Short Course 511C: Making the Invisible Visible: Assessing Higher Order Thinking in your Students

2012 GSA Short Course

Cosponsors: *GSA Geoscience Education Division; National Association of Geoscience Teachers* (*NAGT*).

Bruce Herbert, Texas A&M University

Logistics

Short Course Location

Our short course is being held at the **UNC Charlotte Center City, 320 East 9th Street, room 904**. UNCC is in walking distance of all GSA hotels.

Useful links:

- Map and directions: http://centercity.uncc.edu/sites/centercity.uncc.edu/files/media/Directions.pdf
- Transportation to UNCC: http://centercity.uncc.edu/sites/centercity.uncc.edu/files/media/Transportation%20to%20Center%20City%20Revised%2010-5-2011.pdf
- Get directions from your location: http://centercity.uncc.edu/home/parking-and-directions

Course Logistics (AV, catering)

AV - Each room will have an LCD projector and free wireless for everyone. Most will have computers and chalkboards or white boards. Please feel free to bring your talk on a jump drive (and/or on your lap top). We will have AV assistance starting at 7 a.m. each morning if you have any problems. We will not have extension cords for everyone, so please bring one if you feel it will be needed. We request that everyone bring his or her laptops fully charged (and charge again during lunch) to be safe.

Catering – the catering for each course will be out of your door in the hallway so that they can easily clean up and refresh it without interrupting you. In addition, Einstein Brothers Bagels will be open on the first floor of the UNC Charlotte Center City from 7 a.m. to 2 p.m. both Friday and Saturday.

Short Course Information Desk – We will have a staffed info desk on the first floor of the UNCC so that anyone who is lost or has a question can find a person immediately. This is also where I will be throughout the courses if you need me.

Student Volunteers: Our course has an assigned student volunteer. If you need catering, AV, a temperature change, or have any problems, please see the student assigned to your course. Jennifer Nocerino, GSA Program Officer, Education & Outreach can also be reached directly at 720-883-6613.

Course registration/badges: Course attendees DO NOT need to visit registration prior to attending our course. Attendees will check in at the table outside the room of your course with your student volunteer. The students will have "My Name Is" badges for everyone, a current registration list (as of Thurs 11/1), and a folder which contains an evaluation form and information about our Continuing Education Unit (CEU) Program that will be given to everyone.

Folders/evaluation forms for attendees: The folders will have an evaluation form inside (SC_Eval 2012 – see attached). At the end of your course please ask each person to fill this out and give them to the student once they are completed. He/she has been instructed to remain with you until all evaluations have been collected.

Short Course Wiki

Making the Invisible Visible: Assessing Higher Order Thinking in your Students http://nagt.org/dev/nagt/programs/meetings/GSA12_c.html

Agenda

Time	Topic
1 PM	**Introductions**
	Agenda – Organization of the Short Course
	Logistics
	Individual Stories – Why are you here?
1:20	**Overview of Assessment & Nature of Learning**
1:45	Individual Stories – What would you like to change?
1:55	**Break**
2:05	**Learning objectives and Assessment**
	Nature of "higher order critical thinking" skills
	Earth Science Literacy
	Nature of disciplinary expertise
	Earth & Mind: Thinking and Learning in the Geosciences
	Scientific Practices
	Activity: Teaching Goals Inventory – What learning goals do you value?
2:50	**Break**
3:00	**Backwards Design**
	Understanding by Design (Backwards Design): The Process
	Activity: Rewriting learning goals
3:40	**Break**
3:50	**Classroom Assessment Techniques**
	CATs Resources
	Examples of Useful Classroom Assessment Techniques
	Rubrics
	Activity: Developing Explicit Learning Goals and Assessment Techniques
4:30 PM	**Supporting Your Career: The Scholarship of Teaching & Learning**
	Overview
	Evidence of Excellence
	Activity: Discussion & Reflection
4:55 PM	**Short Course Survey**

Overview of Assessment & Nature of Learning

More than a decade ago, Robert Barr and John Tagg proposed that that U.S. higher education is in the midst of a historic shift from a teaching-centered to a learning-centered model where the primary purpose of colleges and universities is to produce learning rather than providing instruction (*Change*, Nov/Dec 1995). The role of the assessment, where we make student thinking visible, is central to supporting this emerging vision of how higher education can support student learning, especially in those higher order skills championed in liberal education, and move students from peripheral participation to core membership in disciplinary communities.

National and international efforts to reform secondary and tertiary STEM education often call for the participation of academic scientists in the reform effort through the development of partnerships between scientists and educators, though suggested roles are often poorly conceived and rewarded. Improved models of the roles of scientists, mathematicians and engineers in the reform effort should focus on limiting mission creep and building synergy between STEM research in the disciplines and education.

Scientists and educational leaders are needed to support the development and implementation of effective learning environments (both formal and informal) designed around inquiry-based (experiential) learning that supports the transfer of STEM research to the classroom. Educational research has shown that inquiry-based learning is one of the best pedagogical practices to support student development of critical thinking skills and competency in authentic practices including learning with understanding, problem-solving, knowledge transfer, strong metacognitive skills, and decision making. Information technologies are often a central component of effective learning environments because these tools support student manipulation of data, the development and testing of conceptual models based on available evidence, and exposure to authentic, complex and ill-constrained problems.

We will explore assessment of student learning through a backwards design framework championed by Wiggins and McTighe. Our workshop will provide specific examples of specific assessment techniques that can provide insight on student skill development towards general higher order thinking skills as well as disciplinary expertise. These techniques can be used to inform your day-to-day teaching practice, future course design, or help meet accountability programs on your campus. Participants will have an opportunity to collectively develop assessment strategies for their own classes.

Activity: Individual Stories – Why are you here?

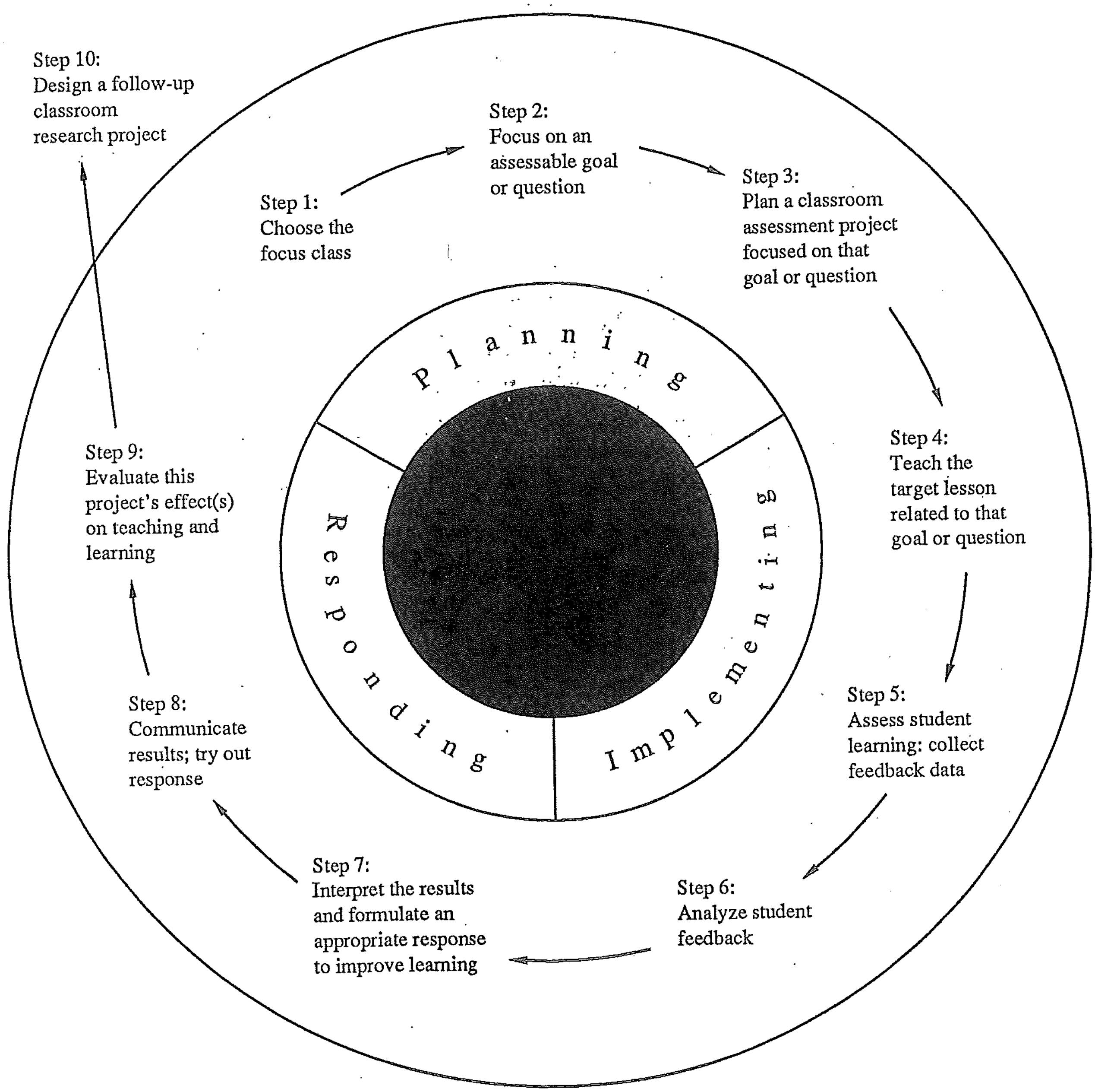
Further Exploration

Presentation: Assessment & Nature of Learning

Readings

- Barr, R. B., and Tagg, J., 1995, From teaching to learning--a new paradigm for undergraduate education: Change, 27(6): 12-26.
- How People Learn: Brain, Mind, Experience, and School: Expanded Edition. National Academy of Sciences (http://www.nap.edu/catalog.php?record_id=9853)
- Pellegrino, J., J. Chudowsky. & R. Glaser, 2001, Knowing what student know: The science and design of educational assessment: Washington, DC, National Academy Press (http://www.nap.edu/catalog.php?record_id=10019).

Figure 4.1. Map of a Classroom Assessment Project Cycle.



Learning Objectives and Assessment

Educational assessment seeks to determine how well students are learning and is an integral part of the quest for improved education. Advances in the study of thinking and learning and in the field of measurement have stimulated people to think in new ways about how students learn and what they know, what is therefore worth assessing, and how to obtain useful information about student competencies. Assessments, especially those conducted in the context of classroom instruction, should focus on making students' thinking visible to both their teachers and themselves so that instructional strategies can be selected to support an appropriate course for future learning (Pellegrino et al., 2001).

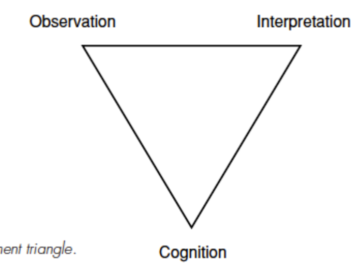


FIGURE 2-1 *The assessment triangle.*

Every assessment, regardless of its purpose, rests on three pillars: a model of how students represent knowledge and develop competence in the subject domain, tasks or situations that allow one to observe students' performance, and an interpretation method for drawing inferences from the performance evidence (Pellegrino et al., 2001).

The model of student knowledge representation and disciplinary competence is explicitly or implicitly stated in our learning goals. You can look to several national initiatives to help (re)define your learning goals. Some of these initiatives are focused on defining goals and rubrics for higher-order or critical thinking skills associated with the liberal arts.

> As part of AAC&U's Liberal Education and America's Promise (LEAP) initiative, the VALUE project seeks to contribute to learning assessment that privileges authentic assessment of student work and shared understanding of student learning outcomes on campuses over reliance on standardized tests administered to samples of students outside of their required courses. The result of this philosophy has been the collaborative development of 15 rubrics by teams of faculty and academic professionals on campuses from across the country.
>
> The *Science College Board Standards for College Success* incorporated learning objectives focused on developing, in all students, the competencies necessary for engaging in scientific practices. Scientific practices, as conceptualized by the College Board, encompass:
>
> - Asking questions that can be tested empirically and structuring those questions in the form of testable predictions*
> - Making observations and collecting data to address questions and to support predictions
> - Searching for regularities and patterns in observations and measurements, e.g., data analysis
> - Using evidence and science knowledge to build scientific explanations, models, and representations
> - Using mathematical reasoning and quantitative applications to interpret data, analyze data, and solve problems

Other initiatives are more focused on developing learning goals and assessment techniques that are situated within the geoscience discipline. Two of the most rigorous initiatives to describe the geoscience knowledge domain and the thinking and reasoning of geoscientists include the SERC

Synthesis of Research on Thinking and Learning in the Geosciences and the Earth Science Literacy Initiative. These descriptions can be used to define learning goals for student engaged in authentic practice in a classroom context.

Activity: Teaching Goals Inventory – What learning goals do you value?

Working together in small teams, complete the Teaching Goals Inventory. Discuss the results with your team and how the valued goals you identified support student learning in your courses and programs. We will reflect our results as a group.

Further Exploration

Presentation: Learning Objectives and Assessment

Readings

- Synthesis of Research on Thinking and Learning in the Geosciences: http://serc.carleton.edu/research_on_learning/synthesis/index.html
- SERC Designing Effective and Innovative Courses: http://serc.carleton.edu/NAGTWorkshops/coursedesign/index.html
- Earth Science Literacy Initiative: http://www.earthscienceliteracy.org/
- Science College Board Standards for College Success: http://research.collegeboard.org/services/scas
- AACU VALUE: Valid Assessment of Learning in Undergraduate Education: http://www.aacu.org/value/index.cfm

Exhibit 2.1. Teaching Goals Inventory, Self-Scorable Version.

Purpose: The Teaching Goals Inventory (TGI) is a self-assessment of instructional goals. Its purpose is threefold: (1) to help college teachers become more aware of what they want to accomplish in individual courses; (2) to help faculty locate Classroom Assessment Techniques they can adapt and use to assess how well they are achieving their teaching and learning goals; and (3) to provide a starting point for discussions of teaching and learning goals among colleagues.

Directions: Please select ONE course you are currently teaching. Respond to each item on the inventory in relation to that particular course. (Your responses might be quite different if you were asked about your overall teaching and learning goals, for example, or the appropriate instructional goals for your discipline.)

Please print the title of the specific course you are focusing on:

____

Please rate the importance of each of the fifty-two goals listed below to the specific course you have selected. Assess each goal's importance to what you deliberately aim to have your students accomplish, rather than the goal's general worthiness or overall importance to your institution's mission. There are no "right" or "wrong" answers; only personally more or less accurate ones.

For each goal, circle only one response on the 1-to-5 rating scale. You may want to read quickly through all fifty-two goals before rating their relative importance.

In relation to the course you are focusing on, indicate whether each goal you rate is:

(5)	Essential	a goal you always/nearly always try to achieve
(4)	Very important	a goal you often try to achieve
(3)	Important	a goal you sometimes try to achieve
(2)	Unimportant	a goal you rarely try to achieve
(1)	Not applicable	a goal you never try to achieve

Rate the importance of each goal to what you aim to have students accomplish in your course.	*Essential*	*Very Important*	*Important*	*Unimportant*	*Not Applicable*
1. Develop ability to apply principles and generalizations already learned to new problems and situations	5	4	3	2	1
2. Develop analytic skills	5	4	3	2	1
3. Develop problem-solving skills	5	4	3	2	1
4. Develop ability to draw reasonable inferences from observations	5	4	3	2	1
5. Develop ability to synthesize and integrate information and ideas	5	4	3	2	1
6. Develop ability to think holistically: to see the whole as well as the parts	5	4	3	2	1
7. Develop ability to think creatively	5	4	3	2	1
8. Develop ability to distinguish between fact and opinion	5	4	3	2	1
9. Improve skill at paying attention	5	4	3	2	1
10. Develop ability to concentrate	5	4	3	2	1
11. Improve memory skills	5	4	3	2	1
12. Improve listening skills	5	4	3	2	1
13. Improve speaking skills	5	4	3	2	1
14. Improve reading skills	5	4	3	2	1
15. Improve writing skills	5	4	3	2	1
16. Develop appropriate study skills, strategies, and habits	5	4	3	2	1
17. Improve mathematical skills	5	4	3	2	1
18. Learn terms and facts of this subject	5	4	3	2	1
19. Learn concepts and theories in this subject	5	4	3	2	1
20. Develop skill in using materials, tools, and/or technology central to this subject	5	4	3	2	1
21. Learn to understand perspectives and values of this subject	5	4	3	2	1

Exhibit 2.1. Teaching Goals Inventory, Self-Scorable Version, Cont'd.

Rate the importance of each goal to what you aim to have students accomplish in your course.	*Essential*	*Very Important*	*Important*	*Unimportant*	*Not Applicable*
22 Prepare for transfer or graduate study	5	4	3	2	1
23. Learn techniques and methods used to gain new knowledge in this subject	5	4	3	2	1
24. Learn to evaluate methods and materials in this subject	5	4	3	2	1
25. Learn to appreciate important contributions to this subject	5	4	3	2	1
26. Develop an appreciation of the liberal arts and sciences	5	4	3	2	1
27. Develop an openness to new ideas	5	4	3	2	1
28. Develop an informed concern about contemporary social issues	5	4	3	2	1
29. Develop a commitment to exercise the rights and responsibilities of citizenship	5	4	3	2	1
30. Develop a lifelong love of learning	5	4	3	2	1
31. Develop aesthetic appreciations	5	4	3	2	1
32. Develop an informed historical perspective	5	4	3	2	1
33. Develop an informed understanding of the role of science and technology	5	4	3	2	1
34. Develop an informed appreciation of other cultures	5	4	3	2	1
35. Develop capacity to make informed ethical choices	5	4	3	2	1
36. Develop ability to work productively with others	5	4	3	2	1
37. Develop management skills	5	4	3	2	1
38. Develop leadership skills	5	4	3	2	1
39. Develop a commitment to accurate work	5	4	3	2	1
40. Improve ability to follow directions, instructions, and plans	5	4	3	2	1
41. Improve ability to organize and use time effectively	5	4	3	2	1
42. Develop a commitment to personal achievement	5	4	3	2	1
43. Develop ability to perform skillfully	5	4	3	2	1
44. Cultivate a sense of responsibility for one's own behavior	5	4	3	2	1
45. Improve self-esteem/self-confidence	5	4	3	2	1
46. Develop a commitment to one's own values	5	4	3	2	1
47. Develop respect for others	5	4	3	2	1
48. Cultivate emotional health and well-being	5	4	3	2	1
49. Cultivate an active commitment to honesty	5	4	3	2	1
50. Develop capacity to think for one's self	5	4	3	2	1
51. Develop capacity to make wise decisions	5	4	3	2	1

52. In general, how do you see your primary role as a teacher?
(Although more than one statement may apply, please circle only one.)

1 Teaching students facts and principles of the subject matter

2 Providing a role model for students

3 Helping students develop higher-order thinking skills

4 Preparing students for jobs/careers

5 Fostering student development and personal growth

6 Helping students develop basic learning skills

Source: Classroom Assessment Techniques, by Thomas A. Angelo and K. Patricia Cross. Copyright © 1993. Permission to reproduce is hereby granted.

Exhibit 2.2. Teaching Goals Inventory, Self-Scoring Worksheet.

1. In all, how many of the fifty-two goals did you rate as "essential"? ________
2. How many "essential" goals did you have in each of the six clusters listed below?

	Cluster Number and Name	*Goals Included in Cluster*	*Total Number of "Essential" Goals in Each Cluster*	*Clusters Ranked—from 1st to 6th—by Number of "Essential" Goals*
I	Higher-Order Thinking Skills	1–8	________	________
II	Basic Academic Success Skills	9–17	________	________
III	Discipline-Specific Knowledge and Skills	18–25	________	________
IV	Liberal Arts and Academic Values	26–35	________	________
V	Work and Career Preparation	36–43	________	________
VI	Personal Development	44–52	________	________

3. Compute your cluster scores (average item ratings by cluster) using the following worksheet.

	A	*B*	*C*	*D*	*E*
	Cluster Number and Name	*Goals Included*	*Sum of Ratings Given to Goals in That Cluster*	*Divide C by This Number*	*Your Cluster Scores*
I	Higher-Order Thinking Skills	1–8	________	8	________
II	Basic Academic Success Skills	9–17	________	9	________
III	Discipline-Specific Knowledge and Skills	18–25	________	8	________
IV	Liberal Arts and Academic Values	26–35	________	10	________
V	Work and Career Preparation	36–43	________	8	________
VI	Personal Development	44–52	________	9	________

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If you are just beginning to experiment with Classroom Assessment, it is not necessary, or productive, to worry too much about linking goals to assessment tools. Many faculty start out by trying a few simple Classroom

The Backwards Design Model

Our efforts so far are aligned with using a backwards design model to support our efforts to improve our teaching practice. The backwards design model centers on the idea that the course or instructional design process should begin with identifying the desired results and then "work backwards" to develop instruction rather than the traditional approach which is to define what topics need to be covered. Their framework identifies three main stages:

Stage 1: Identify desired outcomes and results.
Stage 2: Determine what constitutes acceptable evidence of competency in the outcomes and results (assessment).
Stage 3: Plan instructional strategies and learning experiences that bring students to these competency levels.

The backwards design model was developed to guide course design, but can be adapted to guide programmatic design.

Stage 1. Identify Desired Results

Wiggins and McTighe ask instructors to consider not only the course goals and objectives, but also the learning that should endure over the long term. This is referred to as the "enduring understanding." Wiggins and McTighe suggest that "the enduring understanding" is not just "material worth covering," but includes the following elements:

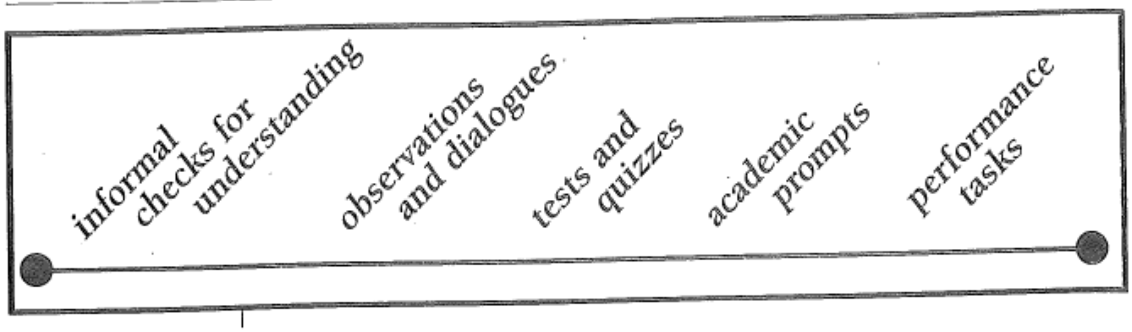
- Enduring value beyond the classroom
- Resides at the heart of the discipline
- Required uncoverage of abstract or often misunderstood ideas
- Offer potential for engaging students

Stage 2. Determine what constitutes acceptable evidence of competency in the outcomes and results (assessment).

The second stage in the design process is to define what forms of assessment will demonstrate that instruction achieved the desired objectives. If your course goals include student learning, then you will have to assess whether students acquired the knowledge, understanding, and skill outlined in section 1. Wiggins and McTighe define three types of assessment:

- Performance Task— The performance task is at the heart of the learning. A performance task is meant to be a real-world challenge in the thoughtful and effective use of knowledge and skill— an authentic test of understanding, in context.
- Criteria Referenced Assessment (quizzes, test, prompts). These provide instructor and student with feedback on how well the facts and concepts are being understood.
- Unprompted Assessment and Self-Assessment (observations, dialogues, etc.).

Figure 7.4
A Continuum of Assessments



Stage 3. Plan Learning Experience and Instruction

In this stage, it is determined what sequence of teaching and learning experiences will equip students to develop and demonstrate the desired understanding and create the evidence required by the assessment.

Activity: Rewriting Learning Goals

In this activity, we will use existing instructional materials from two courses (historical geology or structural geology) to infer the learning goals of the authors of the instructional materials and suggest other learning goals that may be appropriate if the instructional activity was changed.

1. In small groups, consider one of the following sets of instructional materials appropriate for one class period:

- Introduction to faults (GEOL 312 Structural Geology)
- The Great Oxygenation Event (GEOL 106 Historical Geology)
- Your own instructional materials

2. Using the instructional materials provided, infer the likely learning goals and assessment techniques used by the instructors. Where do these goals and assessment techniques fall on the assessment and learning goals continuums, as represented in figures 7.4 and 7.4b? What is likely the dominant instructional activity used by the instructor to meet these goals.

3. Develop a new learning goal and associated performance task that would represent higher order thinking or authentic reasoning. A performance task is a task, a problem, or question that requires students to construct (rather than select) responses and may also require them to devise and revise strategies, organize data, identify patterns, formulate models and generalizations, evaluate partial and tentative solutions, and justify their answers. You are welcome to assume a different instructional activity would be used to meet this new learning goal.

Figure 1.4
UbD Design Standards

Stage 1—To what extent does the design focus on the big ideas of targeted content?

Consider: Are . . .

- The targeted understandings enduring, based on transferable, big ideas at the heart of the discipline and in need of uncoverage?
- The targeted understandings framed by questions that spark meaningful connections, provoke genuine inquiry and deep thought, and encourage transfer?
- The essential questions provocative, arguable, and likely to generate inquiry around the central ideas (rather than a "pat" answer)?
- Appropriate goals (e.g., content standards, benchmarks, curriculum objectives) identified?
- Valid and unit-relevant knowledge and skills identified?

Stage 2—To what extent do the assessments provide fair, valid, reliable, and sufficient measures of the desired results?

Consider: Are . . .

- Students asked to exhibit their understanding through authentic performance tasks?
- Appropriate criterion-based scoring tools used to evaluate student products and performances?
- Various appropriate assessment formats used to provide additional evidence of learning?
- The assessments used as feedback for students and teachers, as well as for evaluation?
- Students encouraged to self-assess?

Stage 3—To what extent is the learning plan effective and engaging?

Consider: Will the students . . .

- Know where they're going (the learning goals), why the material is important (reason for learning the content), and what is required of them (unit goal, performance requirements, and evaluative criteria)?
- Be hooked—engaged in digging into the big ideas (e.g., through inquiry, research, problem solving, and experimentation)?
- Have adequate opportunities to explore and experience big ideas and receive instruction to equip them for the required performances?
- Have sufficient opportunities to rethink, rehearse, revise, and refine their work based upon timely feedback?
- Have an opportunity to evaluate their work, reflect on their learning, and set goals?

Consider: Is the learning plan . . .

- Tailored and flexible to address the interests and learning styles of all students?
- Organized and sequenced to maximize engagement and effectiveness?

Overall Design—To what extent is the entire unit coherent, with the elements of all three stages aligned?

Figure 11.1
Entry Points for the Design Process

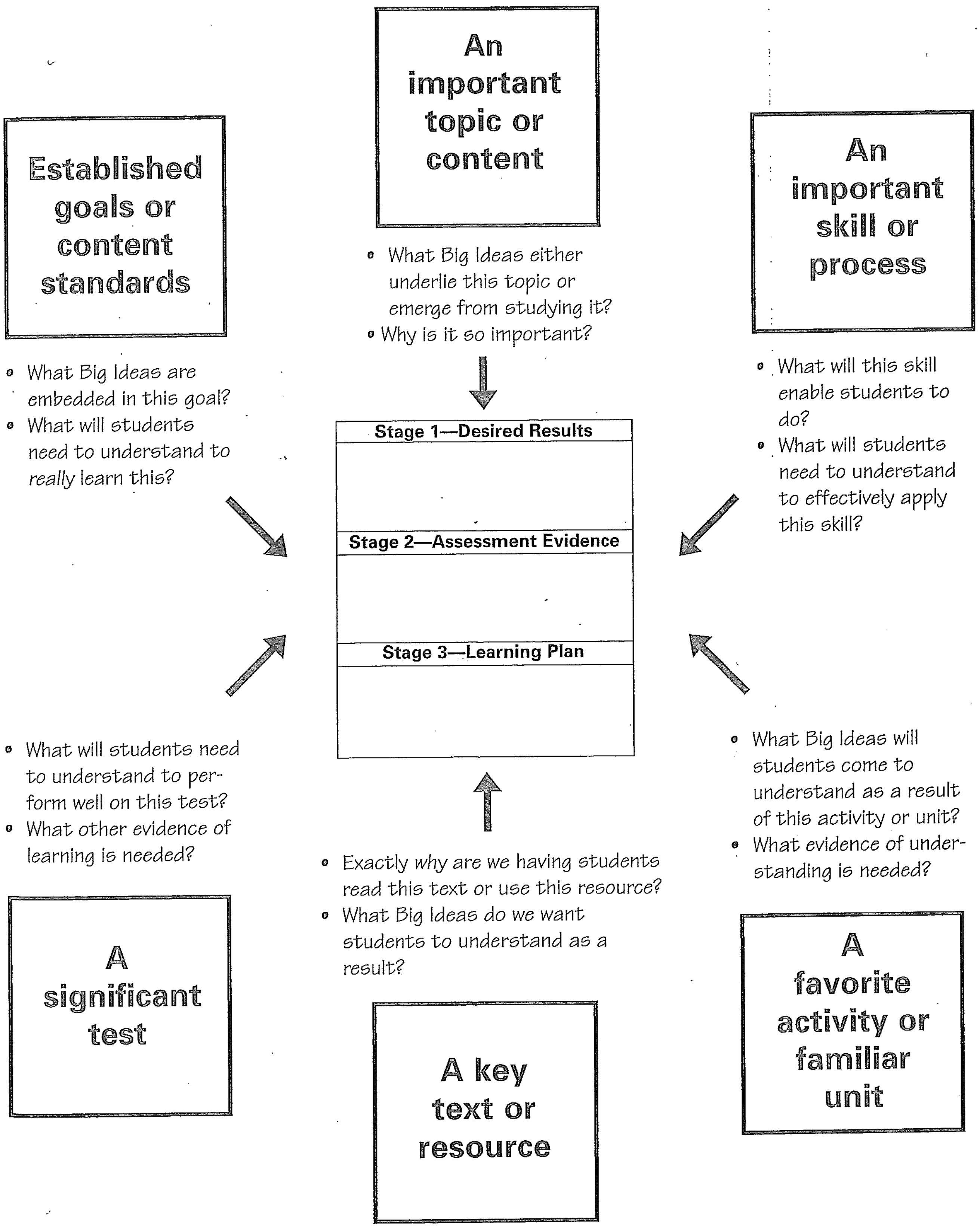


Figure 2.1

Knowledge Versus Understanding

Knowledge	Understanding
• The facts	• The meaning of the facts
• A body of coherent facts	• The "theory" that provides coherence and meaning to those facts
• Verifiable claims	• Fallible, in-process theories
• Right or wrong	• A matter of degree or sophistication
• I know something to be true	• I understand why it is, what makes it knowledge
• I respond on cue with what I know	• I judge when to and when not to use what I know

Figure 3.3
Clarifying Content Priorities

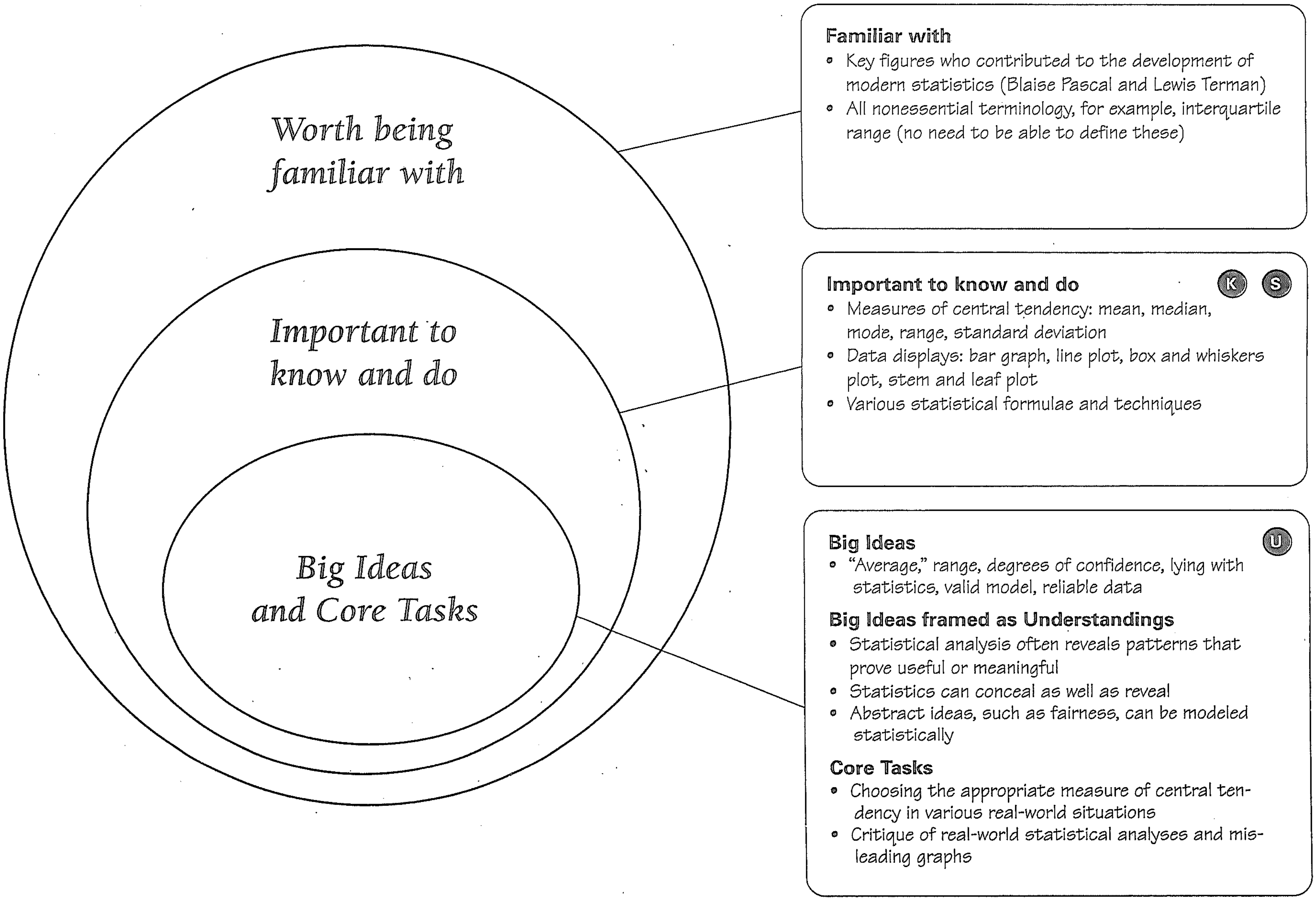


Figure 7.3
Two Approaches to Thinking About Assessment

When thinking like an assessor, we ask—	When thinking like an activity designer (only), we ask—
• What would be sufficient and revealing evidence of understanding?	• What would be fun and interesting activities on this topic?
• Given the goals, what performance tasks must anchor the unit and focus the instructional work?	• What projects might students wish to do on this topic?
• What are the different types of evidence required by Stage 1 desired results?	• What tests should I give, based on the content I taught?
• Against what criteria will we appropriately consider work and assess levels of quality?	• How will I give students a grade (and justify it to their parents)?
• Did the assessments reveal and distinguish those who really understood from those who only seemed to? Am I clear on the reasons behind learner mistakes?	• How well did the activities work? • How did students do on the test?

Figure 7.5
Types of Evidence

Performance Tasks

T

Complex challenges that mirror the issues and problems faced by adults. Ranging in length from short-term tasks to long-term, multistaged projects, they yield one or more tangible products and performances. They differ from academic prompts in the following ways:

- Involve a real or simulated setting and the kind of constraints, background "noise," incentives, and opportunities an adult would find in a similar situation (i.e., they are authentic)
- Typically require the student to address an identified audience (real or simulated)
- Are based on a specific purpose that relates to the audience
- Allow students greater opportunity to personalize the task
- Are not secure: The task, evaluative criteria, and performance standards are known in advance and guide student work

Academic Prompts

OE

Open-ended questions or problems that require the student to think critically, not just recall knowledge, and to prepare a specific academic response, product, or performance. Such questions or problems

- Require constructed responses to specific prompts under school and exam conditions
- Are "open," with no single best answer or strategy expected for solving them
- Are often "ill structured," requiring the development of a strategy
- Involve analysis, synthesis, and evaluation
- Typically require an explanation or defense of the answer given and methods used
- Require judgment-based scoring based on criteria and performance standards
- May or may not be secure
- Involve questions typically only asked of students in school

Quiz and Test Items

OE

Familiar assessment formats consisting of simple, content-focused items that

- Assess for factual information, concepts, and discrete skill
- Use selected-response (e.g., multiple-choice, true-false, matching) or short-answer formats
- Are convergent, typically having a single, best answer
- May be easily scored using an answer key or machine
- Are typically secure (i.e., items are not known in advance)

Informal Checks for Understanding

OE

Ongoing assessments used as part of the instructional process. Examples include teacher questioning, observations, examining student work, and think-alouds. These assessments provide feedback to the teacher and the student. They are not typically scored or graded.

Figure 7.11

Curricular Priorities and Assessment Methods

In effective assessments, we see a match between the type or format of the assessment and the needed evidence of achieving the desired results. If the goal is for students to learn basic facts and skills, then paper-and-pencil tests and quizzes generally provide adequate and efficient measures. However, when the goal is deep understanding, we rely on more complex performances to determine whether our goal has been reached. The graphic below reveals the general relationship between assessment types and the evidence they provide for different curriculum targets.

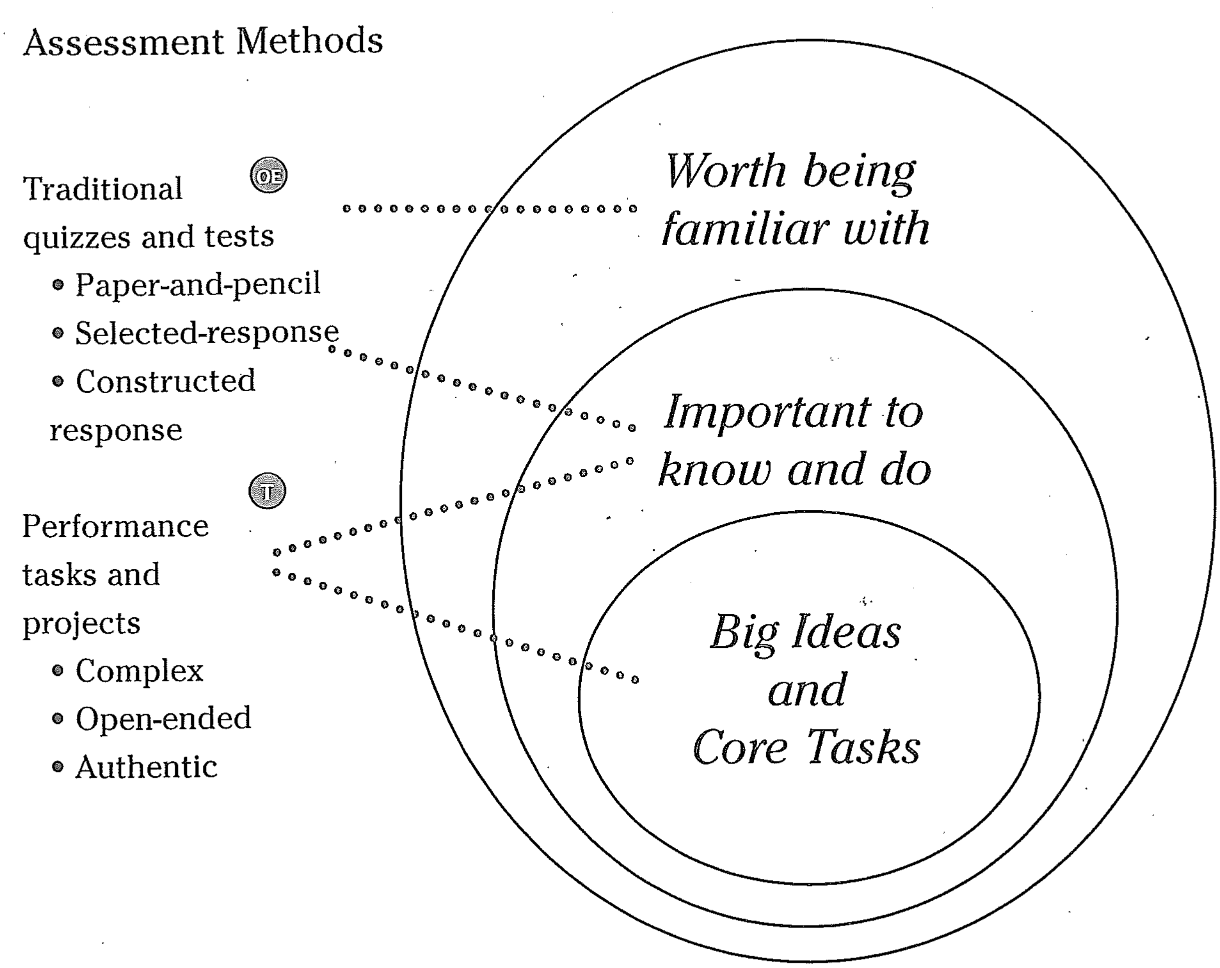


Figure 7.6
Problems Versus Exercises

	Problem	Exercise
The Framing of the Task	The problem statement is clear, but few if any cues or prompts are offered about how to best frame or solve the problem.	The task is either simple or made simple by specific cues or prompts as to the nature of the challenge or how to proceed in meeting it.
The Approach	Various approaches are possible. Figuring out what kind of problem this is and isn't is a key aspect of the challenge; that is, a *strategy* is needed. Some combination of logical method with trial and error will likely be required.	There is one best approach (though it might not be stated), and it is suggested by how the exercise is framed. The learner's ability to recognize and use the "right" *tactic* is a key goal of the exercise.
The Setting	Realistically "noisy" and complicated, typically involving different—sometimes *competing*—variables related to audience, purpose, criteria for judging work, and more.	Simplified to ensure that the only "variable" is the targeted skill or knowledge. (Similar to sideline drills in athletics or fingering exercises in music.)
The Solution	The goal is an appropriate *solution*, mindful of various requirements and perhaps competing variables and cost/benefit considerations. There may be a right answer, but it follows from sound reasoning and a supported argument or approach.	The goal is the right *answer*. The exercise is built to ensure that there is only one right answer, by *design*. Though it may be a puzzling challenge, there is a definite right answer that can be found via recall and plugging in of prior knowledge, with little or no modification.
Evidence of Success	The focus shifts from the answer to the justification of the approach and solution.	The accuracy of the answer and the choice of the "correct" approach.

Figure 7.9

Using the Six Facets to Build Assessments for Understanding

A student who *really* understands . . .

Facet 1. Can explain—*Demonstrates sophisticated explanatory power and insight.* Is able to . . .

a. Provide complex, insightful, and credible reasons—theories and principles, based on good evidence and argument—to explain or illuminate an event, fact, text, or idea; show meaningful connections; provide a systematic account, using helpful and vivid mental models.
   - Make fine, subtle distinctions; aptly qualify her opinions.
   - See and argue for what is central—the big ideas, pivotal moments, decisive evidence, key questions, and so on.
   - Make good predictions.

b. Avoid or overcome common misunderstandings and superficial or simplistic views—shown, for example, by avoiding overly simplistic, hackneyed, or imprecise theories or explanations.

c. Reveal a personalized, thoughtful, and coherent grasp of a subject—indicated, for example, by developing a reflective and systematic integration of what she knows. This integration would therefore be based in part upon significant and apt *direct or simulated* experience of specific ideas or feelings.

d. Substantiate or justify her views with sound argument and evidence.

Facet 2. Can interpret—*Offers powerful, meaningful interpretations, translations, narratives.* Is able to . . .

a. Effectively and sensitively interpret texts, data, and situations—shown, for example, by the ability to read between the lines and offer plausible accounts of the many possible purposes and meanings of any "text" (book, situation, human behavior, and so on).

b. Offer a meaningful and illuminating account of complex situations and people—shown, for example, by the ability to provide historical and biographical background to help make ideas more accessible and relevant.

Facet 3. Can apply—*Uses knowledge in context; has know-how.* Is able to . . .

a. Employ her knowledge effectively in diverse, authentic, and realistically messy contexts.

b. Extend or apply what she knows in a novel and effective way (invent in the sense of innovate, as Piaget discusses in *To Understand Is to Invent*).

c. Effectively self-adjust as she performs.

Facet 4. Sees in perspective—Is able to . . .

a. Critique and justify a position, that is, see it as a point of view; to use skills and dispositions that embody disciplined skepticism and the testing of theories.

b. Place facts and theories in context; know the questions or problem to which the knowledge or theory is an answer or solution.

c. Infer the assumptions upon which an idea or theory is based.

d. Know the limits as well as the power of an idea.

e. See through argument or language that is biased, partisan, or ideological.

(continued on next page)

Figure 7.9 (continued)

f. See and explain the importance or worth of an idea.
g. Take a critical stance; wisely employ *both* criticism and belief (an ability summarized by Peter Elbow's maxim that we are likely to better understand when we methodically "believe when others doubt and doubt when others believe"[2]).

Facet 5. Demonstrates empathy—Is able to . . .
a. Project himself into, feel, and appreciate another's situation, affect, point of view.
b. Operate on the assumption that even an apparently odd or obscure comment, text, person, or set of ideas may contain insights that justify working to understand it.
c. See when incomplete or flawed views are plausible, even insightful, though perhaps somewhat incorrect or outdated.
d. See and explain how an idea or theory can be all too easily misunderstood by others.
e. Watch and listen sensitively and to perceive what others often do not.

Facet 6. Reveals self-knowledge—Is able to . . .
a. Recognize his own prejudices and style and how they color understanding; see and get beyond egocentrism, ethnocentrism, present-centeredness, nostalgia, either/or thinking.
b. Engage in effective metacognition; recognize intellectual style, strengths, and weaknesses.
c. Question his own convictions; like Socrates, sort out mere strong belief and habit from warranted knowledge, be intellectually honest, and admit ignorance.
d. Accurately self-assess and effectively self-regulate.
e. Accept feedback and criticism without defensiveness.
f. Regularly reflect on the meaning of one's learning and experiences.

---

[1]Jean Piaget. (1973). *To Understand Is to Invent: The Future of Education.* New York: Grossman's Publishing Co.
[2]Peter Elbow. (1973). *Writing Without Teachers.* New York: Oxford University Press.

Figure 8.3
Six-Facet Rubric

Explained	Meaningful	Effective	In Perspective	Empathic	Reflective
Sophisticated and Comprehensive: an unusually thorough, elegant, or inventive account (model, theory, explanation); fully supported, verified, justified; deep and broad; goes well beyond the information given	*Insightful:* a powerful and illuminating interpretation or analysis of the importance, meaning, significance; tells a rich and insightful story; provides a revealing history or context	*Masterful:* Fluent, flexible, efficient, able to use knowledge and skill and adjust understandings well in diverse and difficult contexts—masterful ability to transfer	*Insightful and Coherent:* a thoughtful and circumspect viewpoint; effectively critiques, encompasses other plausible perspectives; takes a long and dispassionate critical view of the issues involved	*Mature:* disciplined; disposed and able to see and feel what others see and feel; unusually open to and willing to seek out the odd, alien, or different; able to make sense of texts, experiences, events that seem weird to others	*Wise:* deeply aware of the boundaries of own and others' understanding; able to recognize own prejudices and projections; has integrity—able and willing to act on understanding
Systematic: an atypical and revealing account, going beyond what is obvious or what was explicitly taught; makes subtle connections; well supported by argument and evidence; novel thinking displayed	*Revealing:* a thoughtful interpretation or analysis of the importance, meaning, significance; tells an insightful story; provides a helpful history or context	*Skilled:* competent in using knowledge and skill and adapting understandings in a variety of appropriate and demanding contexts	*Thorough:* a fully developed and coordinated critical view; makes own view more plausible by a fair consideration of the plausibility of other perspectives; makes apt criticisms, discriminations, and qualifications	*Sensitive:* disposed to see and feel what others see and feel; open to the unfamiliar or different; able to see the value and work that others do not see	*Circumspect:* aware of own ignorance and that of others; aware of own prejudices
In-Depth: an account that reflects some in-depth and personalized ideas; student is making the work his own, going beyond the given; there is supported theory, but insufficient or inadequate evidence and argument	*Perceptive:* a reasonable interpretation or analysis of the importance, meaning, or significance; tells a clear and instructive story; provides a revealing history or context	*Able:* limited but growing ability to be adaptive and innovative in the use of knowledge and skill	*Considered:* a reasonably critical and comprehensive look at major points of view in the context of her own; makes clear that there is plausibility to other points of view	*Aware:* knows and feels that others see and feel differently and is somewhat able to empathize with others	*Thoughtful:* generally aware of what he does and does not understand; aware of how prejudice and projection occur without awareness

Developed: an incomplete account, but with apt and insightful ideas; extends and deepens some of what was learned; some reading between the lines; account has limited support, argument, data, or sweeping generalizations; there is a theory with limited testing and evidence	*Interpreted:* a plausible interpretation or analysis of the importance, meaning, or significance; makes sense with a story; provides a telling history or context	*Apprentice:* relies on a limited repertoire of routines, able to perform well in a few familiar or simple contexts; limited use of judgment and responsiveness to feedback or situation	*Aware:* knows of different points of view and somewhat able to place own view in perspective, but weakness in considering worth of each perspective or critiquing each perspective, especially her own; uncritical about tacit assumptions	*Decentering:* has some capacity or self-discipline to walk in others shoes, but is still primarily limited to own reactions and attitudes, puzzled or put off by different feelings or attitudes	*Unreflective:* generally unaware of own specific ignorance; generally unaware of how prejudgments color understanding
Naïve: superficial account; more descriptive than analytical or creative; a fragmented or sketchy account of facts, ideas; glib generalizations; a black-and-white account; less theory than an unexamined hunch or borrowed idea	*Literal:* a simplistic or superficial reading; mechanical translation; a decoding with little or no interpretation; no sense of wider importance or significance; a restatement of what was taught or read	*Novice:* can perform only with coaching or relies on highly scripted, singular "plug-in" (algorithmic and mechanical) skills, procedures, or approaches	*Uncritical:* unaware of differing points of view, prone to overlook or ignore other perspectives; has difficulty imagining other ways of seeing things; prone to ad hominem criticisms	*Egocentric:* has little or no empathy, beyond intellectual awareness of others; see things through own ideas and feelings; ignores or is threatened or puzzled by different feelings, attitudes, views	*Innocent:* completely unaware of the bounds of own understanding and of the role of projections and prejudice in opinions and attempts to understand

Revised and adapted from Wiggins and McTighe (1998). Reprinted with permission. © 1998 Association for Supervision and Curriculum Development.

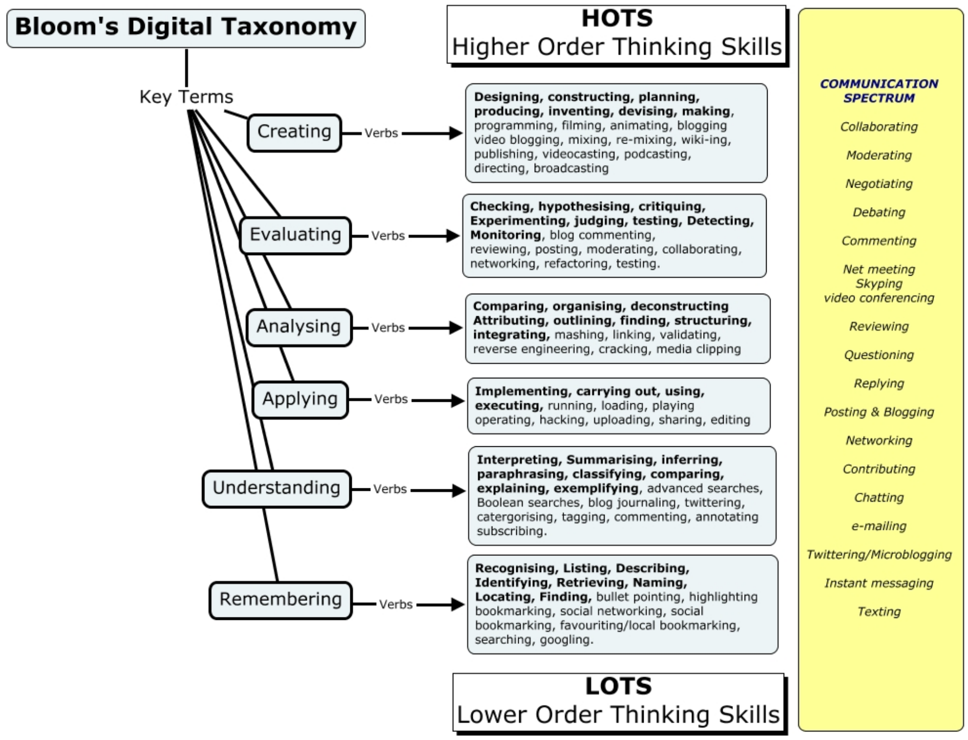


Fig. 7.4b. Using Bloom's Taxonomy to develop learning goals for higher order thinking (http://larryferlazzo.edublogs.org/2009/05/25/the-best-resources-for-helping-teachers-use-blooms-taxonomy-in-the-classroom/).

Further Exploration

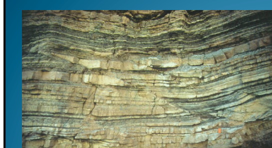
Presentation: Backwards Design

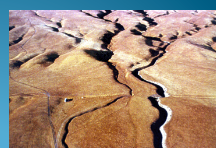
Readings

- ASCD Understanding by Design® Framework: http://www.ascd.org/research-a-topic/understanding-by-design-resources.aspx
- Shepard, L.A., 2000, The role of assessment in a learning culture: Educational Researcher, v. 29, no. 7, p. 4-14.

Introduction to Faults

Features of faulting and
kinematic indicators



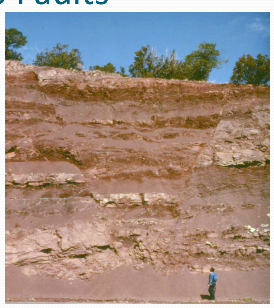


Section Overview

- Introduction – recognizing faults
- Fault geometry & displacement terminology
- Characteristics of faults, fault zones & shear zone
  - Kinematic indicators
- Fault plane geometries
- Fault systems and the relationship of faults to tectonic processes

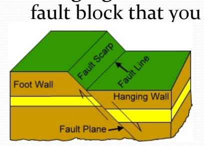
Introduction to Faults

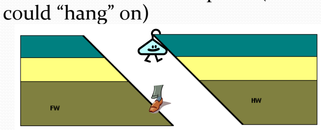
- **Fault** - a surface or narrow zone along which one side has moved relative to the other in a direction parallel to the surface or zone



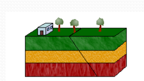
Anatomy of a Fault

- **Fault Scarp** – a line or cliff created by a fault
- **Fault Plane** – the plane on which the fault blocks move up, down, or sideways
- **Foot wall** – fault block below the fault plane (the fault block that you could put your foot on)
- **Hanging wall** – fault block above the fault plane (the fault block that you could "hang" on)

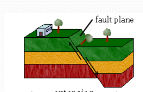


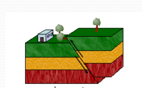


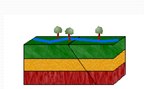
Faulted Rocks

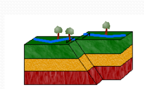


- Three main types of faults:
  - **Normal Fault** – Hanging wall moves down
    - Indicates extension
  - **Reverse Fault** – Hanging wall moves up
    - Indicates compression or shortening
  - **Strike-slip Fault** – blocks slide past each other with no up or down movement



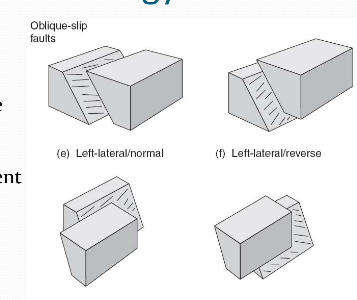






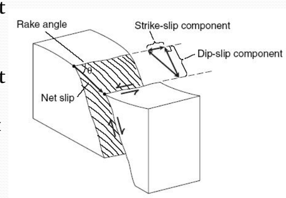
Fault slip terminology

- Oblique slip
- Most faults have some degree of both strike and dip slip movement



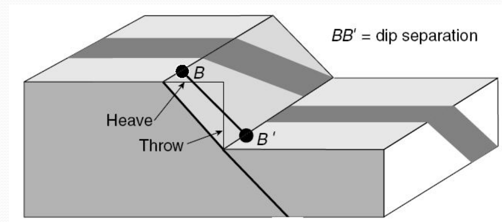
Fault slip terminology

- **Strike slip** component: amount of displacement parallel to strike
- **Dip slip** component: amount of displacement parallel to dip
- **Net slip** – total amount of slip
- **Rake angle** – angle of slip relative to the fault's strike



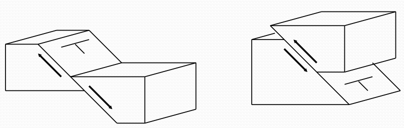
Fault slip terminology

- **Heave** – horizontal component of dip separation
- **Throw** – vertical displacement of dip separation



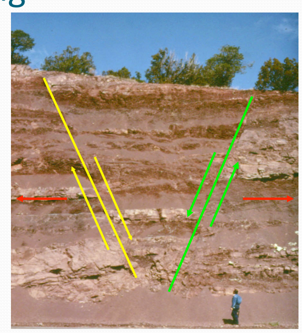
Dip-Slip Motion

- Movement is parallel to the direction of dip
  - Normal faults
  - Reverse faults



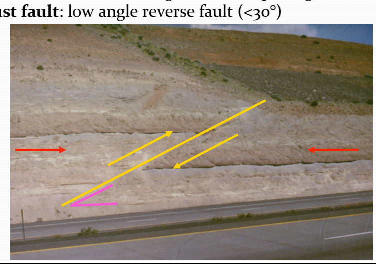
Normal Faulting

- Hanging wall moves down with respect to the foot wall
- Response to extension
- Lengthens the total package of the rocks



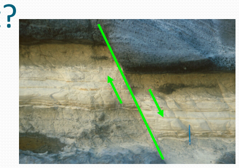
Reverse Faulting

- Hanging wall moves up with respect to the footwall
- Response to compression
- Results in overall shortening of the rock package
- **Thrust fault**: low angle reverse fault (<30°)

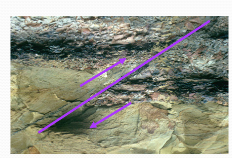


What kind of fault?

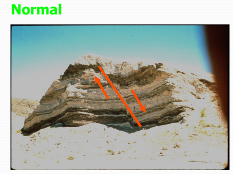
Reverse



Normal



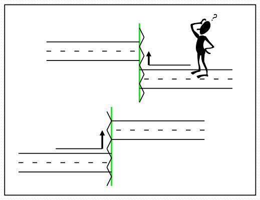
Reverse



Normal

Strike-slip faulting

- Slip is dominantly parallel to the strike of the fault plane
  - Right lateral (dextral)
  - Left lateral (sinistral)
- The term "transform" fault is generally reserved for a strike-slip fault that is coincident with a tectonic plate boundary

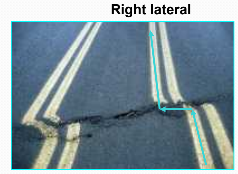


What kind of fault?

Left lateral

Right lateral

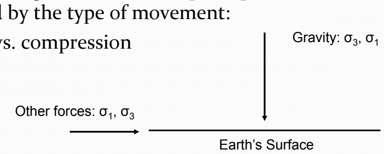
Right lateral



Left lateral

Anderson's Theory of Faulting:

- The earth's surface is a principle plane of zero shear stress
- Orientation of greatest and least principle stresses are determined by the type of movement:
- Extension vs. compression

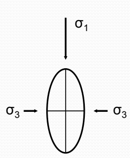


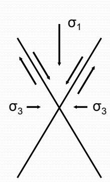
Anderson's Theory of Faulting

- Assumptions:
  - Deformation is brittle
  - Frictional forces are significant
  - Material is homogenous
  - Material is isotropic – same strength in all directions

Anderson's Fault Classification

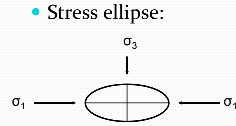
- Normal faults – gravity is greatest principle stress (σ_1)
- Normal faults are typically high angles (50-75°)
- Stress ellipse: Cross sectional view:

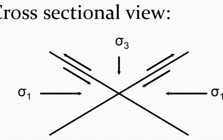




Anderson's Fault Classification

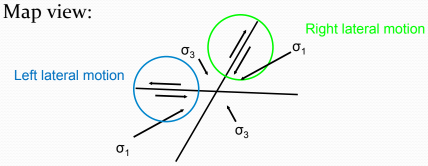
- Reverse faults – gravity is least principle stress (σ_3); greatest principle stress (σ_1) is from other stresses (tectonics)
- Stress ellipse: Cross sectional view:





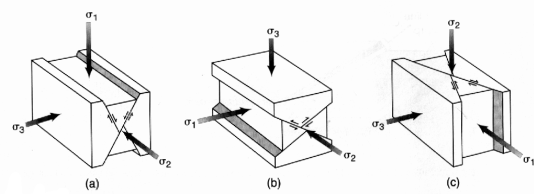
Anderson's Fault Classification

- Strike-slip faults: σ_1 and σ_3 are horizontal to the surface (gravity is σ_2)
- Map view:



Types of faults
- Anderson's classification -

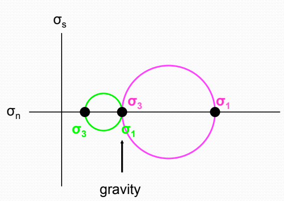
Normal faults　　Reverse faults　　Strike-slip faults



Anderson's theory of faulting. (a) Normal faults, (b) thrust faults, and (c) strike-slip faults.

Who Is Mohr Stressed?

- Thrust faults vs. Normal faults



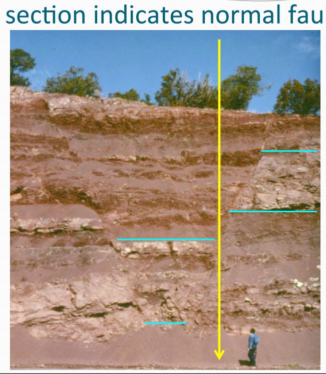
- Normal Fault: greatest principle stress (σ_1) is gravity
- Thrust Fault: gravity is least principle stress (σ_3)

Recognition of faults

- Features intrinsic to faults
  - fractures, offset
- Effects of faulting on geologic or stratigraphic units
  - Repeated or lost section
  - Drag folding
- Physiographic criteria for faulting
  - Fault scarp features

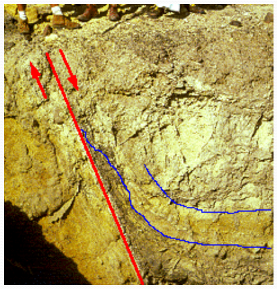
Repeated section indicates reverse

Missing section indicates normal faulting



Drag Folds

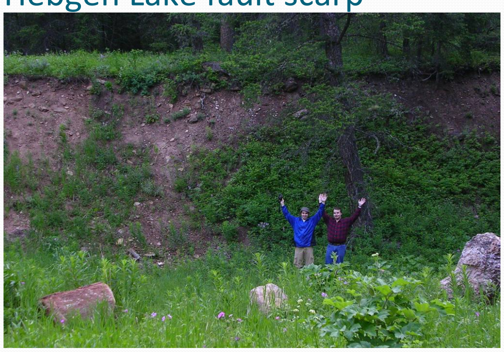
- Drag folding occurs when features are dragged into the fault zone during the faulting



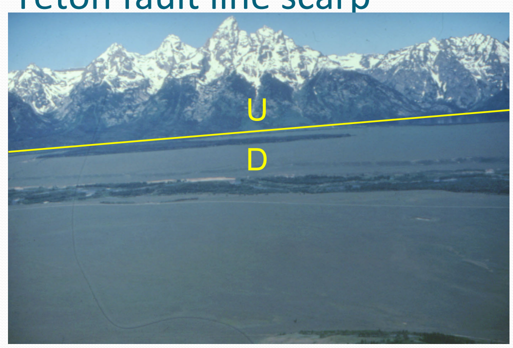
Physiographic criteria for faulting

- **Fault scarp** - continuous linear breaks in slope that result directly from displacement of topography
- **Flatirons** - erosional remnants of fault scarp
- **Fault line scarps** - erosional features that are characteristic of both active and inactive faults

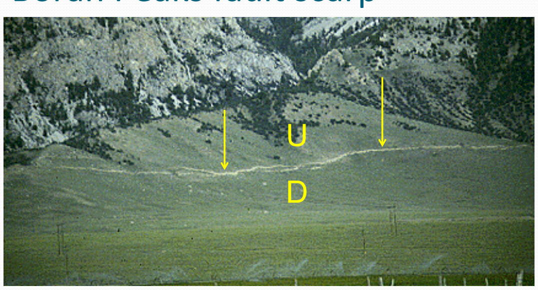
Hebgen Lake fault scarp



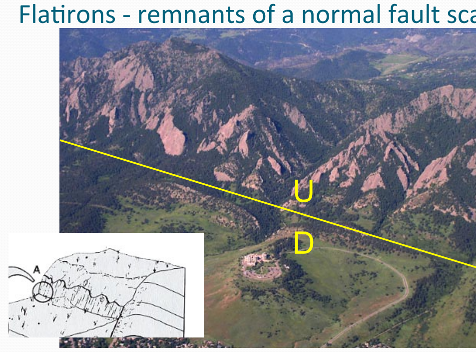
Teton fault line scarp



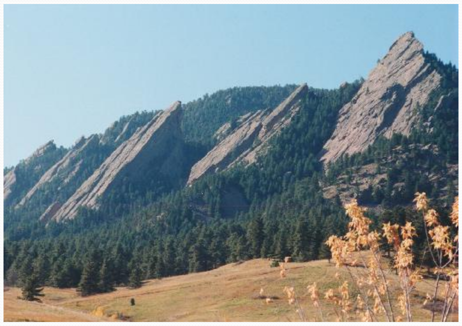
Borah Peaks fault scarp



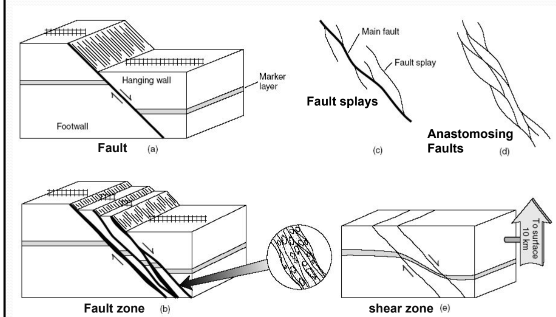
Flatirons - remnants of a normal fault scarp



Flatirons near Boulder CO

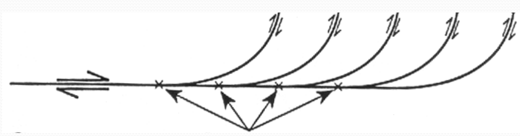


Faults, fault zones, shear zones



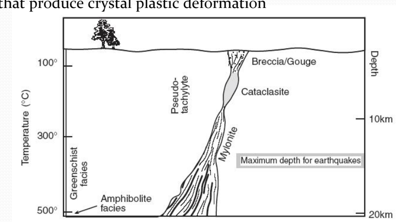
Fault terminations - overview

- **Termination lines** – a line marking the termination of a fault
- **Fault trace** – the termination of a fault at the surface
- **Splay faults** – faults that branch off of a main fault
  - Tend to have the same relative motion as the main fault



The effects of depth:

- Increased Temperature and Confining Pressure
- Brittle faults vs ductile faults
  - **Cataclasis** - rock deformation accomplished by fracture and rotation of mineral grains or aggregates without chemical reconstitution (cataclasite)
  - **Mylonite** – foliated or lineated rocks that form in zones of shear that produce crystal plastic deformation



Brittle fault rocks

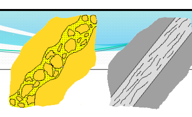
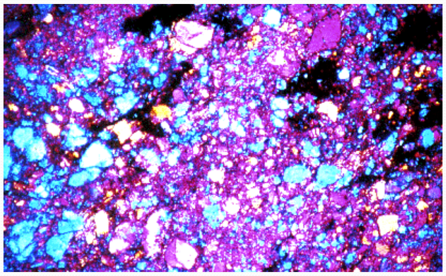


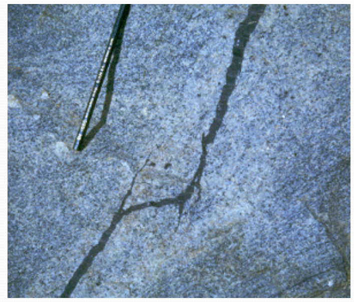
TABLE 8.5	CLASSIFICATION OF BRITTLE FAULT ROCK
Noncohesive Brittle Fault Rocks	
Fault gouge	Rock composed of material whose grain size has been mechanically reduced by pulverization. Grains in fault gouge are less than about 1 mm in diameter. Like breccia, gouge is noncohesive. Shearing of gouge along a fault surface during progressive movement may create foliation within the gouge. Clay formed by alteration of silicate minerals in fault zones may be difficult to distinguish from true gouge.
Indurated gouge	Fault gouge that has been cemented together by minerals precipitated from circulating groundwater.
Fault breccia	Rock composed of angular fragments of rock greater than about 1 mm, and as much as several m across; fault breccia is noncohesive.
Vein-filled breccia	Fault-breccia blocks that are cemented together by vein material. Another term, *indurated breccia*, is synonymous.
Cohesive Brittle Fault Rocks	
Pseudotachylyte	A glass or microcrystalline material that forms when frictional heating melts rock during slip on a fault. Pseudotachylyte commonly flows into cracks between breccia fragments or into cracks penetrating the walls of the fault. In special cases, pseudotachylyte may be several m thick (e.g., impact sites), but generally it is mm to cm in thickness.
Argille scagliose	A fault rock that forms in very fine-grained clay- or mica-rich rock (e.g., shale or slate) and is characterized by the presence of a very strong wavy anastamosing foliation. As a consequence, the rock breaks into little scales or platy flakes.
Cataclasite	A cohesive fault rock composed of broken, crushed, or rolled grains. Unlike breccia, it is a solid rock that does not disintegrate when struck with a hammer.

Breccia

Cataclasite – in thin section

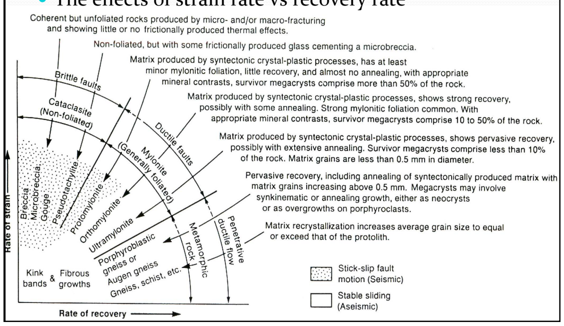


Pseudotachylite

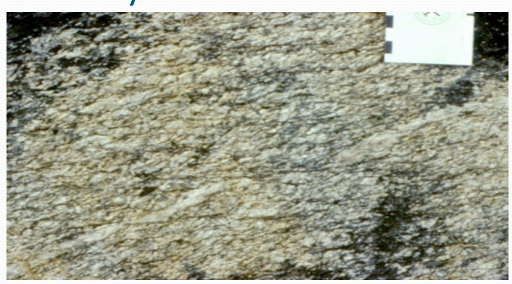


Rock features produced by brittle vs ductile faulting

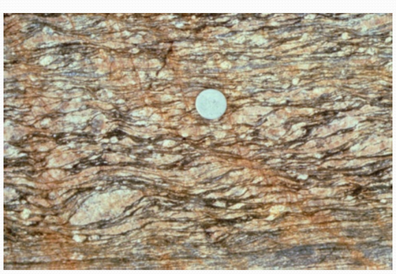
- The effects of strain rate vs recovery rate



Protomylonite



Orthomylonite

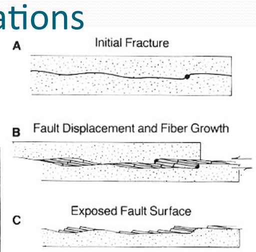


Relative displacement (Kinematic indicators of displacement)

- Slickenfiber lineations
- Secondary fractures (feather joints)
- Fractured porphyroclasts
- Asymmetric porphyroclasts
- Rotated inclusion trails in porphyroblasts

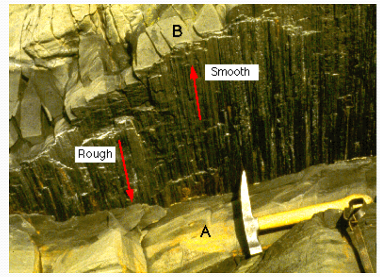
Slickenfiber lineations

- Fibers grow from solutions in pull-apart steps during extensional shear offset on fractures



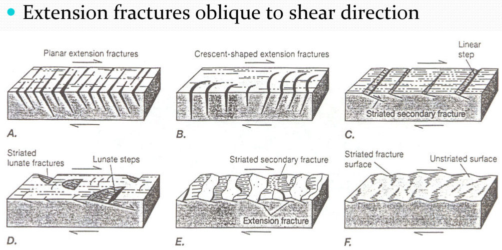
- Rough and smooth directions indicate sense of movement

Slickenfiber lineations



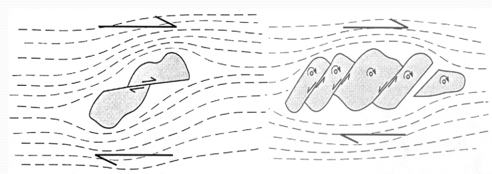
Secondary fractures

- Extension fractures oblique to shear direction



Fractured porphyroclasts

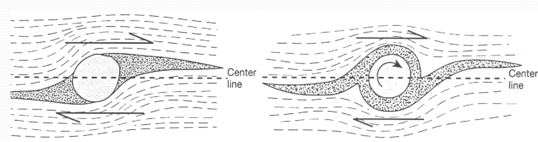
- Synthetic vs antithetic (bookshelf) shear



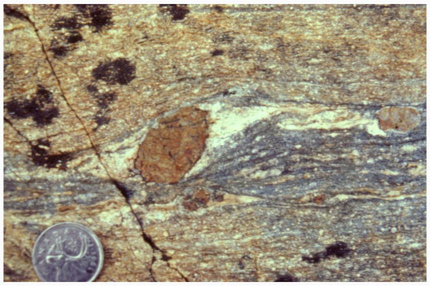
Synthetic fractures

Asymmetric porphyroclasts

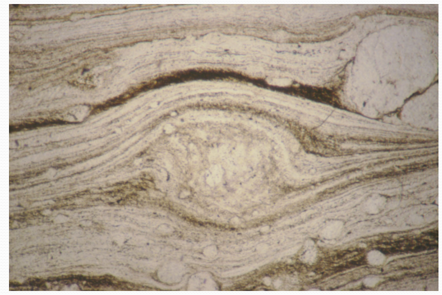
- Sigma (strain shadow) & delta (rotated) porphyroclasts



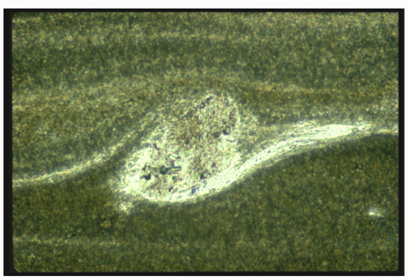
Sigma porphyroclast



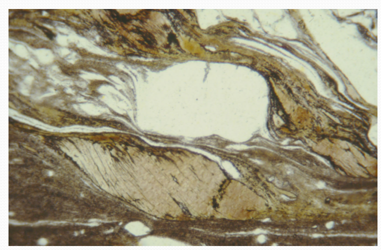
Delta porphyroclast



Delta porphyroclast

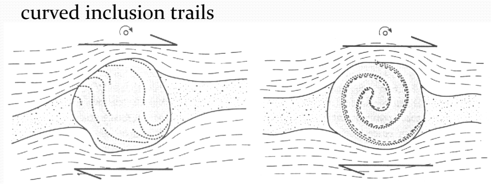


Sigma porphyroclast

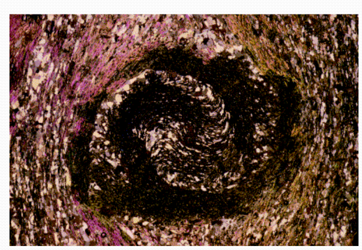


Rotated inclusion trails in porphyroblasts

- Rotation of porphyroblast during growth leads to curved inclusion trails

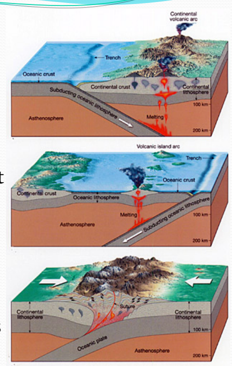


Rotated spiral porphyroclast



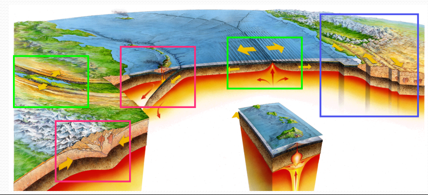
Fault systems are a result of stresses in the upper crust

- Faults are typically part of a fault system or fault array that forms in response to a regional stress field
- Fault arrays may be dominated by a particular type of motion, but may include several different types of fault offset



We will consider the general characteristics of three different types of fault systems

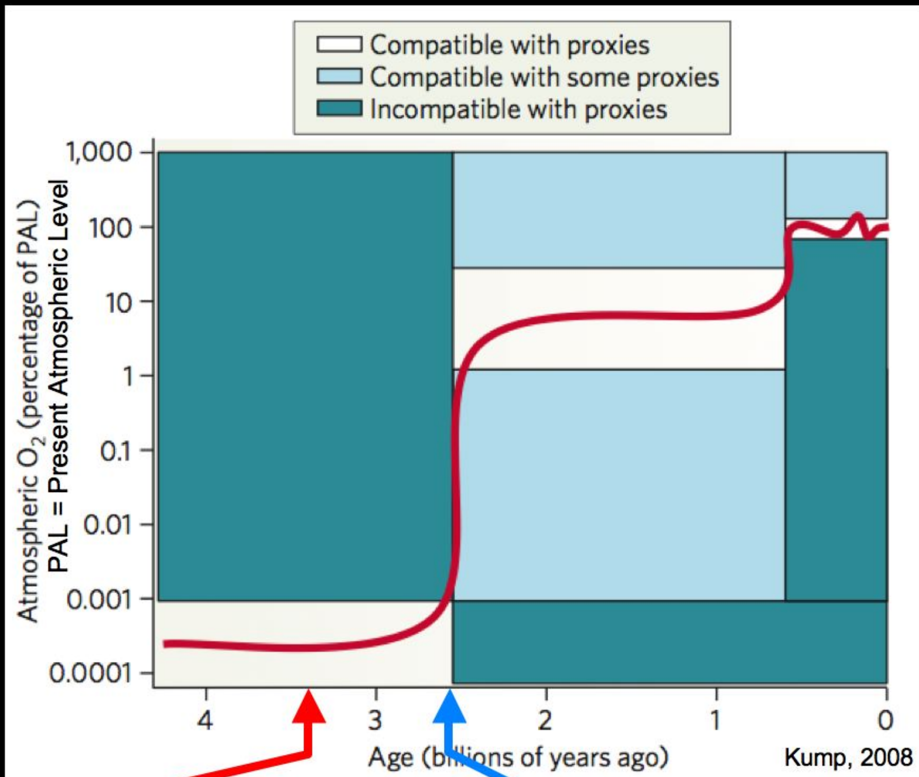
- Thrust fault systems
- Normal fault systems
- Strike-slip fault systems
- During each section, we will considers these fault systems in their tectonic context



The Great Oxygenation Event

GEOL 106 - Historical Geology - © Thomas Olszewski

When Was the Atmosphere Oxygenated?



Buck Reef Chert is 3.416 Ga -- anoxygenic photosynthesis had originated by this time, but maybe much earlier.

The Great Oxygenation Event (GOE) at 2.4-2.32 Ga -- atmospheric O_2 rose sharply from very low levels to 1-10% of PAL.

Lines of evidence for oxygenation of the Earth:

Banded Iron Formations (BIFs)

Stromatolites

Microbial Body Fossils

Biomarkers

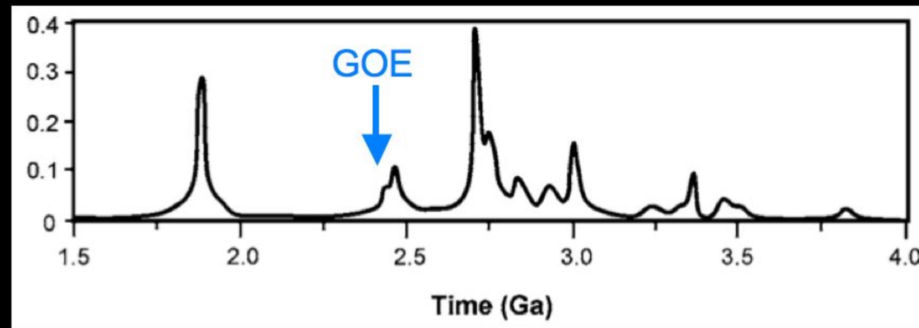
$\delta^{13}C$ isotopes

Mass Independent Sulfur Isotopes (MIS)

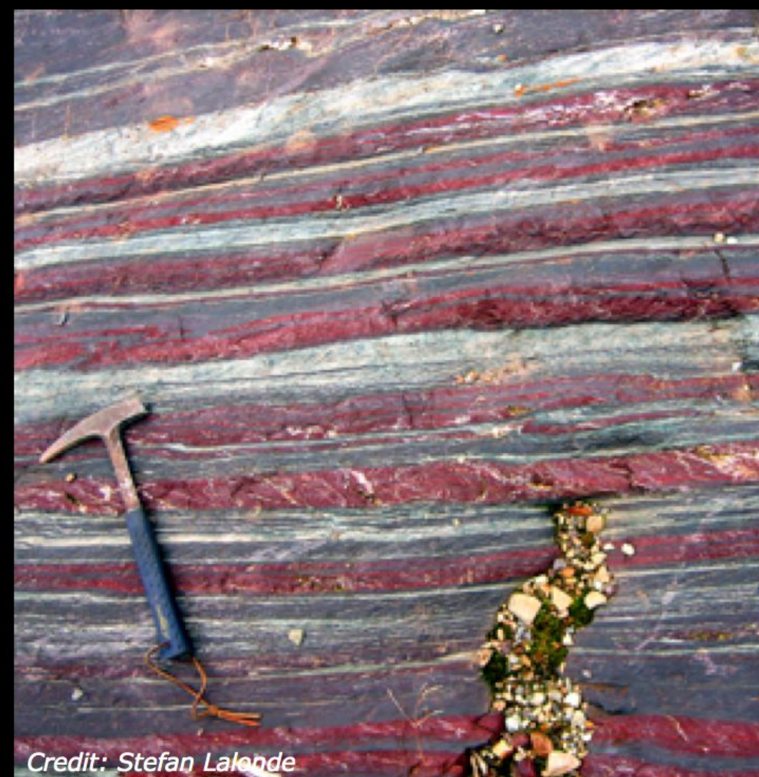
Red beds and redox-sensitive elements

Banded Iron Formations (BIFs)

Banded Iron Formations are sedimentary rocks composed of repeated layers of iron oxides. They are characteristic of specific times in the Precambrian. Such thick accumulations require an abundant source of *dissolved* Fe, indicating that Archean oceans were chemically reduced because reduced Fe is much more soluble than oxidized Fe.



Abundance of BIFs through time. Y-axis is frequency of occurrence (Isley & Abbott, 1999)



<u>Could the oxidant have been O_2 from photosynthesis?</u>

Oxygenic photosynthesis:

$CO_2 + H_2O + \text{energy} \rightarrow CH_2O + O_2$

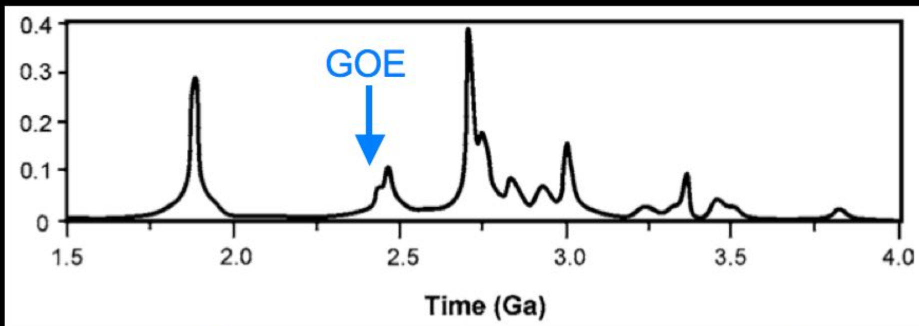
"Rusting" of reduced Fe in primordial ocean:

$4Fe + 3O_2 \rightarrow 2Fe_2O_3$

<u>Magnetite:</u> Fe_3O_4

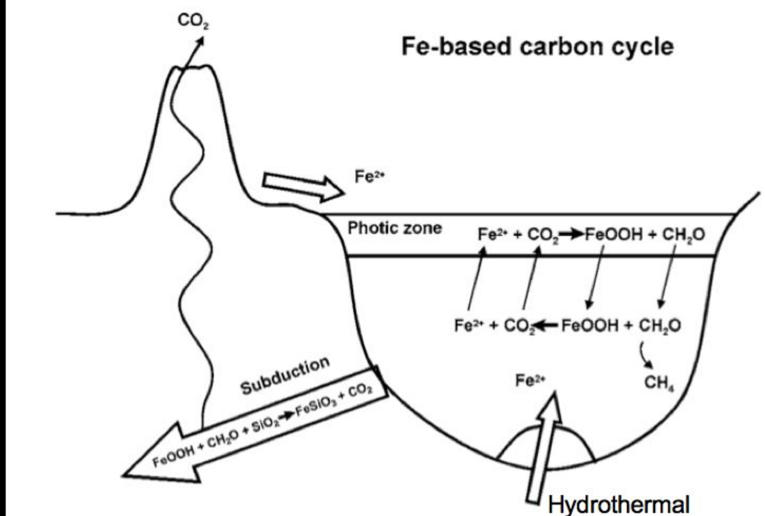
<u>Hematite:</u> Fe_2O_3

Banded Iron Formations (BIFs), cont'd

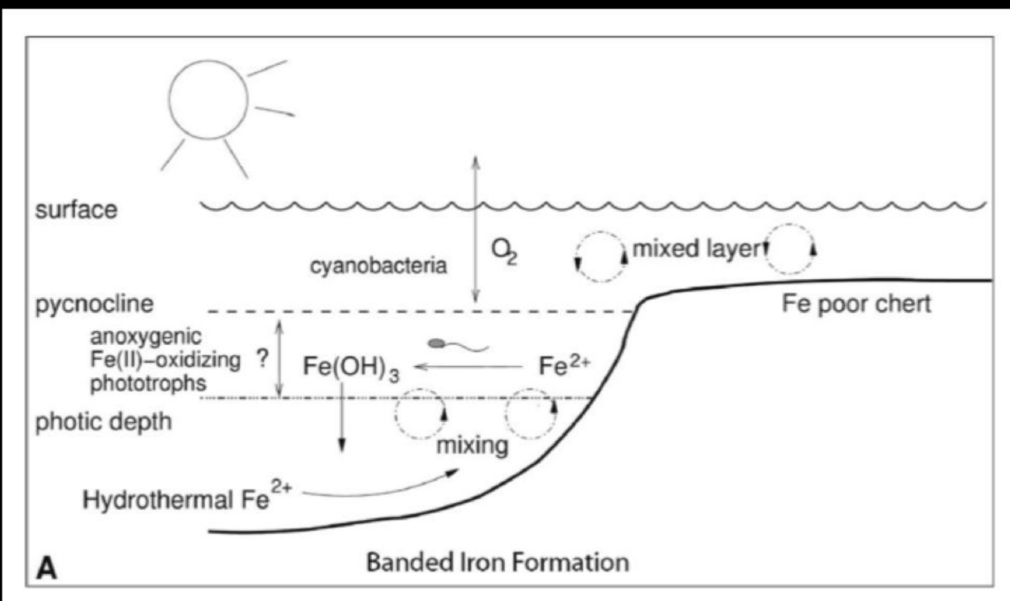


Abundance of BIFs through time. Y-axis is frequency of occurrence (Isley & Abbott, 1999)

The Fe in BIFs is oxidized, but this may not require presence of free O_2. Anaerobic phototrophs are known to oxidize Fe directly.



Cartoon showing an Fe-based carbon cycle as imaged before the evolution of oxygenic photosynthesis. (Canfield, 2005)



Even after the evolution of oxygenic photosynthesis, a source of reduced Fe would have been necessary to precipitate BIFs. (Kappler et al., 2005)

Stromatolites

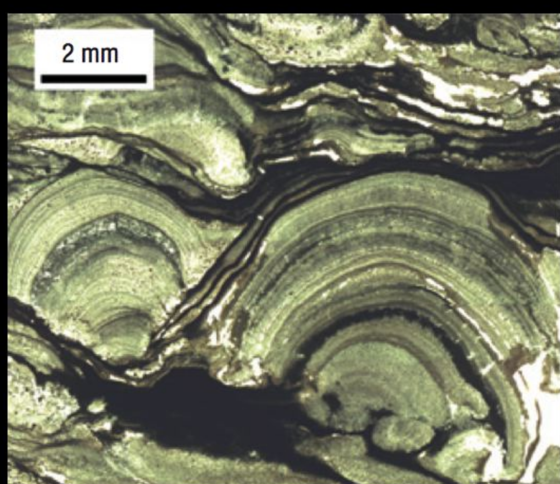
Modern stromatolites are virtually always created by photosynthesizing microbial communities. Evidence for phototropism is preserved in the morphology and microstructure of fossils.

However, stromatolites are NOT diagnostic of oxygen-production per se -- Archean stromatolites could have resulted from *anoxygenic* photosynthesis!

Swaziland Supergroup
South Africa, ~3.4 Ga

Byerly et al., 1986

Strelley Pool Formation,
Australia, ~3.4 Ga



Tumbiana Formation
Australia, 2.724 Ga

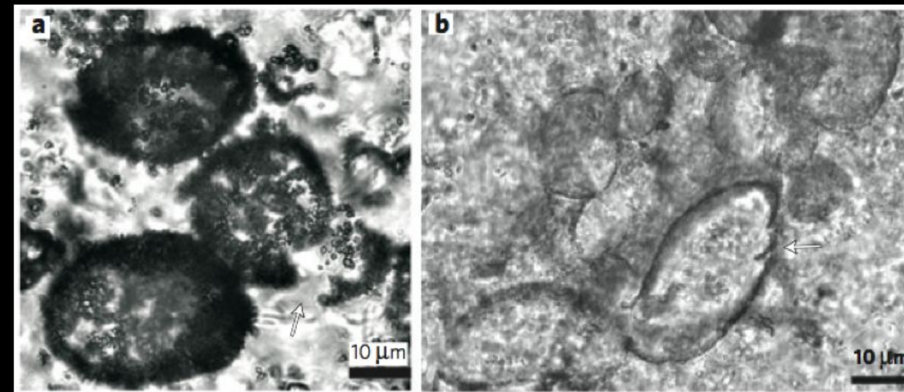
These stromatolites grew in saline lakes that were free of sulfur or iron, leaving only oxygenic photosynthesis as the only likely metabolism for these features. (Buick, 1992)

Photo from Lepot et al. (2008)

Microbial Body Fossils

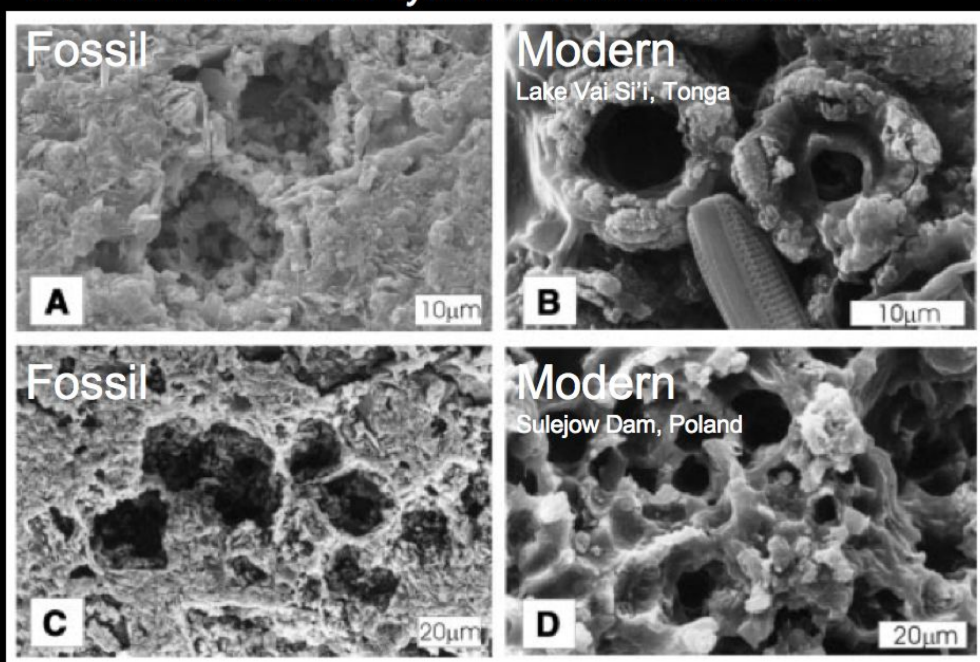
Prokaryotes are difficult to distinguish based on morphology (i.e., what they look like). Claims have been made for Archean fossils, but none are conclusive.

Strelley Pool Formation
Australia, ~3.40 Ga

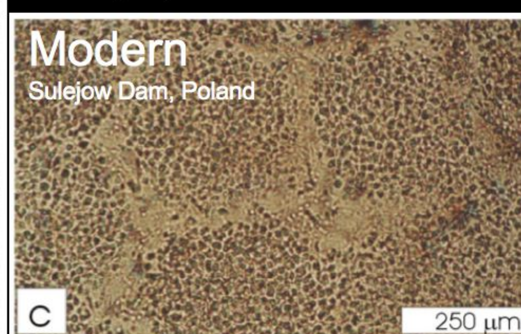


Associated geochemistry suggests a metabolism based on sulfur -- NOT oxygenic photosynthesis!

Nauga Formation
South Africa, ~2.59-2.55 Ga
Best claim for earliest *cyanobacterial* microfossils



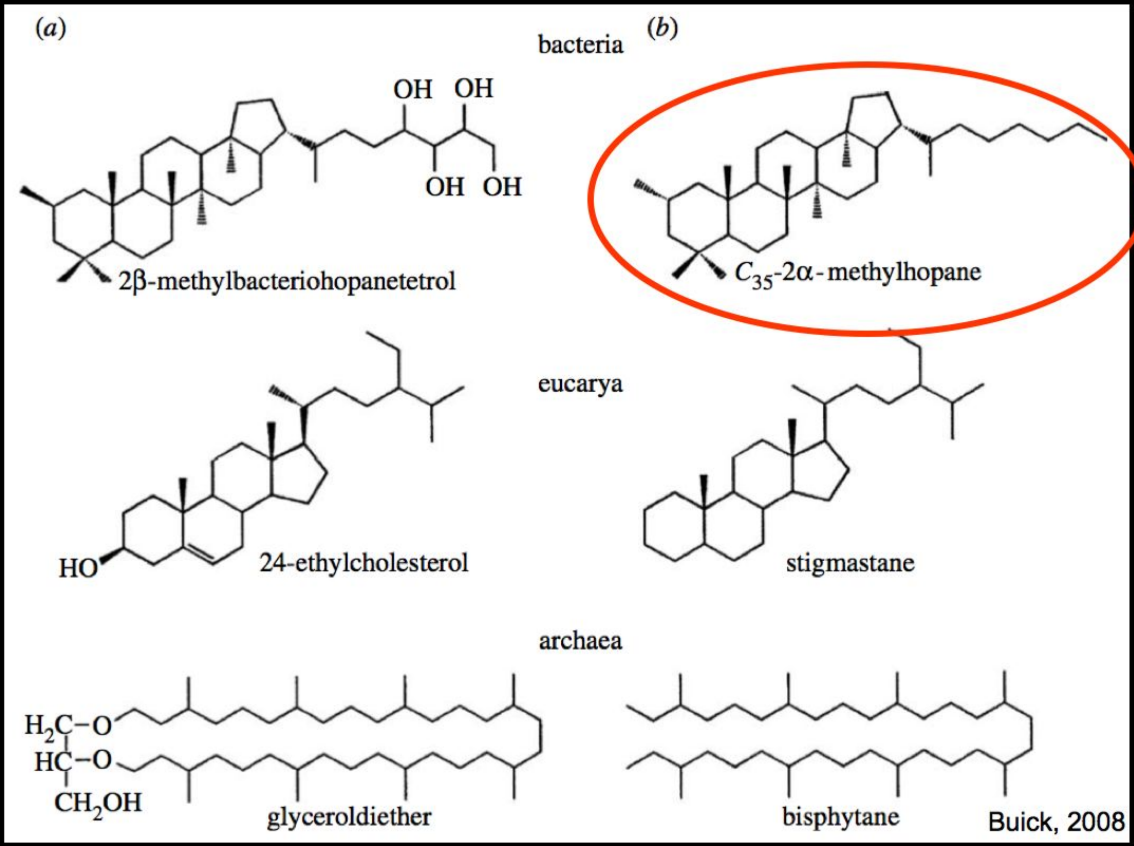
Modern cyanobacteria produce capsules and mucilage sheaths around individual cells and cell clusters forming colonies. Relatively thin inner sheaths enclose single cells and small groups of cells; thicker sheaths enclose larger groups of cells or constitute the outer sheath (capsule) of a colony. (Kazmierczak & Alterman, 2002)



Biomarkers

Biomarker = a fossil molecule that can be tied to a particular living compound; particular biomarkers are restricted to particular types of organism, providing the basis for a "chemical fingerprint"

Biomolecule (living) Biomarker (fossil)



Buick, 2008

2α-methylhopane is almost exclusively produced by *cyanobacteria*!

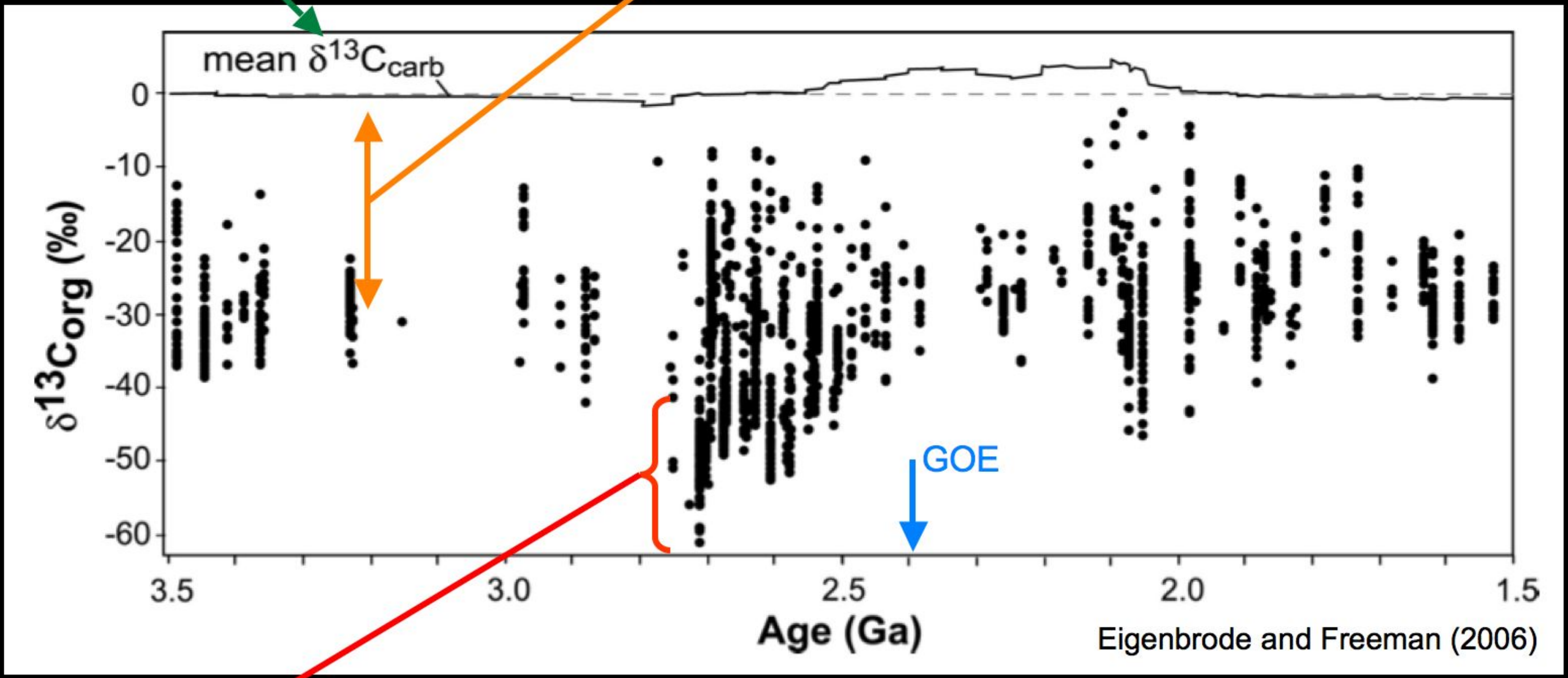
Found in mudrocks of the Maddina Formation Australia, ~2.7 Ga Interbedded with BIF (Brocks et al., 1999)

δ13C Isotopes

Carbon comes in two stable isotopes - ^{12}C and ^{13}C. When living organisms use CO_2 to synthesize organic matter, they favor the lighter isotope, so the carbon isotope signature of organic carbon is "lighter" or "depleted" (i.e., it has lower values of $\delta^{13}C$).

The isotopic signature of *inorganic* carbon can be measured from carbonate minerals that directly incorporate ambient CO_2.

The difference in isotope signature between organic and inorganic carbon is the fractionating effect of biosynthesis of some sort.



Sharp decrease in $\delta^{13}C$ indicates a change in the carbon cycle. *This has been interpreted as the effect of the start of oxygenic photosynthesis.*

Compilation of published organic carbon $\delta^{13}C$ values for all sedimentary rock types plotted by age. Top curve is the mean inorganic carbon $\delta^{13}C$ composition for marine carbonate rocks published by Shields and Veizer (2002).

Mass-Independent Fractionation of Sulfur Isotopes

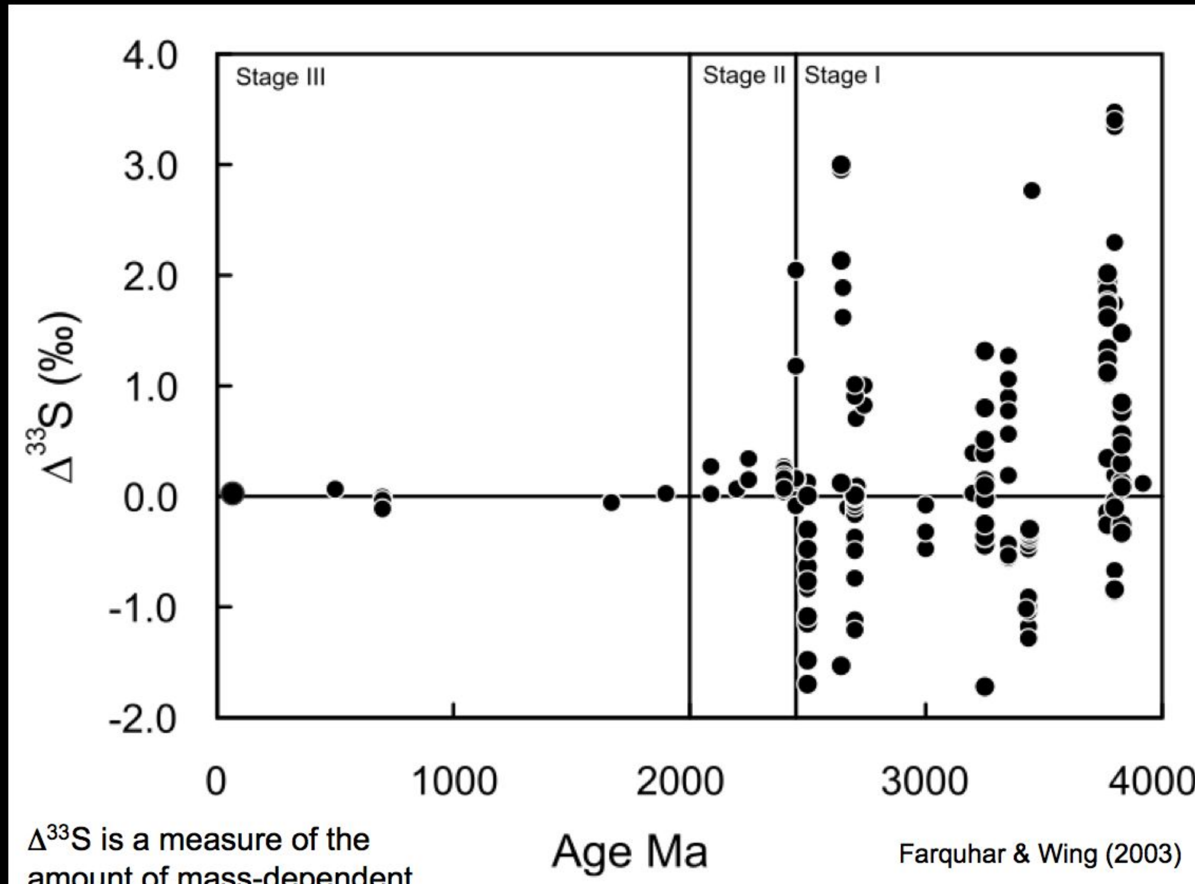
Sulfur has four stable isotopes - ^{32}S, ^{33}S, ^{34}S, and ^{35}S. Like carbon, these isotopes are fractionated (I.e., used in different proportions) in most biotic and abiotic chemical reactions. The degree of fractionation between any pair of isotopes depends on the difference in their atomic mass. In the plot, sulfur isotopes have been measured from ancient sedimentary rock.

~2.45 Ga, there is a change from mass-*independent* fractionation to mass-*dependent* fractionation.

Mass-independent fractionation is characteristic of sulfur reactions driven by ultraviolet light, therefore u/v light must have been significant at Earth's surface before 2.45 Ga.

Ultraviolet light is blocked by ozone, which requires oxygen in the atmosphere. The high deviations from expected mass-dependent S isotope fractionation before 2.45 Ga therefore indicates very low O_2 in the atmosphere in the Archean.

Mass-dependent fractionation starts at 2.32 Ga in South Africa and Canada.



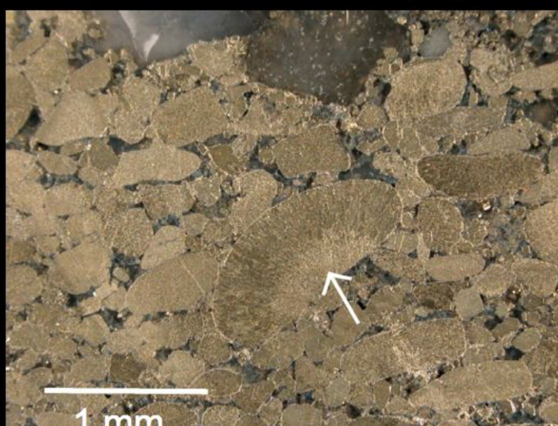
$\Delta^{33}S$ is a measure of the amount of mass-dependent fractionation among the various sulfur isotopes.

Red beds and redox-sensitive elements

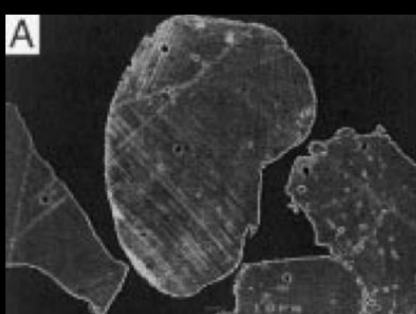
Minerals that are rapidly weathered in the presence of O_2 are preserved as detrital grains before 2.3 Ga.

Pyrite (FeS_2) = O_2 < 0.1 PAL
Uraninite (UO_2) = O_2 < 0.01 PAL
Siderite ($FeCO_3$) = O_2 < 0.001 PAL
(PAL = Present Atmospheric Level)

(MIF of S < 0.00001 PAL)

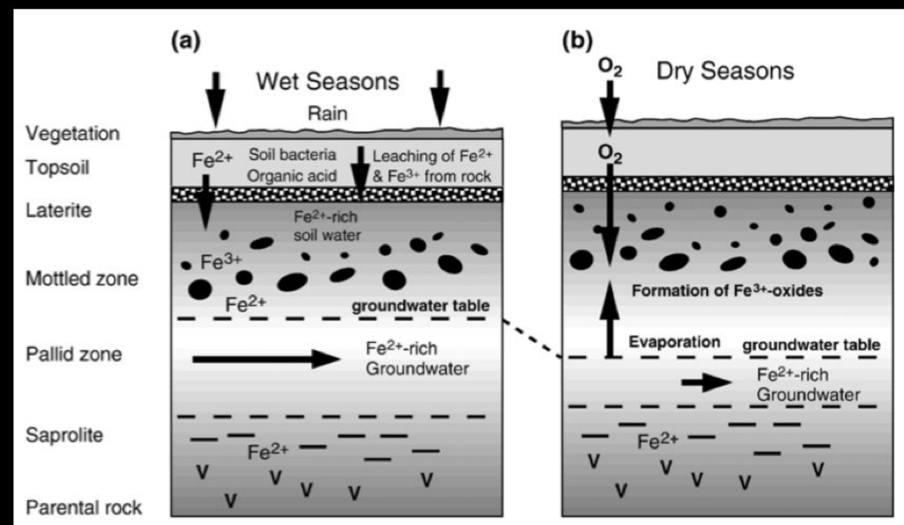


Rounded, detrital pyrite grains (Witwatersrand Basin, South Africa, 2.5 Ga)



Rounded pyrite grain with compositional banding truncated at grain surfaces (Pilbara Craton, Australia, 3.25-2.75 Ga); Backscattered electron (BSE) image

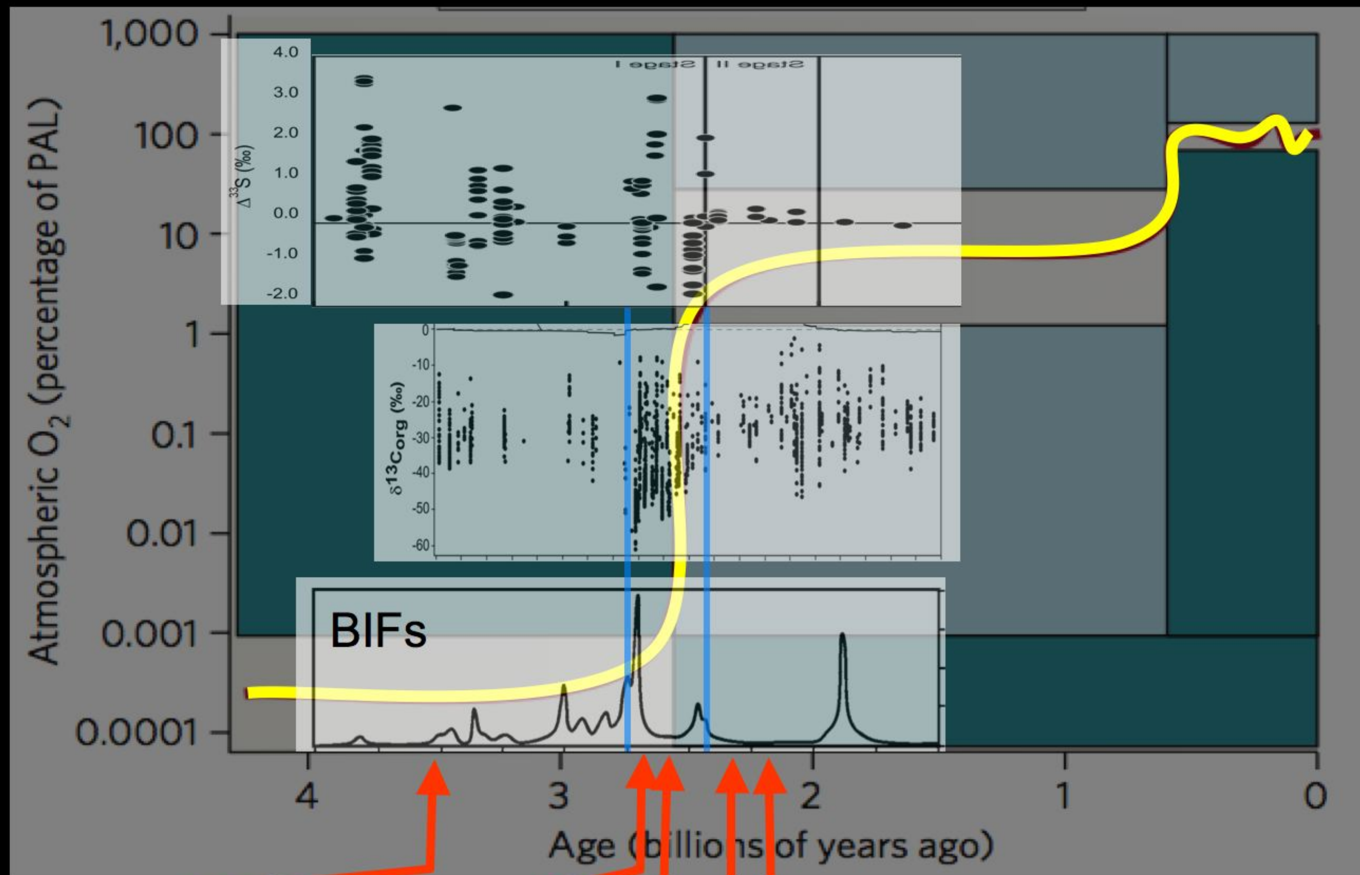
Hekpoort Paleosol (fossil soil)
South Africa, ~2.2 Ga
An ancient weathered basalt lava flow
O_2 > 1% PAL



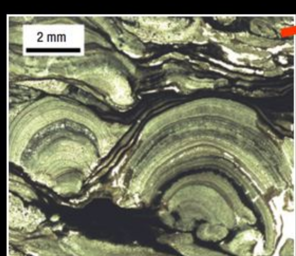
Yamaguchi et al. (2007)

Rise of Oxygen

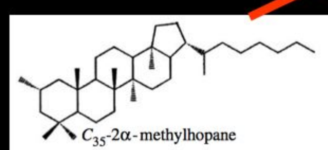
The Great Oxidation Event occurred between 2.4 and 2.3 Ga, but it represents the culmination of multiple evolutionary and chemical events.



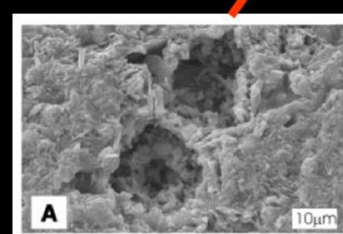
Earliest Stromatolites, 3.4 Ga



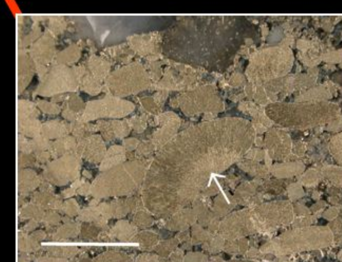
Cyanobacterial
Lake Stromatolites, 2.7 Ga



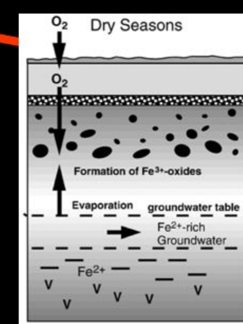
Cyanobacterial
Biomarkers, 2.7 Ga



Cyanobacteria fossils
2.59-2.55 Ga



Detrital redox minerals
2.3 Ga



Red Bed Soils
2.2 Ga

Classroom Assessment Techniques

Classroom Assessment Techniques are formative evaluation methods that serve two purposes. They can help you to assess the degree to which your students understand the course content and they can provide you with information about the effectiveness of your teaching methods. Most are designed to be quick and easy to use and each CAT provides different kinds of information.

Examples of Useful Classroom Assessment Techniques

Following is a partial chart of CAT exercises, indicating the kind of evaluation for which each is intended, what each is called, how each is conducted, what to do with the information you collect, and an approximation of the relative amount of time each requires (Taken from http://www.celt.iastate.edu/teaching/cat.html).

Kind of Evaluation	How It's Done	How to Use	Time Needs
Course Knowledge and Skills			
One-Minute Paper*	During last few minutes of class period, ask students to use a half-sheet of paper and write "Most important thing I learned today and what I understood least."	Review before next class meeting and use to clarify, correct, or elaborate.	Low
Muddiest Point*	Similar to One-Minute Paper but only ask students to describe what they didn't understand and what they think might help.	Same as One-Minute Paper. If many had the same problem, try another approach.	Low
Chain Notes*	Pass around a large envelope with a question about the class content. Each student writes a short answer, puts it in the envelope, and passes it on.	Sort answers by type of answer. At next class meeting, use to discuss ways of understanding.	Low
Application Article	During last 15 minutes of class, ask students to write a short news article about how a major point applies to a real-world situation. An alternative is to have students write a short article about how the point applies to their major.	Sort articles and pick several to read at next class, illustrating range of applications, depth of understanding, and creativity.	Medium
Student-generated test questions*	Divide the class into groups and assign each group a topic on which they are each to write a question and answer for the next test. Each student should be assured of getting at least one question right on the test.	Use as many of the questions as possible, combining those that are similar.	Medium

Kind of Evaluation	How It's Done	How to Use	Time Needs
Attitudes, Values, and Self-Awareness			
Journals	Ask students to keep journals that detail their thoughts about the class. May ask them to be specific, recording only attitudes, values, or self-awareness.	Have students turn in the journals several times during the semester so you can chart changes and development.	Medium
Reactions to Instruction Methods			
Exam Evaluations*	Select a test that you use regularly and add a few questions at the end which ask students to evaluate how well the test measures their knowledge or skills.	Make changes to the test that are reasonable. Track student responses over time.	Medium
Student Rep Group	Ask students to volunteer to meet as a small group with you on a regular basis to discuss how the course is progressing, what they are learning, and suggestions for improving the course.	Some issues will be for your information, some to be addressed in class.	High
Suggestion Box	Put a box near the classroom door and ask students to leave notes about any class issue.	Review and respond at the next class session.	Low to Medium
Peer Review	Work with a willing colleague, pick a representative class session to be observed, and ask the colleague to take notes about his/her impression of the class, your interactions with students, and your teaching methods.	Decide method with the colleague. Discussion is best, but a written report may be more useful in the long term.	High
CTE Classroom Observation	CTE staff will observe a class session you choose and/or video tape a class session.	CTE staff will meet with you to review observations and suggest ways of ivideotapeour teaching effectiveness.	Medium to High
Small Group Instructional Diagnosis (SGID)	Trained facilitators, such as CTE staff, spend a class session eliciting responses from your students about what is effective and what is not so effective in helping them learn. You are not present during the session.	Facilitators meet with you to explain the data they have collected and give you a written report.	High

*Some material in this report is adapted from Angelo, Thomas A. and K. Patricia Cross, 1993, *Classroom Assessment Techniques: A Handbook for College Teachers*, Second Edition, San Francisco: Jossey-Bass Publishers.

Performance assessments measuring the process and products involved with student achievement when engaged in authentic scientific practice. Also referred to as authentic assessment or alternative assessment, performance assessments involve observing student performances and evaluating the products they have created during the tasks. As such, performance assessments reflect authentic geoscience practice. Development of performance assessments is often best done by a disciplinary expert trained to develop assessment.

A rubric is one of the best instruments to use to evaluate the student artifacts developed during performance tasks. This type of assessment can also benefit from portfolio assessments.

Activity: Developing Explicit Learning Goals and Assessment Techniques

In this activity, we will use existing instructional materials from two courses (physical geology or sedimentary geology) to develop learning goals for the instructional activity and an associated performance assessment.

1. In small groups, consider one of the following sets of instructional materials appropriate for one class period:

- GEOL 306 Activity #5: Sedimentary Bedforms (GEOL 306 Sedimentary Geology)
- Discovering Plate Boundaries (http://plateboundary.rice.edu/): (GEOL 104 Physical Geology)
- Your own instructional materials

2. Using the instructional materials provided, develop appropriate learning goals and a performance assessment complete with rubric. A performance task is a task, a problem, or question that requires students to construct (rather than select) responses and may also require them to devise and revise strategies, organize data, identify patterns, formulate models and generalizations, evaluate partial and tentative solutions, and justify their answers. Where do these goals and assessment techniques fall on the assessment and learning goals continuums, as represented in figures 7.4 and 7.4b?

3. Consider the instructional strategies you could use in your classes that that would meet your stated learning goal and performance assessment using the instructional materials provided.

Further Exploration

Presentation: Classroom Assessment Techniques

Readings

- Linn, R. L., Baker, E. L., and Dunbar, S. B., 1991, Complex, performance-based assessment: Expectations and validation criteria: Educational Researcher, 20(8): 15-21.

Online Resources: Rubrics

- AACU Valid Assessment of Learning in Undergraduate Education (VALUE): http://www.aacu.org/VALUE/rubrics/index_p.cfm
- SERC Assessment Using Rubrics: http://serc.carleton.edu/NAGTWorkshops/assess/rubrics.html

Online Resources: Classroom Assessment techniques

- Geoscience Concept Inventory: http://geoscienceconceptinventory.wikispaces.com/
- Student Assessment of their Learning Gains: http://www.salgsite.org/
- Field-Tested Learning Assessment Guide: http://www.flaguide.org/
- SERC Starting Point-Teaching Entry Level Geoscience, Assessment: http://serc.carleton.edu/introgeo/assessment/index.html
- SERC Cutting Edge, Student Learning Observing and Assessing: http://serc.carleton.edu/NAGTWorkshops/assess/index.html

GEOL 306 Activity #5: Sedimentary Bedforms

Introduction

In this activity, you and your group will describe fluid flow over a ripple as seen in an experiment posted on YouTube (http://www.infinitelooper.com/?v=Yfg8LiobIVg&p=n). Assume that the ripple is 1 cm high, that the water density is 1000 kg m^{-3}, and that the water viscosity is 0.001 Pa s. The point of this exercise is to start giving you a qualitative feeling for fluid flow and sediment transport around bedforms.

Describe and diagram the flow field over the ripple in the video. Try to estimate the thickness of the laminar sublayer, both qualitatively and through calculations based on flow measurements. Is the laminar sublayer static or dynamic? How so? How would you predict that sediment transport varies across the surface of the ripple?

You have been assigned to one of four Scientific Specialties and to one of ten Plates or Plate Groupings. The names of your group members are listed in the Excel spreadsheet: PTActivityGroups. In the spreadsheet you will also find the email address of the members of your group.

There are four scientific specialties. These groups will meet Wednesday:

A. Seismology: Earthquakes
B. Volcanology: Volcanic Eruptions
C. Geography: Topography/Bathymetry
D. Geochronology: Seafloor Age

The Plates or Plate Groupings are below. These groups will meet Friday:

1. North American Plate
2. Pacific Plate
3. African Plate
4. South American Plate
5. Eurasian Plate
6. Cocos/Nazca/Caribbean Plates
7. Australian Plate
8. Antarctic Plate
9. Indian Plate
10. Arabian Plate

Each Scientific Specialty group has been provided a world map showing data relevant to locating plate boundaries and understanding plate boundary processes. Each student will be provided two Plate Boundary Maps. You will mark these as described below and turn them in at the end of the exercise. There are a number of colored pencils available in the room for your use.

Wednesday: Assemble in your Scientific Specialty groups with your group's map

Task 1. Look at your group's map and talk about what you see. What you look for will vary with data type. For the point data (volcanoes and earthquakes) you are looking for distribution patterns. For surface data (topography and seafloor age) you are looking for where the surface is high and where it is low, where it is old and where it is young. Work as a group. Let everyone talk about what they see. During this period concentrate on the whole world, not just your assigned plate (if you know what it is).

Task 2. Now focus your attention on the plate boundaries. Identify the nature of your data near the plate boundaries. Is it high or low, symmetric or asymmetric, missing or not missing, varying along the boundary or constant along the boundary, and etc. As a group, classify the plate boundaries based on your observations of your group's data. Restrict yourselves to about 4-5 boundary types. At this point, do not try to explain the data; just **justify** your different classes using your observations! Use the table to record your observations for each boundary class.

Task 3. Using Microsoft Word or a drawing program, label each boundary type in your classification scheme with a different color or symbol. If the data are asymmetric at a particular boundary type, devise a way of indicating that on your plate boundary map. Each person should mark the boundary types identified by the group on their own map. Each person should write down descriptions of the group's plate boundary classifications on the table.

Task 4. Upload the labeled map and the boundary classification table to the elearning website.

Friday: Assemble in your Plate groups

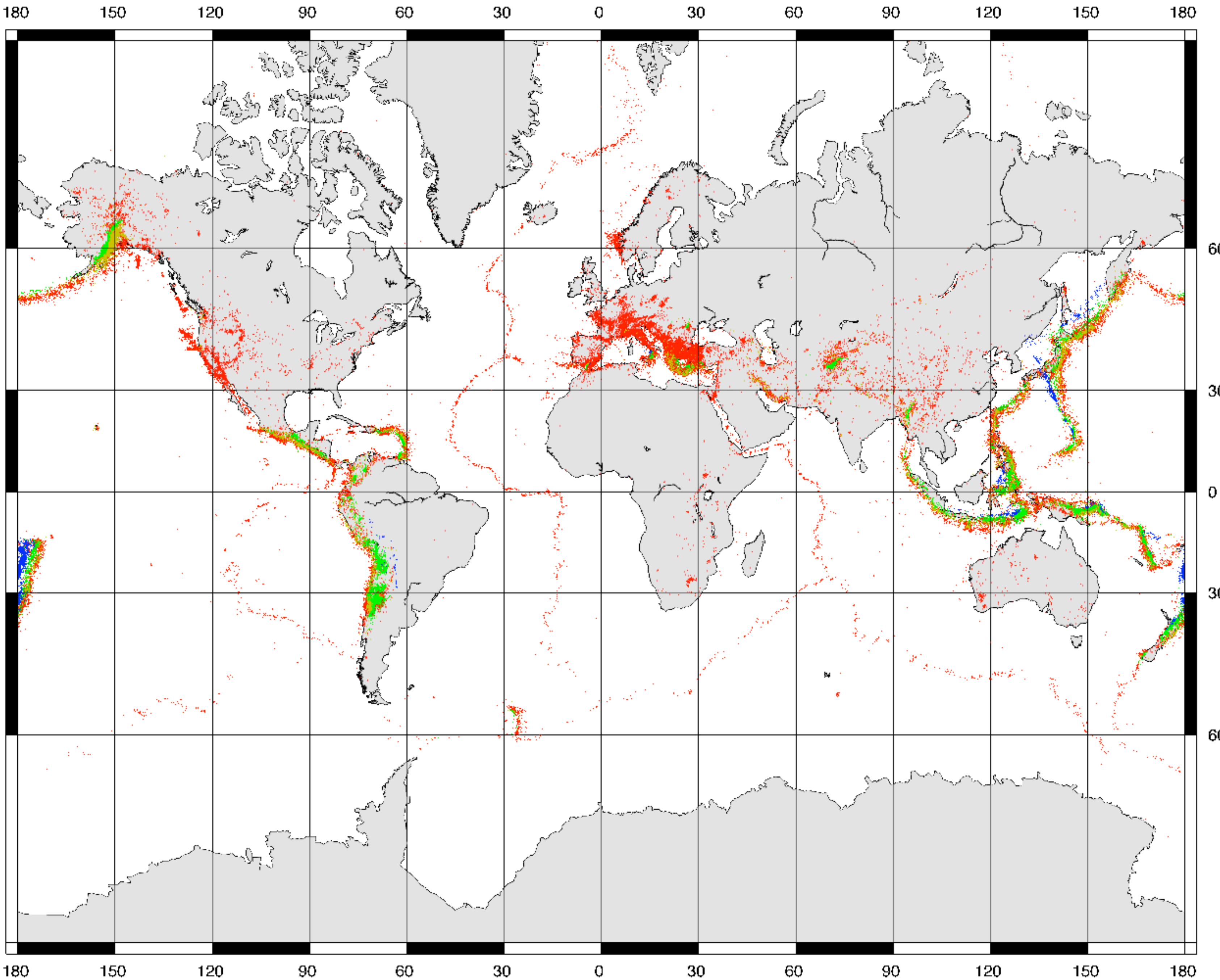
Task 1. Each person should make a brief presentation to the rest of their group about their Scientific Specialty's data and classification scheme. Your group may move to each map in turn while doing this or you may have smaller maps for each group to use.

Task 2. Compare the classifications of boundary type for your plate based on each type of data. Are there common extents (along the boundaries) between the different classifications? Can your plate group come up with a new classification scheme that now includes data from all four Scientific Specialties? As above, assign a color to each of your plate boundary types. If a boundary is asymmetric, be sure to devise a way to represent the asymmetry. Mark the boundaries of your plate or plate grouping using your color scheme on your second Plate Boundary Map. Also write a one-paragraph description of the plate boundary classes you have used. Your description should discuss their group's plate boundary classification scheme and how they classify the boundaries of their plate.

SCIENTIFIC SPECIALTY: SEISMOLOGY

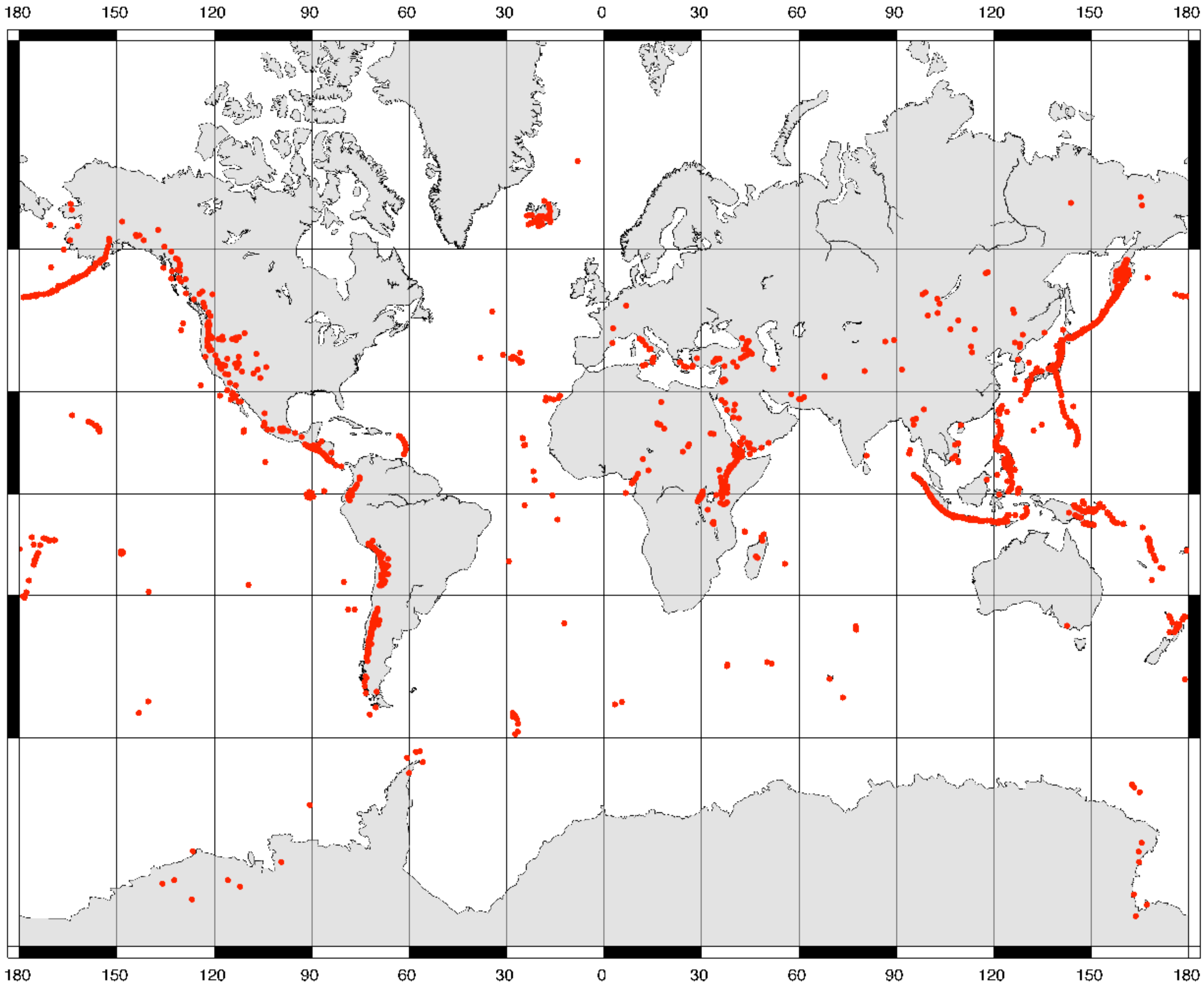
Earthquake Locations 1990 - 1996 (Magnitudes 4 and greater)
Color indicates depth: Red 0-33 km, Orange 33-70 km, Green 70-300 km, Blue 300-700 km

This map is part of "Discovering Plate Boundaries," a classroom exercise developed by Dale S. Sawyer at Rice University (dale@rice.edu). Additional information about this exercise can be found at http://terra.rice.edu/plateboundary .



SCIENTIFIC SPECIALTY: VOLCANOLOGY

Red dots indicate currently or historically active volcanic features
This list obtained from the Smithsonian Institution

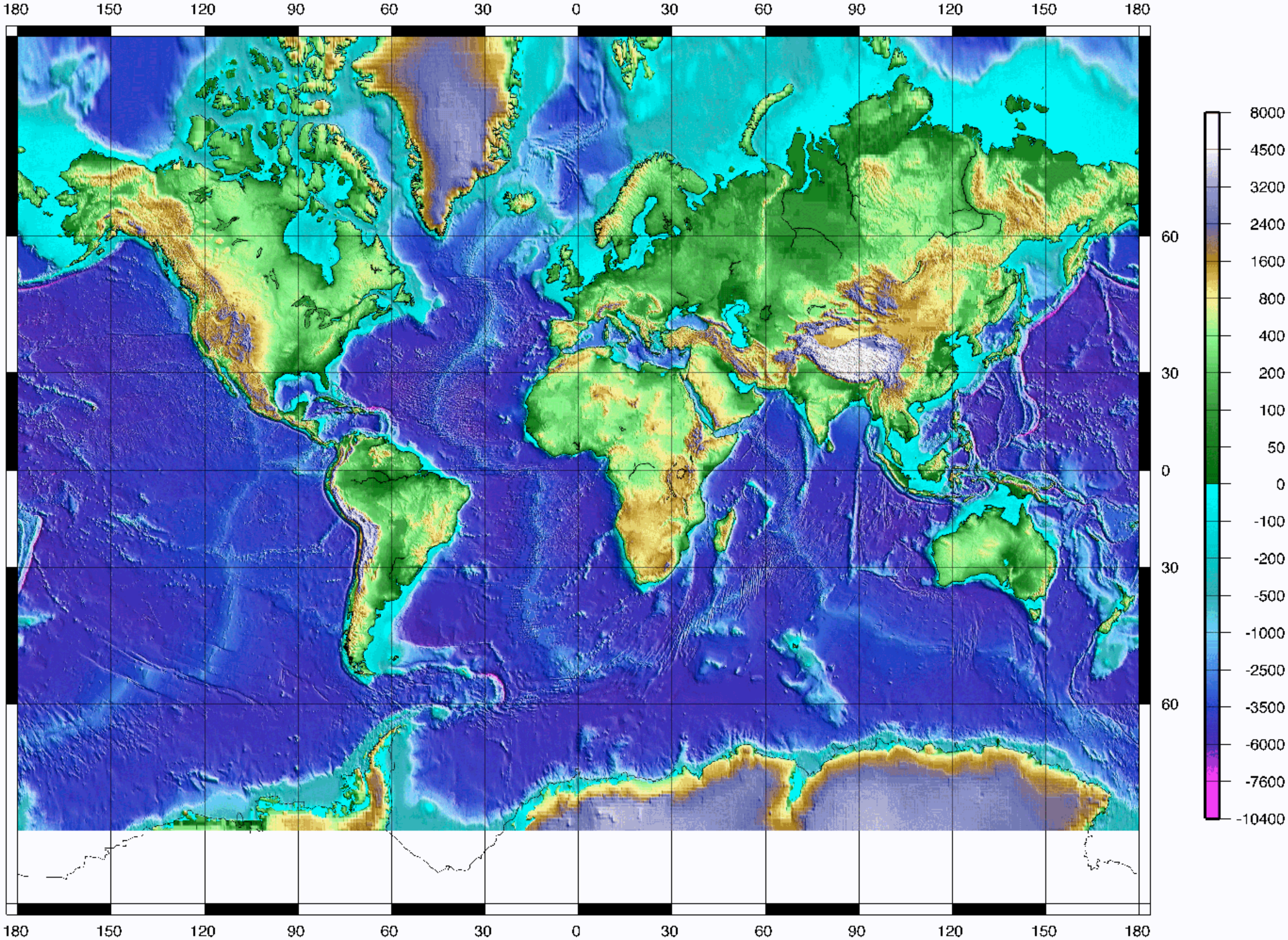


This map is part of "Discovering Plate Boundaries," a classroom exercise developed by Dale S. Sawyer at Rice University (dale@rice.edu). Additional information about this exercise can be found at http://terra.rice.edu/plateboundary .

SCIENTIFIC SPECIALTY: GEOGRAPHY

Elevation in meters above sea level
Map based on widely available dataset ETOPO5

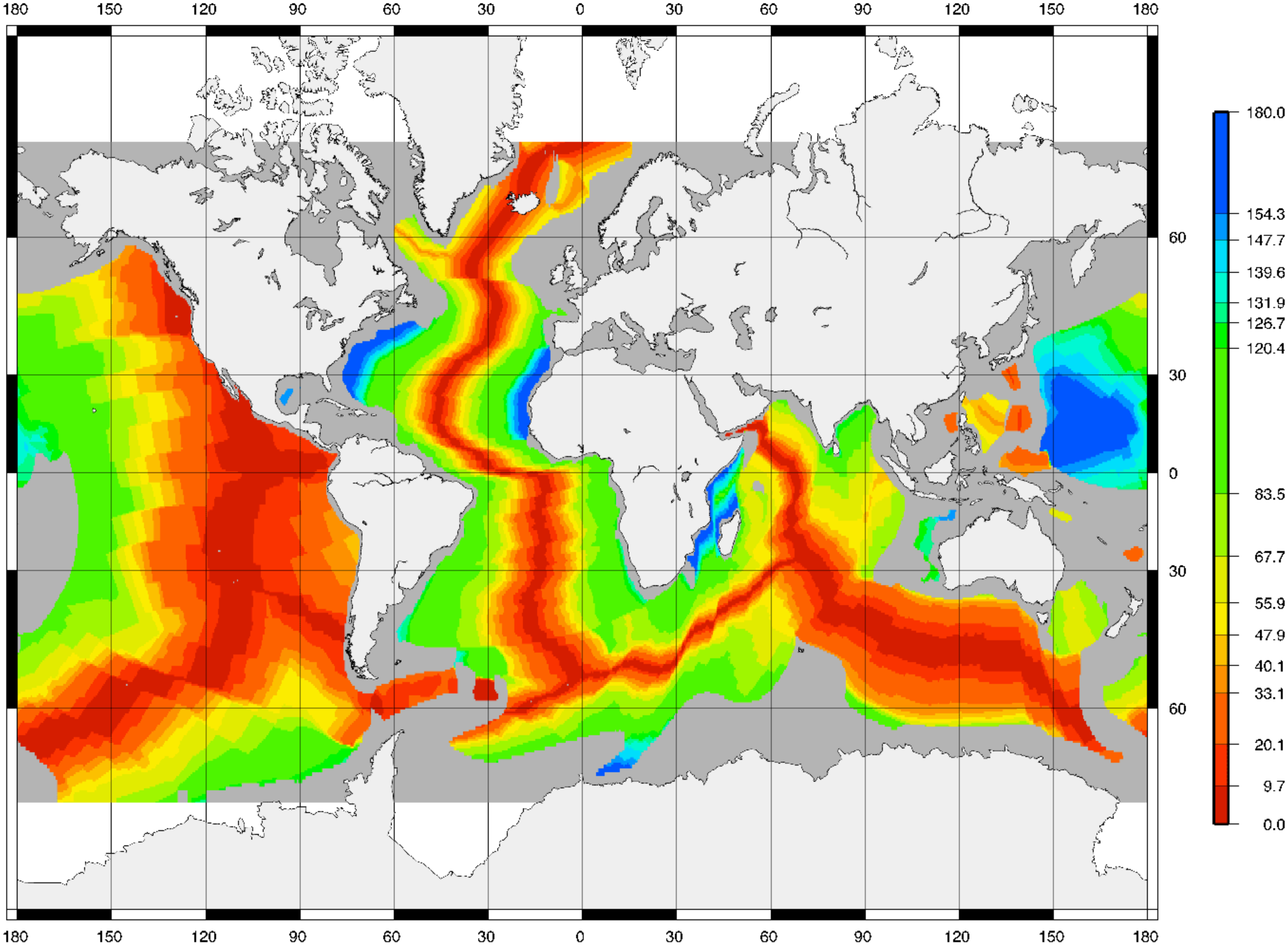
This map is part of "Discovering Plate Boundaries," a classroom exercise developed by Dale S. Sawyer at Rice University (dale@rice.edu). Additional information about this exercise can be found at http://terra.rice.edu/plateboundary .



SCIENTIFIC SPECIALTY: GEOCHRONOLOGY

Seafloor age in millions of years

This map is from Dietmar Mueller, Univ. of Sydney



This map is part of "Discovering Plate Boundaries," a classroom exercise developed by Dale S. Sawyer at Rice University (dale@rice.edu). Additional information about this exercise can be found at http://terra.rice.edu/plateboundary .

Plate Boundaries Map for Scientific Specialties: Wednesday Project

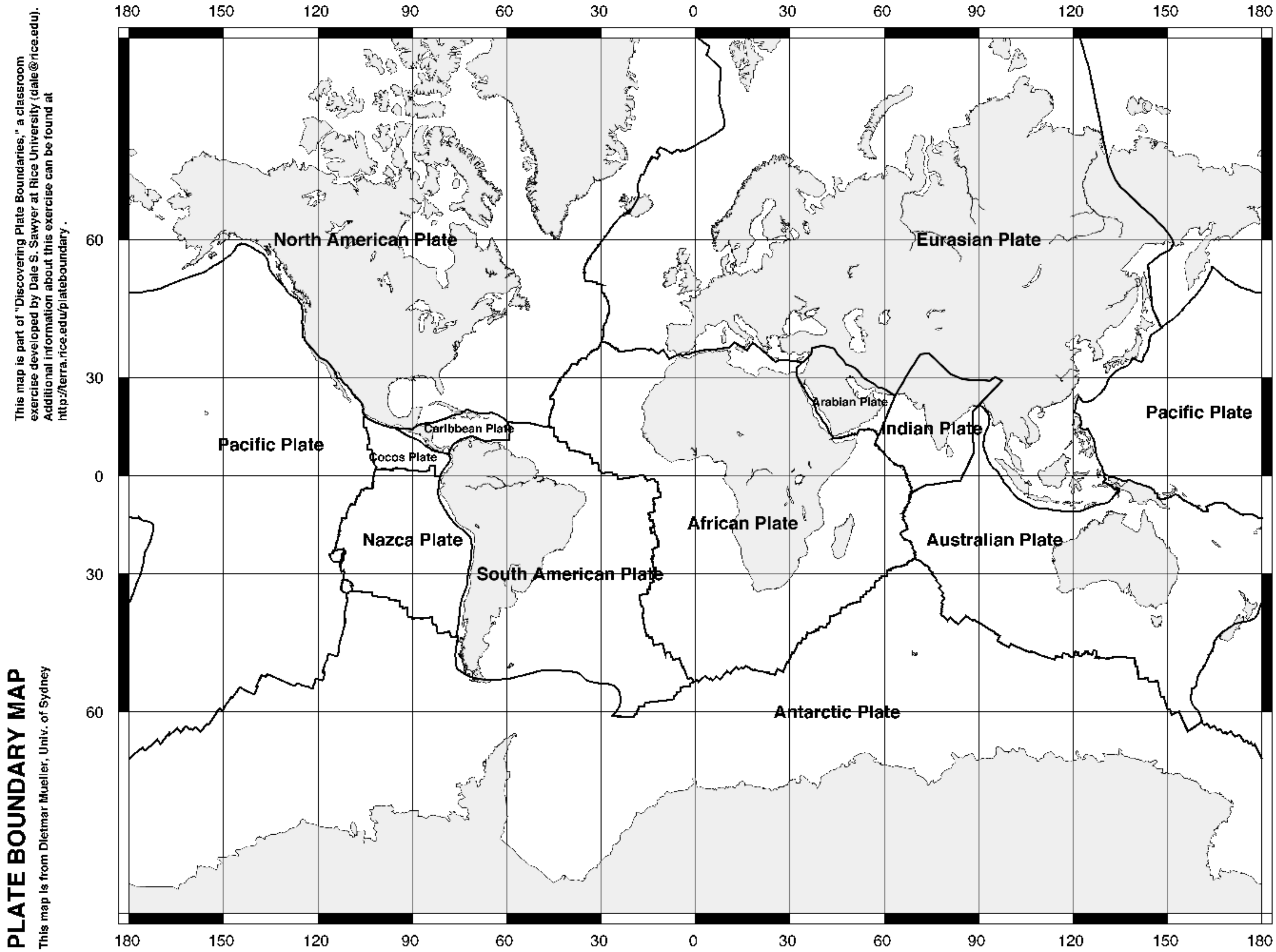


Plate Boundaries Map for Scientific Specialties: Wednesday Project

Identify the nature of your data near the plate boundaries. Is it high or low, symmetric or asymmetric, missing or not missing, varying along the boundary or constant along the boundary, and etc. As a group, classify the plate boundaries based on your observations of your group's data. Restrict yourselves to about 4-5 boundary types. At this point, do not try to explain the data; just **justify** your different classes using your observations!

Characteristics of Boundary Derive from Analysis of Data Maps	**Plate Boundary Classifications**
	Boundary Type A Boundary Type B Boundary Type C (Create More if Needed)

Plate Boundaries Map for Scientific Specialties: Friday Project

Assign a color to each of your plate boundary types. If a boundary is asymmetric, be sure to devise a way to represent the asymmetry. Mark the boundaries of your plate or plate grouping using your color scheme on your second Plate Boundary Map.

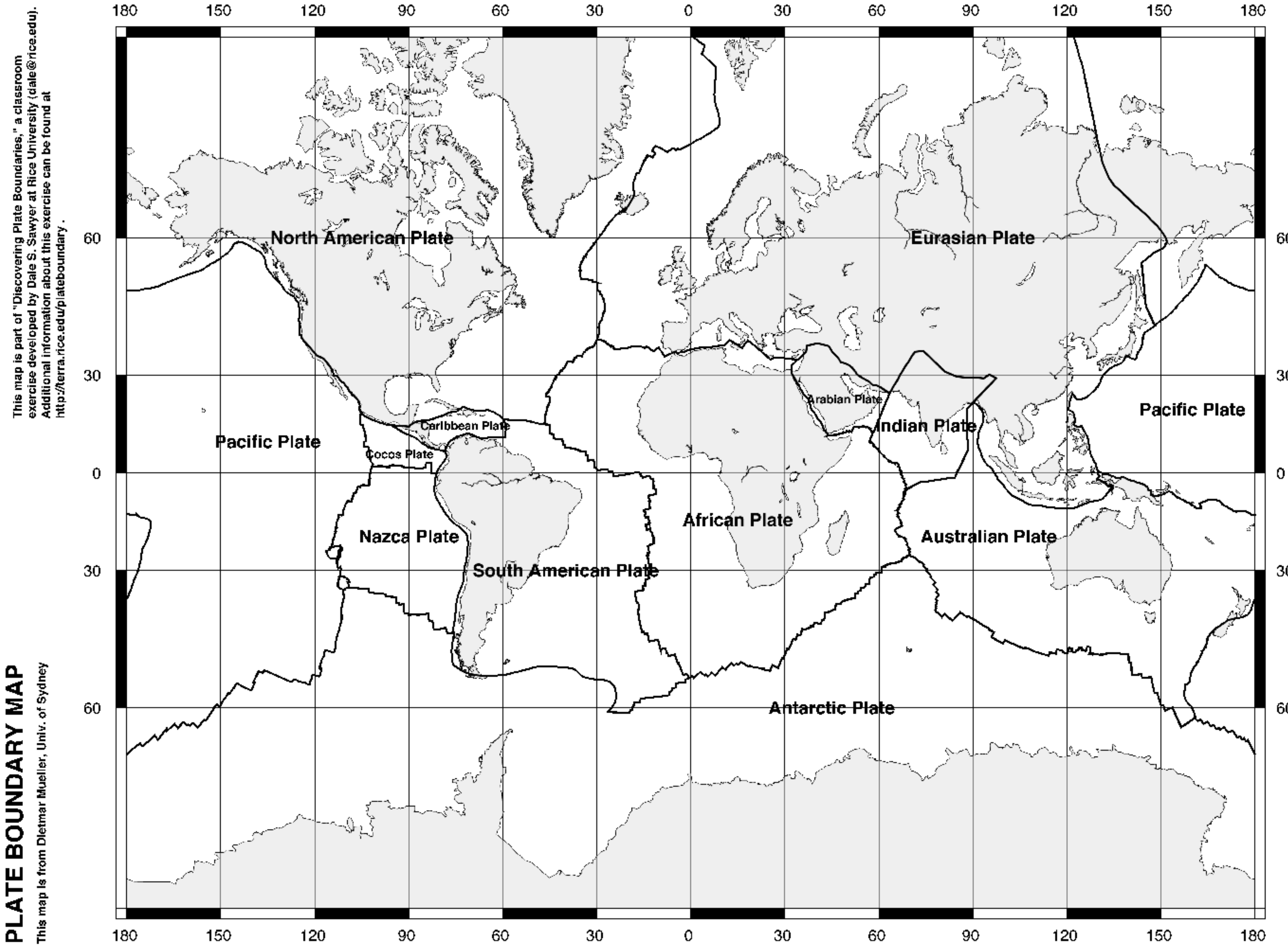


Plate Boundaries Map for Scientific Specialties: Friday Project

Write a one-paragraph description of the plate boundary classes you have used. Your description should discuss their group's plate boundary classification scheme and how they classify the boundaries of their plate.

Description:

Supporting Your Career: The Scholarship of Teaching & Learning

Overview

Evolution of Annual Performance Evaluation

The work of Ernest Boyer and the Carnegie Foundation for the Advancement of Teaching stimulated debate about definitions of scholarship at universities and colleges. Finding that very narrow definitions of scholarship were dominant on most college campuses, Boyer stressed the need to expand the definition of scholarship to include four components: discovery of knowledge, integration of knowledge, application of knowledge, and teaching.

Ernest Boyer, in his 1990 Scholarship Reconsidered: Priorities of the Professoriate, suggested that we should think of scholarship in four ways:

- The scholarship of discovery which we usually mean by research
- The scholarship of integration which emphasizes work that synthesizes disciplinary knowledge
- The scholarship of application which emphasizes engagement of knowledge as the scholar asks, 'How can knowledge be responsibly applied to consequential problems? How can it be helpful to individuals as well as institutions?' and, 'Can social problems themselves define an agenda for scholarly investigation?'
- The scholarship of teaching which emphasizes rigorous study of our teaching as well as informing others of our emerging understanding of teaching practice and its impact on student learning.

Evidence of Excellence

The Carnegie Foundation for the Advancement of Teaching recognized that inadequate models of faculty evaluation addressing the scholarship of teaching & learning may impede adoption of this value at most institutions. The foundation published a guideline that takes the academy through a process for setting standards of scholarly work, documenting scholarship, developing trust in the process and suggesting the qualities of a scholar. Below, I discuss different strategies that may provide evidence of faculty teaching excellence.

Evaluate teaching practices. There are two likely implementation strategies to evaluate the quality of teaching practices.

The first strategy evaluates faculty self-reports of their implementation of specific best practices in the classroom. Departments or the College would have to develop a statement of specific best teaching practices that we agree is likely to have valued student outcomes. This list could be developed based upon standard educational resources such as the National Academy of Sciences book, *How People Learn*. This would have the benefit of being fairly easy to implement as well as directing faculty efforts towards implementation of best teaching practices. This evaluation method has the disadvantage that it does not directly measure the quality of the teaching practice implementation, so these changes will possibly have varied impact on student learning; it does not directly measure student learning; and it will likely have minimal impact on many important educational outcomes that require both in-class and extracurricular change because it focuses faculty effort solely on experimenting with their classroom practice.

The second strategy uses direct observe classroom practice by an impartial observer. The benefit of this evaluation method is that there is direct evidence of the teaching practice of the faculty member. The difficulties with this strategy is limited inter-rater reliability when implemented on a College basis, which means that unless we use a standard, validated method and train all observers to use the tool, our ability to compare evaluations from different observers will be suspect. To overcome this limitation will take a significant amount of work. In addition, this evaluation strategy is also limited in that it does not directly measure student learning, and it will likely have minimal impact on many important educational outcomes that require both in-class and extracurricular change because it focuses faculty effort solely on experimenting with their classroom practice.

My conclusion. As the Markley paper showed, direct classroom observation can be an important piece of evidence in evaluating teaching practice in the College, but there are significant costs that outweigh the benefits.

Evaluate Impact on Program Outcomes: A second strategy is to reward faculty practices that improve program educational outcomes such as the number of students engaged in undergraduate research, graduate school acceptance, or the diversity of our students.

This strategy uses self-reports of faculty educational efforts that are directed toward improving specific program measures that are collected by departments. This would have several benefits including focusing faculty effort on improving important program outcomes that are easy to measure, guiding faculty to address both their in-class and extracurricular activities, and would provide narratives of organizational change that add to the College's reputation both at TAMU and in our disciplinary communities. The major limitation of this strategy is the lack of direct evidence that proves cause and effect between faculty actions and program outcomes.

My conclusion: This strategy seems to have the lowest cost-benefit ratio by far. Faculty would be directed to address the kind of program outcomes that are valued by TAMU and can address the major criticisms being directed toward universities. In addition, this strategy would not require any additional workload being imposed on the organization.

Specific student learning outcomes. The final strategy is focused on directly measuring student outcomes. While this remains the holy grail of educational assessment, there are enough difficulties and uncertainties in implementing this strategy at the organizational level that it really is not an option for most universities and colleges at this time. At the individual faculty level, though, this is a real option because the evidence generated through scholarly activities focused on teaching and learning could be used to support claims of excellence.

My conclusion: This remains the holy grail of teaching evaluation. Each faculty member has to decide what is the correct balance in the risks and rewards for this career strategy.

Activity: Discussion & Reflection

Further Exploration

Presentation: Scholarship of Teaching and Learning

Readings

- Carnegie Academy for the Scholarship of Teaching and Learning (CASTL): http://www.carnegiefoundation.org/scholarship-teaching-learning
- The Scholarship of Teaching and Learning (SoTL): http://cft.vanderbilt.edu/teaching-guides/reflecting/sotl/
- Weiman, C. 2009. A scientific approach to science education: http://www.science20.com/cwieman
- Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering. National Academy of Press: http://www.nap.edu/catalog.php?record_id=13362

Examples of Geoscience Education Research

- Libarkin, J. C., and Anderson, S. W., 2005, Assessment of Learning in Entry-Level Geoscience Courses: Results from the Geoscience Concept Inventory: Journal of Geoscience Education, v. 53, no. 4, p. 394-401.
- McConnell, D. A., Steer, D.N. and Owens, K.A., 2003, Assessment and Active Learning Strategies for Introductory Geology Courses: Journal of Geoscience Education, v. 51, no. 2, p. 205-216.
- Sell, K., Herbert, B. E., Stussey, C. L., and Schielack, J., 2006, Use of physical models and information technology to address undergraduate student mental model development of complex environmental systems: J. Geol. Ed., v. 54, p. 396-407.
- Markley, C.T., Miller, H.R., Kneeshaw, T., and B.E. Herbert. 2009. Influence of teachers' conceptions on classroom education in geology at a research university. J. Geosci. Ed. 57(4): 213-223.

Participants

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Biography: Dr. Bruce Herbert

Herbert, Bruce E. **Expertise:** Biogeochemistry; Geoscience Education. **Education:** BA Chemistry, Colgate; MS Soil Science, Univ. of California-Riverside; PhD Soil Chemistry, Univ. of California-Riverside. **Professional Experience**: Texas A&M Univ, Dept Geology & Geophysics Asst Prof 92-97, Assoc Prof 97-06, Prof 06-present, Assistant Department Head and Graduate Coordinator 07-present, Assoc Director Information Technology in Science (ITS) Center for Learning and Teaching 02-present. **Professional Affilation**: NAGT (member since 2006), GSA; AGU; SSSA; AERA. Prof Service: *School Science and Mathematics*, Assoc Ed 05-2008; College Board Science AP Standards Committee, 06-09; Advisory Board, System-Wide Change: An Experimental Study of Teacher Development and Student Achievement in Elementary Science, (SCALE), NAGT Executive Committee Counselor, 09-present. **Honors/Awards**: Distinguished Lecturer, National Association of Geoscience Teachers 05-09; Association of Former Students (TAMU) Faculty Distinguished Achievement Award in Teaching, 01; Elected, The Academy for Educator Development, Texas A&M University System, 01, Holder of the EOG Teaching Professorship in Geosciences. **Address**: Geology & Geophysics TAMU 3115, College Station, TX 77843-3115; e-mail: herbert@geo.tamu.edu.

Statement of Interest

My research explores questions concerning the biogeochemistry of near-surface environments, including soils, wetlands, aquatic sediments, aquifers, and the coastal margin. We are focused on biogeochemical processes that mediate the interactions between human society and ecosystems, including the fate and bioavailability of contaminants, natural and human perturbations of nutrient and organic carbon, and human impacts on ecosystem functioning.

In addition, I am characterizing human understanding of complex earth systems, the professional development of faculty and teachers, and the design of tertiary educational programs that promote student learning and develop synergy between educational and research activities. I served as the Associate Director of Geosciences in the NSF-supported *Information Technology in Science (ITS) Center for Learning and Teaching* at Texas A&M University (http://its.tamu.edu/), the principal investigator of the NSF Teacher Professional Continuum program entitled *Professional Learning Community Model for Alternative Pathways in Teaching Science and Mathematics, PLC–MAP* (http://plcmets.pbworks.com/), and co-PI of the NSF-sponsored *CIRTL Network - Shaping, Connecting, and Supporting the Future National STEM Faculty* (http://cirtlcafe.net/).

Appendix

These articles are uploaded on the short course wiki.

Barr, R. B., and Tagg, J., 1995, From teaching to learning--a new paradigm for undergraduate education: Change, v. 27, no. 6, p. 12-26.

Libarkin, J. C., and Anderson, S. W., 2005, Assessment of Learning in Entry-Level Geoscience Courses: Results from the Geoscience Concept Inventory: Journal of Geoscience Education, v. 53, no. 4, p. 394-401.

Linn, R. L., Baker, E. L., and Dunbar, S. B., 1991, Complex, performance-based assessment: Expectations and validation criteria: Educational Researcher, v. 20, no. 8, p. 15-21.

Markley, C.T., Miller, H.R., Kneeshaw, T., and B.E. Herbert. 2009. The relationship between instructors' conceptions of geoscience learning and classroom practice at a research university. J. Geosci. Ed. 57(4): 213-223.

McConnell, D. A., Steer, D.N. and Owens, K.A., 2003, Assessment and Active Learning Strategies for Introductory Geology Courses: Journal of Geoscience Education, v. 51, no. 2, p. 205-216.

Sell, K., Herbert, B. E., Stussey, C. L., and Schielack, J., 2006, Use of physical models and information technology to address undergraduate student mental model development of complex environmental systems: J. Geol. Ed., v. 54, p. 396-407.

Shepard, L.A., 2000, The role of assessment in a learning culture: Educational Researcher, v. 29, no. 7, p. 4-14.