GLY4310 Name_____
80 points April 30, 2020
4 took exam
Scores to the left of the answer in red are the number of incorrect responses. Instructor comments and answers are in blue.

Florida Atlantic University
PETROLOGY -- FINAL EXAMINATION KEY

This examination is a TAKE-HOME exam. You may use your textbook, lecture notes, and PowerPoint presentations. It is due no later than 1:00 p.m. on April 30, 2020. Please complete it using WORD (*.rtf format acceptable). Rename the file using your last name followed by the regular file name (i.e. lastname_4310FE_S20.docx). Return it as an e-mail attachment from your FAU e-mail account. Remember you are bound by the provisions of the **FAU Honor Code**.

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 T 1. According to the SCMR. metamorphism is a subsolidus process leading to changes in mineralogy and/or texture (for example grain size) and often in chemical composition in a rock, and may coexist with partial melting.

0 T 2. Metasomatism plays the greatest role when the composition of the country rock is substantially different from that of the magma, especially when the country rock is carbonate-rich.

0 F 3. The structural, magmatic, and metamorphic patterns are produced by a continent plate colliding with an oceanic plate are more complex than when two continental plates collide.

0 F 4. Burial metamorphism is usually accompanied by significant structural deformation.

0 T 5. The Abukuma Belt in Japan is a Buchan type low P/T belt.

0 F 6. The presence of cordierite and andalusite in metamorphic rocks indicates they have been subjected to high pressures.

0 T 7. Burnham's classic study of the Crestmore Quarry in California demonstrated that this was a case of pyrometamorphism,.

Exam Total _____/184 _____% Grade _____

0 T 8. Isograds may be treated as chemical reactions, when possible.

2 F 9. **Cataclasis** referees to mechanical crushing and grinding, with no recrystallization, at great depth in a shear zone.

0 T 10. If two alternative assemblages are compositionally-equivalent, we must be able to relate them by a chemical reaction

0 T 11. Granulite facies form only in water-deficient rocks, either dehydrated lower crust, or areas with high X_{CO_2} in the fluid.

0 F 12. When tie-lines cross on an ACF diagram in which a single metamorphic facies is plotted, it is an indication that equilibrium has been maintained.

0 T 13. Granulites represent temperatures in excess of 700°C, and sometimes as hot as 1000°C. Since temperatures at the depth of a granulite facies rock, with an average geotherm, should be about 500°C, they probably represent areas of crustal thickening with very high geotherms.

0 F 14. In most clockwise P-T-t paths, P_{max} and T_{max} occur at the same time.

0 T 15. . The high P/T facies series typically develops along the outer paired belt and the medium or low P/T series develop along the inner belt (nearer the subduction zone).

0 T 16. The micas are examples of triphormic phyllosilicates

2 F 17. Laccolith intrusions are usually felsic, with lower viscosity magma than lopoliths.

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

0 C 1. The **upper** limit for pressure experienced by crustal rock is:
A. 1 GPa
B. 2 GPa
C. 3 GPa
D. 4 Gpa

0 B 2. Which condition is likely to produce lineation with no foliation?
A. $\sigma_1 > \sigma_2 = \sigma_3$
B. $\sigma_1 = \sigma_2 > \sigma_3$
C. $\sigma_1 > \sigma_2 > \sigma_3$
D. $\sigma_1 = \sigma_2 = \sigma_3$

0 B 3. A contact metamorphic aureole produced by which of the following types of pluton will be easiest to observe?
A. Catazonic
B. Epizonic
C. Mesozoic

0 D 4. Impactites may be recognized by which of the following features?
A. The presence of high pressure silica phases, such as coesite or stishovite
B. Characteristic shock lamellae in quartz
C. Shatter cones in limestone
D. All of the above

0 C 5. Psammites are most apt to be associated with which type of protolith?
A. Carbonates
B. Mafic
C. Quartzo-feldspathic
D. Ultramafic

0 A 6. In phyllites, what Barrovian zones are typically present?
A. Chlorite, Biotite
B. Garnet, Staurolite
C. Staurolite, Kyanite
D. Kyanite, Sillimanite

0 C 7. The Zeolite, Prehnite-pumpellyite, and Pumpellyite(-actinolite) facies are seen where?
A. Comrie schists (Scotland)
B. Franciscan assemblage (California)
C. Haast group (N. Zealand)
D. Skiddaw Aureole (United Kingdom)

0 D 8. What mineral causes the “blue” color in blueschist?
A. Actinolite
B. Chlorite
C. Epidote
D. Glaucophane

0 B 9. Which of the following facies was NOT one of Eskola's initially proposed facies, in 1920?
A. Amphibolite
B. Glaucophane schist (added in 1939)
C. Hornfels
D. Sanidinite

0 D 10. The presence of laumontite, wairakite, and analcime is indicative of which of the following facies?
A. Blueschist
B. Greenschist
C. Prehnite-Pumpellyite
D. Zeolite

0 C 11. The amphibolite facies would include which of the following assemblages?
A. Chlorite, albite, epidote, quartz
B. Glaucophane, lawsonite or epidote
C. Hornblende. plagioclase
D. Pyrope garnet, omphacitic pyroxene

0 B 12. Common orogenic belts. Such as the Barrovian type, belong to which baric series?
A. Low P/T
B. Medium P/T
C. High P/T
D. Amy of the above, depending on the geothermal gradient

0 D 13. In the upper Greenschist facies, what composition of plagioclase is stable?
A. Albite
B. Andesine
C. Labradorite
D. Oligoclase

0 B 14. Who first employed ACF diagrams to the study of metamorphic rocks in 1915?
A. George Barrow
B. Pentii Eskola
C. Akiho Miyashiro
D. C.E. Tilley

0 D 15. What mineral causes the "green" color in greenschist?
A. Actinolite
B. Chlorite
C. Epidote
D. All of the above

0 C 16. The transition from granulite to eclogite. Is marked by the disappearance of one mineral and the appearance of another. Those means are, respectively:
A. Clinopyroxene, amphibole
B. Garnet, orthopyroxene
C. Plagioclase, garnet
D. Quartz, plagioclase

0 A 17. Which contact metamorphic facies correlates with the greenschist regional metamorphic facies?
A. Albite-epidote hornfels
B. Hornblende hornfels
C. Pyroxene hornfels
D. Sanidinite

0 B 18. Ca-poor amphiboles are more common in low pressure phases. Which mineral is an example of this?
A. Actinolite
B. Cummingtonite
C. Hastingsite
D. Hornblende

0 C 19. What type of mineral is jadeite?
A. Aluminum rich amphibole
B. High pressure calcic plagioclase
C. Sodic pyroxene
D. Titanoferrous olivine

0 B 20. A post-crystallization reaction involving water is known as a deuteric reaction. A reaction which involves the conversion of feldspars to a very fine-grained white mica (essentially muscovite) is called:
A. Saussuritization
B. Seritization
C. Serpentization
D. Uralization

0 D 21. Another type of deuteric reaction involves pyroxenes, which are anhydrous. At lower temperatures, they may react with water to produce an amphibole. The replacement can be as reaction rims, patches of pyroxene left in amphibole, or complete replacement. This is called:
A. Saussuritization
B. Seritization
C. Serpentization
D. Uralization

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

0 1. Deformation, common in metamorphic rocks, is seen only when DEVIATORIC Stress is present.

0 2. An increase in temperature or pressure may produce PROGRADE metamorphism.

0 3. In a classic study of rocks from the SE highlands of Scotland, GEORGE BARROW found little change in the sandstones. The pelitic rocks (protolith: shale) he divided into a series of **metamorphic zones** based on the appearance of a new mineral in each zone. He also observed that grain size increased through the zones. This was instrumental in developing the metamorphic grade classification.

0 4. "In any rock or metamorphic formation which has arrived at a chemical equilibrium through metamorphism at constant temperature and pressure conditions, the mineral composition is controlled only by the chemical composition. We are led to a general conception which the writer proposes to call metamorphic FACIES."

0 5. Who wrote the quote in question 4? PENTII ESKOLA

0 6. Who proposed the concept of Facies Series? AKIHO MIYASHIRO

0 7. The LOW P/T baric series is characteristic of high-heat-flow orogenic belts (Buchan or Ryoke-Abukuma type), rift areas, or contact metamorphism

0 8. OMPHACITE is a high-pressure solid solution between augite and jadeite pyroxenes.

0 9. Plutonic intrusive rocks cool very slowly, and pass through the temperature regime usually associated with metamorphism (300-800˚C) slowly enough that reactions may occur. These reactions are called AUTOMETAMORPHIC reactions.

0 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 EXFOLIATED PHASE LATTICES HAVE A SPECIFIC RELATIONSHIP TO THE HOST LATTICE

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

Discussion questions - Write a complete, concise answer to each of the following questions. Diagrams (labeled) may be used to supplement your written answers, where appropriate, and must be shown where requested. Points as shown

4 1. Increased heat promotes recrystallization, especially when two conditions are present.

A. Rocks are fine-grained
B. Environment is static

Explain why. (2 points)

A. Fine-grained rocks have high surface/volume ratios. Chemical reactions occur at surfaces, so the finer the grain size the fast the reaction.

B. Shear stress breaks grains, hindering recrystallization. A static environment has little shear stress.

0 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 (P_{fluid}) on the minerals. Two things may occur to reduce the pressure difference until $P_{fluid} = P_{lith}$. What are they? (2 points)

A. The mineral grains deform, and compress the pore space until $P_{fluid} = P_{lith}$.

B. 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 $P_{fluid} = P_{lith}$.

0.5 3. Zonal metamorphic patterns, in which rocks preserve a geographic sequence of increasing grade, suggests that retrograde metamorphism is not terribly significant. Since cooling in large metamorphic complexes should be slow, time should not be a significant factor in precluding retrograde reactions. What might inhibit them? (1 point)

Retrograde reactions are exothermic. However, this assumes the fluids (water or carbon dioxide) are available for rehydration or recarbonation reactions. In most cases, the fluids are driven off during prograde reactions, and are not available.

0 4. In the middle zone of the Skiddaw Granite (UK), mica inclusions retain the orientation of the external slate matrix, indicating cordierite enveloped aligned micas. For what type of metamorphism is this evidence? (1 point)

It is evidence for the overprint of thermal metamorphism on earlier regional metamorphism.

4 5. The rocks of the Skiddaw Aureole in the Lake District of the United Kingdom contain hornfels. The Comrie Schists in Scotland contain granofels. What are hornfels and granofels, and what is the difference between them? What geologic difference between Skiddaw and Comrie caused the difference in the type of rocks which formed? (3 points)

Both hornfels and granofels are formed by contact metamorphism. Hornfels is very fine-grained, while granofels is medium to coarse grained. Granofels is usually the product of higher temperature conditions. At Skiddaw, the intrusion is a granite. At Comrie, it was a diorite, an intermediate magma considerably hotter then typical granitic magmas.

3 6. At Crestmore, the mineral assemblages become increasing rich in silica at higher grades. Since Mg-bearing carbonates have little silica available, Burnham needed to find the source of the silica. What did he indicate that it was? (1 point)

The only likely source of silica is from silica-rich fluids released from the magma

2.5 7. What is a mylonite? What is the difference between the following type of mylonite? (3 points)

A. Blastomylonite
B. Protomylonite
C. Ultramylonite

Mylonites are cohesive rocks formed in shear zones by ductile flow. Mylonites have between 50-90% fine matrix, while protomylonites have less that 50% fine matrix, and ultramylonites have greater then 90% fine matrix. Blastomylonities show significant recrystallization, probably during an event subsequent to the shearing.

0 8. In an ACF diagram, c = [CaO] - 3.33[P_2O_5]. What is the reason for subtracting [P_2O_5]? (1 point)

C represents the available calcium in metamorphic reactions. If phosphorous is present, apatite will form, reducing the amount of calcium available. By subtracting [P_2O_5] we correct for the amount of calcium used in apatite formation.

5 9. The transition from greenschist to amphibolite is marked by the appearance of two different minerals, either oligoclase or hornblende. In higher pressure sequences (Barrovian) hornblende appears before oligoclase.. In lower P/T terranes (Buchan), and in contact aureoles, the plagioclase appears first. Explain why this occurs. (2 points)

The transition from greenschist to amphibolite facies involves two major mineralogical changes.

1. Increased Ca content of plagioclase, from albite to oligoclase, across the peristerite gap

2. Transition form actinolite to hornblende. At higher temperatures, the amphibole structure is able to accommodate more aluminum and alkali ions.

Both transitions occur at approximately the same grade, but have different P/T slopes. The reactions that generate these changes are complex. The reaction that produces Ca-plagioclase consumes epidote. As pressure increases, the temperature for the calcic plagioclase reactions increases more than for the actinolite-hornblende reactions, so hornblende appears first. At lower pressures, the transition to oligoclase is thermodynamically favored before the transition from actinolite to hornblende.

4 10. Most amphibolites are thus predominantly black rocks with up to about 30% white plagioclase, and plot in the two-phase hornblende-plagioclase region on an ACF diagram. What mineralogical property allows this very simple mineralogical composition? (1 point)

The extensive solid solution of hornblende allows the combination of plagioclase and hornblende to accomodate most of the eleements, and all of the major elements, found in the rocks undergoing metamorphoses.

0 11. Basalts that have been hydrated to become greenstones, and then progressively metamorphosed to higher temperatures have returned to a mineralogy dominated by plagioclase and pyroxene, very similar to the original protolith. The metabasalts produced by this metamorphism differ in one very important respect from the original basalt, and this difference is easily visible in the field. What is the difference? (1 point)

Te texture of such metabasalts is gneissic, completely unlike the parent rock.

3 12. Precambrian blueschists are rare. How can we interpret this? Discuss the three proposed reasons for the scarcity of ancient blueschist, as mentioned in the lecture and in the text. (3 points) Which are possible, which appear very unlikely?

1. There was no subduction before the Cambrian - Very unlikely, since the early earth was hotter than today internally. The heat engine that drives plate tectonics should have been even more active then

2. Geothermal gradients were higher, and the P/T ratio would have been lower - Blueschist minerals would not be possible. This is compatible with the idea of a hotter earth in the past. May be sufficient by itself, or may work together with reason 3.

3. Early metamorphism has been overprinted by later events, and is no longer recognizable - Certainly possible, and may have contiributd to the scarity of ancient blueschist. However, would all old blueschist have been overprinted? That appears unlikely, so reason 2 would still be necessary.

0 13. What is the origin of I-type granitoids? S-type granitoids? (2 points)

I-type granitoids – derived by partial melting of a mantle-derived igneous source (subcrustal underplate, or possibly subducted-slab crust or older higher level pluton)

S-type granitoids – derived by partial melting of peraluminous sedimentary source, previously weathered at the earth's surface

0 14. What does P-T-t stand for? The P-T-t paths shown in the diagrams like the ones in the PowerPoint are deceptive in one very important aspect. What is this? (2 points)

P-T-t stands for pressure-temperature-time. Time is not shown explicitly. The direction of movement is indicated, but the rate of progress can be quite different in different parts of the curve

0 15. What is distinctive about the DUPAL volcanoes? (1 point)

They do not plot on the Northern Hemisphere Reference Line (NHRL) in a plot of $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$, but appear to be enriched with either EMI or EMII. They are located in the Southern Hemisphere, near 30°S latitude.

0 16. Alpine peridotites were quite controversial up until the 1980's, when a reasonable explanation for them was found. What was that explanation? (1 point)

Alpine peridotites are ophiolites, pieces of the ocean floor which were thrust onto the continent, and then pushed upward into the Alps by a plate tectonic collision.

Problems - SHOW ALL WORK - there will be no credit for answers not supported by sufficient work to justify your answer. Show the **formula** used in your calculation, and **identify all parameters**, including **units**, used in the formula. Clearly label your answer, including units if any. Be sure to express your answer to the correct number of significant figures.

8 1. Suppose a reaction takes place with a constant energy barrier of 2685 cal/mol. Calculate K at 585°C. (4 points)

$$K = e^{\frac{-E}{RT}}$$

where K = equilibrium constant (dimensionless)

E = energy barrier (calories/mole)

R = gas constant = 1.987 cal/° mole

T = temperature (Kelvin) - °C + 273.15 = Kelvin

e = natural logarithm base

$$T = 585°C + 273.15 = 858.2\ K$$

$$K = e^{\frac{-2685}{1.987 \cdot 858.2}} = e^{-1.575} = 0.207$$

You need to explain what K and R actually are, not just give a value.

By my signature, and under penalties of the **FAU Honor Code**, I certify that the work shown above is my own, and was not obtained from any other source, other than those listed in the instructions.

_____

Signature

HAVE A GREAT SUMMER
AND STAY SAFE!