The MARGINS Minilessons: Central American Volcanic Arc

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Motivations

- To teach undergraduate petrology students about one arc system in some detail
- To capture some of the excitement of studying arc volcanic rocks
- To build skills in relating plate tectonics to petrography and major element chemistry

Materials

(all can be downloaded from SERC MARGINS minilesson website)

- One powerpoint
- Three handouts

Three Handouts

Lavas of the Central American Arc (Handout Part One)

Using lavas of the Central American volcanic arc (CAVA) to teach about petrogenesis of igneous rocks in subduction zones

Note to Instructor: This "mini-lesson" is best done in "mixed mode", alternating between materials presented by the instructor (using powerpoint "CAVA Petrological Overview") and student reading of material below, intended as individual handouts. This is because color figures show well in a Powerpoint but perhaps will not be reproduced in the handout, and because you will want group responses to questions on the Powerpoint. All of the figures in the handout are provided in the Powerpoint, but not all of the powerpoint figures are presented; Powerpoint slides are also labeled in the lower left if and how they occur in the handout. The instructor is encouraged to modify the Powerpoint as useful for their classes and syllabus. We recommend that students read "Handout Part 1" first, then the instructor should present the Powerpoint segment "Part one: background".

The skills that students will learn/practice in this activity include:

- Calculation of important geochemical parameters such as the MG #,
- Visual estimation of mineral percentages (modes)
- Calculation of normative mineralogies

The concepts that are emphasized through the activity are:

- connection between rock mineralogy and geochemistry via comparison of modal and normative mineralogies,
- recognition that arc magmas are generated by melting of different sources (crust vs. mantle), and
- understanding that certain major element compositions can be used to as first order differentiators to identify primary mantle magmas.

We assume that students already will already have basic knowledge of:

- hand sample and thin section properties of common igneous minerals
- igneous rock hand description, identification and classification
- volcano types
- plate tectonics

Note to Instructors and Students: For classes interested in learning more about the Central American volcanic arc, several other "mini-lessons" in the SERC collection < http://serc.carleton.edu/margins/collection.html > provide activities that give also give detailed information including:

1. "Physical & Chemical variations along the Central American Volcanic arc": Students use data compiled for the NSF MARGINS program to compare heights, volumes, and whole-rock compositions of 39 Quaternary volcanic centers along the Central American arc, together with crustal thicknesses, to assess the possible sources of the magmas and the petrologic processes that have modified them prior to eruption. [http://serc.carleton.edu/margins/minilessons/17640.html]

Notes for Instructors in Part One

1. OVERVIEW of CENTRAL AMERICA

Lavas of the Central American Arc (Handout Part One)

INTRODUCTION

It is challenging to understand the processes that form arc lavas, because these processes and their products - the rocks - vary over so many scales. The subduction zone associated with any convergent plate margin extends hundreds of kilometers into Earth's interior and the overlying arc-trench system that it engenders can be traced for hundreds to thousands of km along strike. Subduction is responsible for some of most dangerous natural hazards: earthquakes, tsunamis and explosive volcanism. Subduction zone magmatism also benefits humanity by producing ore deposits and geothermal energy. Even though subduction has been recognized as a central part of plate tectonics for almost fifty years, we still have much to learn about the operation of this gigantic solid Earth system, which we also call the "Subduction Factory" (Fig. 1). The Subduction Factory recycles raw materials from the seafloor and underlying mantle to create distinctive melts, which ultimately make up the continental crust where most of us live. The huge extent and deeply buried nature of the global Subduction Factory makes it very difficult to study, so most large-scale research projects focused on subduction processes such as MARGINS and GeoPRIMS involve interdisciplinary teams that include geophysicists, geochemists, petrologists, marine geologists, volcanologists, geodynamic modelers, and experimentalists.

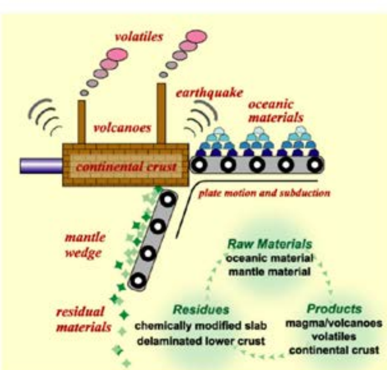


Figure 1. Diagrammatic representation of major processes and products of the Subduction Factory [http://www.jamstec.go.jp/jamstec-e/IFREE/ifree2/ifree2image/fig2_e.gif].

2. Info about Cerro Negro and Ilopango; Modes, QAPF, Norms, TAS, and Mg#

Lavas of the Central American Arc (Handout Part Two)

Using lavas of the Central American volcanic arc (CAVA) to teach about petrogenesis of igneous rocks in subduction zones

In this section, you will learn about three complementary methods that we use to characterize volcanic rocks, using lavas from two distinctive CAVA volcanoes as examples. The three methods are the visual *mode*, the *major element analysis*, and the theoretical *norm*. The mode (short for modal mineralogy) is what you see in the rock as a result of hand specimen and thin section examination – it is the relative volume proportions of the minerals actually in the rock. The major element analysis provides information about the bulk chemical composition of the rock of interest and also provides the basis for calculating the norm (short for normative mineralogy), which is a hypothetical mineralogy for the rock, if all the chemicals were partitioned into minerals. The two volcanoes we will look at in detail are Cerro Negro, in Nicaragua, and Ilopango, in El Salvador (Fig. 8).

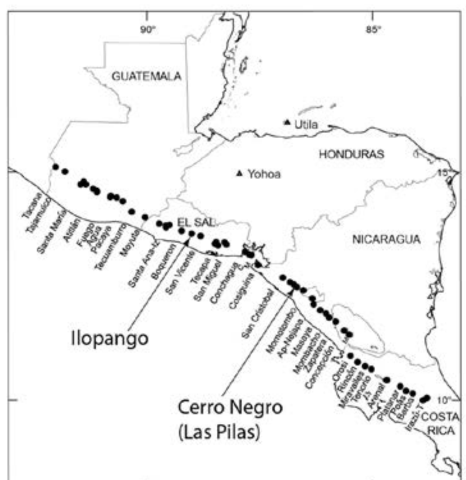


Figure 8. Volcanic centers along the volcanic front of the Central American volcanic arc. Two volcanoes are of special interest here: Ilopango in El Salvador and Cerro Negro in Nicaragua. Cerro Negro is a small volcano associated with the much larger El Hoyo-Las Pilas volcanic complex, and Ilopango is a moderate-sized caldera. Note the right-step offsets in the trend of the arc.

3. Exercise Sheet: Cerro Negro and Ilopango Modes, QAPF, Norms, TAS and Mg#

Lavas of the Central American Arc (Student Activity Sheet)

Name: **Date:**

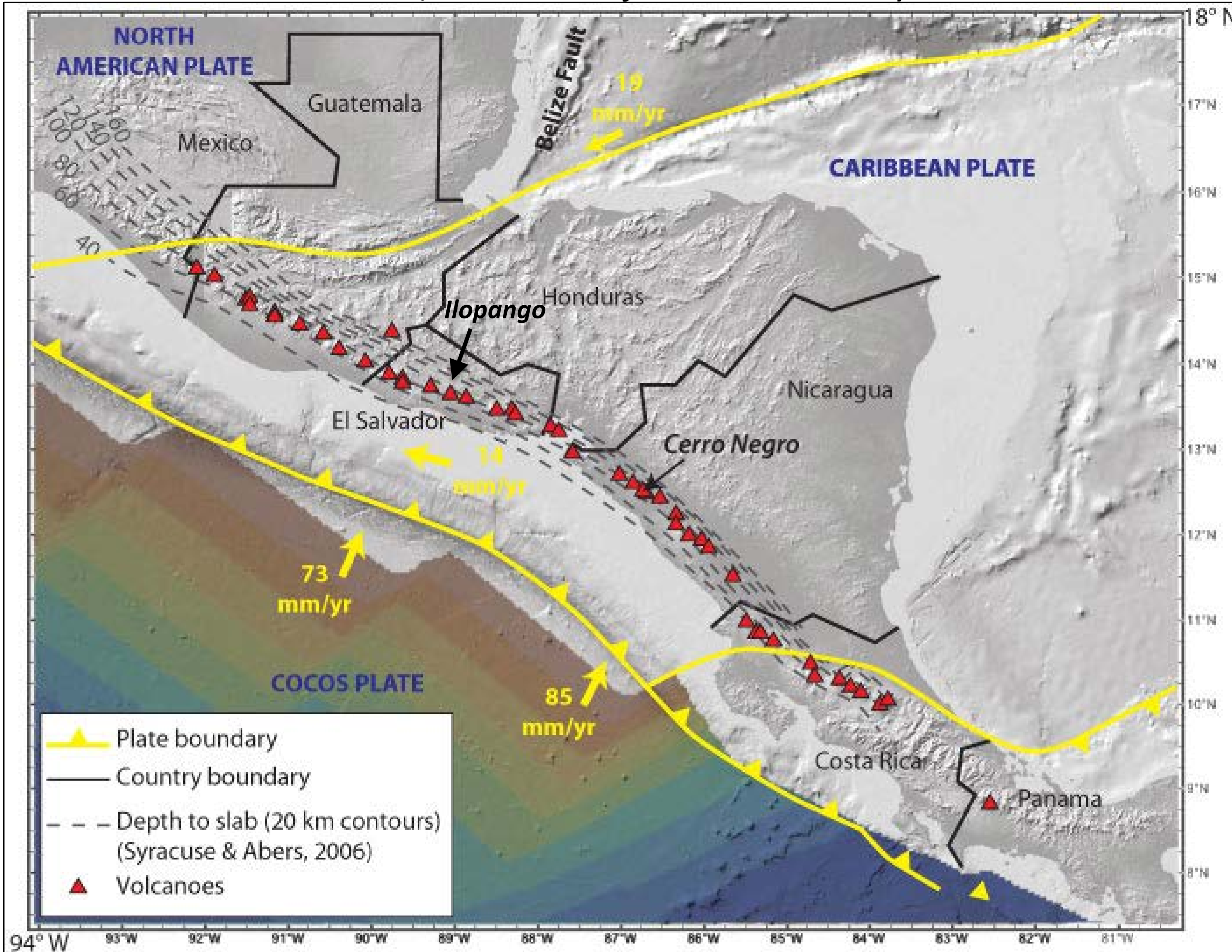
Exercise 1. Modal Mineralogy

A) In the table below, use the modal mineralogy for each sample to calculate renormalized values for the QAPF classification diagram. Plot the sample locations on the diagram (next page), and then record the resulting rock name on the last row of the table. The first sample (EXAMPLE) has been done for you.

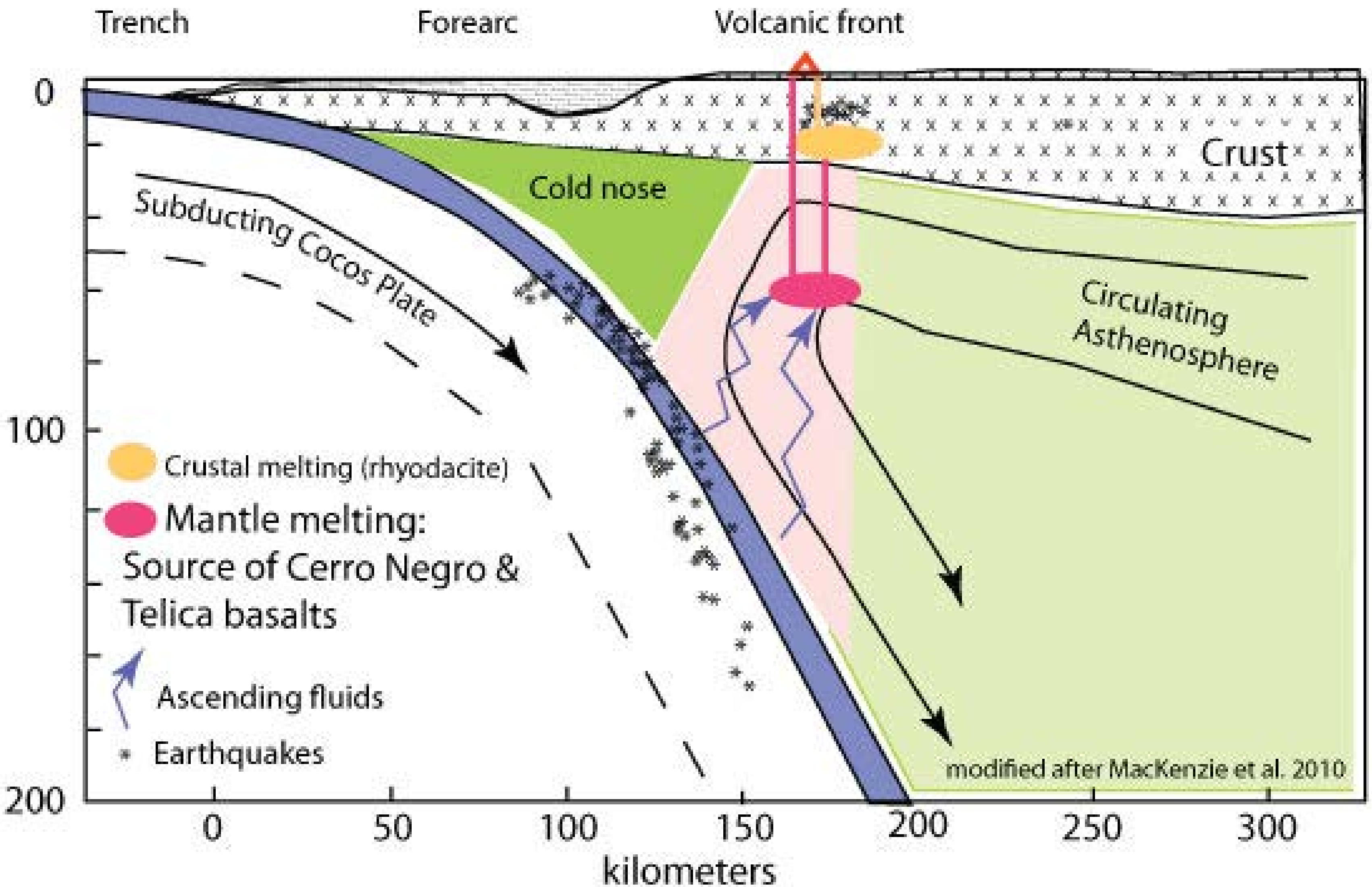
(1) Modal Mineralogy				
Mineral	*EXAMPLE Volume Percent*	*To do Volume Percent*	*To do Volume Percent*	*To do Volume Percent*
Quartz	*25*	*10*	*0*	*0*
Alkali Feldspar	*40*	*25*	*15*	*35*
Plagioclase Feldspar	*15*	*45*	*70*	*25*
Nepheline (feldspathoid)	*0*	*0*	*0*	*20*
Biotite	*12*	*0*	*0*	*16*
Hornblende	*0*	*14*	*0*	*0*
Clinopyroxene	*0*	*6*	*7*	*0*
Olivine	*0*	*0*	*8*	*0*
Magnetite	*8*	*0*	*0*	*4*
Total A	***100***			
(2) Add modal QAPF values				
Quartz	*25*			
Alkali Fsp	*40*			
Plagioclase Fsp	*15*			
Feldspathoid	*0*			
Total B	***80***			
(3) Renormalize QAPF values by dividing each Q, A, P, F value by Total B and multiplying by 100				
Quartz	*25/80 x 100 =31*			
Alkali Fsp	*40/80 x 100 =50*			
Plagioclase Fsp	*15/80 x 100 =19*			
Feldspathoid	*0/80 x 100 = 0*			
Total B	*100*			
QAPF Rock Name	***rhyolite***			

The Central America Arc: 66 slides to show the class

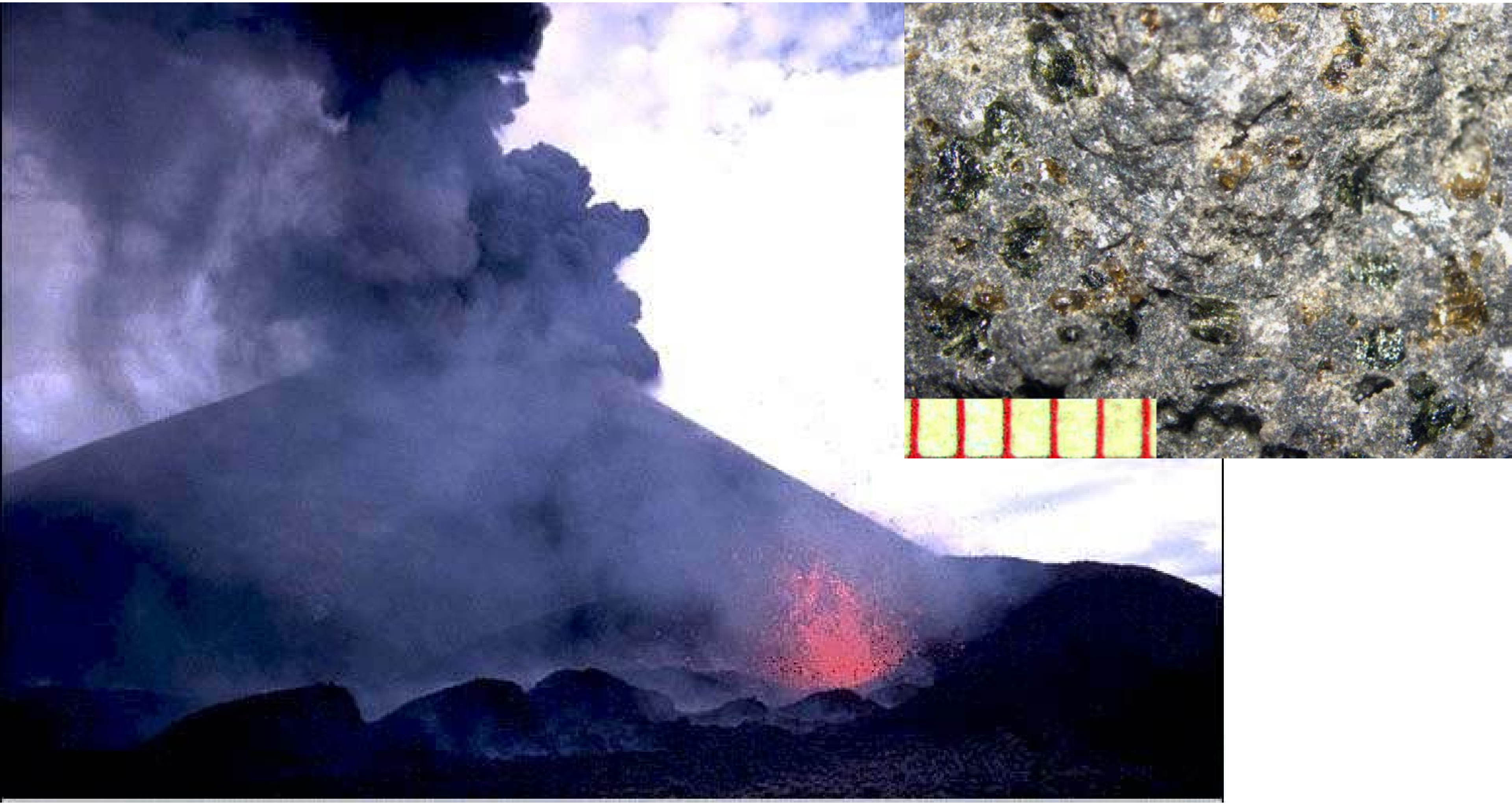
Simplified tectonic map of the Central American convergent margin, national boundaries, the volcanic arc, and location of 2 studied volcanoes)



The Central American Subduction Zone



Cerro Negro, 1968 eruption

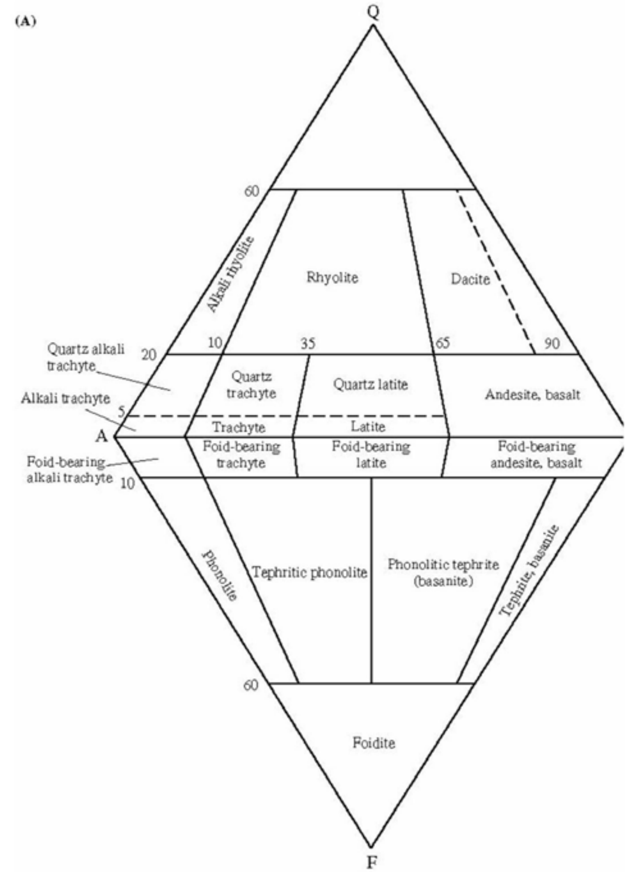


Handout 2 focuses on Cerro Negro, Nicaragua. Ash and cinders erupt from the summit crater in 1968 as a vent near the base of the 150 meter-high cinder cone feeds a basaltic lava flow (R. Decker). Handout 3 walks students through a set of exercises about Cerro Negro (bassalt), then same exercises for Ilopango (rhyodacite)

Cerro Negro exercise 1: Modal Analysis

CN-4 1957-1960 10% MgO

Mode of CAVA lava	
Mineral	*Volume Percent*
Quartz	
Alkali Feldspar	
Plagioclase Feldspar	
Nepheline (feldspathoid)	
Biotite	
Hornblende	
Clinopyroxene	
Olivine	
Magnetite	
Total A	
Quartz	
Alkali Fsp	
Plagioclase Fsp	
Feldspathoid	
Total B	
Alkali Fsp	
Plagioclase Fsp	
Feldspathoid	
Total B	



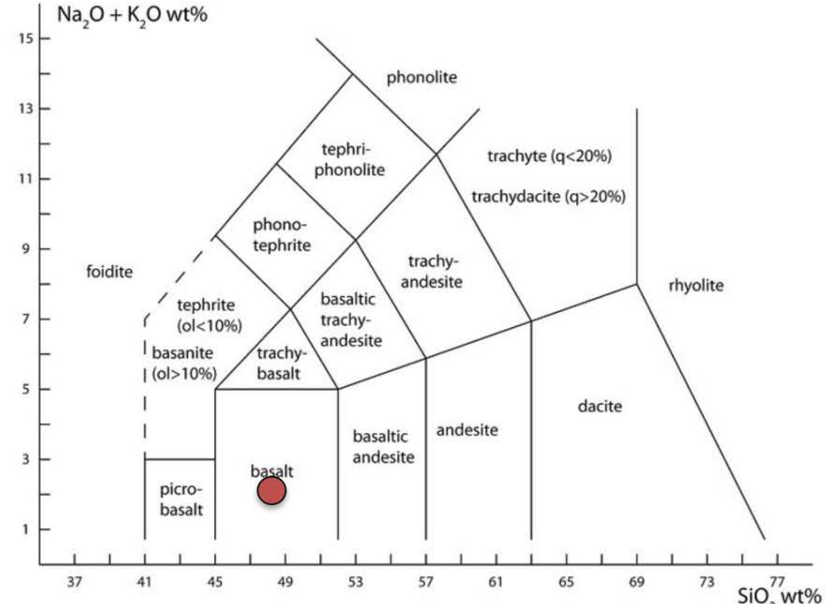
QAPF classification diagram for volcanic rocks.

Cerro Negro exercise 2: The Total Alkalies-Silica (TAS) diagram

Exercise 2. Major Element Chemical Analysis

A) In the table below, calculate the Y plotting values ($Na_2O + K_2O$) needed to classify each geochemical analysis on the Total Alkalies versus Silica diagram provided below. The first sample (CN-4) has been done for you. Write the name of the rock at the bottom of the table.

Oxide	CN-4	CN-6	SAL-IL-4	SAL-IL-5	SAL-IL-1
SiO_2	48.6	50.4	58.21	66.8	70.6
TiO_2	0.65	0.83	0.66	0.4	0.25
Al_2O_3	14.4	20.0	17.6	15.7	14.9
FeO (total)	11.0	9.6	6.45	3.76	2.00
MnO	0.2	0.18	0.14	0.08	0.12
MgO	9.97	3.69	3.34	1.5	0.68
CaO	11.3	11.4	7.62	4.17	2.89
Na_2O	1.78	2.38	3.43	4.28	4.14
K_2O	0.35	0.47	1.12	1.99	2.3
P_2O_5	0.06	0.32	0.23	0.27	0.17
LOI	0.08	0.10	0.35	0.42	1.97
Total	**98.39**				
Good Analysis?	**yes**				
$Na_2O + K_2O =$	***2.13***				
Rock Name	***basalt***				



Total alkalies – silica (TAS) diagram for volcanic rocks. Red dot is sample CN-4.

Cerro Negro Exercise 3: Mg# and primitive vs. fractionated magma: Oxidation state of Fe

B) Re-examine the analyses in the table below (same samples as in Ex. 2A). Calculate the MG# for each sample assuming all of the Fe is Fe2+. Then, split the FeO (total) into Fe3+ and Fe2+ assuming that 25 percent of the FeO total is actually Fe_2O_3 and the rest is FeO (intermediate range from Kelly and Cottrell 2009). Now recalculate the MG# for each sample, and determine whether it is likely to be an unfractionated, primitive mantle melt, or a melt that has either been fractionated or is from the crust.

Oxide	CN-4	CN-6	SAL-IL-4	SAL-IL-5	SAL-IL-1
SiO_2	48.6	50.4	58.21	66.8	70.6
TiO_2	0.65	0.83	0.66	0.4	0.25
Al_2O_3	14.4	20.0	17.6	15.7	14.9
FeO (total)	11.0	9.6	6.45	3.76	2.00
MnO	0.2	0.18	0.14	0.08	0.12
MgO	9.97	3.69	3.34	1.5	0.68
CaO	11.3	11.4	7.62	4.17	2.89
Na_2O	1.78	2.38	3.43	4.28	4.14
K_2O	0.35	0.47	1.12	1.99	2.3
P_2O_5	0.06	0.32	0.23	0.27	0.17
LOI	0.08	0.10	0.35	0.42	1.97
(1) Calculate MG# assuming FeO (total) is all Fe2+					
MG#	**64.5**				
(2) Recalculate FeO and Fe2O3 assuming that Fe2O3 is equal to 25 percent of FeO total					
Fe_2O_3	***2.75***				
FeO	***8.25***				
(3) Recalculate MG# using recalculated FeO					
MG#	**70.9**				
Is sample likely to be primitive mantle melt (MG#>65)?	***yes***				

Cerro Negro Exercise 4: Magmatic fractionation

Lavas of the Central American Arc (Student Activity Sheet)

Exercise 4. Application of methods to investigate petrogenesis of arc lavas

A) The petrogenesis of Cerro Negro, Nicaragua

CN-4 erupted from Cerro Negro in 1957-1960, but then the volcano was pretty quiet for eight years until it erupted again in 1968. In order to understand what happened to the Cerro Negro samples during those eight years, we can compare the mineralogy and geochemistry of Sample CN-6 (1968 lava) to CN-4 (1960 lava). Figure 11 shows hand specimens of these two lavas and you should be able to tell at a glance that they look different: the older lava (CN-4) has more olivine and pyroxene phenocrysts and the younger lava (CN-6) has more plagioclase phenocrysts.

CN-4 1957-1960 10% MgO CN-6 1968 3.7% MgO

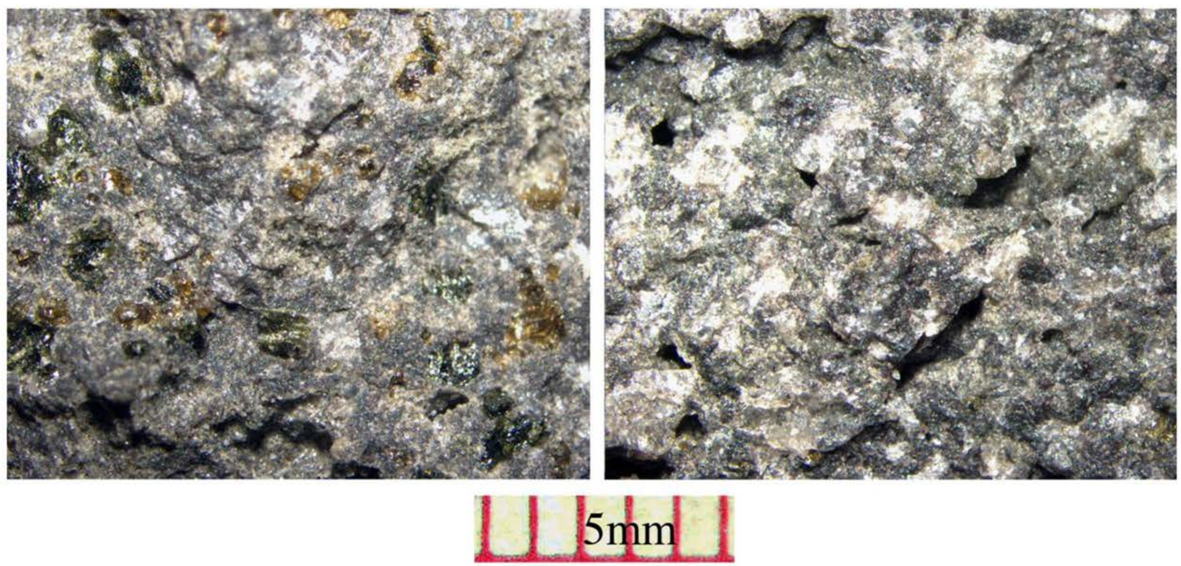
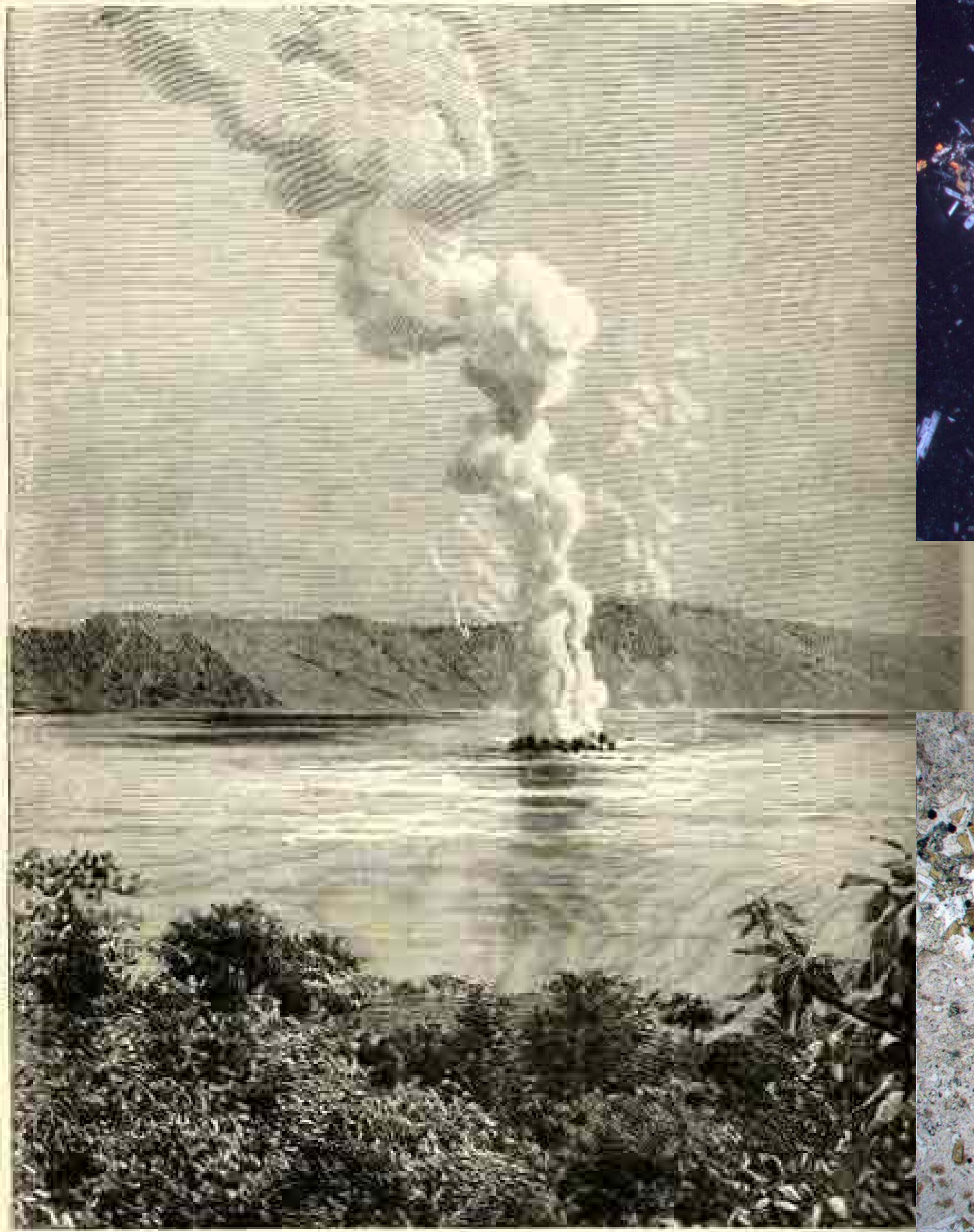
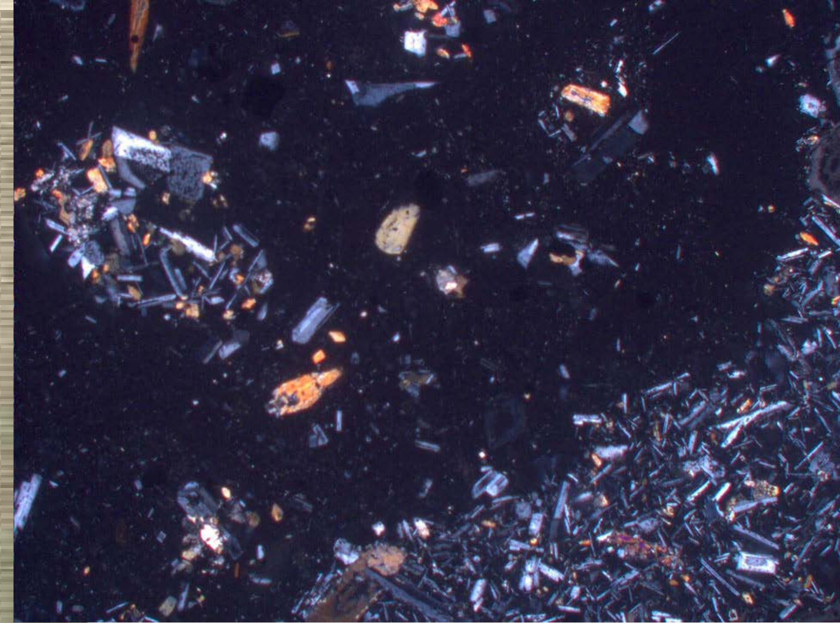


Figure 11. Hand specimens of two Cerro Negro lavas, erupted 8 years apart.

Carry out a modal analysis of CN-6, record your results on the following page, and give the rock a name, using the QAPF diagram (next page). Compare this with the mode and name given from QAPF for CN-4. What are the big differences in the modes of these two lavas?



ILOPANGO VOLCANO, SAN SALVADOR.



Ilopango 1880 eruption of Islas Quemadas, source of IL4

I use it in GEOS 3464 “Igneous and Metamorphic Petrology”
Junior level course. Typically 25 students enrolled.

2 75 minute class sections

First class period: Classes watches powerpoint as part of lecture
Takes home Handouts 1 and 2 and reads before next class.
Second class period works exercise (Handout 3)

Given after 2 lectures on convergent margin magmatism and students read chapter about this in textbook

Class also sees video “Plate Tectonic Basics 1” 9 minute animation about lithosphere and seafloor spreading
https://www.youtube.com/watch?v=6wJBOk9xjto