Department of Earth and Environmental Sciences
California State University, East Bay

ASSESSMENT REPORT 2016-17

GEOLOGY M.S.

17 September
2017

Department of Earth and Environmental Sciences
California State University, East Bay

Assessment Results 2016-17
Geology M.S.

Contents

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Geology M.S. Program Learning Outcomes

Students graduating with an M.S. in Geology from Cal State East Bay will be able to:

1. attain an advanced understanding of the relationship between geologic materials and their physical and chemical properties. (Geologic Materials)

2. collect, analyze, and interpret data using advanced discipline-specific methods, techniques, and equipment. (Data & Analysis)

3. critically analyze geological and environmental issues through the evaluation of current scientific literature, and present an argument clearly and persuasively in written and oral form. (Communication)

4. conduct geologic research, including preparation of a project or thesis; the result should be of high enough quality to be presented at a professional meeting. (Research)

5. understand geologic time, evolution, Earth's place in the Universe, and global-scale processes such as plate tectonics, earth systems interactions, and climate change. (Geologic Time)

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Geology M.S. Program ILO Alignment Matrix

The table below shows which Institutional Learning Outcomes (ILOs) are addressed by each of the Program Learning Outcomes (PLOs) listed above.

	MS PLO 1 Geologic Materials	MS PLO 2 Data Analysis	MS PLO 3 Communication	MS PLO 4 Research	MS PLO 5 Geologic Time
ILO 1: Thinking & Reasoning	X	X	X	X	X
ILO 2: Communication			X	X	
ILO 3: Diversity			X		X
ILO 4: Collaboration		X	X	X	
ILO 5: Sustainability			X		X
ILO 6: Specialized Education	X	X	X	X	X

Curriculum Map for Program Student Learning Outcomes
CSU East Bay, Dept. of Earth & Environmental Sciences
Degree Program: M.S. in Geology

			Program Learning Outcomes				
Field	**Course**	**Title**	**1. Geologic Materials**	**2. Data Analysis**	**3. Communi-cation**	**4. Research**	**5. Geol. Time**
GEOL	6020	Seismic Exploration	P	M			
GEOL	6040	Near Surface Geophysics	P	M			
GEOL	6310	Isotope Geochemistry	I	P	P		M
GEOL	6320	Groundwater	I	M	P		P
GEOL	6411	Engineering Geology	M	M			
GEOL	6414	Earthquake Geology	P		M		M
GEOL	6430	Tectonic Geomorphology	I		P		M
GEOL	6811	Graduate Seminar			M		
GEOL	6899	Project		P	P	M	
GEOL	6910	University Thesis		M	M	M	

Proficiency Levels: I = Introduced; P = Practiced; M = Mastered

Quantitative Literacy (QL) is competency and comfort in working with numerical data. Individuals with strong QL skills possess the ability to reason and solve quantitative problems from a wide array of contexts and situations.

This rubric may be applied to student assignments that involve all or parts of any of the department's Program Learning Outcomes (PLOs).

	Capstone 3	**Milestone** 2	**Milestone** 1	**Milestone** 0
Interpretation *Ability to explain information presented in mathematical forms (e.g., equations, graphs, diagrams, tables, words)*	Provides accurate explanations of information presented in mathematical forms. Makes appropriate inferences based on that information.	Provides accurate explanations of information presented in mathematical forms.	Provides somewhat accurate explanations of information presented in mathematical forms, but occasionally makes minor errors related to computations or units.	Attempts to explain information presented in mathematical forms, but draws incorrect conclusions about what the information means.
Representation *Ability to convert relevant information into various mathematical forms (e.g., equations, graphs, diagrams, tables, words)*	Skillfully converts relevant information into an insightful mathematical portrayal in a way that contributes to a further or deeper understanding.	Competently converts relevant information into an appropriate and desired mathematical portrayal.	Completes conversion of information but resulting mathematical portrayal is only partially appropriate or accurate.	Completes conversion of information but resulting mathematical portrayal is inappropriate or inaccurate.
Calculation	Calculations attempted are successful and sufficiently comprehensive to solve the problem. Calculations presented clearly and concisely.	Calculations attempted are mostly successful and sufficiently comprehensive to solve the problem.	Calculations attempted are either unsuccessful or represent only a portion of the calculations required to comprehensively solve the problem.	Calculations are attempted but are both unsuccessful and are not comprehensive.
Application / Analysis *Ability to make judgments and draw appropriate conclusions based on the quantitative analysis of data, while recognizing the limits of this analysis*	Uses the quantitative analysis of data as the basis for deep and thoughtful judgments, drawing insightful, carefully qualified conclusions from this work.	Uses the quantitative analysis of data as the basis for competent judgments, drawing reasonable and appropriately qualified conclusions from this work.	Uses the quantitative analysis of data as the basis for workmanlike (without inspiration or nuance, ordinary) judgments, drawing plausible conclusions from this work.	Uses the quantitative analysis of data as the basis for tentative, basic judgments, although is hesitant or uncertain about drawing conclusions from this work.
Assumptions *Ability to make and evaluate important assumptions in estimation, modeling, and data analysis*	Explicitly describes assumptions and provides compelling rationale for each. Shows awareness that confidence in final conclusions is limited by the accuracy of the assumptions.	Explicitly describes assumptions and provides compelling rationale for why assumptions are appropriate.	Explicitly describes assumptions.	Attempts to describe assumptions.
Communication *Expressing quantitative evidence in support of the argument or purpose of the work (in terms of what evidence is used and how it is formatted, presented, and contextualized)*	Uses quantitative information in connection with the argument or purpose of the work, presents it in an effective format, and explicates it with consistently high quality.	Uses quantitative information in connection with the argument or purpose of the work, though data may be presented in a less than completely effective format or some parts of the explication may be uneven.	Uses quantitative information, but does not effectively connect it to the argument or purpose of the work.	Presents an argument for which quantitative evidence is pertinent, but does not provide adequate explicit numerical support.

M.S. Geology Program

Assessment Summaries, 2016-2017

Overview

We evaluated student work from selected courses in the Geology MS Program 2016-2017 to assess how well Program Learning Outcomes (PLOs) were met. PLOs evaluated during this period are 4) Research and 5) Geologic Time and Processes.

GEOL 6910 University Thesis - Fall 2016, Winter 2017: Research

Thesis and Project Research. The department requires students on the thesis and project tracks to carry out original research "the result of which should be of high enough quality to be presented at a professional meeting". All five department faculty are active in research and offer a range of research projects that elicit student participation. A survey was carried out to determine the frequency with which students presented work at professional meetings and/or published work in peer-reviewed journals.

Students entering the M.S. program typically have not been involved in research during their undergraduate years. M.S. students become actively involved in research, typically during the second year, and at a higher level of intensity/time commitment if they are on the thesis track. Over the last 5 years, 15 students have presented their research findings at professional meetings, including **all** of the students who pursued the thesis option. Moreover, four students were first authors or co-authors on journal articles in peer-reviewed publications, an additional indication that the research is of high quality. Students pursuing the project option do not typically present the outcome of their project at a professional meeting; however, that has been because of timing, logistical, or financial issues, and not because the project is not of high enough quality to be presented at a professional meeting. The program learning outcome centered around research is achieved at a level above and beyond the stated objective. The department faculty could consider raising the level of expectations or requiring oral presentation of project research (oral presentation and defense of thesis research is already required).

Student presenters at professional meetings 2013-2017:

- Pamela Beitz: Society for Ecological Restoration 'World Conference', Madison, WI, October, 2013.

- Elizabeth DeRubeis: Groundwater Resources Association Biennial Meeting, Sacramento, CA, October, 2012; CSU WRPI Conference, Long Beach, CA, June, 2013; co-author on abstract for the Geological Society of America Annual meeting, Denver, CO, Nov. 2013; co-author on abstract for Goldschmidt Conference, Sac., CA, June 2014.

- Patrick Harms: Groundwater Resources Association Annual Meeting, Sacramento, CA, October, 2013. American Geophysical Union Fall Meeting, December, 2014.

- Daniel Segal: Groundwater Resources Association Biennial Meeting, Sacramento, CA, October, 2012; CSU WRPI Conference, Long Beach, CA, June, 2013; co-author on abstract for the American Geophysical Union Annual Meeting, San Francisco, CA, December, 2013.

- Andrew Renshaw: Groundwater Resources Association Annual Meeting, Sacramento, CA, October, 2014, Geological Society of America Annual Meeting October, 2014, CSU WRPI Conference, Fresno, CA, April, 2015, Groundwater Resources Association Biennial Meeting, Sacramento, CA October, 2015.

- Amanda Dienhart: Groundwater Resources Association Biennial Meeting, Sacramento, CA October, 2015

- Menso de Jong: Groundwater Resources Association Annual Meeting, Sacramento, CA October, 2014

- Marcelino Vialpando: CSU WRPI Conference, Fresno, CA, April, 2015, American Geophysical Union Annual Meeting, San Francisco, CA December, 2015, Groundwater Resources Association Biennial Meeting, Sacramento, CA October, 2015.

- Elizabeth Peters: American Geophysical Union Annual Meeting, San Francisco, CA December, 2015, Groundwater Resources Association Biennial Meeting, Sacramento, CA October, 2015.

- Faithe Lovelace: Groundwater Resources Association Biennial Meeting, Sacramento, CA October, 2015.

- Nathan Veale: Groundwater Resources Association Annual Meeting, Concord, CA September, 2016 (winner of student poster competition); American Geophysical Union Annual Meeting, San Francisco, CA December, 2016; European Geophysical Union Annual Meeting, Vienna, Austria, April, 2017.

- Joanne Chan: American Geophysical Union Annual Meeting, San Francisco, CA December, 2015

- Adrian Mcevilly: American Geophysical Union Annual Meeting, San Francisco, CA December, 2015; Seismological Society of America Annual Meeting, Reno, NV, April, 2016; Seismological Society of America Annual Meeting, Denver, CO, April, 2017

- Ayoola Abimbola: American Geophysical Union Annual Meeting, San Francisco, CA December, 2015; Seismological Society of America Annual Meeting, Reno, NV, April, 2016.

- Jennifer Galvin: American Geophysical Union Annual Meeting, San Francisco, CA December, 2015

- Seth Shuler: American Geophysical Union Annual Meeting, San Francisco, CA December, 2015; Society of Exploration Geophysics, Denver, CO, March, 2016

- Ian Richardson: American Geophysical Union Annual Meeting, San Francisco, CA December, 2016; Seismological Society of America Annual Meeting, Denver, CO, April, 2017

GEOL 6310 Isotope Geochemistry – Fall 2016: Geologic Time.

The assignment used for assessment is one of five homework/problem set assignments given throughout the quarter. Completion of the activity requires a thorough understanding of the ‘age equation’ and ‘isochrons’, which are used to calculate rock ages from isotope ratios and the half-life of the radioactive isotope applied. Radiometric dating allows quantitative assignment of ages to rocks and revolutionized the field of geology in the 20th century. The expository essay portion of the assignment requires knowledge of the assumptions used, and properties of, one of the most commonly applied isotope systems to date igneous rocks ($^{39}Ar/^{40}Kr$). The first five categories of the quantitative literacy rubric were used to evaluate student work on the problem set.

Out of 20 possible, overall scores ranged from 13.5 to 18, with an average of 15.4 and standard deviation of 1.5. Five of eight students demonstrated at the least the basic level of competency in all areas of quantitative literacy. Only one student displayed an exemplary level in more than one area of quantitative literacy. A thorough mastery of advanced algebra, calculus, basic statistics, and graphing is an expected pre-requisite for the course, but some students lack the basic preparation and others have the necessary preparation but their quantitative skills are quite rusty. A knowledge of igneous processes such as cooling rates for different minerals and chemical composition of different minerals is also expected. Most students have a basic understanding of these concepts but many lack a deeper understanding of how these processes affect e.g., retention of parent or daughter elements. Understanding the assumptions inherent in using the age equation and isochrons is a critical to applying the mathematics and interpreting the result, and was evaluated via the problems and the essay. Only 2 students scored >1 on the ‘assumptions’ portion of the rubric.

Possible ways to improve learning outcomes for this assignment are: 1)a pre-assignment that gives students practice with advanced algebra and graphing skills, 2)formal review of mineralogy and petrology with a focus on minerals and elements used in radiometric dating, 3)an additional, optional, session where students work on problems with the instructor present. In the future, similar assessment material will be assigned since calculating rock ages from isotopic data and isochrons is a key student learning outcome for this course.

Assignment – Geologic Time

GEOL 6310 Isotope Geochemistry HOMEWORK 2 due Oct 17

End of chapter problems from Faure and Mensing:

Ch. 4: 2, 4, 5

Ch. 5: 7 (can use Excel), 8, 9

Ch. 6: 1, 2 (Interpret the difference between the answers to 1 and 2)

Ch 7: 1

AND

Write an expository essay of about 1000 words that **compares and contrasts** the K-Ar and the $^{40}Ar/^{39}Ar$ methods. Include, for example, the type of samples that can be dated, which concentrations and isotopic ratios must be analyzed and the type of instrumentation required to measure each. Which method is in more frequent use in recent decades, and why? Also, briefly discuss practical considerations such as the amount of sample required, cost of analysis and time required for an analysis, and greatest possible precision of the final age.

GEOL 6310 Isotope Geochemistry HOMEWORK 2 Answers

End of chapter problems from Faure and Mensing:

Ch. 4: 2, 4, 5

2. mass spectrometry

$m = r^2B^2e/(143.5)^2V$

$$m = \frac{(15.24)^2\ (5000)^2\ (1)}{(143.5)^2\ (3187)}$$

$$m = \frac{232.2576 \times 2.5 \times 10^7}{2.0721 \times 10^4 \times 3187}$$

$$m = \mathbf{87.92}\ \text{amu}$$

4. isotope dilution method of determining a precise elemental concentration

Atomic weight of the spike Rb:

$$\begin{aligned} At.Wt.\ Rb_s &= 0.954 \times 86.9092 + 0.046 \times 84.9117 \\ &= 82.91137 + 3.90593 \\ &= \mathbf{86.8173} \end{aligned}$$

Use equation 4.38

$$N_W = S_W \left(\frac{At.Wt._N}{At.W._S}\right)\left(\frac{Ab_S^A - R_m\ Ab_S^B}{R_m\ Ab_N^B - Ab_N^A}\right)$$

$$N_W = 29.45 \left(\frac{85.4677}{86.8173}\right)\left(\frac{0.954 - 1.12 \times 0.046}{1.12 \times 0.7217 - 0.2783}\right)$$

$$N_W = 29.45 \times 0.98445 \left(\frac{0.9036}{0.5300}\right)$$

$$N_W = \mathbf{49.428}\ \mu g$$

Concentration of Rb = 49.428/0.35 = 141.2 ppm

5. Atomic weight of spike Sr:

AtWtSr = 0.10x87.9056 + 0.025x86.9089 + 0.08749x85.9092 + 0.0001x 83.9134

Isotope	abundance	mass (amu)	mass x abundance
^{88}Sr (S)	10.00%	87.9056	8.7905600
^{87}Sr (S)	2.50%	86.9089	2.1727225
^{86}Sr (S)	87.49%	85.9092	75.1619591
^{84}Sr (S)	0.01%	83.9134	0.0083913
			86.1336329
sum	1.76	atomic weight W_S=	

$$^{87}Sr/\,^{88}Sr = {}^{87}Sr\,/\,^{86}Sr \times {}^{86}Sr/\,^{88}Sr = 5.30 \times 0.1194 = 0.63$$

Isotope Ratio	Composition	mass (amu)	Ab =	mass x abundance
$^{88}Sr/^{88}Sr$ (N)	1	87.9056	56.85%	49.9741902
$^{87}Sr/^{88}Sr$ (N)	0.63	86.9089	35.98%	31.2660971
$^{86}Sr/^{88}Sr$ (N)	0.1194	85.9092	6.79%	5.8314053
$^{84}Sr/^{88}Sr$ (N)	0.0068	83.9134	0.39%	0.3243915
				87.3960840

atomic weight W_N=

$$\text{AtWtSr}_M = 0.06807 \times 85.9092 + 0.36078 \times 86.9089 + 0.00102 \times 83.9134 + 0.57011 \times 87.9056$$

$$= 5.84783 + 31.25499 + 0.08559 + 50.11586$$

$$= \mathbf{87.40427}$$

$$S_W = 3.55 \times 5.05 = 17.927\ \mu g$$

$$\frac{\text{At. Wt. Sr}_M}{\text{At. W. Sr}_s} = \frac{87.40427}{86.1336} = 1.01475$$

$$N_W = 17.927 \times 1.01475 \left(\frac{0.8749 - 2.05 \times 0.10}{2.05 \times 0.57011 - 0.06807}\right)$$

$$N_W = 17.927 \times 1.01475 \times 0.60863$$

$$N_W = \mathbf{11.071}\ \mu g$$

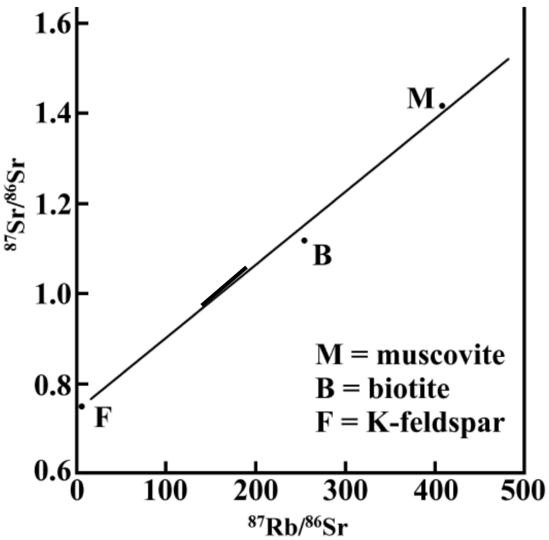
$$\text{Concentration of Sr}_M = \frac{11.071}{1.25} = \mathbf{8.86}\ \mu g\ (\text{ppm}).$$

Ch. 5: 7, 8, 9

7. mineral isochron

Mineral	$\frac{^{87}Sr}{^{86}Sr}$	$\frac{^{87}Rb}{^{86}Sr}$
Muscovite	1.4125	409.62
Biotite	1.1400	254.64
K-feldspar	0.7502	4.6908

Least squares: slope (m) = 0.00162838, intercept (b) = 0.73779



Rb-Sr isochron date:

$$m = e^{\lambda t} - 1$$

$$t = \frac{1}{\lambda} \ln(m + 1)$$

$$t = \frac{1}{1.42 \times 10^{-11}} \ln(0.00162838 + 1)$$

$$t = \frac{0.0016270}{1.42 \times 10^{-11}} = 114.6 \times 10^6 \text{ y or } \mathbf{114.6} \text{ Ma}$$

$$\left(\frac{^{87}Sr}{^{86}Sr}\right)_0 = \mathbf{0.7377}$$

The initial $^{87}Sr/^{86}Sr$ ratio is 0.7377, which is high compared to the 0.7040 used to calculate individual mineral ages, and may indicate that the Sr was homogenized at this higher value during metamorphism. Or, the minerals may have crystallized from a magma that contained Sr having an elevated $^{87}Sr/^{86}Sr$ because it formed by remelting of old continental rocks. So, the Rb-Sr date is recording the time since the minerals cooled through their blocking temperatures, either following metamorphism or after crystallization from magma. Since this is a pegmatite, the latter explanation is somewhat more likely. This age is in the Early Cretaceous, but since we don't know where the pegmatite is located, we can't say much more by way of interpretation.

8. Get date from isochron equation

$$t_{best} = \frac{1}{1.42 \times 10^{-11}} \ln\left[\frac{0.955 - 0.7040}{62.5} + 1\right]$$

$$t_{best} = \frac{\ln 1.004016}{1.42 \times 10^{-11}} = \mathbf{282.25} \times 10^6 \text{ y}$$

Maximum date:

$^{87}Sr/^{86}Sr = 0.955 + 0.001 = 0.956$

$^{87}Rb/^{86}Sr = 62.5 - 1.9 = 60.6$

$$\frac{^{87}Sr}{^{86}Sr} = \left(\frac{^{87}Sr}{^{86}Sr}\right)_0 + \frac{^{87}Rb}{^{86}Sr}\left(e^{\lambda t} - 1\right)$$

$$t = \frac{1}{\lambda}\ \ln\left[\frac{^{87}Sr/^{86}Sr - \left(^{87}Sr/^{86}Sr\right)_0}{^{87}Rb/^{86}Sr} + 1\right]$$

$$t_{max} = \frac{1}{1.42 \times 10^{-11}}\ \ln\left[\frac{0.956 - 0.7040}{60.6} + 1\right]$$

$$t_{max} = \frac{\ln 1.00415841}{1.42 \times 10^{-11}} = \mathbf{292.23} \times 10^{6}\ y$$

Minimum date

$^{87}Sr/^{86}Sr = 0.955 - 0.001 = 0.954$

$^{87}Rb/^{86}Sr = 62.5 + 1.9 = 64.4$

$$t_{min} = \frac{1}{1.42 \times 10^{-11}}\ \ln\left[\frac{0.954 - 0.7040}{64.4}\right] + 1$$

$$t_{min} = \frac{\ln 1.00388198}{1.42 \times 10^{-11}} = \mathbf{272.84} \times 10^{6}\ y$$

9. mineral and whole rock isochrons

Whole-rock samples

See graph of the Rb-Sr isochron

Least-squares regression of whole-rock samples:

Linear correlation coefficient = 0.9984

Slope (m) = 0.01445742

Intercept (b) = 0.70538

Rb-Sr isochron date (t_r)

$$t = \frac{1}{\lambda} \ln (m + 1)$$

$$= \frac{1}{1.42 \times 10^{-11}} \ln 1.01445742$$

t_r = **1010.8** Ma

Minerals of rock 3 plus whole-rock

Least-squares regression

Linear correlation coefficient = 0.99999

Slope (m) = 0.00412208

Intercept (b) = 0.77482

Rb-Sr mineral date (t_m)

$$t_{miner.} = \frac{1}{1.42 \times 10^{-11}} \ln 1.00412208$$

$t_{miner.}$ = **289.69** Ma

Minerals of rock 5 plus whole-rock

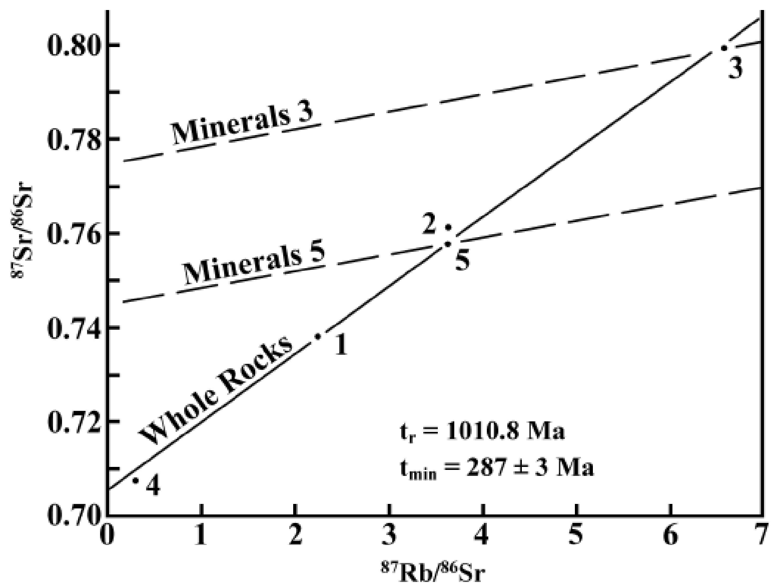
Linear correlation coefficient = 0.99995

Slope (m) = 0.00403286

Intercept (b) = 0.74518

$$t_{miner.} = \frac{1}{1.42 \times 10^{-11}} \ln 1.00403286$$

$t_{miner.}$ = **283.43** Ma



The rocks of the Baltimore Gneiss crystallized at 1011 Ma, likely during the Grenville orogeny. The $^{87}Sr/^{86}Sr$ of the protolith (intercept for whole rock isochron) is 0.70538, suggesting a prior crustal history (e.g., volcanic or sedimentary). The Baltimore Gneiss was metamorphosed at about 287 Ma (Early Permian) during the Appalachian orogeny. The isotopic composition of Sr in the minerals was homogenized at this time such that the $^{87}Sr/^{86}Sr$ of the minerals took on the same value as the rocks in which they occurred. Thus, mineral and whole-rock Rb-Sr systems may respond differently to metamorphic events. ^{87}Sr generated by Rb decay occupies unstable lattice sites in Rb-rich minerals and tends to migrate out of the crystal if subjected to a thermal pulse, even of a magnitude below the melting temperature. However, Sr released from Rb-rich minerals such as mica and K-feldspar will tend to be taken up by the nearest Sr sink such as plagioclase or apatite. Hence, the whole-rock system may remain closed, even though mineral systems are open.

Ch. 6: 1, 2 (Interpret the difference between the answers to 1 and 2)

1.

$$^{40}Ar^* = \frac{\lambda_e}{\lambda}\ ^{40}K\ (e^{\lambda t} - 1)$$

$$t = \frac{1}{\lambda}\ \ln\left[\frac{^{40}Ar^*}{^{40}K}\left(\frac{\lambda}{\lambda_e}\right) + 1\right]$$

Number of ^{40}K atoms per gram

$$^{40}K = \frac{8.45 \times 2 \times 6.022 \times 10^{23} \times 0.0001167}{94.196 \times 100}$$

where At.Wt. of K_2O = 94.196,

the "2" is needed because each mole of K_2O contains 2 moles of K,

Avogadro's Number (A) = 6.022×10^{23} atoms/mol,

Ab^{40}K = 0.0001167 (decimal fraction), and

the "100" in the denominator reduces the amount of K_2O from per hundred grams to per gram.

$^{40}K = 2.0938 \times 10^{-7} \times A$ atoms/g

Number of $^{40}Ar^*$

$^{40}Ar^* = 6.016 \times 10^{-10} \times A$ atoms/g

Calculate the K-Ar date

$$t = \frac{1}{\lambda}\ \ln\left[\frac{^{40}Ar^*}{^{40}K}\left(\frac{\lambda}{\lambda_e}\right) + 1\right]$$

$$t = \frac{1}{5.543 \times 10^{-10}}\ \ln\left[\frac{6.016 \times 10^{-10} A}{2.0938 \times 10^{-7} A}\left(\frac{5.543 \times 10^{-10}}{0.581 \times 10^{-10}}\right) + 1\right]$$

t = 48.8 Ma which is early Eocene

2.

$$^{40}K = \frac{0.6078 \times 2 \times 0.0001167A}{94.196 \times 100} = 1.506 \times 10^{-8} A \text{ atoms/g}$$

$$^{40}Ar^* = 0.462 \times 10^{-10} \text{ A atoms/g}$$

$$t = \frac{1}{5.543 \times 10^{-10}} \ln \left[\frac{0.462 \times 10^{-10} A}{1.506 \times 10^{-8} A} \left(\frac{5.543 \times 10^{-10}}{0.581 \times 10^{-10}} \right) + 1 \right]$$

$$t = \frac{\ln 1.02926750}{5.543 \times 10^{-10}} = 0.005204 \times 10^{10} \text{ y}$$

T = 52.0 Ma, which is also early Eocene. The K-Ar date of the hornblende is older than that of the coexisting biotite because hornblende has a higher blocking temperature than biotite. One can estimate a cooling history of this monzonite, given that the blocking temp. of biotite is 373C and that of hornblende is 685C (as given in text). So the cooling rate is (685-373)C/(52.0-48.8)Ma = 97.5°C/million yrs

Ch 7: 1

$$\frac{^{49}Ar^*}{^{39}Ar} = \frac{e^{\lambda t} - 1}{J}$$

$$t = \frac{1}{\lambda} \ln \left[\left(\frac{^{40}Ar^*}{^{39}Ar} \right) J + 1 \right]$$

$$\lambda = 5.543 \times 10^{-10} \text{ y}^{-1}$$

$$t = \frac{1}{5.543 \times 10^{-10}} \ln (12.31 \times 1.925 \times 10^{-2} + 1)$$

$$t = \frac{\ln 1.236967}{5.543 \times 10^{-10}} = 383.6 \times 10^{6} \text{ y}$$

which is Devonian

xxxxxx

10-17-2016

Geology 6310: Isotope Geochemistry

HW2 Essay

A Comparative Review of $^{40}K/^{40}Ar$ and $^{40}Ar/^{39}Ar$ Dating

Potassium naturally exists in 3 isotopic states, potassium-39, potassium-40, and potassium-41, and potassium-39 is the most prevalent with an abundance that is over 90%. Of these isotopes potassium-40 is unstable, has a half-life of 1.251 billion years, and 10.5 percent of potassium-40 decays by electron capture or emission of a positron to form argon-40. 89.5% of potassium-40 decays by beta emission forming calcium-40; $^{40}K/^{40}Ca$ dating is less effective than $^{40}K/^{40}Ar$ dating because calcium-40 has a high natural abundance because it commonly incorporates into crystal lattice of many minerals. Argon-40, on the other hand, has low abundance and is chemically inert meaning any argon trapped in minerals should be expected to be radiogenic. $^{40}K/^{40}Ar$ dating uses the ratios of radioactive potassium-40 and radiogenic argon-40 to calculate ages of rocks (Faure and Mensing, 2005).

Unfortunately not all radiogenic argon-40 within minerals is necessarily generated internally within minerals. Due to the unreactive nature of noble gases, argon-40 will not form chemical bonds inside minerals and will readily diffuse out of rocks even at low temperatures, making rocks date younger. This excess gas also gets incorporated into other minerals within the same rock, making it date older. $^{40}Ar/^{39}Ar$ dating corrects for these errors that arise from argon diffusion. Argon-39 is an unnatural unstable isotope with a half-life of 269 years and decays to potassium-39 by beta emission. Potassium-39 is transformed to argon-39 by bombarding a sample by neutrons in a nuclear reactor (Faure and Mensing, 2005). The argon-39 generated can be used as a proxy to derive the amount of potassium-40 present in a sample (Lee, 2013).

$^{40}K/^{40}Ar$ dating can be performed on any potassium bearing rock or mineral. Potassium feldspar tends to not be a good choice as argon diffuses more readily. Any metamorphism can greatly affect argon concentrations in rocks; for example, the Idaho springs gneiss experienced a complete loss of argon in all minerals within 3 m of the contacted of the Eldora stock. $^{40}K/^{40}Ar$ dating is most effective on biotite, muscovite, and hornblende; however, because of the low melting temperatures of micas; increasing temperatures cause the weakening of the crystal structure allowing argon to diffuse at a higher rate. Whole rock dating can be done on fine grained igneous rocks if there are not foreign inclusions present; however, since potassium is not extracted from the same location on a sample, rocks that are very fine grained or glassy may give erroneous dates because the rock is not chemically homogeneous. Some $^{40}K/^{40}Ar$ dating has also been done on metasedimentary rocks (Faure and Mensing, 2005).

$^{40}Ar/^{39}Ar$ dating works for any rock in which potassium-argon dating can be used. $^{40}Ar/^{39}Ar$ dating can also be used in rocks composed of low potassium bearing minerals, such as amphibole, pyroxenes, plagioclase, and magnetite. Also fine grained rocks do not need to be homogenous as one sample tests for both argon-40 and argon-39 at the same time (Faure and Mensing, 2005).

In order to date rocks using the $^{40}K/^{40}Ar$ method, the concentration of potassium must be found by first dissolving a powdered rock sample in hydrofluoric acid. The isotope ratios in the sample can be determined using fluorescent polarization, inductively coupled plasma spectrometry, atomic absorption spectrometry, and isotope dilution by adding concentrated spike of potassium to the sample. X-ray fluorescence and neutron activation can be used on solid samples. Argon-40 concentrations are found by heating a powdered rock sample in a vacuum allowing argon gas to release from the sample. Isotope dilution is achieved by mixing released argon-40 with an enriched argon-38 spike. Once non-noble gases are removed from the sample a mass spectrometer can find $^{40}Ar/^{38}Ar$ and $^{38}Ar/^{36}Ar$ ratios (Faure and Mensing, 2005).

For $^{40}Ar/^{39}Ar$ dating the sample is irradiated then argon-39 is found with the same method as argon-40 is found simultaneously. $^{40}Ar/^{39}Ar$ ratios are measured using mass spectrometry; however, in order to calculate a date, the sample must be mixed with a flux monitor, a sample with a known age. Atmospheric argon-36 is removed mathematically using the ratio $^{36}Ar/^{39}Ar$. Incremental heating by use of a laser can be used to measure a series of ratios over time. If the system has not lost any argon, the ratios of both argon isotopes should be constant. The spectrum of dates derived using laser ablation can determine if argon was diffused out of minerals, or excess argon-40 adhering to mineral surfaces (Faure and Mensing, 2005).

$^{40}Ar/^{39}Ar$ dating has largely replaced $^{40}K/^{40}Ar$ dating in recent decades because $^{40}K/^{40}Ar$ dating requires assumes a closed system. Incremental laser ablation can also be used for the consideration of argon gain or loss from the system. $^{40}Ar/^{39}Ar$ does not require two samples in order to analyze each isotope allowing for finer grained rocks to be dated without problems arising from chemical heterogeneities in the rock. $^{40}Ar/^{39}Ar$ dating can be done on smaller samples allowing minerals with lower potassium contents to be accurately dated. Smaller sample sizes also cut down on costs especially when dealing with rare rocks, such as moon rocks and meteors. For $^{40}Ar/^{39}Ar$ dating, only isotopes of argon need to be tested for, thus saving additional time and money. Miniaturization of sample sizes also reduces contamination of samples from atmospheric Argon (Faure and Mensing, 2005).

$^{40}Ar/^{39}Ar$ dating is dependent on flux monitors, and using a flux monitor with an incorrect age can cause systematic errors. Calcium isotopes can cause interference in $^{40}Ar/^{39}Ar$ dating because unstable calcium isotopes can decay to Ar-36 through Ar-40. This can cause errors in measurements of total argon if an Argon-38 spike is added. Corrections can be made for this, but a small amount of uncertainty in measurement can occur. Overall $^{40}Ar/^{39}Ar$ dating tends to be more accurate and has precision in the order of 10,000 years (Faure and Mensing, 2005).

Works Cited

Faure, G., Mensing, T. M., & Faure, G. (2005). *Isotopes: Principles and applications*. Hoboken, NJ: Wiley.

Lee, J. K. W. (2013). Ar–Ar and K–Ar Dating. In W. J. Rink & J. Thompson (Eds.), *Encyclopedia of Scientific Dating Methods* (pp. 1–27). Dordrecht: Springer Netherlands. Retrieved from http://dx.doi.org/10.1007/978-94-007-6326-5_40-1

Department of Earth and Environmental Sciences, CSCI

CALIFORNIA STATE UNIVERSITY EAST BAY

ASSESSMENT PLAN: M.S. in Geology

Updated Winter 2015 by Jean Moran, Luther Strayer, and Mitchell Craig

PROGRAM MISSION

CSUEB Missions, Commitments, and ILOs, 2012 version

CSUEB Geology M.S. Program Description

To serve graduate students who are employed during the day, all graduate courses in the Department of Earth and Environmental Sciences are offered in the evenings and on weekends. In addition to regular catalog courses, recent graduate seminars and advanced topics courses have dealt with such subjects as sediment transport and modern depositional environments, rock mechanics, applied geophysics, isotope hydrology, tectonics and sedimentation. Additional facilities and part-time employment may be secured through Co-op programs, the Lawrence Berkeley and Lawrence Livermore National Laboratories, and the U.S. Geological Survey in Menlo Park. Candidates for this degree must be prepared to engage in significant individual research. Lately, student research in this department has included such topics as hydrogeology, near surface geophysics, areal geology and slope stability, geochemistry, structural geology, engineering geology, and neotectonics.

PROGRAM STUDENT LEARNING OUTCOMES (PLOs)

Students graduating with a M.S. in Geology will be able to:

PLO 1 *ILO 1,6*	Attain an advanced understanding of the relationship between geologic materials and their physical and chemical properties. *(Geologic Materials)*
PLO 2 *ILO 1,4,6*	Collect, analyze, and interpret data using advanced discipline-specific methods, techniques, and equipment. *(Data & Analysis)*
PLO 3 ILO 1,2,3,4,5,6	Critically analyze geological and environmental issues through the evaluation of current scientific literature, and present an argument clearly and persuasively in written and oral form. *(Communication)*
PLO 4 *ILO 1,2,4,6*	Conduct geologic research, including preparation of a project or thesis; the result should be of high enough quality to be presented at a professional meeting. *(Research)*
PLO 5 *ILO 1,3, 5,6*	Understand geologic time, evolution, Earth's place in the Universe, and global-scale processes such as plate tectonics, earth systems interactions, and climate change. *(Geologic Time)*

Year 1: 2013-2014

1. Which PLO(s) to assess	PLO 3 *(Communication)*, PLO 4 *(Research)*
2. Assessment indicators	GEOL6320 Term Paper, GEOL6414 Precis & Oral Presentation, GEOL6910 Prospectus
3. Sample (courses/# of students)	GEOL6320/10, GEOL6414/15, GEOL6910/2.
4. Time (which quarter(s))	Fall 2013, Winter 2014, Spring 2014
5. Responsible person(s)	Luther Strayer, Jean Moran
6. Ways of reporting (how, to who)	The report was delivered to the Chair, and distributed to the faculty. It was also included within the department's annual program report.
7. Ways of closing the loop	Areas of improvement were discussed at faculty meetings, improvements and revisions to future courses are expected.

Year 2: 2014-2015

1. Which PLO(s) to assess	PLO 1 *(Geologic Materials),* PLO 5 (*Geologic Time),*
2. Assessment indicators	Course assignments and projects, with department rubric.
3. Sample (courses/# of students)	GEOL6040/14, GEOL6310/10, GEOL6430/15
4. Time (which quarter(s))	Fall 2014, Winter 2015, Spring 2015.
5. Responsible person(s)	Mitchell Craig, Jean Moran, Luther Strayer.
6. Ways of reporting (how, to who)	Reports first to the Chair and then to the entire faculty for comment & discussion. An end-of-year meeting will be devoted to evaluating assessment results and “closing the loop.”
7. Ways of closing the loop	Identified “areas for improvement” will be incorporated into modified/updated core courses for future majors

Year 3: 2015-2016

1. Which PLO(s) to assess	PLO 2 *(Data & Analysis),* PLO 3 *(Communication)*
2. Assessment indicators	Course assignments and projects, precis & oral presentations of topical journal articles in the field, MS prospectus, MS project, MS thesis. Department rubrics will be used.
3. Sample (courses/# of students)	GEOL6320/15, GEOL6620/17, GEOL6811/12, GEOL6899/4, GEOL6910/2.
4. Time (which quarter(s))	Fall 2015, Winter 2016, Spring 2016.
5. Responsible person(s)	Luther Strayer, Jean Moran, department faculty.
6. Ways of reporting (how, to who)	Reports first to the Chair and then to the entire faculty for comment & discussion. An end-of-year meeting will be devoted to evaluating assessment results and “closing the loop.”
7. Ways of closing the loop	Identified “areas for improvement” will be incorporated into modified/updated core courses for future majors. Issues with the Thesis process will be discussed and acted upon.

Year 4: 2016-2017	
1. Which PLO(s) to assess	PLO 4 *(Research),* PLO 5 *(Geologic Time).*
2. Assessment indicators	Course assignments and projects, precis & oral presentations of topical journal articles in the field, MS prospectus, MS project, MS Thesis. Department rubrics will be used.
3. Sample (courses/# of students)	GEOL6040/15, GEOL6414/15, GEOL6811/12, GEOL6899/5, GEOL6910/3.
4. Time (which quarter(s))	Fall 2016, Winter 2017, Spring 2017.
5. Responsible person(s)	Mitchell Craig, Luther Strayer, and affiliated faculty.
6. Ways of reporting (how, to who)	Reports first to the Chair and then to the entire faculty for comment & discussion. An end-of-year meeting will be devoted to evaluating assessment results and “closing the loop.”
7. Ways of closing the loop	We will assess progress made since 2015-2016, adjust strategies. Revise program requirements concurrently with quarter-to-semester conversion.

Year 5: 2017-2018	
1. Which PLO(s) to assess	PLO 1 *(Geologic Materials)*, PLO 2 *(Data & Analysis)*
2. Assessment indicators	Course assignments and projects, precis & oral presentations of topical journal articles in the field, MS prospectus, MS project, MS Thesis. Department rubrics will be used.
3. Sample (courses/# of students)	GEOL6020/15, GEOL6414/15, GEOL6899/6, GEOL6910/3.
4. Time (which quarter(s))	Fall 2017, Winter 2018, Spring 2018.
5. Responsible person(s)	Luther Strayer, Jean Moran, Mitchell Craig.
6. Ways of reporting (how, to who)	Reports first to the Chair and then to the entire faculty for comment & discussion. An end-of-year meeting will be devoted to evaluating assessment results and “closing the loop.”
7. Ways of closing the loop	Assess progress made since 2016-2017, adjust strategies.