Geological Field Research:
An Ideal Course 'Recipe' for Advanced Undergraduate and Beginning Graduate Students

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The Recipe

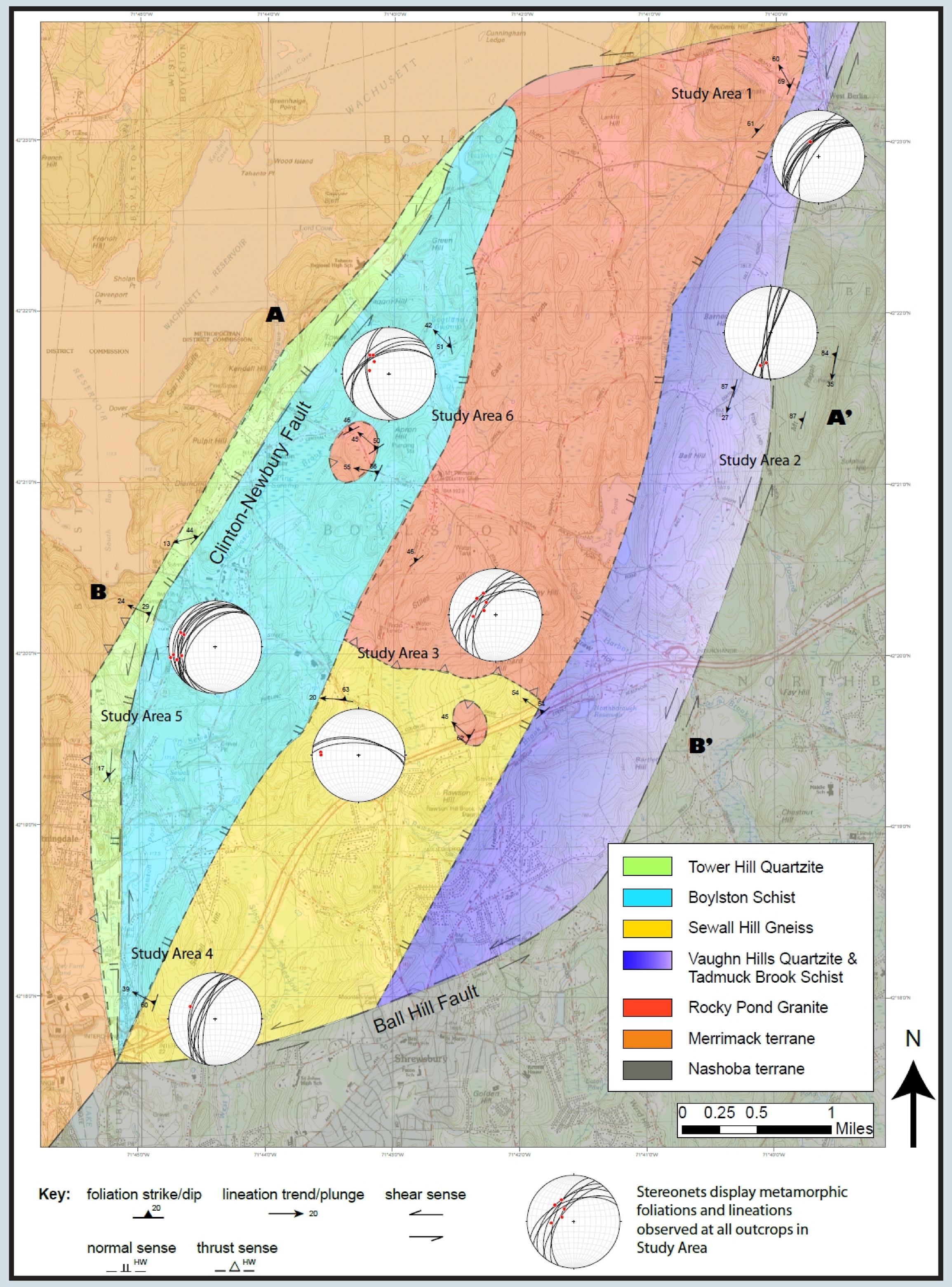
A **Geological Field Research course** is an excellent way for students to learn to design and carry out their own (field- based) research.The course is set up in three parts:

In the **first** part, students write a brief **research proposal** including hypotheses, tests and a work plan for the next two weeks. We study appropriate literature and take an introductory field trip to the field area.

The **second** part focuses on **field work**.

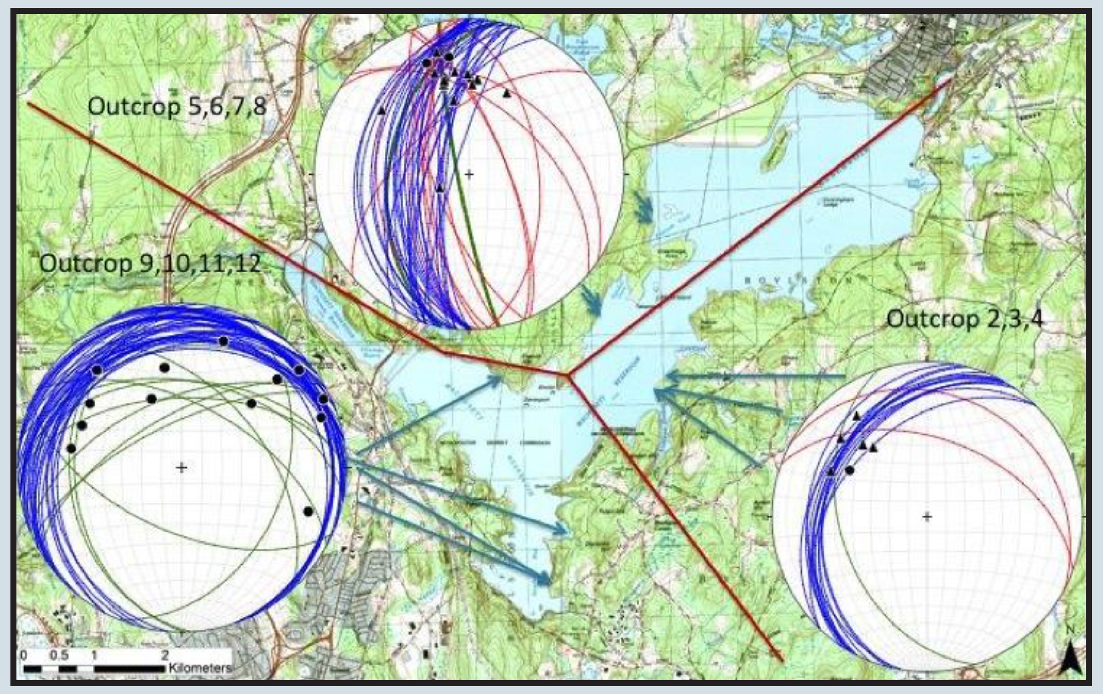
In the **third** part, students prepare a geological map and appropriate cross sections, and **write a report** presenting rock descriptions, structural analysis, a geological history, and interpretation of results in the context of the hypotheses posed in the proposal.

The course can be taught in three weeks as a three-credit course, where each part described above takes one week. It can easily be modified into a longer (but not shorter) course, and/or one that is taught over several weekends and a number of weekday in-class meetings during the semester. It is best if students work in groups of two, not only for safety, but so that they can discuss and learn from each other.



Example of mapping and structural analysis (above) carried out by Boston College student Nick Cokonis (below, studying normal-sense movement along the Clinton-Newbury Fault) in 2014.

A typical Massachusetts outcrop.



Example of structural analysis carried out by Colorado School of Mines undergraduate student Kaleb McMaster and Boston College undergraduate students Abby Sullivan and Hannah Chambless. They split up Merrimack terrane metasedimentary rocks in three structural domains based on trends on orientations of foliations/bedding (blue), fold axial planes (green) and fold hinge lines (circles) of rounded, mostly isoclinal folds, and fold axial planes (purple) and fold hinge lines (triangles) of chevron folds. They then unraveled the structural history of each domain and compared them with structures reported in the literature.

Learning Goals and Outcomes

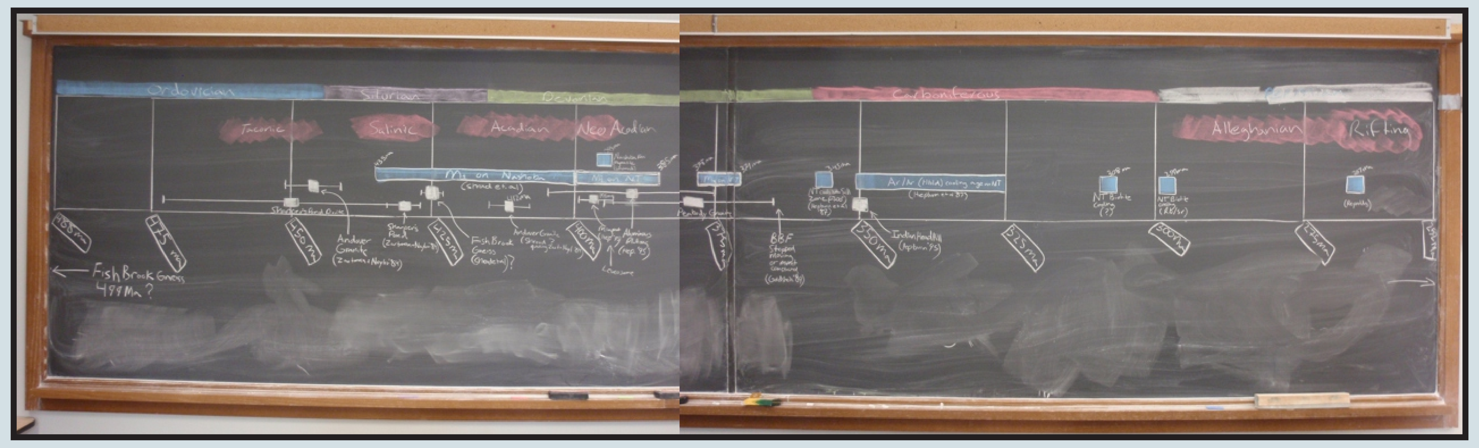
Students gain experience in geological mapping and field methods in general, but, perhaps more importantly, they learn how to **formulate a testable hypothesis, carry out the research and write a concise and clear report**. They also read each other's proposals, and give each other **constructive feedback** through a mock NSF panel discussion. Furthermore, they learn how to deal with **field logistics** and to **collaborate** with their field partners.

The effectiveness of the course can (on top of the student deliverables and course evaluations) be assessed through course-specific questionnaires at the beginning and the end of the course to monitor students' skills, expectations, goals and confidence.

Example of Self-Assessment Questionnaire

How much did you gain in the following areas as a result of your field research experience? Please circle: (1) no gains (2) a little gain (3) moderate gain (4) good gain (5) great gain
(the items below are ordered from high score (top) to low score (bottom) in my 2014 course)
Comfort in working collaboratively with others.
Conducting observations in the field.
Collecting the data needed to answer your research question.
Confidence in your ability to do well in future science courses.
Identifying limitations of research methods and designs.
Planning and carrying out field work.
Formulating a research question that could be answered with data.
Ability to think creatively.
Ability to work independently.
Writing a scientific proposal/report.
Managing your time.
Feeling prepared for advanced coursework or thesis work.
Confidence in your ability to contribute to science.
Comfort in discussing scientific concepts with others.
Analyzing data for patterns.
Problem-solving in general.
Figuring out the next step in a research project.
Understanding the theory and concepts guiding your research project.
Defending an argument when asked questions.
Understanding journal articles.
Conducting database or internet searches.

Open questions asked *(with very variable answers in 2014)*
What was the best thing about your field research experience?
What could be improved?
What surprised you about doing field research?



Timeline of depositional, igneous and metamorphic/deformation events in the Nashoba terrane, compiled from the literature by Boston College undergraduate student Keegan Dougherty, and Colorado School of Mines PhD student Wes Buchanan and MSc student Peter Brice, in 2012.

Project Example
Eastern Massachusetts Appalachians

Student: Wes Buchanan

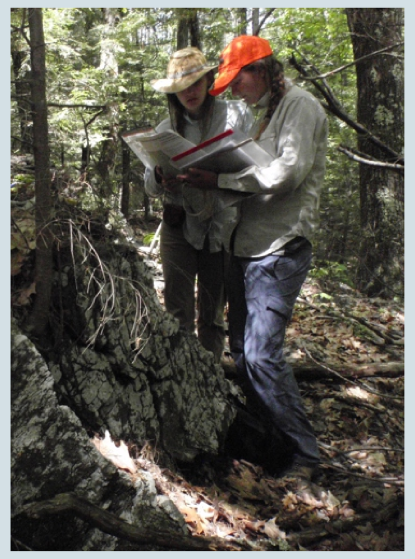
Problem: The Nashoba terrane in eastern Massachusetts displays a higher metamorphic grade and older cooling ages than its neighboring Merrimack and Avalon terranes. The Nashoba terrane does not show evidence for Alleghanian deformation and metamorphism, while the other two terranes do. How did the Nashoba terrane get exhumed early, but escape Alleghanian deformation and metamorphism? What can we learn from the internal structure of the Nashoba terrane about its possible exhumation history?

Approach: Conduct detailed structural mapping and analysis of selected well-exposed areas in the Nashoba terrane to unravel the exhumation and possibly earlier deformation history.

Outcome: Asymmetric folds in migmatitic rocks indicate NW-side down, sinistral movement under high-grade metamorphic conditions. These are overprinted by low-grade subvertical NW-side down localized meter-scale shear zones. The questions of how the Nashoba terrane is sandwiched between two terranes of lesser metamorphic grade, and how the Nashoba terrane seemingly escaped widespread Alleghanian deformation and metamorphic overprint was not answered during the course, but is part of Wes Buchanan's PhD research.

What happened in the following two years? Please see Wes Buchanan's poster for course results and more!

Colorado School of Mines PhD student Wes Buchanan, teaching an attentive student the basics of strike and dip.



Colorado College undergraduate students Madison Andres and Virginia Hill locating themselves on the map while trying to distinguish bedding from cleavage (not an easy task!).

Colorado School of Mines undergraduate student Kaleb McMaster, measuring fold hinge lines with a compass.

Teamwork! Boston College undergraduate students Hannah Chambless and Abby Sullivan and Colorado School of Mines undergraduate student Kaleb McMaster, collaborating efficiently and cheerfully on their proposal.

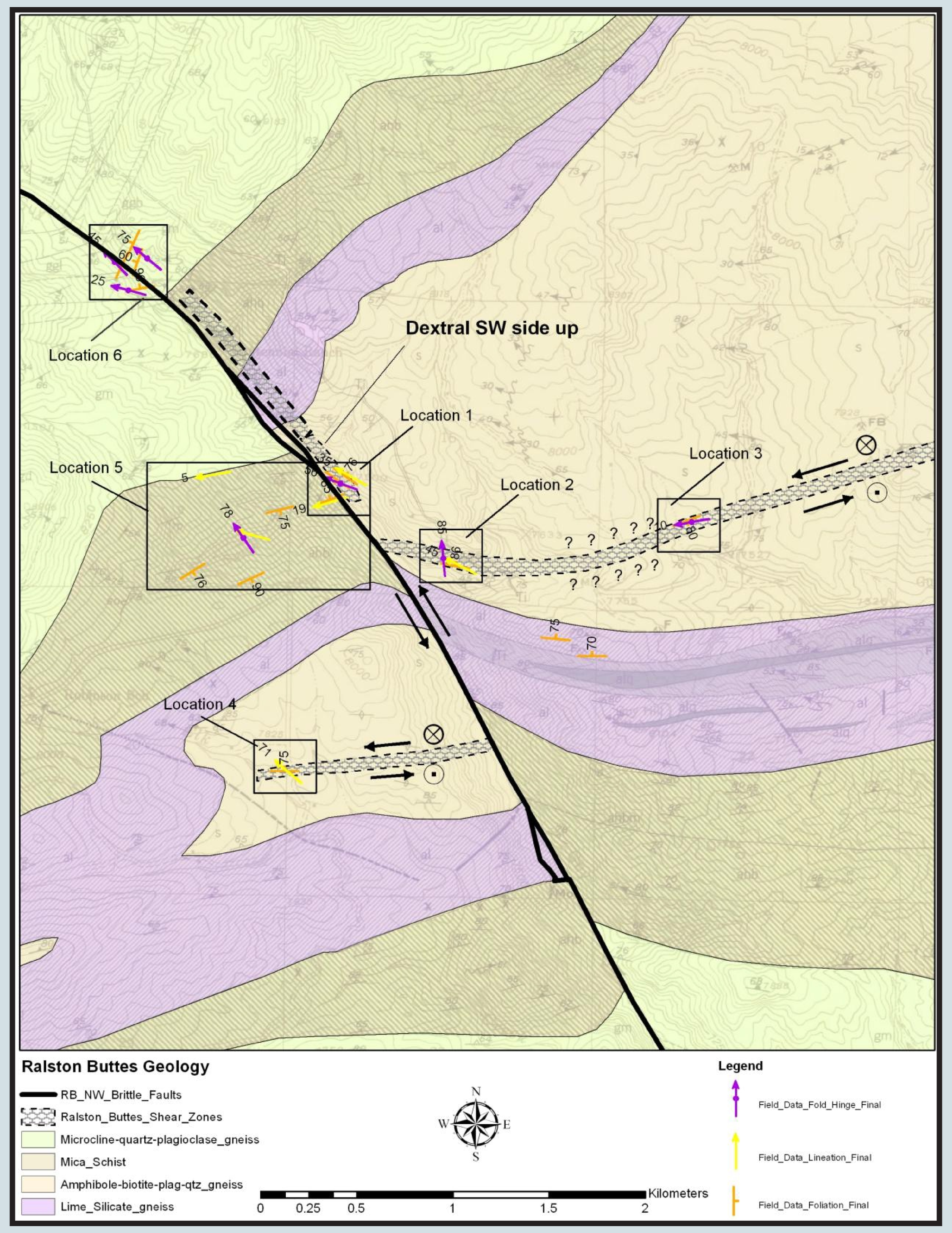
Project Example
Colorado Front Range

Students: Patrick Quigley and Tsolmon Gonchig

Question: Do NW-trending Tertiary brittle structures in the Colorado Front Range have a ductile, possibly Paleoproterozoic, component, perhaps related to movement along the Idaho Springs Ralston shear zone? If so, these NW-trending structures, and mineralization along them, may be controlled by Paleoproterozoic structures.

Test: Search for ductile deformation along these structures and test whether these structures are truly older shear zones and cannot have been part of the penetrative deformation that is present elsewhere.

Outcome: In one outcrop (only...) there is evidence for ductile deformation that is not part of the penetrative deformation outside the shear zones and possibly Paleoproterozoic. Thus, the NW-trending faults and mineralization along them may be controlled by earlier ductile (Paleoproterozoic?) structures.



Benefits

The Geological Field Research course is ideal for students who will be conducting thesis research involving a significant structural mapping component. Especially students who will be conducting (thesis) research in the area where the course is taught will be well prepared. Furthermore, the course is an excellent way for the instructor to learn more about the field area. This is in particular useful for faculty trying to start new research projects in an area they are not fully familiar with. Thus, the course serves both students and instructors well, not only because of the learning and teaching experience, but also by possibly enhancing their research. Some of the course projects form the topic of or basis for conference presentations, and possibly more. For example:

Quigley, P., Gonchig, T., Kuiper, Y.D., 2014. The potential significance of northwest-trending structures in the Colorado Rocky Mountain Front Range and their relationship with and potential significance to the Colorado Mineral Belt. Association for Mineral Exploration British Columbia Roundup.

Buchanan, J.W., Kuiper, Y.D., 2013. Preliminary structural analysis of the Nashoba Formation, eastern Massachusetts. Geological Society of America, Abstracts with Programs, Vol. 45, No. 1, p. 90.

Dougherty, K., Kuiper, Y.D., 2013. Structures and kinematics of the Clinton-Newbury shear zone along the NW margin of the Nashoba terrane, eastern Massachusetts. Geological Society of America, Abstracts with Programs, Vol. 45, No. 1, p. 91.