**Sage Hen Flat module: Notes for Instructors**

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Much of what needed to be said is in the “Introduction to the Students”.

Because you are using real and unpublished data, we request that you respect the intellectual property that the data represent.

We are unsure how well teaching field geology remotely – which is required for the summer of 2020 – will go for teaching students how to be good scientists. The reason that we developed this module was because it provided some real opportunities to distinguish between different published models. At a minimum, students should leave this module with the idea that all published maps are not correct. But, we also thought that we could utilize the differences of the Ernst & Hall (1987) geological map and the Bilodeau & Nelson (1993) geological map to explicitly address uncertainty in making field maps. We distinguish between uncertainty associated with data (we apply this to the foliation and lineation – e.g., fabric – data in the Sage Hen flat pluton) and uncertainty associated with the model (e.g., cross sections, including the difference between the two geological maps). The powerpoints that discuss uncertainty were the product of active, interdisciplinary research and a lot of work to get the message clear.

We have designed the material to fit into a “traditional” fieldcamp exercise, running for 5-6 days. One could eliminate the “fault” day, which is the most interpretive. The exercise could be extended to more days by reading of the primary literature, with oral presentations and written work by students. The timelines are only suggestions that highlight the available resources.

Because the data is all unpublished – even in abstracts – we think that the students should feel free to use any resources that they can obtain online or through the library to help evaluate their interpretation. That decision, however, is up to the instructors.

The video on Fabrics in Granites was made for instructors that did not have familiarity with this subject. That powerpoint is available: I suspect that the students would prefer if someone gave that as a live presentation.

We anticipate, with your guidance, that the students will be able to make a reasonable interpretation of the data. However, it is equally important – in our opinion – that the student makes some cognitive gains. In particular, we would like the student to move from “uncertainty is not useful” to “uncertainty is very useful and drives the interpretations”. That is, we hope that this module can help move students from a black-and-white worldview (e.g., Map A is wrong; Map B is right) to a nuanced world view in which data has varying quality and interpretations have different strengths and weaknesses. We think that movement on this issue is a critical step toward becoming a better scientist.

Finally, we have an optional reading assignment on Day 1. We think that having the students read Richard Feynman’s Cargo Cult Science essay might really help them appreciate that uncertainty is critical for being a professional scientist. We have included that essay with a supplied reading guide in the teaching materials. Because that is a large deviation from a traditional fieldcamp approach, we have made it optional.

In brief, some of the goals of the modules are:

1. Incorporate uncertainty into both observations and interpretations, realizing that no interpretation is certain.
2. Acceptance that published work is not “fact”, even if published by scientists with strong reputations.
3. Develop an ability to assess your own uncertainty; this skills is an affirmation of your own scientific ability.
4. To make a claim or an interpretation, you need to provide evidence to back up that claim. The evidence itself has uncertainty and the interpretation necessarily has more uncertainty.
5. Get insight into the process of science as it is done by professionals.

“The Answer”

We have tried to construct the module so that it matters more how the students get to an answer and articulate the evidence for it, than exactly what they propose. Given that caveat, here is our interpretation based on our time there. Both published maps have shortcomings. The thrust fault interpretation of Ernst & Hall (1987) is almost certainly incorrect. The geology does not support that model and the gravity data is completely inconsistent with it. Rather, the intrusive contact of Bilodeau & Nelson (1993) is almost certainly correct. That said, both published maps continue the granite to great depth. The maximum thickness of the pluton is 600 m; if a different density contrast is used, the maximum thickness may be only 200 m. The pluton is a thin sheet relative to its length & width. This interpretation is completely consistent with the lack of wallrock deformation.

While Clem Nelson was a superb mapper, particularly of stratigraphy, the major weakness of the Bilodeau & Nelson (1993) geological map is the lack of faults. It is certain that there are EW-oriented faults on the north end of County Line Hill. Likewise, there are zones of cataclasis along sections of the north margin of the pluton (where the pluton/wallrock contact is oriented NS). Further, there is compelling evidence for cataclastic offset on EW-oriented faults that are in the correct orientation to offset the Jursassic dike within the Sage Hen Flat pluton. Whether the fault movement explains the relative offset of the dike segments from a single, continuous dike is unknown.

The normal faults are trickier, and for this subject, you will get just my (BT) opinion. I think that there are NS-oriented normal faults (Miocene to present; W-side down) throughout the pluton, but the evidence for them is suggestive at best. A Basin-and-Range fault in this orientation in the valley on the west side of the pluton – approximately where Ernst & Hall (1987) speculate there is a thrust fault – might explain the relations that caused Ernst & Hall to suggest a thrust fault in that location.

We hope that you find this module useful, however you incorporate it into your teaching. Please contact the lead author if you need any more information. Also, we would appreciate knowing how the module went for your field class, so we can provide a better experience for others, if possible.

**Fieldcamp schedule for Sage Hen Flat module, White Mountains, California**

**Day 1: Overview of White Mountains**

Activity 1: Pre-module assessment

Activity 2: Overview of this module

Activity 3: Optional reading assignment of **Cargo Cult Science** (with supplied reading guide)

Activity 4: **Video overviewing the White Mountains geology (video with Sven Morgan, University Michigan – Dearborn)**

Activity 5: Student-lead exploration of stratigraphy and overall geology of the White Mountains: Detailed examination of published geological maps (worksheet)

Activity 6: Using vegetation and color in GoogleEarth to determine rock type/stratigraphy (worksheet)

Activity 7: Developing a stratigraphic section of units in the field area (stratigraphic section)

At the end of the day, students turn in:

1. Quiz/Reading Guide
2. Worksheet on pre-Jurassic units and geology of White-Inyo mountains
3. A 1-page summary of geological history of White Mountains
4. Worksheet on GoogleEarth investigation of the field area
5. A stratigraphic section

Materials needed:

1. Pre-assessment of exercise
2. Overview of the White Mountains geology video
3. Worksheets

**Day 2: Data uncertainty and Sage Hen Flat pluton**

Activity 1: **Powerpoint overviewing granitic fabrics**

Activity 2: **Data uncertainty module**: Instructor-led or student self-directed powerpoint about data uncertainty

Activity 3a: Student-lead exploration of granitic AMS fabrics in the Sage Hen Flat pluton, including using Google Earth to plot granitic fabrics in Sage Hen Flat. Role of dispersion.

Activity 3b: Student-lead exploration of mineralogy of Sage Hen Flat pluton, including using Google Earth to understand granitic fabrics in Sage Hen Flat. Role of interpolation.

Activity 3c: Student-lead exploration of microstructures of Sage Hen Flat pluton, including using Google Earth to understand granitic fabrics in Sage Hen Flat. Role of interpretation/inference & interpretation.

Activity 4: Student activity: Making a schematic cross section through Sage Hen Flat pluton (pluton only) using fabric, mineralogy, and microstructure data

At the end of the day, students turn in:

1. Cross-section through Sage Hen Flat (pluton only)

Materials needed:

1. Overview of granitic fabrics (field and microstructure) video
2. Data uncertainty module powerpoint

<https://docs.google.com/presentation/d/1Chtcrj5gxQRdm_UNQkzCtBNVqBSRwlh_ZwxPp9M4tAY/edit?usp=sharing>

1. Transition to AMS data powerpoint
2. Google Earth dataset with orientations
3. Template/Instructions for cross-sections through plutonic bodies

**Day 3: Model uncertainty and western contact of Sage Hen Flat pluton**

Activity 1: **Model uncertainty module**: Instructor-led or student self-directed powerpoint about model uncertainty

Activity 2: Self-evaluation of each student’s cross-section through Sage Hen Flat pluton

Activity 3: Using uncertainty in workflow. Exploring western ridge (GoogleEarth). Students work in small groups. Give examples of the use of interpretational uncertainty.

Activity 4: Evaluation of model uncertainty for B&N map & E&H map on the western contact of the Sage Hen flat pluton

Activity 5: Student activity: Make a geological map of the western contact of Sage Hen Flat pluton

Students produce:

1. Evaluation of cross-section through Sage Hen Flat pluton
2. Worksheet of uncertainty in the field
3. Worksheet for evaluation of B&N vs E&H geological map
4. A geological map with contacts in the western field area

Materials needed:

1. Digital copies of two published maps of Sage Hen Flat
2. Model uncertainty powerpoint

<https://docs.google.com/presentation/d/1RU2PHXFQkreJK8VqYoWbxit4zHhYgcWp28skArUbCEQ/edit?usp=sharing>

1. Google Earth dataset with orientations
2. Digital copies of two published maps of Sage Hen Flat
3. Blank map of western area for students

**Day 4: Gravity data and inversion model of Sage Hen Flat pluton**

Activity 1: Powerpoint overviewing gravity data

Activity 2: Instructor-led discussion of uncertainties of gravity data

Activity 3: Individual. Make “sketch” cross sections of the Sage Hen flat pluton and answer questions.

Activity 4: Student working in small groups: Creating structure contour maps for the lower contact of Sage Hen flat pluton.

Activity 5: Individual: Making a cross section through Sage Hen flat with correct pluton geometry.

Materials needed:

1. Powerpoint
2. Guided questions
3. Bilodeau and Nelson (1993) map.

Students produce:

1. Two “sketch” diagrams of NS and EW cross sections through Sage Hen Flat pluton.
2. Guided work through Sage Hen Flat gravity inversion (comparison to other data sets)
3. Structure contour maps for the lower contact of Sage Hen flat
4. Detailed cross-section through the field area

**Day 5: Normal faulting within and adjacent to the Sage Hen Flat pluton (optional)**

Activity 1: View powerpoint about faults in the area.

Acitivity 2: Students work in small groups. Using GoogleEarth, explore Tres Plumas area to N of Sage Hen Flat, where there are Neogene basalt flows. Compare faulting in basalts vs faulting in granite, for assessment of uncertain of faults in different rock types.

Activity 3: Students work in small groups. Using the criteria developed for the Tres Plumas area, apply the same logic to the possible locations of faults around Sage Hen Flat. Evaluate the proposed fault, and provide evidence for the location and extent of the faults. For each fault, propose an uncertainty ranking.

Activity 4: Individual. Constrain the timing of the faults (if present). Are all there only normal faults? If so, are they all associated with Basin and Range extension? Are there older, pre-existing faults?

Activity 5: Individual. Make a cross-section across the entire B-B’ line of Bilodeau and Nelson. Use all available data. This will be the final cross-section for this project.

Materials needed:

1. Powerpoint
2. GoogleEarth maps of proposed faults near Sage Hen flat
3. USGS geological maps of Mt Barcroft and Blanco Mountain
4. Bilodeau & Nelson (1993); Ernst & Hall (1987) geological maps

Students produce:

1. Evaluation of each proposed fault near Sage Hen flat
2. A tectonic history of faulting in the Sage Hen flat area
3. A cross-section through Sage Hen flat area, with faults if appropriate

**Day 6: Write-up of results**

Activity 1: Individuals create cross sections and final map

Activity 2: Individuals write up a page on tectonic history

Activity 3: Individuals write up a report on the two published interpretations and their own interpretation. Evidence is cited for the different models. Criteria are outlined to distinguish favored hypotheses. (This is similar to a discussion section of a published geology paper.)

Activity 4: Post-module assessment

Materials needed:

1. Clean sheets for maps
2. Topographic profile
3. Post-module assessment

Students produce:

1. Geological map of the Sage Hen flat area (the extent of B&N map)
2. Cross sections through the Sage Hen flat area (the extent of B&N map)
3. 2 page tectonic history
4. 3-6 page report that explicitly provides comparison of maps. Cite evidence and use uncertainty. Report must include report of positive and negative attributes of all discussed models.
5. References list. This includes all materials used in writing the report, including maps. Use correct GSA format.