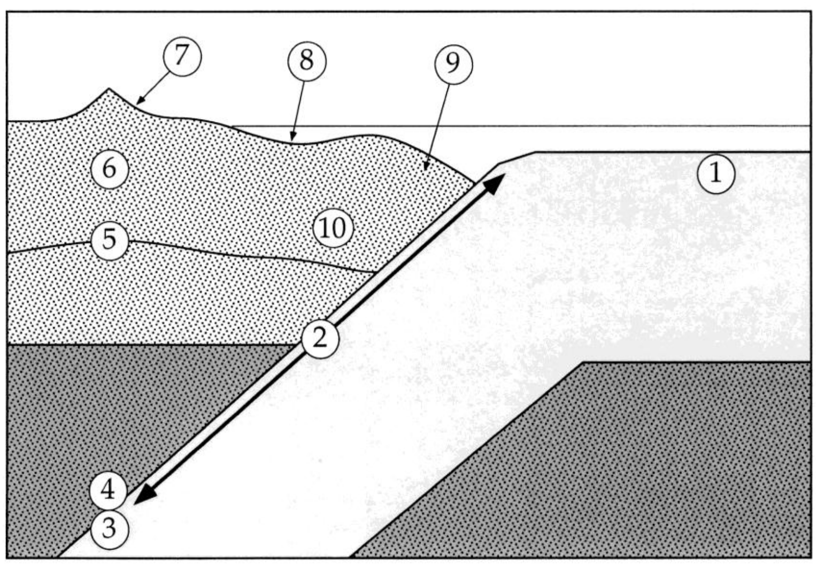


Figure SED.1b: This cross-section is the key to 10 segments of the project

Island Arc Project — Sedimentary Segment
Stratigraphic Column for Step 8

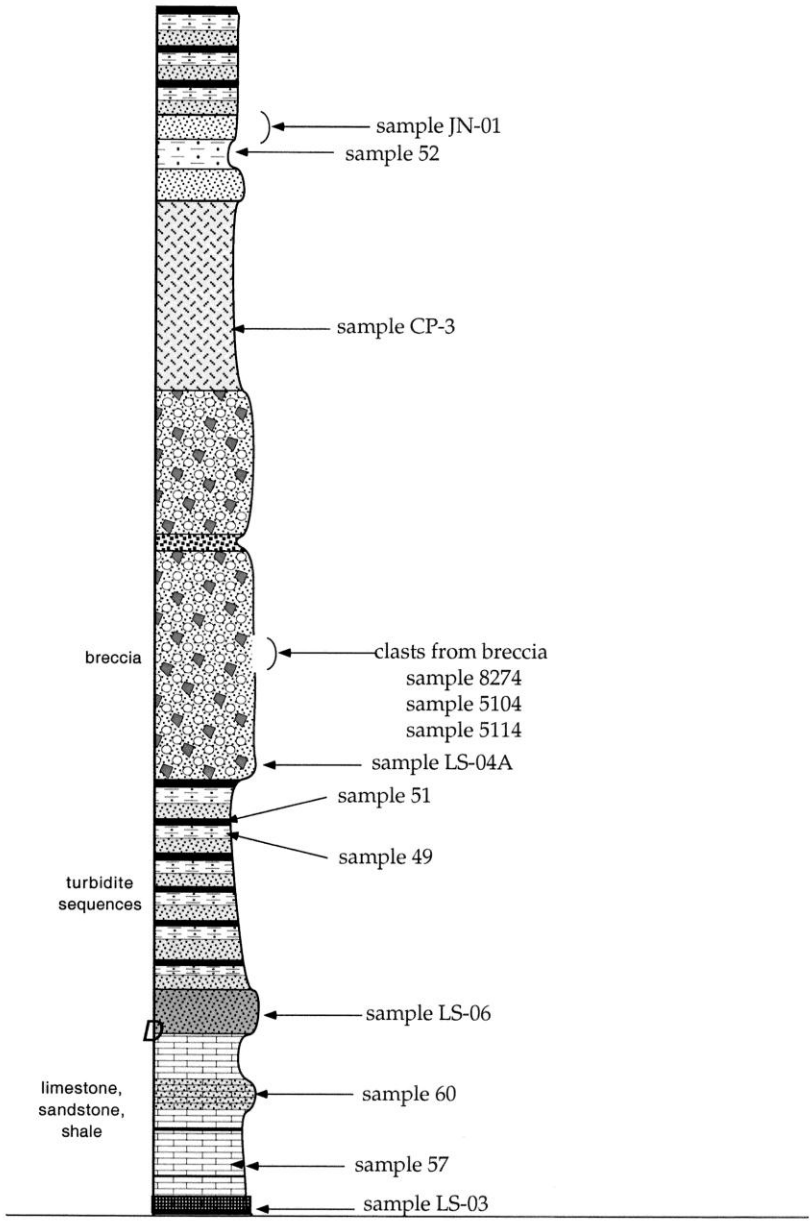
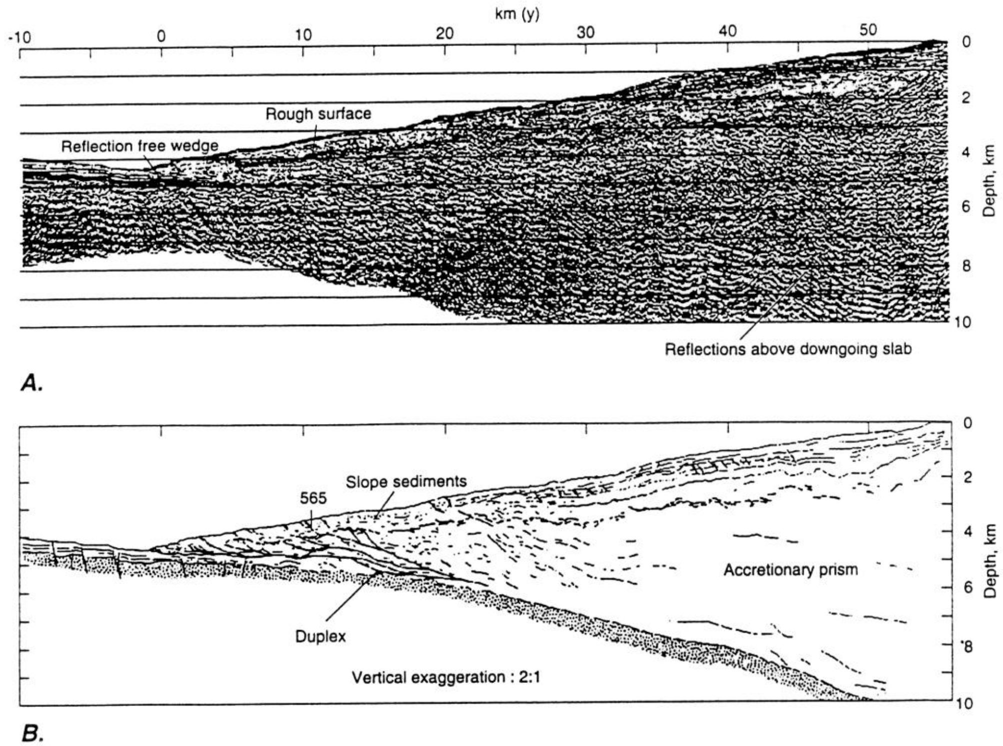


Figure SED.2: Stratigraphic column for a portion of the forearc basin.

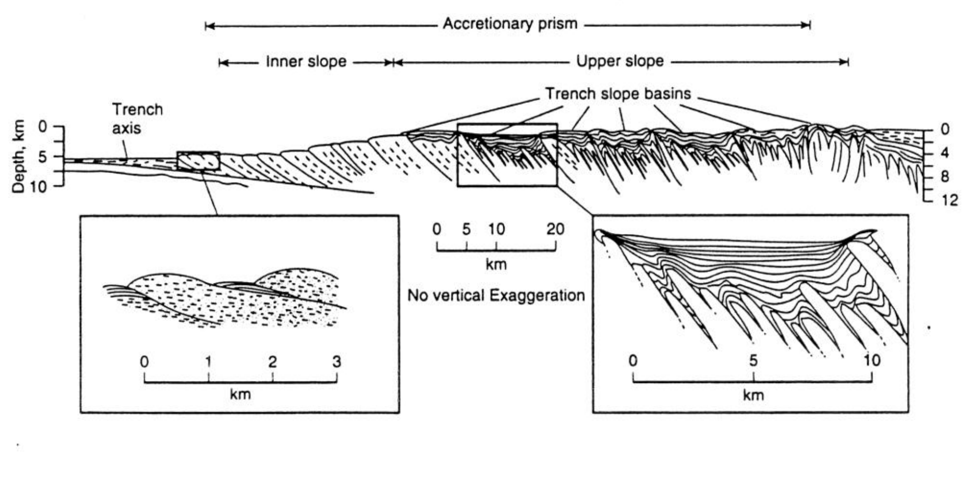
SED 3

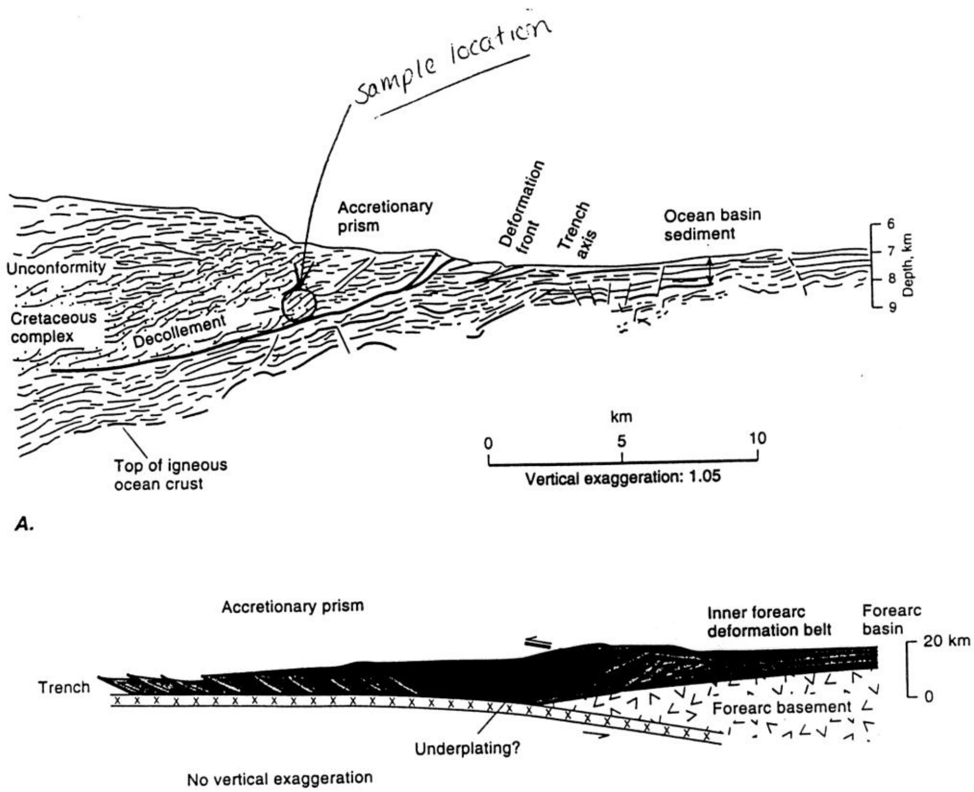
~~Figure 7.9~~ Underplating of the accretionary prism off Costa Rica. *A*. Migrated seismic reflection profile off Costa Rica showing complex reflections. Note reflections above downgoing slab. *B*. Line-drawing interpretation of the seismic reflection profile in (*A*) that shows underplating of the accretionary prism by duplex formation. *(After Shipley et al., 1992)*



SED 4

~~Figure 7.7~~ Structure of an accretionary prism: the Sunda arc. The inner trench slope and forearc basin region are underlain by an accretionary prism of imbricate thrusts and trench slope basins. Accreted sediments are thrust over the slope sediments (*insets*). Compared with the inner trench slope area, the thrust faults are steeper under the forearc basin and involve older sediments in the faulting. *(After Moore et al., 1980)*





B.

SED 5
~~Figure 7.10~~ Deformation styles in accretionary prisms. *A.* Line drawing of seismic reflection depth section across the Japan Trench off northeast Honshu. Note the undeformed sediments beneath the master décolletement. *B.* Schematic cross section of an accretionary prism, an example of a two-sided accretionary complex. The wedge is largely detached from both the downgoing slab and the forearc crust. *(A. after von Huene and Scholl, 1991; B. after Unruh and Moores, 1991; Torrini and Speed, 1989; Silver and Reed, 1988)*

Petrographic Report

Name: ______________________ Sample #: LS-03

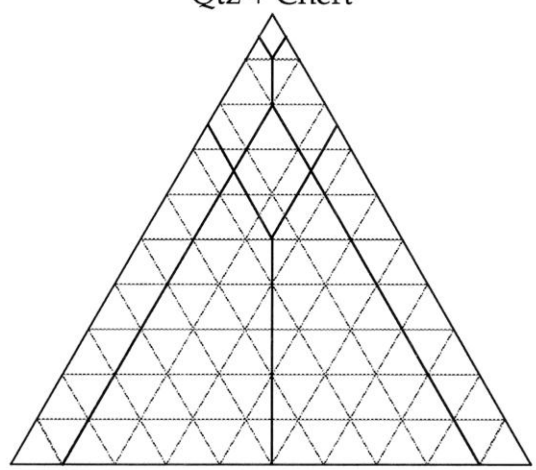
Size	
Morphology	
Sorting	
Textural Maturity	

Composition

% Matrix	
% Quartz	
% Feldspar	
% Rock Fragments	

Other Constituents:

Detailed Rock Name (see Table 13-4, p258)



Interpretations

Suggest a likely provenance. Justify your choice.
Comment briefly on the transport distance based on the textural and mineralogical maturity

Petrographic Report

Name: ______________________ Sample #: 60

Brief Description of the Rock

Dunham Classification *identify the grain types to specifically name the rock e.g., ooid grainstone*	
Possible Environments *be very general*	

Sample #: 57 *Note that this thin section is a bit thick*

Brief Description of the Rock

Dunham Classification *identify the grain types to specifically name the rock e.g., ooid grainstone*	
Possible Depositional Environments *be very general*	

Briefly describe the history of this rock:

Petrographic Report

Name: ____________________ Sample #: LS-06

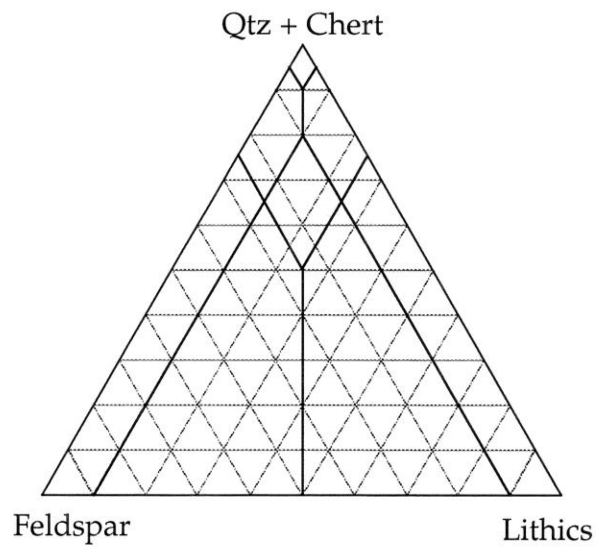
Size	
Morphology	
Sorting	
Textural Maturity	

Composition

% Matrix	
% Quartz	
% Feldspar	
% Rock Fragments	

Other Constituents:

Detailed Rock Name (see Table 13-4, p258)



Interpretations

Suggest a likely provenance. Justify your choice.

Comment briefly on the transport distance based on the textural and mineralogical maturity

Petrographic Report

Name: ______________________ Sample #: 49

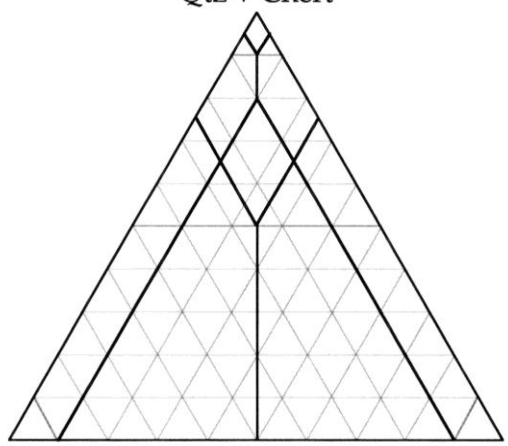
Size	
Morphology	
Sorting	
Textural Maturity	

Composition

% Matrix	
% Quartz	
% Feldspar	
% Rock Fragments	

Other Constituents:

Detailed Rock Name (see Table 13-4, p258)



Interpretations

Suggest a likely provenance. Justify your choice.

Comment briefly on the transport distance based on the textural and mineralogical maturity

Petrographic Report

Name: ______________________ Sample #: 51

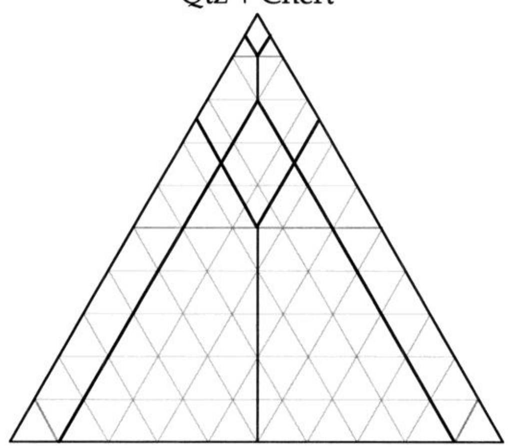
Size	
Morphology	
Sorting	
Textural Maturity	

Composition

% Matrix	
% Quartz	
% Feldspar	
% Rock Fragments	

Other Constituents:

Detailed Rock Name (see Table 13-4, p258)



Interpretations

Suggest a likely provenance. Justify your choice.

Comment briefly on the transport distance based on the textural and mineralogical maturity

Petrographic Report

Name: ______________________ Sample #: LS-04A

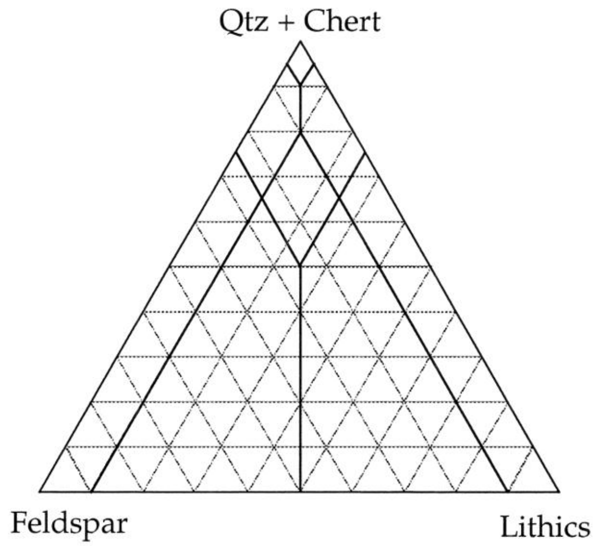
Size	
Morphology	
Sorting	
Textural Maturity	

Composition

% Matrix	
% Quartz	
% Feldspar	
% Rock Fragments	

Other Constituents:

Detailed Rock Name (see Table 13-4, p258)



Interpretations

Suggest a likely provenance. Justify your choice.

Comment briefly on the transport distance based on the textural and mineralogical maturity

Petrographic Report on Clasts from the Breccia

Sample #: 8274 Name: ______________________

Rock Type (extrusive igneous; intrusive igneous; chemical sedimentary; clastic sedimentary):
Abbreviated Rock Name:

Sample #: 5104

Rock Type (extrusive igneous; intrusive igneous; chemical sedimentary; clastic sedimentary):
Abbreviated Rock Name:

Sample #: 5114

Rock Type (extrusive igneous; intrusive igneous; chemical sedimentary; clastic sedimentary):
Abbreviated Rock Name:

Petrographic Report

Name: ______________________ Sample #: CP-3

Hand Sample Description:

"Phenocryst" Assemblage

"Lithics" Assemblage

Modal Ash

Modal Lapilli

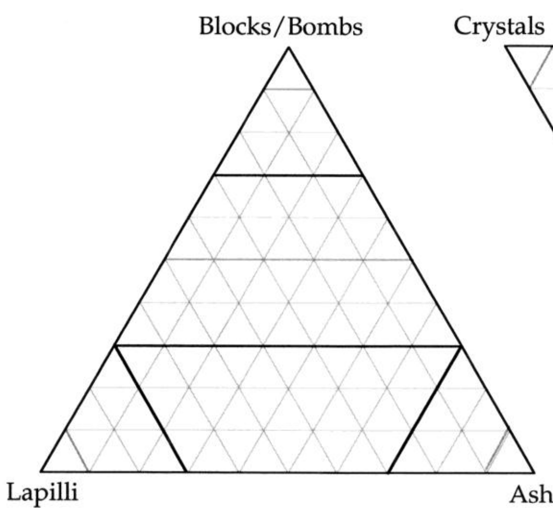
Modal Blocks

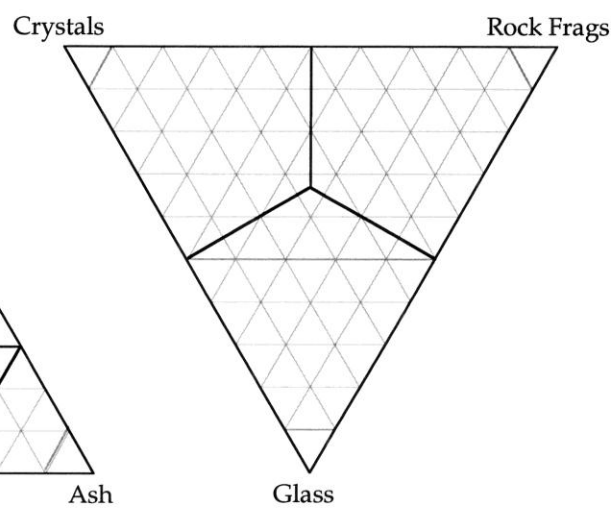
Modal Crystals

Modal Glass

Modal Rock Fragments

Give a complete rock name:





Petrographic Report

Name: ______________________ Sample #: 52

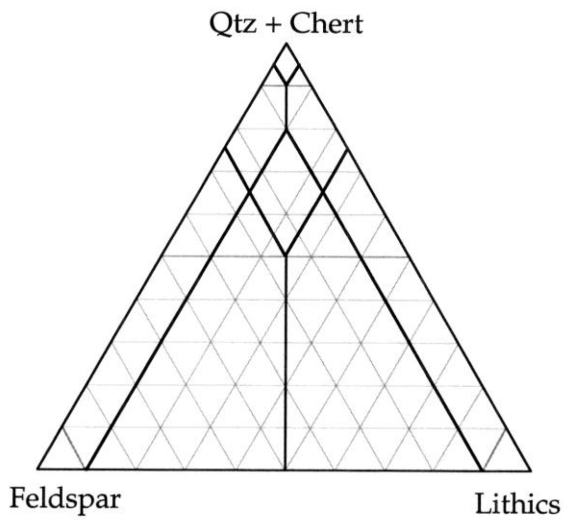
Size	
Morphology	
Sorting	
Textural Maturity	

Composition

% Matrix	
% Quartz	
% Feldspar	
% Rock Fragments	

Other Constituents:

Detailed Rock Name (see Table 13-4, p258)



Interpretations

Suggest a likely provenance. Justify your choice.

Comment briefly on the transport distance based on the textural and mineralogical maturity

Petrographic Report

Name: ______________________ Sample #: JN-01

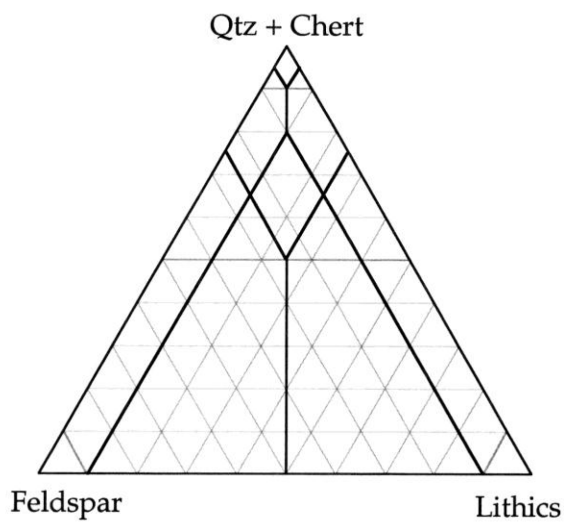
Size	
Morphology	
Sorting	
Textural Maturity	

Composition

% Matrix	
% Quartz	
% Feldspar	
% Rock Fragments	

Other Constituents:

Detailed Rock Name (see Table 13-4, p258)



Interpretations

Suggest a likely provenance. Justify your choice.

Comment briefly on the transport distance based on the textural and mineralogical maturity

Petrographic Report for Olistoliths from the Accretionary Prism

Name: ______________________________

Sample #: **BR-5**

Rock Type (chemical sedimentary; clastic sedimentary; metamorphic rock):	
Abbreviated Rock Name:	Protolith:

Sample #: **56** *NOTE: this thin section is extremely thick — look at the circled area only.*

Rock Type (extrusive igneous; intrusive igneous; chemical sedimentary; clastic sedimentary):	
Abbreviated Rock Name:	Origin of the Rock:

Sample #: **PS-3cd**

Rock Type (chemical sedimentary; clastic sedimentary; metamorphic rock):	
Abbreviated Rock Name:	Protolith:

Sample #: **1059**

Rock Type (chemical sedimentary; clastic sedimentary; metamorphic rock):	
Abbreviated Rock Name:	Protolith:

Petrographic Report

Name: ______________________________

Sample #: PS-3aoc

Rock Type (chemical sedimentary; clastic sedimentary; metamorphic rock):	
Abbreviated Rock Name:	Protolith:

GY202: Introduction to Petrology – Block 5
METAMORPHIC SEGMENT OF THE ISLAND ARC PROJECT

INSTRUCTIONS: Be sure to show ALL OF YOUR WORK as neatly as possible. Include units in every step where appropriate. Please circle your final results.

STEP 1: Something to Subduct

INTRODUCTION

Oceanic crust, which is only about 10 km thick, is created at mid-ocean ridges. It is composed of five different compositional components. The lower portion of oceanic crust is composed of gabbro that formed in magma chambers. The floor of these gabbro bodies consists of layered cumulates including pyroxenites and peridotites which attest to the importance of fractional crystallization in the petrogenesis of MORB. The gabbro magma chambers are periodically tapped to feed surface lavas flows. The intrusive expression of the tapping process is an extensive “sheeted” dike complex that overlies the gabbros. The sheeted dike complex is characterized by thousands of diabase dikes that intrude older dikes so that each dike has only one quenched margin. These dikes fed lavas at the surface that formed distinctive pillow basalts. The sheeted dikes and pillow lavas form the upper portion of oceanic crust. As the crust moves away from the crest of the mid-ocean ridge, the pillow lavas become partially or wholly buried beneath deep ocean sediment. It is these five components of oceanic crust – cumulates, gabbros, sheeted diabase dikes, pillow lavas, chert – that get subducted at convergent plate boundaries, although much of the sediment is scraped off of the crust and incorporated into the accretionary prism.

As it turns out, the originally glassy pillow lavas and initially pristine, unaltered diabase dikes are not the rock types that end up getting subducted. Instead these originally pristine mafic igneous rocks are metamorphosed by hydrothermal fluids near mid-ocean ridges prior to being subducted. Thus the top of down-going slab is composed of metamorphic rocks with mafic bulk compositions – the protoliths being MOR basalt and MOR diabase. In this exercise, you will examine two such metamorphic rocks in order to better understand the metamorphic reactions that take place at the top of the down-going slab during subduction.

IN PREPARATION:

1) Review Chapter 22 of Blatt & Tracy
2) Review the optical properties of the minerals you’d expect in altered MORB

INSTRUCTIONS

Please do not attempt to do this exercise until you have reviewed the relevant pages of chapter 22. Glance at the thin sections of sample 898 and sample 80 and then answer the questions below. Note that sample 898 is a metamorphosed pillow basalt and sample 80 is a foliated mafic schist. You should only need about 15 minutes to do this exercise and other folks will be waiting so please be efficient.

1) Do these rocks preserve any relict minerals or textures from the protoliths?
2) In what metamorphic facies did these rocks form?
3) What type of reaction dominated the transformation from the primary igneous mineralogy to the metamorphic assemblage preserved in these rocks?
4) What type of metamorphism affected these samples?

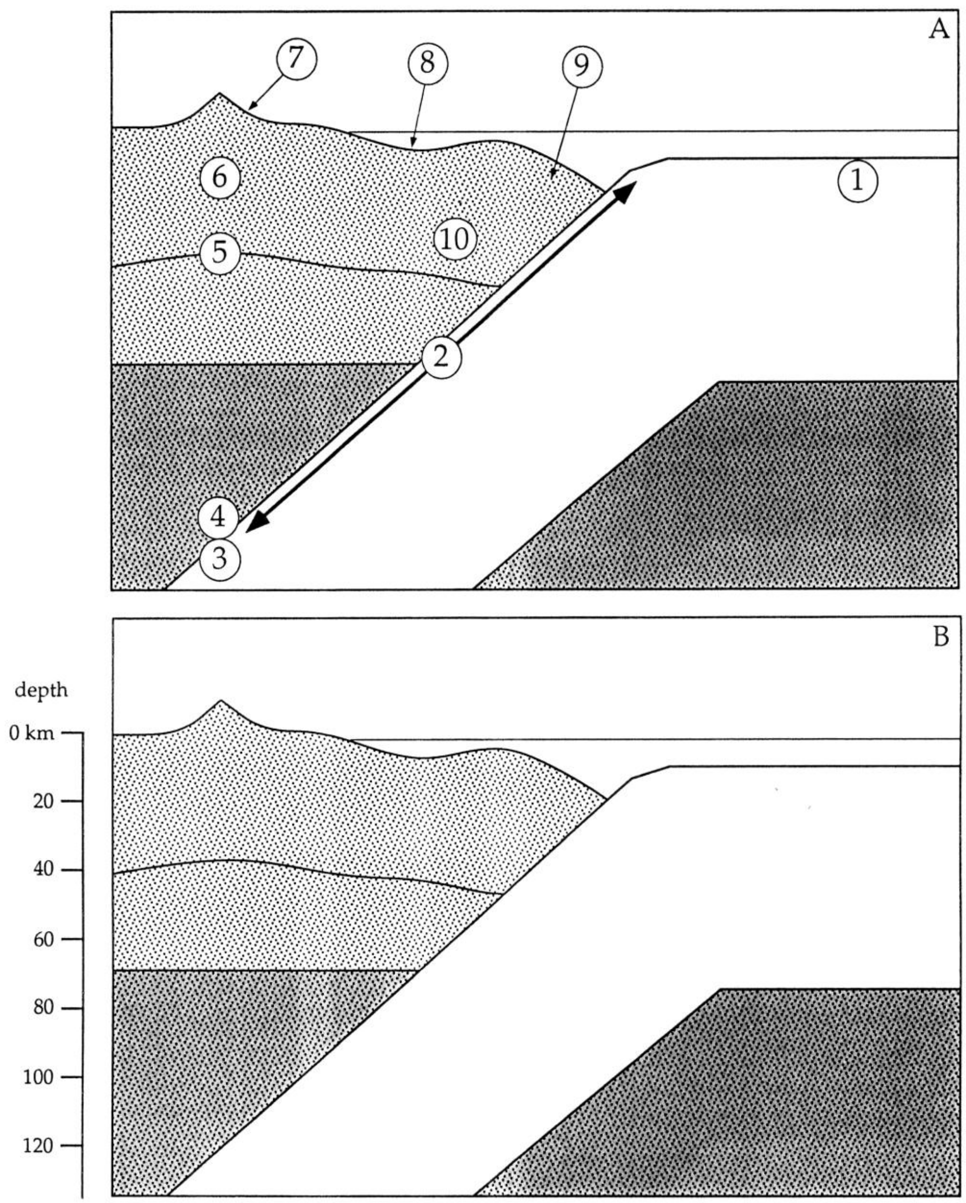


Figure MET.1A&B: Cross-sections of the island arc project

STEP 2: RETURNING THE CRUST TO ITS PLACE OF ORIGIN

INTRODUCTION:

In this step we will track the metamorphic reactions that occur in the down-going slab as it descends into the mantle. If you've read chapter 22 and have not completed Step 1, you can still proceed with Step 2, the most important Step in the Metamorphic Component of the Island Arc Project. The purpose of Step 2 is to see what happens to the MOR basalt and diabase as the oceanic lithosphere descends into the mantle. The first goal of your intellectual journey down a subduction zone is to refresh your memory of the geometry of our island arc system – study figure MET.1. Next, study and comprehend the information in figures MET.2-6. These figures are your key for efficiency. Without their warehouse of information you will not finish this project in time. However, if you heed our advice you will dispose of this Step in record time; time befitting a truly professional metamorphic petrologist. Don't attack the thin sections until you've understood the metamorphism of mafic rocks in a subduction zone.

BECOMING ACQUAINTED WITH THE SUBDUCTION ZONE

Based on your newly acquired expertise in subduction zone metamorphism, answer the following questions.

1) Explain why the slab probably doesn't melt.
2) If the slab were to melt, would the top of the slab be more likely to melt or would the base of the oceanic crust be more likely to melt? Explain.
3) What reaction(s) are responsible for releasing the water required to induce melting in the mantle wedge at 100-125 km depth?
4) What part of the slab is undergoing such reactions at those depths?
5) Reconsider question A in STEP 4 (IAPIGN). Let's assume that the reaction shown below is responsible for releasing all of the water (use 1.7×10^{14} g H_2O) that was added to the 10 km^3 of mantle at 125 km depth. Calculate the total mass of Epidote and glaucophane consumed to produce the required mass of water.

$$3epidote + glaucophane = 4omphacite + 2garnet + 11H_2O$$

epidote:470 g/mol
glaucophane: 800 g/mol
omphacite: 290 g/mol
garnet: 426 g/mol
H_2O: 18 g/mol

6) Given the following densities (g/cm^3) and assuming all of the water leaves the slab, calculate the % volume change in the crust of the down-going slab resulting from this reaction.

epidote: 3.50 g/cm^3 *glaucophane: 3.48* g/cm^3
omphacite: 3.45 g/cm^3 *garnet: 3.60* g/cm^3

STEP 3: PROGRESSIVE METAMORPHISM OF MAFIC CRUST

Study the hand specimen and thin section of each of five samples from the top of a down-going slab in a subduction zone. Determine the characteristic minerals (refer to figure MET.4) present in the *peak assemblage*. In other words, **IGNORE ANY RETROGRADE REACTIONS**. For each rock complete the following.

1) Fill out the petrographic report by listing the characteristic minerals of the peak assemblage (pay close attention to any hints provided on the petrographic reports).
2) Plot the position of the bulk composition on the appropriate ternary diagram (see the page of ternary diagrams after the petrographic reports) and identify as specifically as possible the metamorphic facies.
3) Plot the position of the peak assemblage on the thermal gradient curve A in figure MET.7 and estimate the depth at the time of peak conditions.

Petrographic Report

Name: ______________________________

sample 618

Peak Assemblage	Specific Metamorphic Facies
omphacitic cpx	
glaucophane	**Depth During Peak Conditions**
*	

sample 785

Peak Assemblage	Specific Metamorphic Facies
glaucophane	
epidote	**Depth During Peak Conditions**
(paragonite)	

sample 847

Peak Assemblage (identify the other phases)	Specific Metamorphic Facies
glaucophane	
*	
*	**Depth During Peak Conditions**
*	
titanite (sphene)	
tourmaline	

Suggest a possible geochemical origin for the chemical constituents of the tourmaline. (Hint boron is not an abundant trace element in basalts) sample Fr-15

Peak Assemblage	Specific Metamorphic Facies
lawsonite	
glaucophane	
quartz	Depth During Peak Conditions
plagioclase	

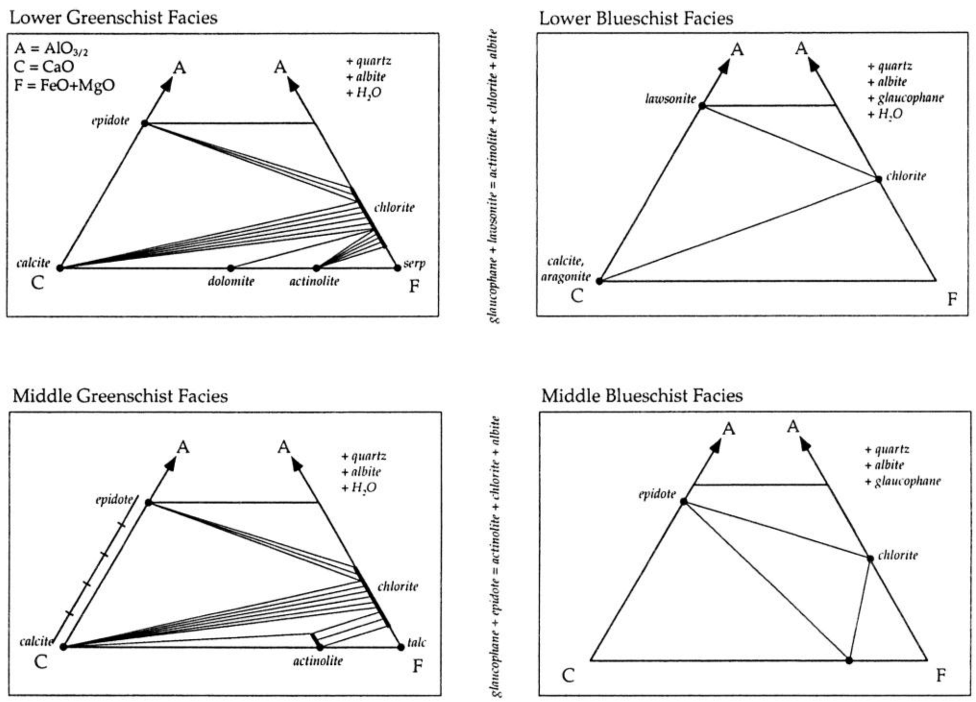
sample 1798

Peak Assemblage	Specific Metamorphic Facies
**(specific mafic)=*	
garnet	
(paragonite) = secondary	Depth During Peak Conditions
(rutile)	

Figure MET.4: Progressive metamorphism of a mafic bulk composition from greenschist facies, through blueschist facies to eclogite facies. Note that each step has excess H_2O released as hydrous minerals breakdown to progressively less hydrous assemblages. the five boxes below chart the progression of reactions and assemblages characteristic of each step along the P-T path.

The Greenschist to Blueschist Transition: The reaction that signifies this transition depends upon the pressure of the transition. The transitions from lower greenschist to lower blueschist facies and from middle greenschist to middle blueschist facies are shown below along with the critical reaction for each. Typical mafic bulk compositions contain lawsonite at lower blueschist facies and contain one of three 4-phase assemblages at middle blueschist facies:

glaucophane+epidote+albite+chlorite
glaucophane+epidote+chlorite+actinolite
glaucophane+epidote+albite+actinolite



Prograde Blueschist Facies Metamorphism: As blueschist facies conditions progress, the compositions coexisting glaucophane, chlorite and actinolite become increasingly magnesian as shown below by the continuous reaction on the AęFM diagram.

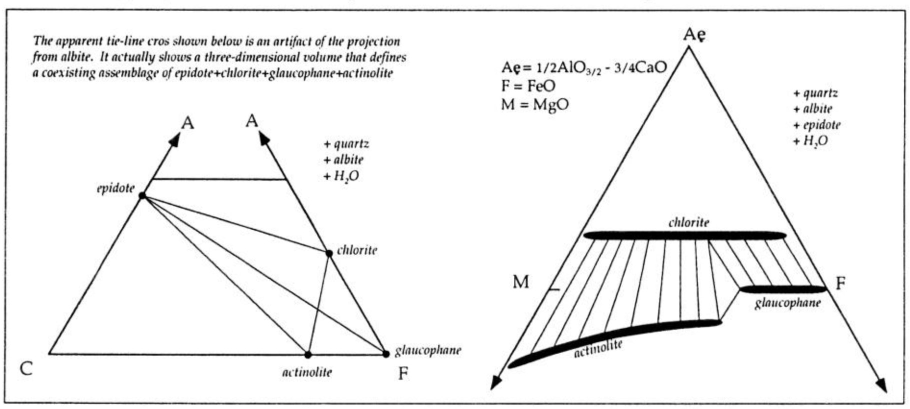
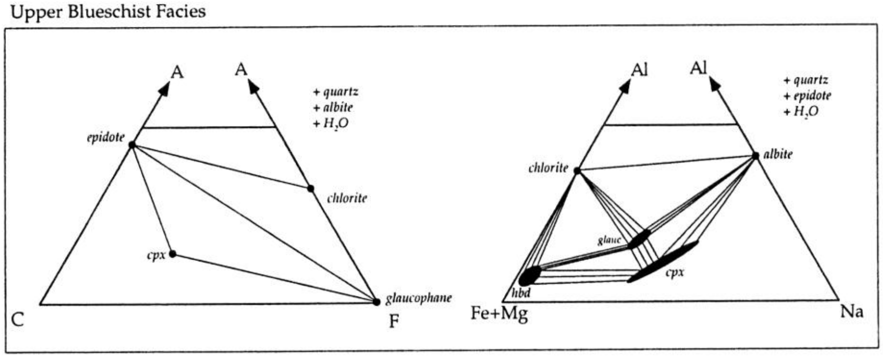


Figure MET.4: — continued

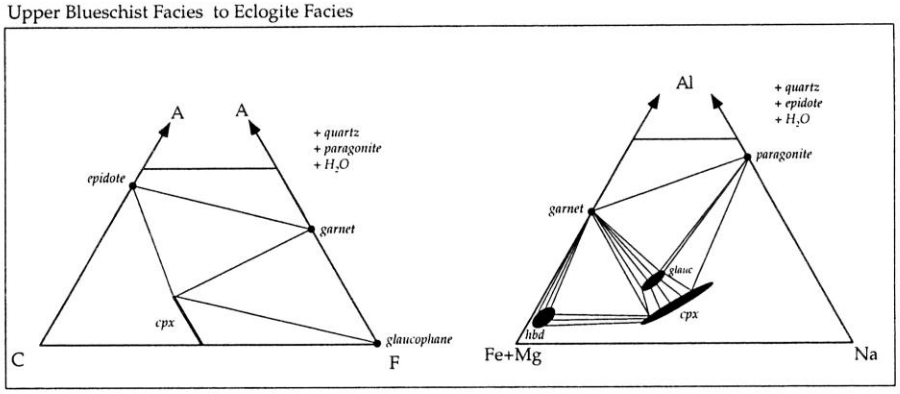
Upper Blueschist Facies: Although clinopyroxene (omphacite) appears in the assemblage, plagioclase is present. notice also that a calcic-amphibole may be present in some bulk compositions

Upper Blueschist Facies



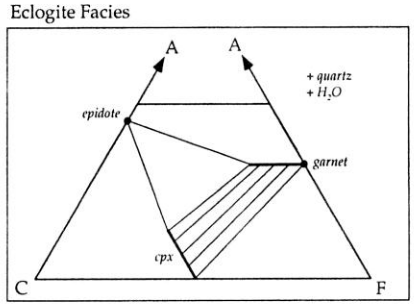
Upper Blueschist Facies to Eclogite Facies Transition: Eclogite facies is is characterized by the association of garnet (pyrope - grossluar solid solution) and omphacitic clinopyroxene and by the absence of plagioclase (which has reacted to form paragonite - sodium analogue of muscovite). Eclogites typically contain quartz and may contain accessory kyanite and/or rutile.

Upper Blueschist Facies to Eclogite Facies

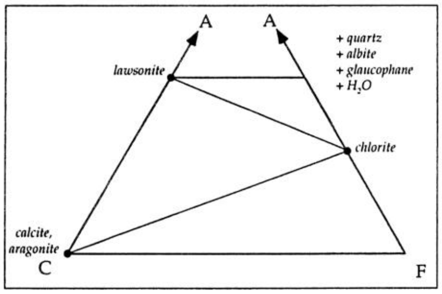


Eclogite Facies: the binary assemblage omphacite + garnet has expanded to encompass most of the common bulk compositions

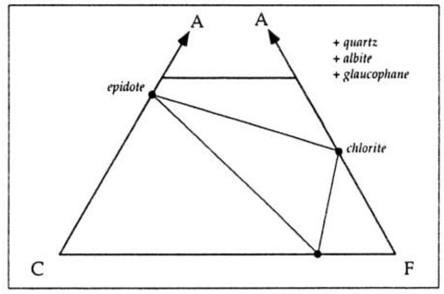
Eclogite Facies



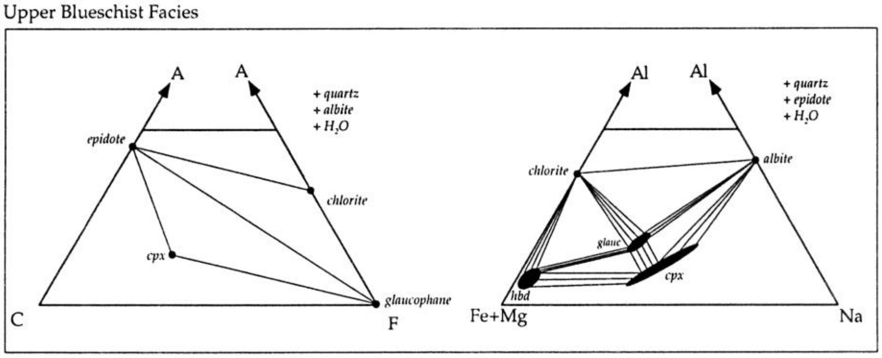
Lower Blueschist Facies



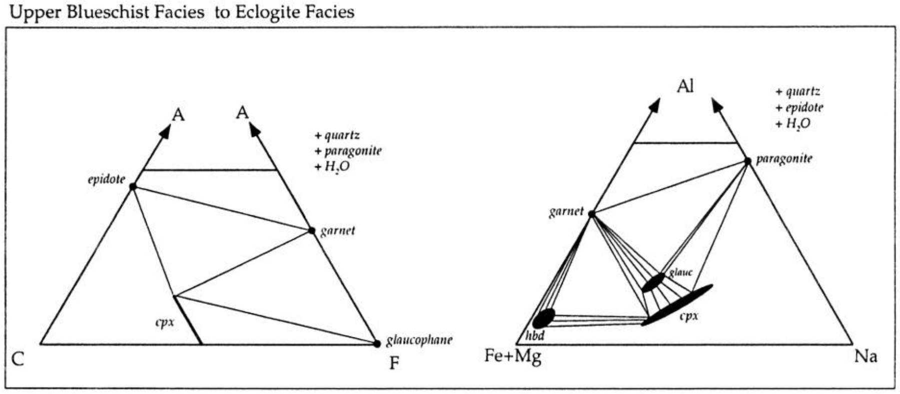
Middle Blueschist Facies



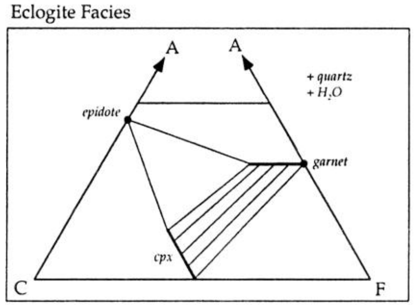
Upper Blueschist Facies



Upper Blueschist Facies to Eclogite Facies



Eclogite Facies



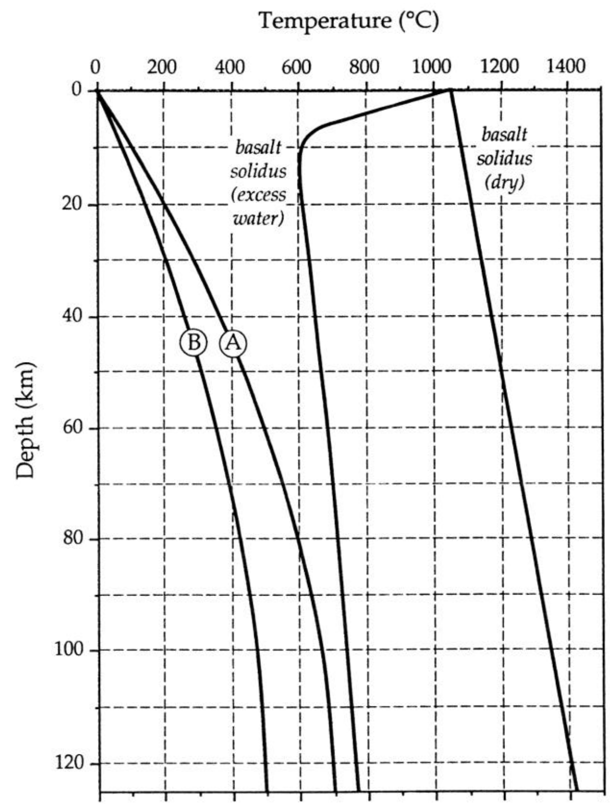


Figure MET-2: The thermal structure of the down-going slab to 125 km depth. Curve A is the thermal gradient at the top of the down-going slab. Curve B is the thermal gradient at the base of the oceanic crust in the down-going slab assuming the oceanic crust in the slab is 10 km thick. Also shown are the solidii for dry basalt and basalt in the presence of excess water. These solidii represent the melting points for oceanic crust in the down-going slab.

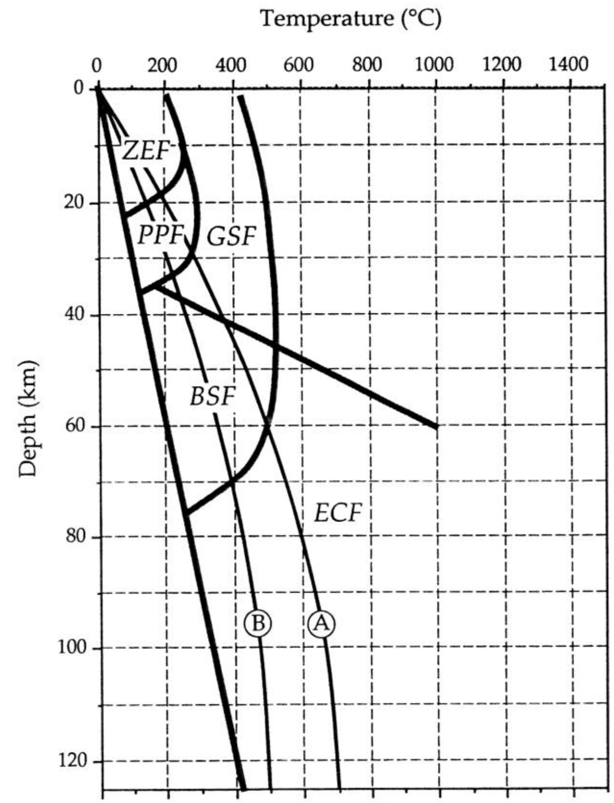


Figure MET-3: Facies boundaries for high P, low T metamorphism. The thermal gradients from Fig. MET.2 are also shown. Note that gradient A, representing the top of the slab, passes through the greenschist facies field. ZEF = zeolite facies; PPF = prehnite-pumpellyite facies; GSF = greenschist facies; BSF = blueschist facies; and ECF = eclogite facies.

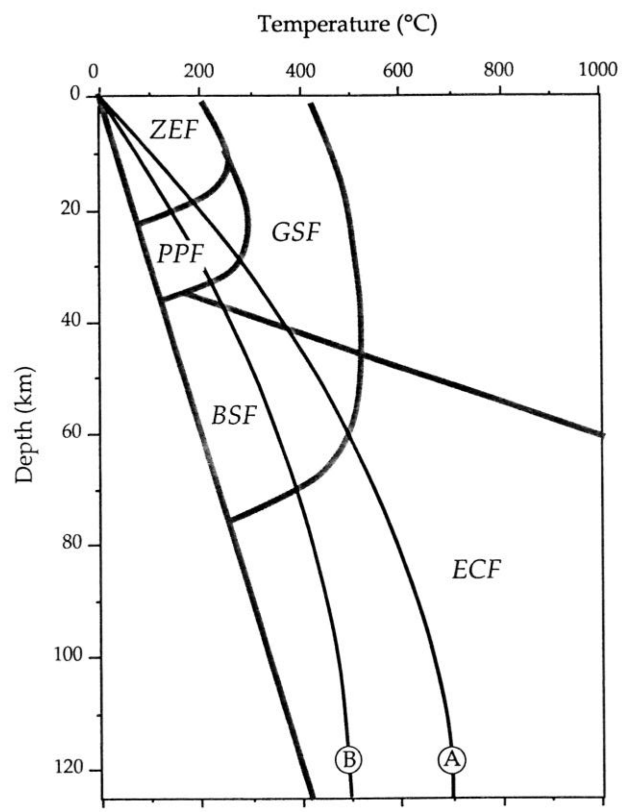


Figure MET-5: Metamorphic facies traversed by the down-going slab. Abbreviations as in figure MET.3.

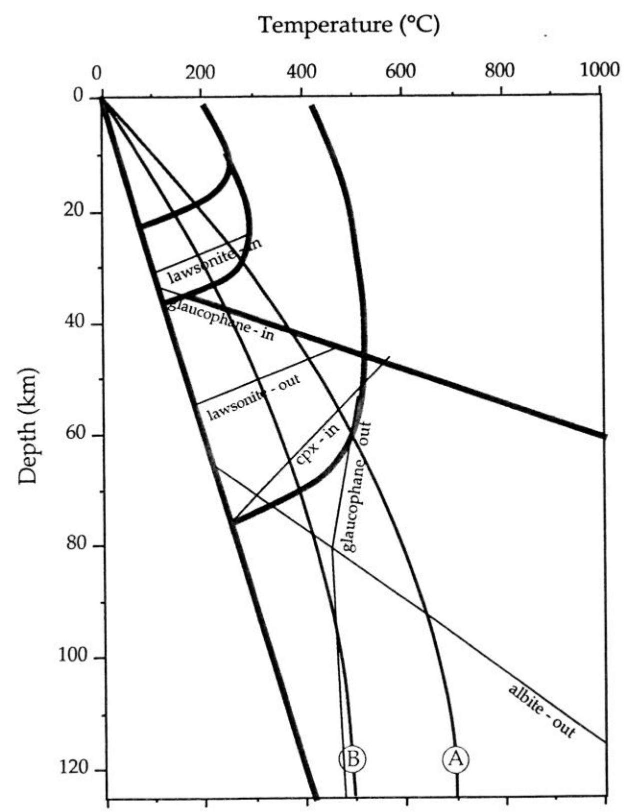


Figure MET-6: Reaction boundaries for high P, low T metamorphism of a mafic bulk composition. Compare to the phase diagrams shown in Figure MET.4.

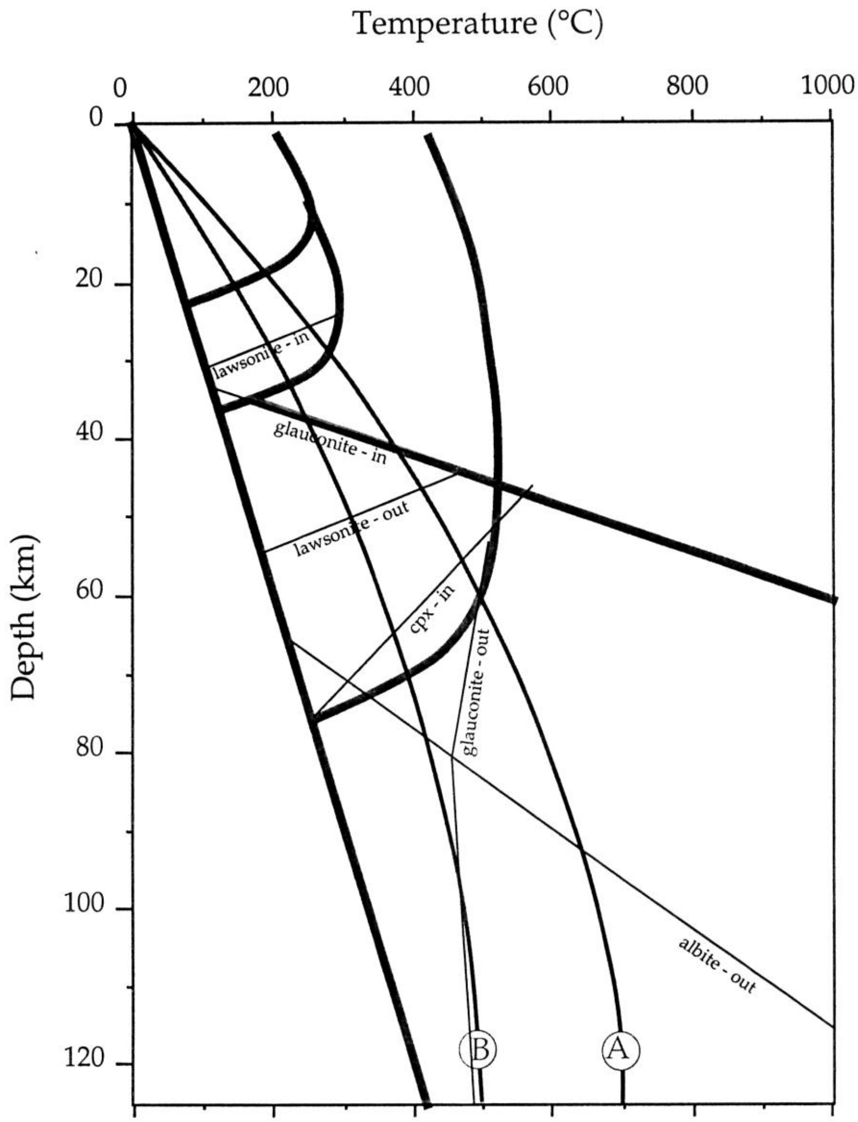


Figure MET-7: plot the positions of your peak assemblages here or be square!

STEP 10: TWO FINAL INVESTIGATIONS

A. METAMORPHIC BELTS

INTRODUCTION

In this exercise you will examine the petrology of a mafic pluton called the Noblehawk plutonic complex. This occurs typically in the same part of the arc which experiences volcanism (i.e. steps 6 and 7). The nature of this metamorphism is quite distinct from steps 1-3 above. When the entire arc experiences this type of metamorphism on a large scale, it creates a belt of metamorphism that is generally higher-temperature and lower-pressure than the rocks you studied in steps 1-3. This example is designed to allow you to contrast the two belts of metamorphism that occur in island arcs (modern and ancient). In this section, you will consider the effect of the plutonism you studied in steps 5 & 6 on the surrounding country rock. This particular pluton intrudes both metamorphic and sedimentary rocks. A cross-section of the complex is shown in Figure 1.

PART I: GEOLOGIC HISTORY OF THE NOBLEHAWK COMPLEX

Study the geologic cross-section of the Noblehawk plutonic complex in Figure 1. Using the basic geological principles that dictate the relative timing of geologic events, reconstruct the geologic history of processes and events that led to development of the complex. Use the space below and follow the example provided. If the timing of two or more events cannot be determined, be sure to indicate the ambiguity.

PART II: METAMORPHISM OF THE COUNTRY ROCKS

Let's imagine the state of the complex at a time when the magma chamber is actively crystallizing but not much melt has crystallized yet. The country rocks around the pluton will be heated by the magma and undergo metamorphism. Figure 4 shows the geology and provides some relevant information about the system at this time. The instantaneous thermal state of the country rocks are shown on Figures 5a & b. The goal of this set of problems is to determine the metamorphic conditions in the pelite layers adjacent to the pluton.

Figure 1: Geology of the Noblehawk plutonic complex

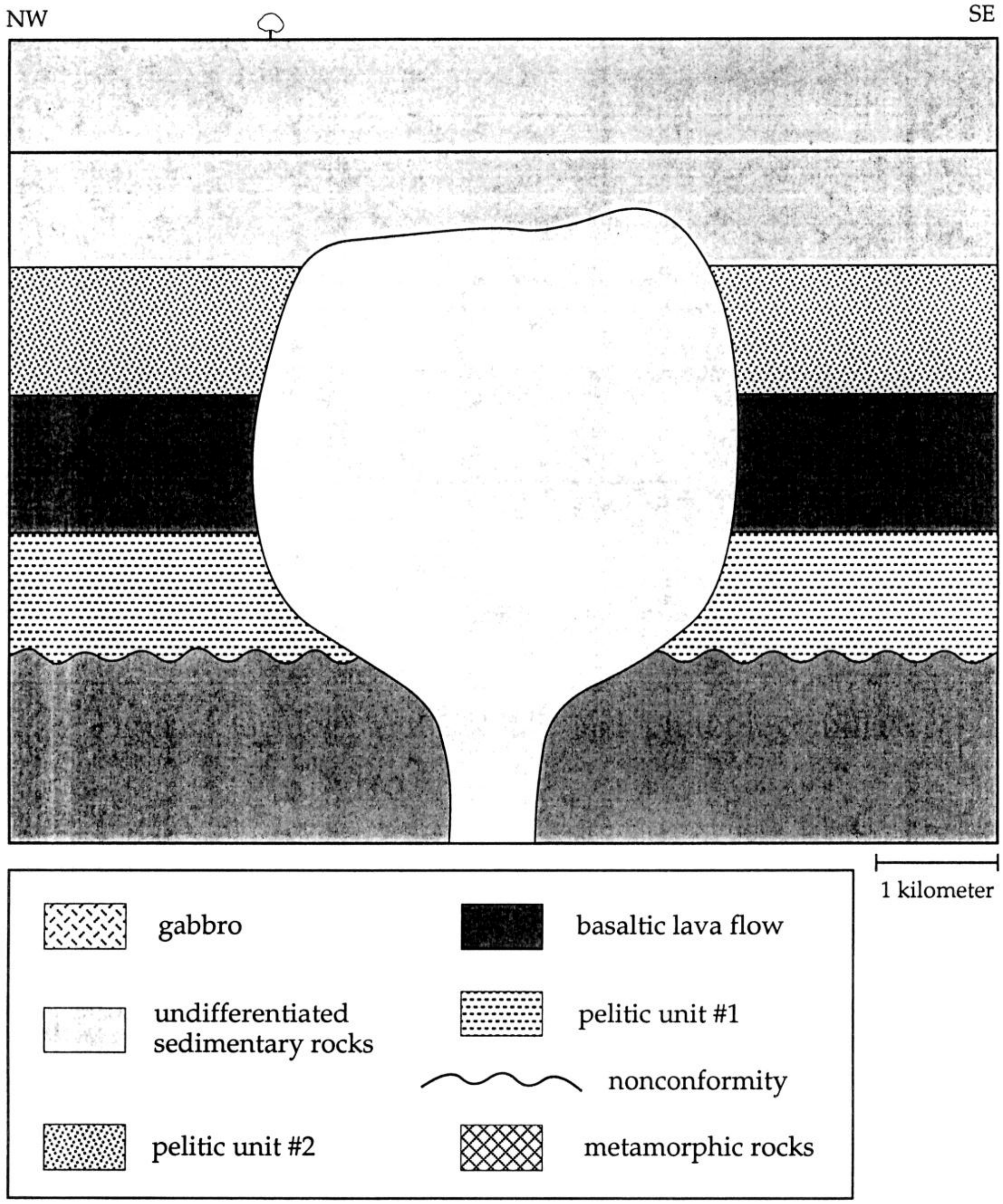


Figure 4: Cross-section of magma chamber early in the crystallization crystallization

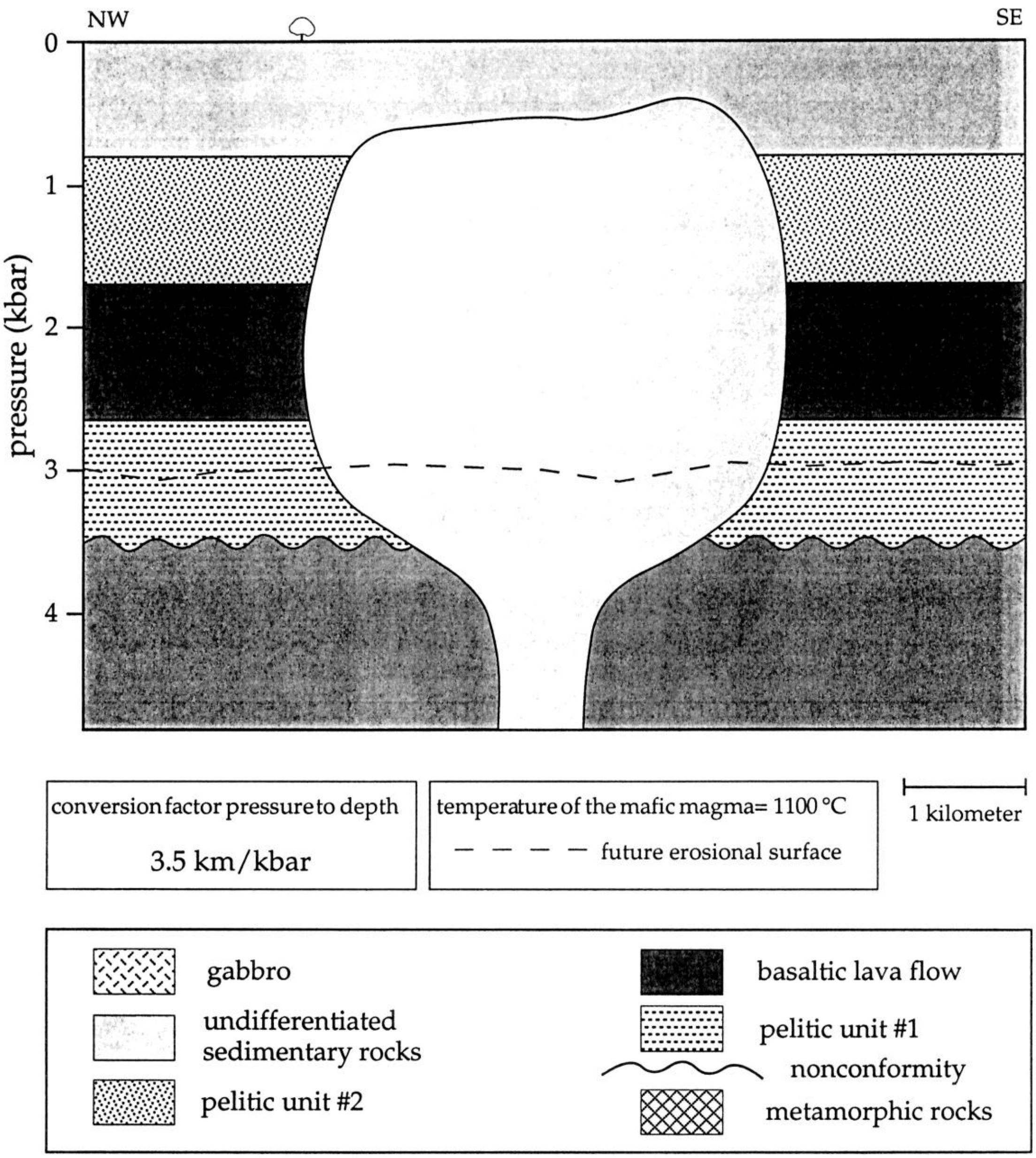


Figure 5a: Thermal gradients in the country rock adjacent to the magma chamber

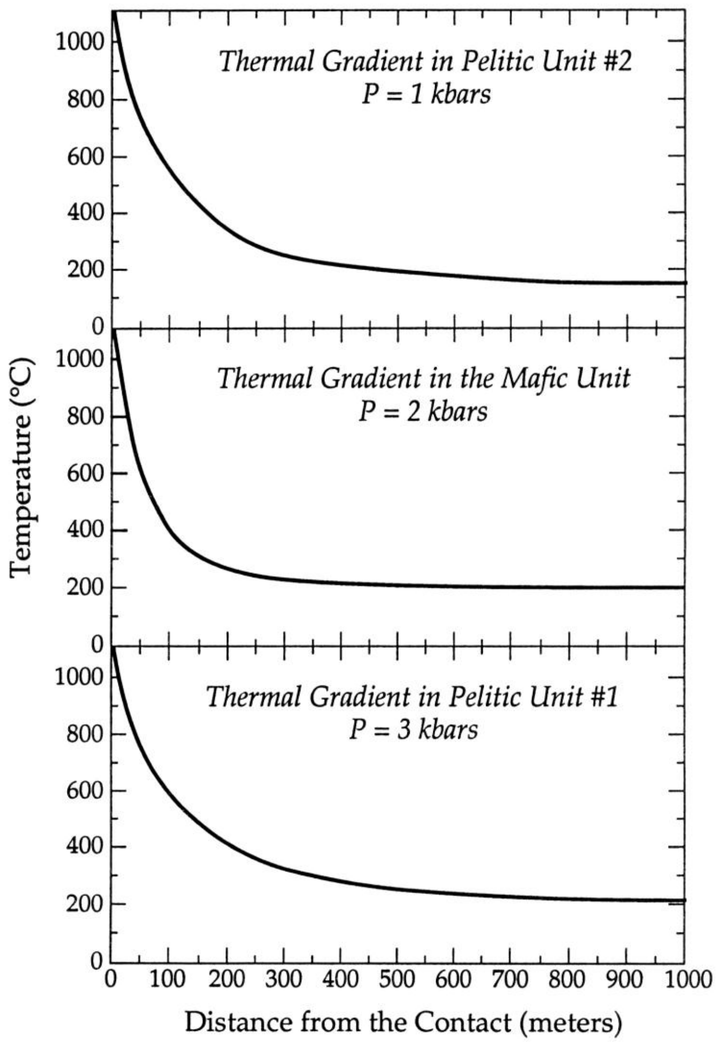
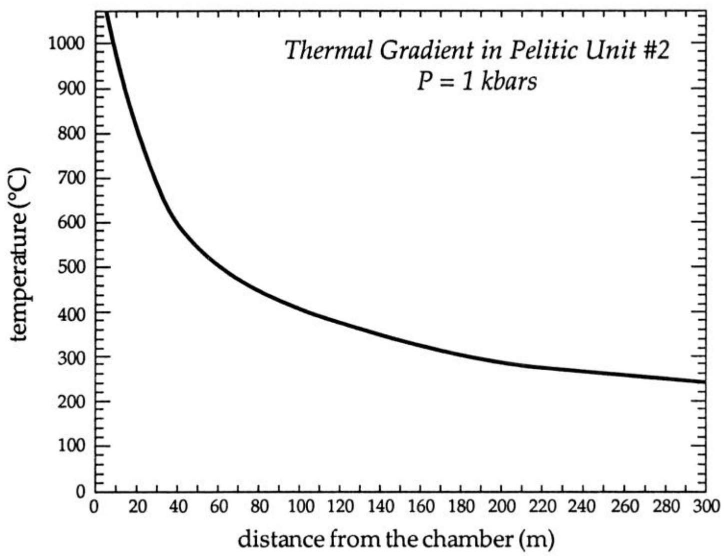
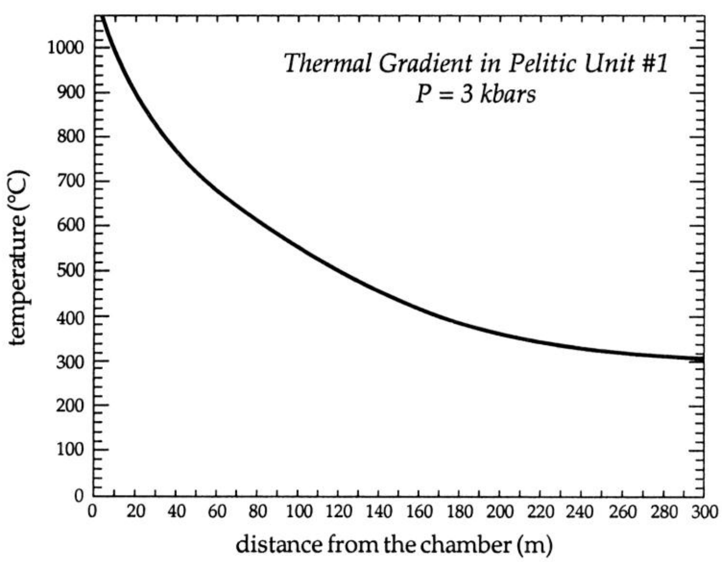


Figure 5b: Blow-up views of the thermal gradients in the country rock adjacent to the magma chamber





THE PROBLEMS & QUESTIONS

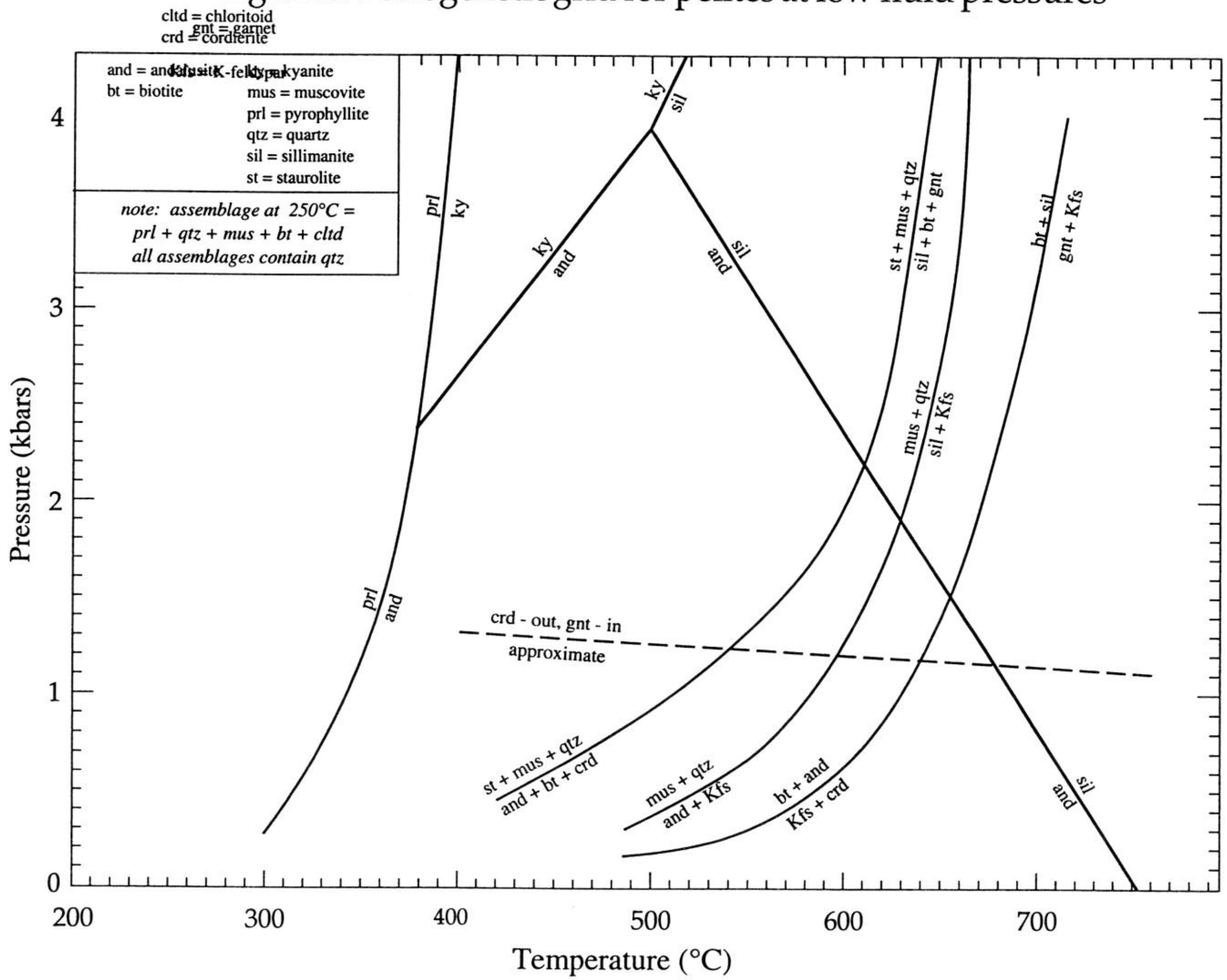
1) On the phase diagram in Figure 6, draw line segments that portray the range of temperatures present in pelitic unit #1 and in pelitic unit #2. Use the temperatures from Figure 5a.
2) Each line segment should cross a number of reaction boundaries. For each reaction boundary crossed by each line segment, write the chemical reaction and give the temperature at which each reaction should proceed.
3) Let's go to future for a moment. Assuming that the instantaneous thermal gradients shown in Figure 5b were actually preserved by the mineral assemblages in the rock, answer the following questions.
    a. Suppose that the pluton was eroded to the dashed line in pelite unit #1 as shown in Figure 4. If you collected a rock in pelitic unit #1 located exactly 66 meters from the contact with the gabbro pluton, what mineral assemblage and textures would you find in thin section?
    b. Suppose that the pluton was eroded to a depth equivalent to the 1 kb level during the time of metamorphism. What mineral assemblage and textures would you see in a rock from pelitic unit #2 collected exactly 34 meters from the contact?
4) Assuming the thermal profiles represent instantaneous temperatures in the crust, draw the ambient geothermal gradient prior to intrusion of the magma. Use the temperature values in Figure 5a.
5) 1100°C exceeds the solidus temperature of pelites, therefore, at least some part of the pelitic layers adjacent to the pluton will partially melt. The following problems & questions explore the generation and subsequent history of the melt. The fundamental parameters and relationships required for this problem are listed below.

Parameters & Assumptions
Pelite solidus: $P=0.05T-33$
pelite C_p=0.25 cal/°C g and does not change as a function of melt production
heat required to melt 100% of the pelite = 100 cal/g

    a) Using Figure 5b and any calculations you deem useful, determine the maximum distance from the magma chamber at which each pelite layer will partially melt. (20 points)
    b) Now, determine the temperature of the pelitic units halfway between the edge of the chamber and the furthest point from the contact where the pelitic layers contain melt (you just determined these values in 5a). Use that temperature to calculate the average degree of partial melting in the pelitic layers adjacent to the pluton. (NOTE: if you had an equation for the temperature gradients, this problem would be solved by integrating that equation from 0 to X meters where X is the answer from problem 5a.)
    c) Based on your knowledge of the physical and chemical behavior of melts as well as the chemical composition of pelites, what do you suppose would happen if the melt produced in the pelite layers entered the mafic magma chamber?

6) You have located a sample from pelitic unit 1 that contains coexisting garnet and biotite. You run the sample to an electron microprobe and obtain the following mineral composition data.

Figure 6: Petrogenetic grid for pelites at low fluid pressures



OXIDE	GARNET	BIOTITE
SiO_2	37.26	34.22
Al_2O_3	21.03	18.97
TiO_2	n/d	1.23
MgO	2.46	9.98
FeO	32.45	17.50
MnO	6.08	0.12
CaO	1.03	0.01
Na_2O	n/d	0.27
K_2O	n/d	7.79

First, using your classroom exercise format, calculate the equilibration temperature for this pair. _________________________ (attach your spreadsheet)
Then, decide by comparison with Figure 6, whether this represents a prograde or retrograde temperature. _________________________

7) Examine hand sample and thin section # (W?)
   1. What mineral suggest this was a high-temperature metamorphic rock?
   2. Which reaction from figure 6 is most similar to this sample?
   3. What evidence can you cite for partial melting (rather than injection by granitic dikes) in this sample.

PART III: METAMORPHIC FACIES SERIES

Refer to the attached copy of Fig. 19-3 from your text. Plot two thick curves on this figure. One will show a probable path of progressive metamorphism for the samples you examined in steps 1-3. Show the facies that our cube of rock passed through during subduction on the figure. Label this curve: High P/T. Then draw a second curve that shows the direction our sample in step 10, Part A, passed through during metamorphism. Broaden that curve to reflect what might happen if this metamorphism occurred over a large region. Label it Low P/T. Write a brief paragraph, suing your text and results of this project to describe how and why geologists find two belts of metamorphism (one High P/T and one Low P/T) in island arcs. What are their spatial relationships to each other and to the trench?

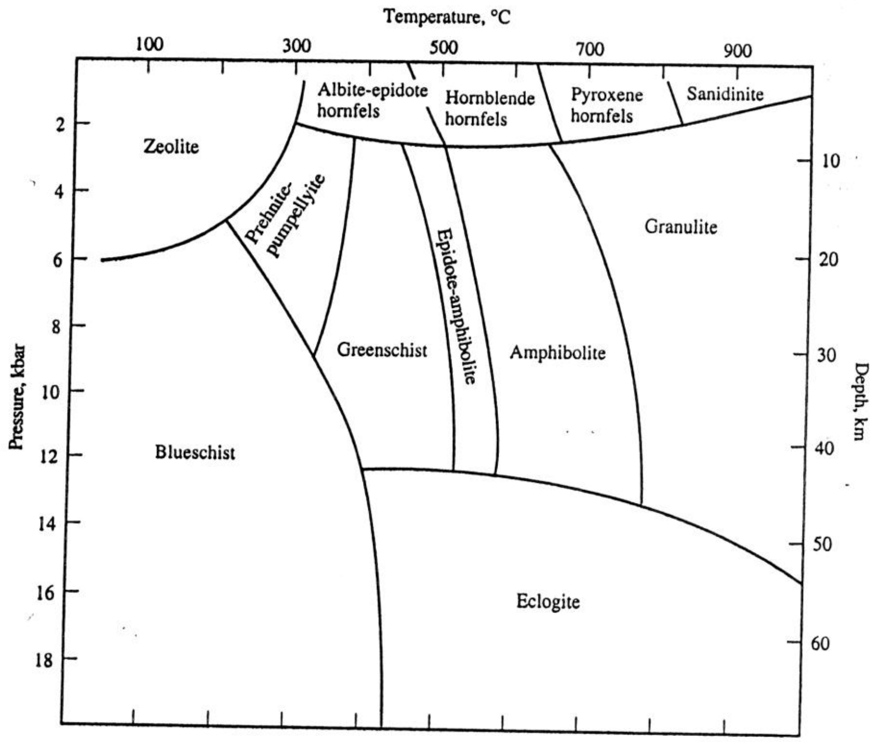


FIGURE 19-3

Plot of the P(depth)-T plane showing current status of the distribution of the metamorphic facies. Note that the low-pressure hornfels facies is subdivided into three subfacies: albite-epidote, hornblende, and pyroxene; the highest contact metamorphic facies is the sanidinite facies. Various subfacies names have been proposed for most of the major metamorphic facies. Note that all boundaries are approximate and gradational.

B. TIMING AND RATES

INTRODUCTION:

How long does it take oceanic crust to cycle through an island arc? How much time is involved in the full cycle of island arc activity? These data should help you to answer these very important questions. Sketch a plate from ridge through the subduction zone and label the ages at each step. Pay attention to the angle of subduction. Calculate (show on the sketch) the total time the plate spent for each major step using the data below (beginning with ridge to trench time).

Table MET.1: Starting Data and Assumptions

island arc system existed in the past
spreading rate: 5 cm/yr (constant over lifetime of the arc)
rate of subduction: 5 cm/yr (assume no rollback)
assume that both the trench and sample 898 are 1200 km from the sprading center
angle of subduction = 60° (measured from the horizontal down)

Table MET.2: Absolute Ages			
Sample	Method	Age (Ma)	Significance
898	$^{40}Ar/^{39}Ar$ mineral	64.9	Timing of metamorphism
28	U-Pb baddelyite	38.0	Crystallization age
24	U-Pb zircon	37.9	Crystallization age
26	U-Pb zircon	37.9	Eruption age
JN-01	U-Pb zircon	38.0-37.9	Detrital ages from sandstone
CP-03	U-Pb zircon	37.8	Eruption age

C. SUMMARY PAPER:

PREPARE A ONE-PAGE SUMMARY OF THE MAJOR PROCESSES WHICH EFFECTED THE BLOCK OF SUBDUCTING MATERIAL THROUGHOUT THE TEN STEPS!