Geology Final Exam

Geology and Art

Fall, 2004

This exam covers the material that was presented in lecture, lab and on field trips. It is a closed-book, closed-notes exam; you must rely on the information that you have learned this quarter. You have until 11:30 to complete the exam. Please write clearly so that I can understand your answers. Make sure to read the directions for each section.

Multiple Choice Section (36 points)

There may be one, several, or no correct answers for each question. Circle the letter(s) that are correct.

1. Which of the following is always true concerning a mineral?
   (a) heterotrophic
   (b) specific proportion of elements
   (c) contains oxygen in its chemical formula
   (d) ordered atomic structure

2. Rocks are correlated (the means of determining the equivalence of rock units between two or more different places) using
   (a) unusual, or "key" beds
   (b) elastic limits
   (c) index fossils
   (d) elevation

3. The crystallo-chemical classification is based on
   (a) chemical composition
   (b) energy dispersal patterns
   (c) crystal healing powers
   (d) crystal structure

4. As magma cools, the chemical constituents are reorganized into a variety of minerals. The type and character of minerals that crystallize is depend on
   (a) lunar cycles
   (b) cooling history (temperature)
   (c) depth of crystallization (pressure)
   (d) composition of the original magma

5. Which mineral has the highest concentration of silicon?
   (a) hematite
   (b) plagioclase feldspar
   (c) olivine
   (d) pyroxene

6. If the magma that produced a rhyolite had cooled before reaching the Earth's surface, we would call it a
   (a) basalt
   (b) granite
   (c) obsidian
   (d) diorite

7. Geologists (at least structural geologists) refer to the yield point as
   (a) a triangular yellow sign
   (b) the limit of elastic deformation
   (c) all deformation beyond this point is ductile
   (d) the core-mantle boundary

8. Which are characteristic of normal faults?
   (a) head wall moves up relative to the foot wall
   (b) head wall moves down relative to the foot wall
   (c) extensional deformation triggers faulting
   (c) compressive deformation triggers faulting

9. If a rock was deep in the crust and nearly at its melting point, which of the following things would tend to trigger melting
   (a) additional heat (increased temperature)
   (b) increased pressure
   (c) addition of water
   (d) decreased pressure

10. A basaltic magma can be produced by a 5-10% dry partial melt of
(a) basalt
(b) plagioclase feldspar
(c) mantle (peridotite)
(d) diorite

11. Burial metamorphism, a type of regional metamorphism, usually produces
(a) foliated rocks
(b) faults
(c) diagenesis
(d) nonfoliated rocks

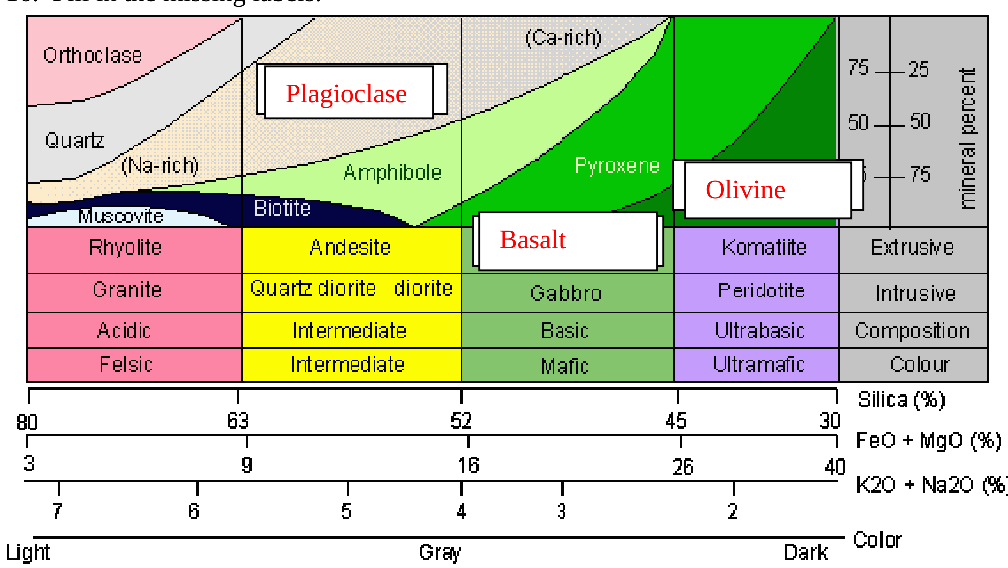
12. The following conditions promote regional metamorphism?
(a) fluids
(b) heat
(c) time
(d) pressure

13. Which of the following are complex ions?
(a) NaCl
(b) H_2O
(c) $(Mg,Fe)_2SiO_4$
(d) CO_3^{2-}

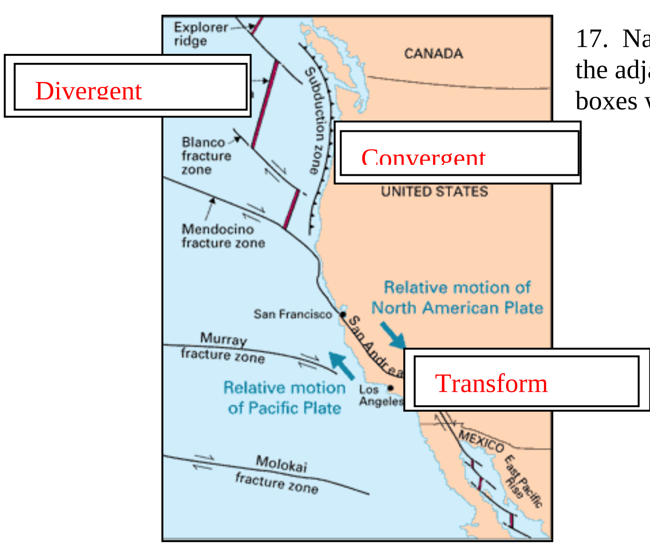
14. Which of the following are phyllosilicates?
(a) olivine
(b) clay minerals
(c) biotite
(d) calcite

15. Which of the following factors increase chemical weathering rates?
(a) increased temperature
(b) plants
(c) decreased surface area
(d) hyperventilation

16. Fill in the missing labels.



17. Name the three types of tectonic plate margins pictured in the adjacent figure. Label the margins by filling in the three boxes with the correct terms.



Short Answer Section (35 points)
Answer any 7 of the following 9 questions. Your answer should be concise. The number of asterisks indicate the degree of difficulty, from *(challenging) to ***(damn tough). Challenge yourself.

18. Differentiation of magma may occur by partial melt and fractional crystallization. Describe one of these two processes.*

Chemical differentiation by partial melt: the process of forming magma through the incomplete melt of a parent rock. Lower temperature minerals melt first and so as melting progresses the magma becomes progressively more mafic (iron and magnesium rich). The first melt is felsic.

Chemical differentiation by fractional crystallization: the composition of a magma and rock can be changed by the separation during solidification. This removal of crystals changes the bulk composition of the remaining system, making the remaining melt increasingly felsic (aluminum and silica rich).

19. Describe the difference between uniform and differential stress (a figure might help the explanation).*

Uniform (lithostatic) stress is when the stress at a particular point within the Earth is the same in all directions. Differential stress is when the stress differs depending on the direction. If vertical stess is greater than horizontal stress you get extension and if horizontal stress is greater than vertical stress you get compression.

20. Describe one geologic feature that you observed on a field trip this quarter that made you change the way you looked at the landscape.*

Various

21. Describe the *Principle of Stratigraphic Superposition* as it relates to the adjacent photograph.**

The Principle of Stratigraphic Superposition states that strata are deposited in sequence, on above the other, and the chronologic order in which strata were deposited is from the bottom to the top. In this example, the shales that were deposited in a pond are stratigraphically lower than the Columbia River Basalt flow, and are therefore older. Additional evidence of this can be seen at the contact where the hot basalts reacted with the wet shales that were previously deposited (pillow structures).

22. If you were hiking up the Elwah River drainage in the Olympic mountains on the way to the Olympic hot springs and found outwash gravels that contained clasts of granite, what interpretation about the local geology could you make?**

Like we saw along the Skokomish drainage basin, it means that the continental glacier that extended south during the Pleistocene had traveled at least this far up the Elwah drainage in order to drop granitic boulders. There are no granites within the Olympic mountains so these clasts must have been transported here during a continental glacial event.

23. As you sit in the hot springs (remember nudity is prohibited), you measure the temperature of the water entering the pool at 54 °C (138 F). If the geothermal gradient for the region is 30°C km^{-1} how deep has the water come along the Hurricane Fault to get to you? (Assume the surface temperature is 15°C).**

54°C – 15°C = 39°C   39°C /30°C km^{-1} = 1.3 kms

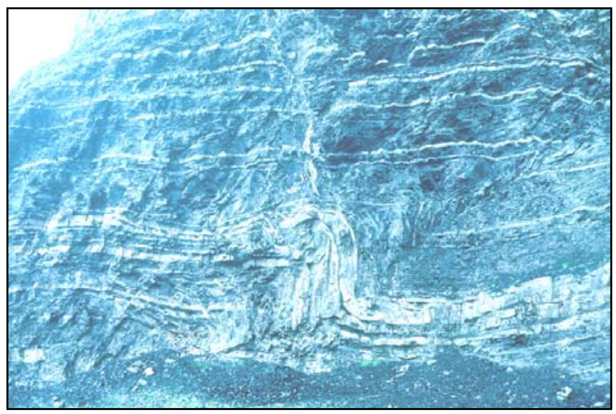
The surface temperature (15°C) must be subtracted from the total temperature before using the geothermal gradient to calculate depth.

How hot would the water be if it were coming from 2.2 kms deep?

2.2 kms * 30°C km^{-1} = 66°C

66°C +15°C = 81°C

24. This is an example of a drag fold from Gaspe Peninsula, Canada. Drag folds form along faults. ***



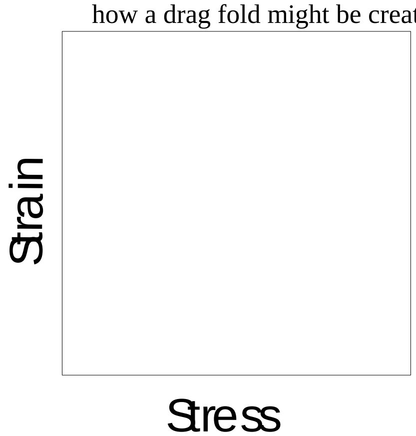
(a) Based on the character of the fold, is this a normal or reverse fault?

Reverse

(b) Draw a line along the fault.

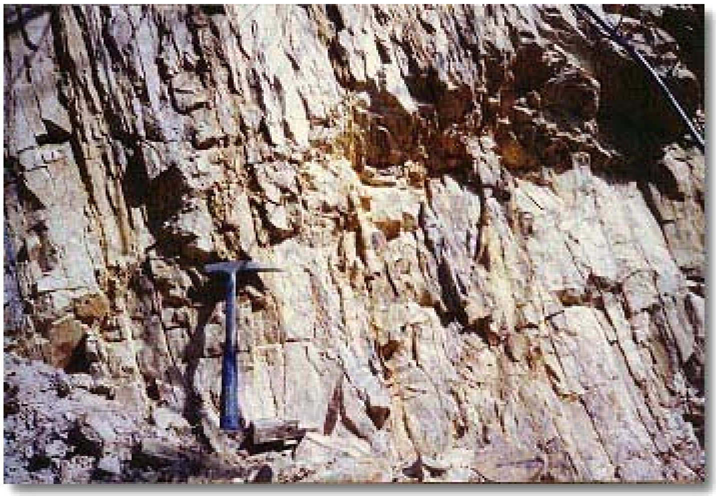
Line from bottom left to top right

(d) Using the following chart, explain how a drag fold might be created.



25. Describe the rock sample and explain (interpret) how a rock like this could have formed (hint: the dark groundmass has the composition of basalt).**

Basalt porphyry is an igneous rock in which 50% or more of the rock is coarse mineral grains in a fine-grained basaltic matrix. The large grains are called pheocrysts. In this case they are probably plagioclase (Ca-rich) crystals that crystallized early as the basaltic magma cooled below the Earth's surface. At some point the magma was remobilized and extruded onto the Earth's surface and cooled quickly, creating the fine grained (dark) groundmass.



26. If you found this high-grade metamorphic rock (mica schist) while driving through the North Cascades, what interpretations could you make about the manner in which it formed?**

A high –grade metamorphic rock must have been produced by the solid state recrystallization of the parent rock at high temperatures (greater than 500°C) and high pressures (several kbar). Since the rock is foliated, there must have been differential pressure present and the principal (compressional) stress orientation was horizontal. This rock probably formed near a plate boundary, possibly associated with a collisional event.

Interpretation (29 points)
Read the excerpt from a paper published in the Geologic Society of America Bulletin and answer the questions concerning it. You may not know all of the terminology in the paper, but you should still be able to interpret most of it and answer the questions.

Active Tectonics of the Seattle Fault and Central Puget Sound, Washington: Implications for earthquake hazards

1999, Johnson, S.Y., Dadisman, S.V., Childs, J.R., and Stanley, W.D.: GSA Bulletin, v. 111,, p. 1042-1053.

ABSTRACT

We use an extensive network of marine high-resolution and conventional industry seismic-reflection data to constrain the location, shallow structure, and displacement rates of the Seattle fault zone and crosscutting high-angle faults in the Puget Lowland of western Washington. Analysis of seismic profiles extending 50 km across the Puget Lowland from Lake Washington to Hood Canal indicates that the west-trending Seattle fault comprises a broad (4-6 km) zone of three or more south-dipping reverse faults. Quaternary sediment has been folded and faulted along all faults in the zone but is clearly most pronounced along fault "A", the northernmost fault, which forms the boundary between the Seattle uplift and Seattle basin. Analysis of growth strata deposited across fault "A" indicate minimum Quaternary slip rates of about 0.6 mm/yr. Slip rates across the entire zone are estimated to be 0.7 to 1.1 mm/yr.

The Seattle fault is cut into two main segments by an active, north-trending, high-angle, strike-slip fault zone with cumulative dextral (right lateral) displacement of about 2.4 km. Faults in this zone truncate and warp reflections in Tertiary and Quaternary strata and locally coincide with bathymetric lineaments. Cumulative slip rates on these faults may exceed 0.2 mm/yr. Assuming no other crosscutting faults, this north-trending fault zone divides the Seattle fault into 30-40 km long western and eastern segments. Although this geometry could limit the area ruptured in some Seattle fault earthquakes, a large event about 900 A.D. ago appears to have involved both segments. Regional seismic-hazard assessments must (1) incorporate new information on fault length, geometry, and displacement rates on the Seattle fault, and (2) consider the hazard presented by the previously unrecognized, north-trending fault zone.

INTRODUCTION

The Seattle fault is a zone of thrust or reverse faults that strikes through downtown Seattle in the densely populated Puget Lowland of western Washington (Fig. 1). The fault coincides with large gravity and magnetic anomalies (Danes et al., 1965; Finn et al., 1991) and forms the boundary between an uplift of Tertiary rocks to the south and the Seattle basin to the north (Johnson et al., 1994). The Seattle fault is considered active (e.g., Gower et al., 1985; Bucknam et al., 1992), however its precise location, lateral geometry, displacement history, and slip rates are poorly defined. We collected an extensive network of marine high-resolution seismic-reflection profiles across the Seattle fault to better define these uncertainties and provide constraints for earthquake hazard assessments. Our purpose in this paper is to present the results of these marine geophysical surveys and local complementary onland investigations. Previous interpretations of the Seattle fault were derived from conventional industry seismic-reflection data (Johnson et al., 1994, Pratt et al., 1997) collected from Puget Sound, and these data were also incorporated in our analysis. Because much of the geologic framework of the Puget Lowland is obscured by Quaternary deposits, dense vegetation, Puget Sound waterways, and urban sprawl, marine seismic surveys provide critical information for understanding the structure and evolution of the region.

THE SEATTLE FAULT

Danes and others (1965) first suggested the presence of a significant west-trending fault in the Puget Lowland through Seattle on the basis of gravity data. They inferred a steeply north-dipping zone consisting of two parallel normal faults with about 11 km of vertical slip. Gower and others (1985) briefly outlined geologic relationships across the Seattle fault, and Yount and Holmes (1992) suggested the fault dipped to the south and had reverse displacement. Johnson and others (1994) used industry seismic-reflection data from Puget Sound to show that the Seattle fault is a broad zone comprising south-dipping thrust or reverse faults. Johnson and others also inferred that the Seattle fault has been active from about 40 Ma to the present, and linked north-vergent thrust faulting to flexural subsidence in the adjacent Seattle basin (Fig. 1). They suggested the Seattle fault represents a restraining transfer zone between right-lateral shear zones near Hood Canal and the southwest Washington Cascade foothills (Fig. 1; Gower et al., 1985). Pratt and others (1997) subsequently proposed a complementary model in which the Seattle fault is one structural component of a north-directed thrust sheet that underlies the central Puget Lowland from the Black Hills on the southwest to the southern Whidbey Island fault (Johnson et al., 1996) on the north.

Gower and others (1985) suggested that the large thickness of Quaternary strata in the Seattle basin indicate possible large Quaternary offsets, and noted an uplifted Holocene marine terrace within the Seattle fault zone at Restoration Point. Bucknam and others (1992) documented as much as 7 m of uplift at Restoration Point and inferred that it occurred during a large (M > 7) earthquake on the Seattle fault about 900 A.D. This earthquake was accompanied by a tsunami in Puget Sound (Atwater and Moore, 1992), landslides in Lake Washington (Fig. 2A, B; Jacoby et al., 1992; Karlin and Abella, 1992, 1996) and rock avalanches in the Olympic Mountains (Fig. 1; Schuster et al., 1992).

Rates of displacement and earthquake recurrence intervals for the Seattle fault are essentially unknown. Thorson (1993) used elevations of glacial deltas to infer about 9 m of uplift along the Seattle fault in the last 16,000 yrs, which suggests that most postglacial uplift occurred on the ~900 A.D. event and that recurrence intervals for such large events must be on the order of several thousand years. However, Thorson (1996) also speculated that motion on the Seattle fault over the last 15,000 years may be anomalous because of deglaciation and that relevant recurrence intervals could be shorter or longer. After assuming a thrust-sheet model of deformation, Pratt and others (1997) used fault-segment lengths and fold geometries to deduce an average slip rate of 0.25 mm/yr for the Seattle fault over the last 40 million years. However, other models of Puget Sound structure are possible and there is no basis for assuming that this inferred long-term Tertiary rate applies to the Quaternary. Pratt and others also calculated the total surface area of the Seattle fault from their model and concluded that earthquakes of magnitude 7.6 to 7.7 were possible.

Seismogenic depths below Puget Sound are typically about 15 to 25 km (Ludwin et al., 1991). Since 1970 when the regional seismic network became operational, the largest two earthquakes associated with the Seattle fault include a M 5.0 event that occurred at a depth of about 17 km beneath Point Robinson on 29 January 1995 (Dewberry and Crosson, 1996), and a M 4.9 event that occurred at a depth of 7 km beneath Point White on southwestern Bainbridge Island on 23 June 1997.

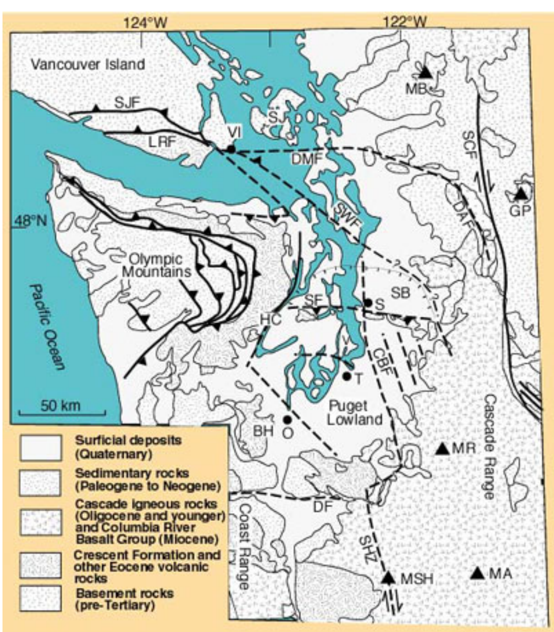


Figure 1. Schematic geologic map of northwestern Washington showing the Puget Lowland and flanking Cascade Mountains, Coast Range, and Olympic Mountains. Abbreviations for cities: O = Olympia; S = Seattle; T = Tacoma; VI = Victoria. Abbreviations for faults (heavy lines), modern Cascade volcanoes (triangles) and other geologic features: BH = Black Hills; CBF = Coast Range Boundary fault; DAF = Darrington fault; DF = Doty fault; DMF = Devils Mountain fault: GP = Glacier Peak; HC = Hood Canal; LRF = Leech River fault; MA = Mount Adams; MB = Mount Baker; MR = Mount Rainier; MSH = Mount Saint Helens; SB = Seattle basin; SCF = Straight Creek fault; SF = Seattle fault; SHZ = Saint Helens zone; SJ = San Juan Islands; SJF = San Juan fault; SWF = southern Whidbey Island fault. Geology from maps and compilations of Tabor and Cady (1978), Washington Public Power Supply System (1981), Gower and others (1985), Walsh and others (1987), Whetten and

others (1988), Yount and Gower (1991), Tabor and others (1993), and Tabor (1994).

27. Based on this paper, what evidence is there that the Seattle fault has been active within the past 1.8 million years (Quaternary Period).

“Quaternary sediment has been folded and faulted along all faults in the zone but is clearly most pronounced along fault "A", the northernmost fault, which forms the boundary between the Seattle uplift and Seattle basin. Analysis of growth strata deposited across fault "A" indicate minimum Quaternary slip rates of about 0.6 mm/yr”

If Quaternary age sediments have been deformed by the fault, it must have been active during the past 1.8 million years.

28. If the Quaternary slip rate of the Seattle fault is 0.6 mm/yr, calculate the total displacement that has occurred during the Quaternary.

Total displacement = 0.6 mm/yr * 1,800,000 years = 1,080,000 mm = 1080 meters or 1.08 kms

If this rate was constant since the beginning of the Miocene (5.3 million years ago), how much total displacement would you expect?

Total displacement = 0.6 mm/yr * 5,300,000 years = 3,180,000 mm = 3180 meters or 3.18 kms

29. If the Seattle is a reverse (thrust) fault, which block is moving up relative to the other? Is Restoration Point north or south of the Seattle fault?

The south block is moving up relative to the north block and Restoration Point is south of the Seattle fault because:

“Bucknam and others (1992) documented as much as 7 m of uplift at Restoration Point and inferred that it occurred during a large ($M > 7$) earthquake on the Seattle fault about 900 A.D”

If uplift occurred during movement along the Seattle fault, it must have been part of the block south of the fault because the northern block went down.

30. The paper states “Pratt and others also calculated the total surface area of the Seattle fault from their model and concluded that earthquakes of magnitude 7.6 to 7.7 were possible.” What factor(s) might limit the magnitude to less than 8.0? Why would a magnitude 9.0 be unlikely?

The rocks aren’t strong enough to accumulate that much elastic energy. There is brittle failure (earthquake) before enough energy to produce a magnitude 9.0 has accumulated along the fault.