GLY4310 88 points 18 took exam Name_____ April 30, 2010

Florida Atlantic University PETROLOGY -- FINAL EXAMINATION KEY

Scores to the left of the answer in red are the number of incorrect responses. Instructor comments and answers are in blue. Questions in gray, with answers marked NG, were duplicates and were not graded.

True-False - Print the letter T or F in the blank to indicate if each of the following statements is true or false. Illegible answers are wrong. (1 point each)

- 0 <u>T</u> 1. The largest difference between orogenic metamorphism and burial metamorphism is the lack of significant structural deformation during burial metamorphism.
- 0 <u>T</u> 2. Many orogenic episodes produce repeated episodes of deformation and metamorphism, leaving a polymetamorphic imprint.
- 2 <u>F</u> 3. All minerals show the transition from brittle to ductile under very similar conditions.
- 1 <u>F</u> 4. Prograde metamorphic reactions are exothermic.
- 3 <u>T</u> 5. Barrow found a much greater change in the pelitic rocks he studied, compared to the sandstones.
- 1 <u>T</u> 6. It is possible for an index mineral to be present in a zone of higher grade than its own.
- 0 <u>F</u> 7. When andalusite is present, the pressure at the time of formation exceeded 0.4 GPa.
- 0 <u>T</u> 8. At very low metamorphic grade, reaction rates are slow.
- 1 <u>T</u> 9. Ca-bearing minerals, like laumonite, prehnite, and pumpellyite are stable in waterrich, carbonate-free fluids.
- 2 <u>F</u> 10. The Franciscan belt lies nearer the former subduction zone than the Sierra belt. The Sierra belt is richer in alkaline elements than the Franciscan belt.
- 2 <u>F</u> 11. Ordinary prograde metamorphic reactions are common in high-temperature mafic igneous rocks.
- 1 <u>F</u> 12. The original facies classification was based primarily on metamorphosed felsic rocks.
- 2 <u>T</u> 13. There is little difference in mafic rock facies that develop at low, medium, or even high pressure.

- 1 Т 14. If equilibrium is maintained, there is a correlation between the An content of plagioclase and the temperature at which metamorphism was occuring. 1 Т 15. Hydrous pelitic and quartzo-feldspathic rocks do not reach granulite grade. 0 Т 16. Eclogites span a greater temperature range than any other facies. F 17. Greenschist-amphibolite facies, such as those of Western North Carolina, require an 3 average continental crustal geotherm to form. 1 F 18. For most P-T-t paths, P_{max} and T_{max} occur at the same time. 4 F 19. Counterclockwide P-T-t paths are found only in granulite facies rocks. F 0 20. Metamorphic grade is most closely related to P_{max} . Т 2 21. In a Buchan sequence, oligoclase appears before hornblende. F 2 22. In the low-grade mafic assemblages, complete alteration of the protolith minerals occurs, and it is easy to define new chracteristic mineral assemblages. Т 1 23. The presence of garnet in a facies indicates it formed at medium to high pressures. 2 Т 24. Eclogites associated with xenoliths in kimberlites or basalts belong to the hightemperature group. 2 Т 25. The Franciscan trajectory has a large increase in pressure with a relatively small increase in temperature. 2 F 26. New minerals will growth during deformation, parallel to σ_1 . 27. All minerals show the transition from brittle to ductile under very similar conditions. NG NG 28. Prograde metamorphic reactions are exothermic. 1 Т 29. Cordierite has a large molar volume, which indicates it is stable at low pressures. <u>NG</u> 30. The original facies classification was based primarily on metamorphosed mafic rocks. NG 31. Ordinary prograde metamorphic reactions are common in high-temperature mafic igneous rocks.
 - NG 32. Eclogites associated with xenoliths in kimberlites or basalts belong to the low-temperature group.

- <u>NG</u> 33. Greenschist-amphibolite facies, such as those of Western North Carolina, require an average continental crustal geotherm to form.
- <u>NG</u> 34. For most paths, Pmax and Tmax occur at the same time.
- 0 <u>T</u> 35. Blueschist preservation, rather than blueschist generation, may be more important in determining whether blueschist rocks are seen in a region.
- 7 <u>T</u> 36. If a rock is found in the middle of the QAP part of the IUGS diagram, it is silica excessive.
- 8 <u>T</u> 37. As they travel deeper in the mantle, the velocity of both P and S waves increases.
- 2 <u>T</u> 38. Slow-spreading ridges have a pronounced axial valley, 30 to 50 kilometers in width, and 1-5 kilometers in depth. Inward facing fault scarps are seen, a feature shared with continental rift zones. An inner rift valley is often present, 3-9 kilometers in width, with a flat floor.
- 3 <u>F</u> 39. Carbon dioxide solubility is very high in silicate melts.
- 5 <u>T</u> 40. Hornblende is a lower temperature mineral in Bowen's Reaction Series than augite.
- 3 <u>F</u> 41. Basaltic magmas have much higher volatile contents, on average, than granitic magmas.

Multiple-Choice - Choose the best response to each statement or question. Print the letter corresponding to your choice in the blank. (1 point each)

- 2 <u>B</u> 1. Which of the following is the most effective mineralizer?
 - A, Water
 - B. Fluoride ion
 - C. Carbon dioxide
 - D. Sulfur dioxide
- 2 <u>A</u> 2. Load pressure is another name for:
 - A. Lithostatic pressure
 - B. Hydrostatic pressure
 - C. Tectonic pressure
 - D. Impact pressure
- 0 <u>B</u> 3. Where might the geothermal gradient be lower than average?
 - A. Near zones of crustal thickening or crustal extension
 - B. In a subducting plate
 - C. Near an igneous intrusion
 - D. Above a hot spot

- <u>A</u>
 <u>A</u>
- 5 <u>C</u> 5. During ocean floor metamorphism, which pair of elements is removed from the protolith?
 - A. Fe, Mg
 - B. Na, Mg
 - C. Ca, Si
 - D. K, Ti
- 2 <u>D</u> 6. Which of the following terms is used in place of fault-zone metamorphism? A. Dislocation metamorphism
 - B. Shear-zone metamorphism
 - C. High-stress metamorphism
 - D. All of the above
- 1 <u>A</u> 7. Which British petrologist made one of the first systematic studies of metamorphic rocks types, their variation, and the mineral assemblages generated in an episode of progressive metamorphism?
 - A. George Barrow
 - B. Penteii Eskola
 - C. Viktor Goldschmidt
 - D. Peter Wyllie
- 2 <u>B</u> 8. Phyllonites are foliated cohesive rocks rich in what mineral?
 - A. Plagioclase
 - B. Mica
 - C. Pyroxene
 - D. Olivine
- 3 <u>C</u> 9. A cohesive high-strain rock that has undergone significant recrystallization is known as what?
 - A. Phyllonite
 - B. Microbreccia
 - C. Blastomylonite
 - D. Cataclasite

- 1 <u>B</u> 10. Who first formulated the idea of metamorphic facies?
 - A. C.E. Tilley
 - B. Pentii Eskola
 - C. George Barrow
 - D. Alfred Harker
- 3 <u>B</u> 11. Who proposed the addition the zeolite and prehnite-pumpellyite facies to Eskola's original set of five facies?
 - A. Escola
 - B. Coombs
 - C. Fyfe
 - D.All of the above
- 0 <u>C</u> 12. The starting material from which a reaction or recrystallization begins is called what? A. Granofels
 - B. Isograd
 - C. Protolith
 - D. Spillite
- 0 <u>C</u> 13. Which of the following minerals might be used to characterize the onset of metamorphism?
 - A. Garnet
 - B. Omphacite
 - C. Prehnite
 - D. Zoisite
- 13 <u>C</u> 14. Which of the following describes tension? Tension mean pulling apart, hence σ_3 is negative

A. $\sigma_1 > \sigma_2 > \sigma_3$ B. $\sigma_1 > \sigma_2 \approx \sigma_3$ C. $\sigma_1 > \sigma_2$, both + ; σ_3 is negative D. Either A or B

- <u>NG</u> 15. Which British petrologist made one of the first systematic studies of metamorphic rocks types, their variation, and the mineral assemblages generated in an episode of progressive metamorphism? Hint: His study area was the Scottish Highlands.
 - A. G. Barrow
 - B. P. Eskola
 - C. V. Goldschmidt
 - D. A. Miyashiro

0 <u>C</u> 16. Under extreme conditions, frictional heating will produce partial melting, creating glass. Rocks with glassy seams are called what?

- A. Fault gouge
- B. Hornfels
- C. Pseodotachylyte
- D. Shatter cones

- 6 <u>B</u> 17. Who proposed the addition of the ganulite, epidote amphibolite, and glaucophane schist facies to Eskola's original set of five facies?
 - A. Coombs
 - B. Eskola
 - C. Fyfe
 - D. Goldschmidt

0 <u>D</u> 18. Where might a low P/T baric series be found?

- A. Rift zone
- B. High heat flow orogenic zone
- C. Contact metamorphic zone
- D. All of the above
- 4 <u>B</u> 19. The Barrovian type of metamorphic trajectory is characteristic of which baric series? A. High P/T
 - B. Medium P/T
 - C. Low P/T
 - D. May be any of the above
- 3 <u>C</u> 20. As pressure increases, amphibolite or ganulite facies rocks transform to eclogogies. It is the initial breakdown of which mineral that marks this tansition?
 - A. Enstatite
 - B. Hornblende
 - C. Plagioclase
 - D. Garnet
- 10 <u>C</u> 21. The name of this important mineral group comes from words meaning "oblique" and "break", in allusion to their triclinic structure.
 - A. Epidote
 - B. Feldspathoid
 - C. Plagioclase feldspar
 - D. Silica
- 7 <u>D</u> 22. This subclass consists of three-dimensional structures, and includes the most common minerals in the crust of the earth
 - A. Inosilicate
 - B. Nesosilicate
 - C. Sorosilicate
 - D. Tectosilicate
- 2 <u>B</u> 23. Large crystals formed by relatively slow cooling of magma below the earth's surface are called:
 - A. Phaneritic
 - B. Phenocrysts
 - C. Pyroclasts
 - D. Xenocrysts

- 11 <u>B</u> 24. In the Hawaiian Island sequence of basaltic eruptions, alkaline basalt is seen in all of the following stages except:
 - A. Pre-shield
 - B. Shield-building
 - C. Post-shield
 - D. Post-erosional

Fill-Ins - Write in the word or words which best completes each statement or answers each question. (1 point per blank)

- 0 1. Metamorphism produced by decreasing temperature and pressure is called <u>RETROGRADE</u> metamorphism.
- 9.5 2. Parallel belts like the Sanbagawa and Ryoke belts, usually separated by a fault, are seen in a number of regions around the Pacific Ocean. What name did Miyashiro give to such belts?

PAIRED METAMORPHIC BELTS

0 3. In metamorphic assmblages, the symbol \pm is short for what phrase?

WITH OR WITHOUT

4 4. As grade increases, the color of hornblende changes fro green to brown. Why?

DUE TO INCREASING TI CONTENT IN THE HORNBLENDE

7 5.Hydrous pelitic and quartzo-feldspathic rocks do not reach granulite grade. Why?

WHEN AQUEOUS FLUIDS ARE PRESENT, PELITIC AND QUARTZO-

FELDSPATHIC ROCKS WILL BE ABOVE THE SOLIDUS AT LOW TO MEDIUM PRESSURE. MELTING WILL BEGIN. MIGMATITES MAY FORM.

- TRESSORE. MEETING WILL BEGIN, MIGMITTIES WITT FOR
- 3.5 6. Granulites are thought to form in regions of crustal thickening. Why?

AREAS OF CRUSTAL THICKENING HAVE VERY HIGH GEOTHERMS, WHICH ALLOWS GRANULTIES TO REACH THE 700-1000° C RANGE THEY REQUIRE TO FORM.

7. A vitric tuff on the pyroclastic classification chart will consist mainly of fragments of what?
 GLASS

28.5 8-9 What is the chemical difference between orthopyroxenes and clinopyroxenes? How does it affect their structure?

THE PYROXENE STRUCTURE HAS TWO DISTORTED OCTAHEDRAL SITES, M1 AND M2. IN ORTHOPYROXENES, THE CATIONS ARE MAGNESIUM, IRON, OR A MIXTURE. BOTH HAVE THE SAME SIZE, AND CAN OCCUPY EITHER M1 OR M2, CREATING AN ORTHORHOMBIC STRUCTURE. IN CLINOPYROXENES, CALCIUM IS PRESENT IN ADDITION TO Mg AND Fe. SINCE Ca IS LARGER, THE STRUCTURE IS DISTORTED, BECOMING MONOCLINIC.

17.5 10. Perthite is described as, "The host is K-spar, with albite lamellae appearing as a coherent intergrowth." What does the term coherent mean, as it is used here?

COHERENT MEANS THE EXSOLVED PHASE LATTICES HAVE A SPECIFIC RELATIONSHIP TO THE HOST LATTICE

11.5 11. If a rising diapir were to follow adiabatic (without loss of heat) conditions, then the rock temperature would follow the adiabat. This curve is a loss of about 12°C/GPa. It is impossible to follow a true adiabat, but rapidly rising masses would come close. The melting curve is decreasing about 130 C/GPa, so it is possible for the rock to initiate melting. Once melting begins, the heat of fusion will consume energy, and keep the adiabatic path to a shallow slope. Melting will occur, but slowly, and with limited quantities of melt. The process is called <u>DECOMPRESSION MELTING</u>. When petrologists attempt to determine the average chemistry of MORB, they extract glass from the basalt, and measure the chemistry. Why?

GLASS IS UNSOLIDIFIED MAGMA THAT HAS NOT UNDERGONE ANY MAGMATIC DIFFERENTIATION PROCESSES

12 13. Why is lead thought to be a good indicator of contamination of mantle rocks?

THE MANTLE CONTAINS VERY LITTLE LEAD, SO MANTLE SAMPLES WITH HIGH LEAD CONCENTRATIONS ARE PROBABLY CONTAMINATED BY NON-MANTLE ROCKS. 4.5 14. Divergent boundaries more likely to be found in oceans than on a continent. One reason for this is that oceans cover 70% of the earth's surface, whereas continents cover only 30%. What is the other reason?

THE OTHER IS THAT THE OCEANIC LITHOSPHERE IS MUCH THINNER (10 KM) THAN CONTINENTAL LITHOSPHERE. THIS RESULTS IN RIFTS ON LAND EITHER OPENING, SPLITTING A CONTINENT AND CREATING A NEW OCEAN, OR FAILING, AND BECOMING AN AULACOGEN. SINCE A RIFT ON THE OCEAN FLOOR IS NO LONGER CONTINENTAL, CONTINENTAL RIFTS SIMPLY DO NOT LAST FOR LONG.

Discussion Questions - Write a complete, concise answer to the following questions. Diagrams (labeled) may be used to supplement your written answers, where appropriate. (2 points each)

8.0 1. A student studies the fluid inclusions in a rock. They form a planar array. Will careful analysis of the fluid allow the student to determine the composition of the original fluid associated with metamorphism? Why?

PROBABLY NOT. PLANAR ARRAYS ARE USUALLY FORMED BY POST-

METAMORPHIC FLUIDS SEEPING INTO THE ROCK ALONG CRACKS.

10.5 2. Below a certain depth, around 10 km, the pressure at the point of mineral contact, P_{lith}, will be very much greater then the pressure exerted by the intergranular fluids on the minerals. One of two things may happen to reduce this imbalance. What are they?

1. THE MINERAL GRAINS DEFORM, AND COMPRESS THE PORE SPACE UNTIL

 $P_{FLUID} = P_{LITH}.$

2. PRESSURE SOLUTION OCCURS. MINERALS AT THE STRESSED CONTACTS BETWEEN GRAINS HAVE A HIGHER FREE ENERGY THAN ADJACENT GRAINS NOT IN CONTACT. THEY MAY DISSOLVE AND BE REPRECIPITATED IN THE PORE SPACE. THIS LOWERS THE OVERALL FREE ENERGY OF THE SYSTEM, AND ALSO ALLOWS THE GRAINS TO MOVE CLOSER TOGETHER, AS WELL AS FILLING THE PORE SPACES. THIS CONTINUES UNTIL $P_{FLUID} = P_{LITH}$. 1 3. What is pyrometamorphism? How might it occur?

PYROMETAMORPHISM IS A VERY HIGH TEMPERATURE TYPE OF CONTACT METAMORPHISM. XENOLITHS WHICH FALL INTO MAGMA CHAMBERS MAY BE RAPIDLY HEATED, AND SHOW SUBSTANTIAL ALTERATION. WALL ROCKS IN OR NEAR VOLCANIC NECKS ARE ANOTHER EXAMPLE. PARTIAL MELTING OF COUNTRY ROCK IS COMMON.

9 4. Ocean-floor metamorphism involves considerable chemical replacement. What elements are principally involved? What is the source of the new ions?
 THE MAJOR REPLACEMENT IS OF CA AND SI BY MG AND NA. SODIUM AND

MAGNESIUM COME FROM SEA-WATER, WHICH INFILTRATES ROCK NEAR THE MAGMA-WALL ROCK BOUNDARY.

3 5. What is the difference between fault gouge and fault breccia?

FAULT BRECCIA IS BROKEN, CRUSHED ROCK FILLING IN ALONG THE FAULT. GOUGE IS A CLAYEY ALTERATION OF THE BRECCIA, PRODUCED BY GROUNDWATER PERCOLATING DOWN THE FAULT ZONE.

5 6. What two minerals are considered characteristic of impact metamorphism? What other material is often found in impact zones?

COESITE AND/OR STISHOVITE, HIGH-PRESSURE POLYMORPHS OF SILICA, ARE THE CHARACTERISTIC MINERALS. AMORPHOUS GLASS, PRODUCED BY IMPACT MELTING, IS OFTEN PRESENT.

15 7. What important contribution did Viktor Goldschmidt make to the study of equilibrium mineral assemblages?

GOLDSCHMIDT STUDIED A SERIES OF CONTACT METAMORPHOSED HORNFELSES WHOSE PROTOLITHS INCLUDED PELITIC, CALCAREOUS, AND PSSAMITIC ROCKS. THIS PROVIDED A CONSIDERABLE VARIATION IN PARENT ROCK COMPOSITION, BUT GOLDSCHMIDT FOUND SIMPLE MINERAL ASSEMBLAGES OF SIX OR FEWER MAJOR MINERALS IN THE INNER ZONE OF AUREOLES AROUND GRANITIC INTRUSIONS AROUND THE OSLO AREA OF SOUTHERN NORWAY. HE NOTED THAT THE EQUILIBRIUM MINERAL ASSEMBLAGE WAS RELATED TO THE BULK COMPOSITION, AT A PARTICULAR METAMORPHIC GRADE, AND THAT PAIRS OF MINERALS WERE CONSISTENTLY SEEN TOGETHER, SUCH AS ANORTHITE-HYPERSTHENE OR DIOPSIDE-ANDALUSITE.. 26 8. The transition from the greenschist to the amphibolite facies involves two major mineralogical changes. What are they?

 INCREASED CA CONTENT OF PLAGIOCLASE, FROM ALBITE TO OLIGOCLASE, ACROSS THE PERISTERITE GAP
 TRANSITION FORM ACTINOLITE TO HORNBLENDE. AT HIGHER TEMPERATURES, THE AMPHIBOLE STRUCTURE IS ABLE TO ACCOMMODATE MORE ALUMINUM AND ALKALI IONS.

Short-Answer Questions - Write a complete, concise answer to **one** of the following **two** questions. **Please answer on the following page, and write the number of the question you are answering in the blank provided.** (5 points)

1. There are six major categories of protolith rocks for metamorphic reactions. Name and briefly describe any three categories. Indicate the places these rocks might be found, and their characteristic chemistries.

1. Ultramafic rocks - Mantle rocks, cumulates, and komatites. Characteristic chemistry: Very high Mg, Fe, Ni, and Cr

2. Mafic rocks - Basalts, gabbros, some graywackes. Characteristic chemistry: High Mg, Fe, Ca

3. Pelitic Rocks - Fine-grained clastic clays and silts, deposited either on stable platforms or in offshore wedges. Characteristic chemistry: High Al, K, and Si

4. Calcareous rocks: Sedimentary limestones and dolostones. Marls are impure carbonates which contain sand or shale, and thus may be richer in elements associated with pelitic rocks. Characteristic chemistry: High Ca, Mg, and CO2.

5. Quartz rocks - Oceanic cherts, composed of radiolarian skeletons, or high-energy continental sand deposits, which are nearly pure quartz. Characteristic chemistry: SiO2
6. Quartzo-feldspathic rocks - Arkosic sediments, granitoid or rhyolitic igneous rocks. Characteristic chemistry: High Si, Na, K, and Al

2. Barrow defined a series of six metamorphic zones based on the presence of index minerals for his Scottish Highlands site. Name three of the six zones, and describe the rocks characteristically associated with each zone. Also describe the minerals which might be associated with each zone.

Chlorite zone - Slates or phyllites

Minerals: Chlorite, muscovite, quartz, albite

Biotite zone - Phyllites, schists Minerals: Biotite, chlorite, muscovite, quartz, albite

Garnet zone: Garniferous schists Minerals: Red almandine garnet, biotite, chlorite, muscovite, quartz, albite or oligoclase

Staurolite zone: Schists Minerals: Staurolite, biotite, muscovite, quartz, garnet and plagioclase

Kyanite zone - Schists Minerals: Kyanite, biotite, muscovite, quartz, and plagioclase, ±garnet, ±staurolite.

Sillimanite zone - Schists and gneisses

Minerals: Sillimanite, biotite, muscovite, quartz, plagioclase, and garnet, ±staurolite, ±kyanite.

Question #	Times Answered	Points Missed	Average Missed
1	15	13.5	0.9
2	3	1.0	0.3

Final Exam Grades

91.3		
89.1		
87.5 - 2		
85.8	A+	
84.7		
83.1		
82.0 - 2	A	$\mathbf{MEDIAN} = 81.7$
80.9		
80.3		
79.8 - 2	A-	MEAN = 79.5 (90.3%)
77.6	B+	
73.7	В	
70.4	B-	
60.5		
59.4	D+	

Previous Final Exam Results

Spring 2010	Mean = 79.5 (90.3%)
Spring 2008	Mean = 76.2 (86.6%)
Spring 2006	Mean = 81.3 (92.4%)
Fall 2001	Mean = 76.4 (86.8%)

Total Exam Results (Possible = 208)

201.0		
200.6		
196.5		
193.8	A	
189.2	A-	
183.5		
181.3	B+	
178.9		
178.3	B	Median = 175.2
172.0		Mean = 172.4 (82.9%)
168.7	B-	
166.1		
164.8 - 2		
160.1	C+	
150.9		
147.0	C-	
128.4	D-	

Exams Overall

Spring 2010	Mean = 82.9%, B-
Spring 2008	Mean = 80.7%, B-
Spring 2006	Mean = 84.8%, B
Fall 2001	Mean = 81.9%, B-