

**SYLLABUS**  
**GEO 660A & B – FIELD GEOLOGY**  
**SUMMER 2016**

**DESCRIPTION:** The capstone six-week summer field course for undergraduate geoscience majors in several Jackson School degree options. Taught annually outdoors at sites in west Texas, New Mexico, Colorado, Wyoming, Montana, Idaho and Utah by up to ten faculty/research scientists. The course consists of ~ 15 single or multi-day projects that focus on aspect of field description and interpretation. Products generated include measured sections, reports, photopan interpretations, cross sections, maps and stereonet. Geo660A and Geo660B are two separate three week courses; students may enroll for one or both.

**INSTRUCTORS:** Field Camp Director: Dr. Mark Helper, JGB 4.112  
helper@mail.utexas.edu  
Phone: Office - 471-1009  
Cell – 512-924-2526  
Other Instructors & Assistant Instructors: See attached.

**TEACHING ASSISTANTS:** See attached.

**GRADING:** Field Projects, Field Tests, Presentations..... 100%

Project scores are weighted by the number of days in the field. The number of projects varies by instructor, locality, weather and year. Single day individual exercises (field tests) are weighted double. See the attached course schedule and calendar for details.

This course carries the Independent Inquiry flag. Independent Inquiry courses are designed to engage you in the process of inquiry over the course of a semester, providing you with the opportunity for independent investigation of a question, problem, or project. You should therefore expect a substantial portion of your grade to come from the independent investigation and presentation of your work.

**PREREQUISITES:** A grade of C or better in Geo. 420K and Geo. 428, or permission of field camp director.

**OTHER ITEMS:** **Announcements and course information will be posted on the 660 website at <http://www.geo.utexas.edu/courses/660/default.htm>. Check it often prior to departure for updated information about the travel schedule, lodging addresses, a calendar of projects, sign-up details, etc.**

Academic dishonesty will not be tolerated. Anyone in violation of University policy (see Student Handbook) will receive a failing grade and is subject to additional punitive measures, which may include expulsion from the University. Expectations during group work will be clearly stated by all instructors prior to commencement of projects. If you are unclear about what constitutes dishonesty or unsanctioned collaboration, ASK. Do not assume that one instructor's rule apply to all projects.

**REQUIRED ITEMS:** See attached list.

## Course Objectives

Why a capstone course in field geology? Geology is first and foremost a field science. Field geology and field geologists provide literally the ground truth for geologic concepts and theories of how the earth works. *The degree to which we, as geologists, are successful observers and interpreters of rocks in the field depends in large measure on what we are prepared to see and record.* The old adage “I wouldn’t have believed it if I hadn’t seen it” is, in the case of field geology, more truthfully “I wouldn’t have seen it if I hadn’t believed it”. We explore. We discover. Unfortunately, without sufficient experience and preparation we also frequently ignore what we don’t recognize or understand. This class is part of that preparation.

*Successful field work also depends greatly on how well we can formulate and test ideas while in the field.* Without proper preparation, including a strong grounding in field methods, we are little better than rock hounds out for a day of casual collecting. Field geology is not merely collecting data and samples; it is about making sense of the geology around you, about making geologic interpretations. Landscapes are histories, with time marked by boundaries in the rocks, soil and sediment. A geologic map or a measured section is the articulation of that history, with each line marking a before and after, a hiatus that might last a second or a billion years. Through our maps and graphical logs, we represent time as space. *The ability to create, read and interpret such product is best developed from training and practice in a field setting.* It all begins by making and recording observations. An accurate record in the form of a map, measured section, photograph, sketch, a carefully documented sample, field notes, etc. provides a permanent, solid basis upon which to develop testable ideas and interpretations – the plot of the story. Without such evidence, interpretations are fanciful fables; there is no scientific basis to objectively evaluate them.

*Field proficiency has long been a distinguishing characteristic of our science.* As a geoscientist, you are expected to be a proficient scientific observer and recorder. Your unique skills and training in this area separate you from lawyers, engineers, chemists and other professionals with whom you might one day work. Geology is rooted in the scientific method, so the processes of formulating and testing hypotheses through careful data collection are fundamental skills that need to be mastered in a field setting.

Our principal objectives this summer are to: 1) learn and apply geologic field methods to *describe, measure, map, sample and report on* rocks in the field. Like all sciences, geology has its own vocabulary and its own set of techniques by which we learn to read the rock record. There is no better way to learn than by being totally immersed in a subject. Three or six weeks of field experiences, away from Austin and life’s distractions, provides that immersion.

Some of you may find this an uncomfortable experience. Unlike many subjects, field work cannot be mastered by studying hard, nor is there a set formula for successfully interpreting the rocks you will study. You will learn largely by doing and making mistakes. Get comfortable with this idea now and you’ll be less anxious in the long run.

Finally, it is often said “The best geologist is the one who has seen the most rocks” and there is much truth to it. With field experiences we develop “professional vision” – the ability to quickly recognize important field relationships and ignore or set aside those that are not. Three or six weeks of field immersion provides the substantial beginnings of a mental catalog of rocks and field relationships, a framework to build upon in future classes, later field work and a future career in the geosciences.

## 660 STAFF, SUMMER 2016

### Faculty

<sup>2</sup> Dr. David Mohrig	Sedimentology, depositional systems
<sup>2</sup> Dr. Christopher Zahm	Structural Geology, Basin Analysis
<sup>2</sup> Dr. Charles Kerans	Carbonate Depositional Systems
<sup>1</sup> Dr. Peter Flaig	Clastic sedimentology, depositional systems
<sup>2</sup> Dr. Timothy Meckel	Structural geology, tectonics
<sup>1,2</sup> Dr. Mark Helper	Cordilleran geology, geology of crystalline rocks
<sup>1,2</sup> Dr. Randall Marrett	Structural geology, brittle deformation
<sup>1,2</sup> Dr. Brian Horton	Basin Analysis, tectonics
<sup>1</sup> Dr. James Gardner	Volcanology
<sup>2</sup> Dr. Whitney Behr	Structural geology, petrology

### Expertise/Interests

### Assistant Instructors (Faculty Advisor)

<sup>1,2</sup> Tomas Capaldi, Ph.D. Candidate	Basin Analysis (Horton; 1 year 660 experience)
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### Teaching Assistants (Faculty Advisor)

<sup>1</sup> Lily Jackson, Ph.D. Candidate	Basin Analysis (Horton)
<sup>1</sup> Sarah George, Ph.D. Candidate	Basin Analysis (Horton)
<sup>1</sup> Margo Odlum, Ph.D. Candidate	Geochron., Basin Analysis (Stockli)
<sup>2</sup> Cody Colleps, M.S. Candidate	Geochron. (Stockli; 2 years 660 experience)
<sup>2</sup> Chelsea Mackaman-Lofland, Ph.D. Candidate	Basin Analysis (Horton)
<sup>2</sup> Peter Gold, Ph.D. Candidate	Neotectonics (Behr)

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<sup>1</sup> Teaches all or part of 660A

<sup>2</sup> Teaches all or part of 660B

## EQUIPMENT LIST - GEO 660

### **Required Materials:**

- Field notebook (e.g., engineer's field book)
- Clipboard (8 1/2 x 11 size) **with cover**
- Geologic hammer
- Hand lens (10x)
- Small squirt bottle of dilute (approx. 10%) HCl
- Grain size card
- Six-inch ruler (best is the Post ruler with protractor on it)
- Protractor (bring spare rulers & protractors; many students lose several)
- Pencils and erasers (again, the number depends on how many you lose)
- 2 or 3 drafting (mechanical) pencils (recommend Pentel or equivalent 0.5 mm or 0.3 mm lead, hardness F or 3H) and spare leads
- Colored pencil set that will keep a point (at least 10 colors); pencils with hard, water-fast lead are preferred
- Pencil sharpener or pointer, and/or sandpaper – for colored pencils
- Technical pens with fine-line points and black ink (Sizes 00, 0, 1, are desirable)
- Tablet of 8 1/2 x 11" tracing paper
- Tablet of 10 square to the inch of 8 1/2 x 11" graph paper
- Liquid paper (optional)
- The textbooks and lab manual from GEO 420K and GEO 428
- Calculator
- Watch
- Carrying bag (shoulder bag or daypack)
- Proper field clothes, long pants, long-sleeve shirts, jacket (see note on gear)
- Sun screen/block lotion
- Hat, wide brim
- Hiking boots, broken in (avoid non-lace boots; see note on gear)
- Rainwear (it will rain; see note on gear)
- Canteen (2 or 3, one-quart water bottles, a Camel-Back or some other water storage container)
- Warm sleeping bag and pad\*\* (see note on gear)
- Towels, washcloth
- Flashlight and/or headlamp
- Plate, cup, silverware

### **Desirable Materials:**

- Digital Camera
- Masking tape
- Scotch tape
- Tweezers (important for run-ins with cactus)
- Insect repellent
- Minor first aid kit for bug bites, thorns, blisters (moleskin), etc.
- Small pair of binoculars (not necessary but useful for "long-range" mapping)
- Whistle (if you are prone to getting lost and have a weak voice)
- Safety goggles or other eye protection (see field course policy handout regarding this and hard hats)
- Sharpie markers to label rocks

### **Prohibited Items:**

- Firearms
- Illegal drugs
- Consumption of alcoholic beverages in University vehicle

## **Gear for Geo. 660**

The equipment list for Geo. 660 contains items that many of you may not own that can be relatively expensive. Below are some ideas on adequate equipment at reasonable prices. A little searching on the web can yield tremendous dividends.

### Boots

Footwear is the single most important item for a field course. Good boots provide traction, protection and support for your feet. Tennis or basketball shoes are not adequate for the latter two reasons, nor are cowboy boots for the former. A wide variety of boot styles are available, from those with low-or high-top nylon/leather uppers, to all-leather boots. Leather boots provide maximum protection, support and, with the proper soles, excellent traction. Most today are designed with backpacking in mind, which requires relatively rigid uppers and maximum padding to provide comfort and support for carrying heavy loads. Once broken-in, a well-made boot of this type is unsurpassed for field use. They are the best at keeping feet dry, provide an important measure of protection from cactus and other thorny plants, and will usually (but not always) outlast a softer boot.

The major disadvantage of leather boots is price; a decent pair now costs over \$150, with many in the \$180-\$250 range. Do you need leather boots at this price for 6 weeks of fieldwork? No. A well-made, cheaper pair of "soft" boots can be adequate if: 1) you're relatively agile and light on your feet; 2) you're field pack doesn't weigh more than about 40 lbs.; 3) you're not prone to kicking cactus. I worked in soft boots for many years and, although they lasted little more than one season, I've was very happy with the lowest-priced models of Merrill, Vasque and Asolo boots, which can often be found on sale (or on the web) for less than \$80/pair. Well-made pairs by major manufacturers sell at list prices of \$70 - \$200. Less well made varieties tend to lack side support (foot tends to roll sideways when walking across slopes) and can quickly come apart (soles detach, front rand comes off) after limited use. High-top boots provide ankle support and will keep scree and dirt out when moving down-slope on loose ground.

Regardless of the boots you select, you will be much more comfortable if you use well-padded socks with a clean pair of thin sock liners. Sock liners wick moisture from your feet and are easy to wash/rinse at the end of a day.

### Rain gear

A good, well-fitting, waterproof coat is a necessity, not a luxury. We have never experienced a summer where it didn't rain. Two summers were exceedingly wet, raining nearly every day and for several days on end. We camp and cook outdoors and are in the field every day, rain or shine. Strong winds and colder temperatures often accompany rain in the mountains.

Adequate rain gear need not cost 100's of dollars, but a \$5 plastic poncho, which is only marginally better than a plastic trash bag, won't work in such conditions, nor will a thin nylon shell sprayed with Scotchguard. Lower-priced (\$20-50) raincoats and rain pants, which are usually made of plastic- or coated nylon, are adequate and widely available in a variety of styles. The best of the least expensive brands is probably Frogg Toggs. Medium-priced coats (typically \$50-100) are somewhat lighter-weight, usually better ventilated, may have an attached hood and are thus more comfortable to work in. They are, however, no more water repellent than lower-priced varieties, sometimes less so. High-priced rainwear is general constructed of one or more "miracle" fabrics; lightweight materials that are touted to "breathe" while also being waterproof. In my opinion (based on several coats, boots, mittens, and a few other items) these fabrics are vastly overrated for the price. Nonetheless, such coats are generally ruggedly constructed, fit well, and typically have many desirable features (multiple pockets, armpit zippers, internal drawstrings, ancillary ventilation, etc.). Again, they are no more waterproof than much lower priced models. Ponchos and umbrellas don't work well in windy weather.

Regardless of what you type of coat you choose be sure it's large enough to allow for insulating layers underneath. Have a pair of rain pants.

### Sleeping Bags and Pads

This summer, you will spend about 30 nights sleeping on the ground in a tent. Nighttime temperatures can be as low as 30° in June and are commonly 40°-50°. Blankets are only marginally adequate in such conditions; a sleeping bag provides better heat retention and insulation. The enormous price range for sleeping bags reflects differences in insulating materials, weight and construction. At the high end are extremely light, down-filled bags made of waterproof, breathable fabrics that have a comfort range that extends to -30° F. These bags are uncomfortably warm for all but the coldest conditions. At the low end are cotton bags with natural or synthetic fiber insulation, some of questionable construction, which may or may not keep you warm at temperatures below 50°. In between is a very large spectrum of nylon shell, down- or synthetic fiber-filled bags that are more than adequate for summer camping in the US Rockies. Fiber-filled bags are light, dry quickly, are easy to clean, are nearly as warm as down, and pack to a small volume. Like wool, they provide warmth even when wet. Down bags are typically more expensive, slow to dry and nonfunctional when wet. If you are concerned about your sleeping bag keeping you warm, bring a pair of long underwear to sleep in and make sure you have a good sleeping pad. I also use a sleeping bag liner to extend the temperature range of my bag.

A sleeping pad or foam mattress provides insulation from cold ground and a measure of comfort. A closed-cell foam or inflatable pad provides the best insulation. A blanket beneath your sleeping bag is better than nothing.

### Tents

The Department no longer supplies tents. Tent prices have come down in recent years and very well made, 2- or 3- person tents are available for \$200 or less. In evaluating a tent for this summer, ask yourself the following: Will the tent withstand windy (30-40 mph) conditions? If it has fiberglass poles the answer is likely no. Is it waterproof (or can it be made waterproof) in a sustained, heavy downpour? If the tent fly does not extend most of the way to the ground the answer is no. Do I have all the parts? A waterproof ground cloth (a sheet of heavy mil plastic will do) keeps the floor of your tent from absorbing water and protects against punctures.

### Clothing

You should have clothing that will allow you to live and work comfortably in both cold (40°) and hot (100°+) weather. Cold is best dealt with by wearing layers that can be donned and shed as needed. For maximum comfort your outermost layer should be windproof; rain coats/pants are adequate. Beneath this, a layer that will trap air (sweater, sweat shirt, fleece jacket, down vest, etc.) comes next, underlain by one or more thin layers (T-shirt, long sleeved shirt) that provide additional warmth and wick perspiration from your skin. As much as 70% of your body's heat loss occurs through your head; if you're cold put a hat on.

A wide brim hat, bandanna, and sunblock are essential for working in the deserts of western US. Finally, you will be traveling or working outdoors nearly every day of the 6 weeks. You will load and unload your gear, along with ice chests, cook boxes, tarps, etc., many, many times along the way. It is to your and everyone else's benefit to travel light. Examine every piece of clothing you pack critically; do you really need it? Keep in mind that there will be opportunities to do laundry at most places we visit and we will not be anywhere that requires anything more than field clothing.

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**Jackson School of Geosciences Department of Geological Sciences**  
**Field Trip and Field Course Policies**

The Department of Geological Sciences conducts numerous field activities (field trips, field geology courses, and field research). Because students are exposed to a variety of situations and experiences that are different from those found in the classroom, special rules of conduct are necessary. Traveling and field work involves hazards and risks, so each person must exercise care to avoid personal injury to others. Examples of dangers specific to field work are the use of geologic picks, poisonous snakes, tick bites, toxic plants, falling, and slippery rocks encountered when hiking on steep slopes or crossing streams. Other dangers, as well as damage to property, may be created by carelessness. The Department has access to certain private properties and use of private facilities whose future availability will depend upon proper consideration for these resources by everyone. Students who abuse University or personal property during a field trip, or who jeopardize the health and safety of other people, will be required to leave the field trip immediately. These persons will be subject to appropriate academic evaluation and possible disciplinary action by the Office of the Dean of Students.

**The Department has the following rules and recommendations which apply to field activities.**

1. **Liability and Waiver.** The University requires all students to sign a liability release form (accompanying form). This form must be signed and returned before a student is allowed to participate in field activities.
2. **Medical Care.** A medical form must be filled out by all students. Any student who has medical problems (e.g. asthma, diabetes, metabolic disorders, allergies, trick knees) should inform the field trip leader or supervising professor. If you require special medications, it is your responsibility to insure that they are available when needed. Field activities are sometimes in very remote areas, and immediate medical assistance is not possible.
3. **Health Insurance.** Every student taking a *field course* must have medical insurance. Student health insurance is available at minimal cost through the Student Health Center (471-4955). Students taking field trips as part of normal classes who do not have health insurance will be provided with insurance for the field trips only.
4. **Clothing and protective cover.** Wear suitable clothes. We recommend wearing a hat, long pants, and good hiking boots in some areas. These help prevent sunstroke, insect bites, and bad encounters with cacti or thorny shrubs. You may want to bring insect repellent, and we also suggest the use of sunscreen. Consider significant possibilities of rain or cold weather.
5. **General field hazards.** Insects, poisonous snakes, and toxic plants may be found on any field trip or course. Wearing suitable clothing and boots helps reduce these hazards. Remember to check yourself for ticks which can transmit diseases such as Rocky Mountain spotted fever, Lyme disease, etc. Ticks should be removed immediately; be sure to remove the body with head intact. Do not use a match to kill the tick first. Watch for, don't play with, and avoid snakes. Five students on Department trips have been bitten by rattlers since World War II; try not to be the sixth. If you are allergic to such things as bee stings, you must bring appropriate medication. A few other common sense rules: stay out of the water if you can't swim; stay out of thunderstorms, particularly at high elevations, and out of flashflood-prone areas in any rain. Some field areas have steep cliffs that you are not required to and should not climb; use common sense and follow your instructor's advice in such areas.
6. **Head and eye protection.** We recommend eye protection when using, or around someone using, a geologic pick, hammer, or other tools. Hard hats should be used in mines, quarries, steep road cuts, or other areas where rock falls or blows to the head could occur; some sites may require these protective devices. Safety glasses and hard hats can be checked out from the Department storeroom.
7. **Firearms.** Possession of firearms or facsimiles at any time during any field course or field trip is forbidden.
8. **Drugs and alcohol.** Use or possession of illegal drugs at any time is forbidden. Alcoholic beverages may NOT be consumed at any time while traveling in a University vehicle.
9. **Department equipment.** Take care of Department property. Our equipment normally gets hard use and current budgets are tight, so treat it as you would your own.

**You have previously read and agreed by signature to follow the Field Trip/Field Course Policies for departmental field activities given above. Please keep them in mind this summer.**

## 2016 Class Rosters (on 5/3/16)

<b>Last Name</b>	<b>First Name</b>	<b>Email</b>	<b>Course</b>
Aguilera	Kimberly	kimberlyaguilera@utexas.edu	660A&B
Alfaro	Jasmin	jasmin_8595@yahoo.com	660A&B
Anderson	Matthew	mda2236@utexas.edu	660B
Anderson	David	mr.anderson09@utexas.edu	660A&B
Baker	Christian	cabaker117@utexas.edu	660A&B
Bell	Chloe	bellchloe24@gmail.com	660A&B
Berti	Allison	allisonberti@utexas.edu	660A&B
Black	Christian	cblack9488@gmail.com	660A&B
Bowman	Emilie	emibow27@gmail.com	660A&B
Cabrera	Reynaldo	cabrerajr.reynaldo@gmail.com	660A&B
Cleveland	Victor	vcleveland2@yahoo.com	660A
DaFov	Laura	lauradafov@gmail.com	660A&B
Draper	Cody	cody.draper@utexas.edu	660A&B
Ellis	Thaddeus	tellis17@utexas.edu	660A&B
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Xue	Zehao	zehaoxue@utexas.edu	660A&B
Zehani	Zach	rickshawrampage@gmail.com	660B
Zerr	Jackson	jacksonzerr@yahoo.com	660B

## SCHEDULE FOR GEO 660A&B, SUMMER 2016

- May 24 Travel to Albuquerque, NM; **Drs. Helper & Gardner** (Super 8 Midtown)
- May 25 AM: Travel to Los Alamos, N.M., PM: Jemez Mts. proj.; **Drs. Helper & Gardner** (BNM camping)
- May 26-29 Valles Caldera projects; **Drs. Helper & Gardner** (camping, Bandelier N.M.; Hampton Inn)
- May 30 Travel to Grand Junction, CO; **Dr. Helper** (dorms, Colorado Mesa University)
- May 31-June 4 Book Cliffs Sed./Strat. Projects; **Drs. Helper & Flaig** (dorms, Colorado Mesa University)
- June 5 Travel to Grand Teton N.P.; **Drs. Marrett & Helper** (camping, Grand Teton N.P.)
- June 6 Grand Teton/Yellowstone project; **Drs. Marrett & Helper** (camping, Grand Teton N.P.)
- June 7 Day Off; **Drs. Marrett & Helper** (camping, Grand Teton N.P.)
- June 8 Travel to Canyon Ferry, MT; **Drs. Helper & Marrett** (camping, Kim's Marina)
- June 9-11 Big Belt Mts. mapping projects; **Drs. Helper, Marrett & Horton** (camping, Kim's Marina)
- June 12 Big Belt Mts. field trip; **Drs. Marrett, Horton & Helper** (camping, Kim's Marina)
- June 13 Field Test; **Drs. Helper, Marrett & Horton** (camping, Kim's Marina)
- END 660A**
- June 14 Travel to Cardwell, MT; **Drs. Helper, Marrett & Horton** (camping, Lewis and Clark Caverns S.P.)
- June 15-17 Sevier Belt mapping projects; **Drs. Marrett, Horton, Behr & Helper** (camping, L& C Caverns S.P.)
- June 18 Field Test; **Drs. Marrett, Horton, Behr & Helper** camping, L& C Caverns S.P.)
- June 19 Day Off; **Drs. Marrett, Behr & Helper** (camping, L& C Caverns S.P.)
- June 20 Travel to Butte, Hecla; **Drs. Marrett, Meckel, Behr & Helper** (camping, Deerlodge N.F.)
- June 21-24 Hecla Project; **Drs. Marrett, Meckel, Behr & Helper** (camping, Deerlodge N.F.)
- June 25 Travel to Price, UT; **Dr. Helper** (Super 8 Inn)
- June 26 Travel to Molas Lake, CO; **Drs. Helper & Kerans** (camping, Molas Lake)
- June 27-29 Sed./Strat. projects, Molas Lake area; **Dr. Helper, Zahm & Kerans** (camping, Molas Lake)
- June 30 Travel to Abiquiu, NM; **Drs. Helper & Kerans** (camping, Ghost Ranch)
- July 1-3 Sed./Strat. projects, Colorado Plateau; **Drs. Mohrig & Kerans** (camping, Ghost Ranch)
- July 4 Return to Austin; **Drs. Mohrig & Kerans**

## **MONEY FOR MEALS**

- *All meals while camping and all lunches, except on travel days, will be provided.*
- All hotels during the trip will provide at least a continental breakfast (bread, pastry, juice, coffee) and some may have hot food. If you eat a hardy breakfast you may want to purchase additional breakfast food – it will not otherwise be provided.
- *You will need money to purchase lunch and dinner during some hotel stays. These days are May 24, 28, 29; June 25, 30; July 4 (6 total days).*

Ice chest/refrigerators will be available to store food/medicine during hotel stays. You will be able to make a lunch from food we purchase for this purpose before going into the field, *provided you are leave yourself time to do so before departure. All lunch food is put away at 7:45 AM.*

## Geo660A&B Trip Addresses, Summer 2016

### **660A: May 24-June 13**

#### **May 24**

##### [Super 8 Midtown](#)

2500 University Blvd., N.E.  
Albuquerque, NM 87107  
505-888-4884

#### **May 25-27**

##### **Group Campsite Juniper Campground** [Bandelier National Monument](#)

Los Alamos, NM  
No phone or mailing address  
Emergency Calls - 505-672-3861

#### **May 28 & 29**

##### [Hampton Inn](#)

124 State Highway 4  
Los Alamos, NM 87544  
505-672-3828

#### **May 30-June 4**

##### [Colorado Mesa University](#)

Dormitories  
Grand Junction, CO 81501-3122  
(970)248-1020

#### **June 5-7**

Coulter Bay Group Campsite  
[Grand Teton National Park](#)  
no phone or mailing address  
EMERGENCY Contact:  
(307) 739-3473

#### **June 8-13**

Kim's Marina and Resort  
campground  
8015 Canyon Ferry Rd.  
Helena, MT 59602  
(406) 475-3723

#### **June 8-13**

##### [Western Wyoming](#) [Community College](#)

2500 College Dr.  
Rock Springs, WY 82902  
307-382-1600

### **660B: June 14-July 4**

#### **June 14 & 19**

##### [Lewis and Clark Caverns S.P.](#)

PO Box 949  
Three Forks, MT 59752  
406-287-3541  
(EMERGENCY CALLS ONLY)

#### **June 20-24**

##### [Beaverhead National Forest,](#) [Dillon Ranger District](#)

Primitive camping at Hecla,  
Pioneer Mts., near Melrose, MT  
no phone or mailing address

#### **June 25**

##### [Super 8](#)

180 N Hospital Dr.  
Price, UT 84501  
435-637-8088

#### **June 26-29**

##### [Molas Lake Campground](#)

Silverton, CO 81433  
no phone or mailing address

#### **June 30-July 3**

Group Campsite  
[Ghost Ranch Conference Center](#)  
HC 77, Box 11  
Abiquiu, NM 85710-9601  
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## ***COURSE DESCRIPTION, GEO 660A&B, SUMMER 2016***

### **DAYS 1-6 (May 24-29)**

#### **Geology and volcanology of a supervolcano – the Valles Caldera, Jemez Mountains, New Mexico – Drs. Gardner and Helper – See Route Maps 1 & 2**

The Valles caldera of the Jemez Mountains is *the* classic locality for understanding the nature of large-volume caldera eruptions. Exception preservation and outstanding exposures of Pleistocene eruptive products (ash flow and air fall tuffs, lava flows, lava domes) provide an unparalleled opportunity to examine, map and describe the hallmarks of these enormous, explosive eruptions.

After a full day and a half drive from Austin, we arrive in Los Alamos, NM to establish a camp at Bandelier National Monument, the site of native American cliff and ground dwellings intimately linked to the geology of the Bandelier Tuff, one eruptive product of the caldera. On our first day (Day 2) we begin with a visit to the main canyon of the Monument, Frijoles Canyon, where we map and describe a beautifully exposed Maar deposit, and examine other aspects of pre-caldera and caldera forming volcanism. We also get a glimpse of the pre-caldera topography, as exposed in the canyon walls.

Days 3-6 are devoted to learning to recognize, interpret and map the intrusive and eruptive products of calderas, beginning with a field trip through the caldera followed by two mapping exercises that examine the geometry and sequence of volcanic deposits.

### **DAY 7 (May 30)**

#### **Travel to Grand Junction, Colorado – Dr. Helper – See Route Map 2**

North of Los Alamos we reenter the Rio Grande Rift, crossed first on our way from Albuquerque on Day 2. As we drive north along the western rift margin into Colorado we enter the San Luis Basin, the northern most rift basin (half graben) of the Rio Grande Rift. As recently as 400 Ka, this was a closed basin that hosted a giant pluvial lake, ancient Lake Alamosa. Southward catastrophic release of the lake water is thought to have created the northern segment of the Rio Grande River in New Mexico, helping integrate a vast drainage catchment that by 200 Ka resembled the modern Rio Grande watershed. We leave the Rio Grande Rift near Saguache, CO, turning NW to skirt the northern edge of the huge Oligo-Miocene San Juan volcanic field and make our way out into the valleys of the Gunnison and Uncompahgre Rivers on the western slope of the Rockies. At Montrose, the Uncompahgre Uplift comes into view as we enter the Colorado Plateau and follow the Uncompahgre River north to Grand Junction, Colorado.

### **DAYS 8-12 (May 31–June 4)**

#### **Late Cretaceous Western Interior Seaway; Book Cliffs, western Colorado and eastern Utah – Drs. Peter (Pete) Flaig and Mark Helper**

Here we examine, document and interpret the development of a clastic wedge that built out into the Late Cretaceous Western Interior Seaway. This part of the course involves logging and interpretation of clastic sedimentary strata, facies analysis, correlation of logged sections, and the application of sequence stratigraphic concepts in an outcrop setting. Within a large, prograding clastic wedge that was built out into the Cretaceous interior seaway, the emphasis is on the Sego Sandstone and allied units. Excellent continuous exposures of these rocks in the Book Cliffs provide both vertical and lateral control on facies relationships. Outstanding vertical sections permit discrimination among wave-, tide- and river-dominated delta deposits, and recognition of marine to fluvial transitions.

- **Day 7 PM**: Introduction and evening in-dorms Book Cliffs correlation exercise, time permitting
- **Day 8**: Woodside Kenilworth Fm wave-dominated deltas outcrop project

- **Day 9:** Floy/Basin Segoe tide-dominated deltas outcrop project
- **Day 10&11:** Harley Dome Segoe to Neslen marine-fluvial transition outcrop correlation project
- **Day 12:** Rangely Lloyd to Segoe outcrop project

### **DAY 13 (June 5)**

#### **Travel to Grand Teton National Park, Wyoming – Drs. Helper and Marrett – See Route Map 3**

A long drive this day takes us north across the Uinta Basin, through its upturned northern margin and into the Precambrian-cored, Laramide Uinta Mountains. We traverse the entire Phanerozoic section in doing so, with conveniently labeled formation markers along the way! Highway signs en route describe the Formations as we climb upward into older rocks, reaching the Precambrian core of the range near the Flaming Gorge of the Green River. From there we descend the north flank of the Uintas, entering progressively younger strata as we enter Wyoming and the Green River Basin. A bit farther north, we enter the Rock Springs Uplift, where Cretaceous strata are gently tilted in all directions by an asymmetric dome. Exposed here are deposits of the Cretaceous interior seaway very similar to those of the Book Cliffs. Above these are Tertiary lake deposits of the Green River Formation, famous for its fish fossils and freshwater limestones. Our route follows the Green River Basin to its northern terminus, where a thick-skinned Laramide uplift, the Wind River Mountains, intersect the thin-skinned Sevier fold-thrust belt near Jackson, WY. The geology of this corner is made even more complex by what's on the other side, the Teton Mountain Range, visible as we crest the basin margin and from our campsite in Grand Teton National Park.

Along our route we may make stops to see/visit:

- Dinosaur National Monument near Vernal, UT
- Phosphate mining operations on the south flank of the Uinta Mountains
- Flaming Gorge (Mesoproterozoic red beds) at the Flaming Gorge Dam on the Green River

### **DAY 14 (June 6)**

#### **Neotectonics and glaciation – Drs. Helper and Marrett**

This day we examine the products and processes associated with the glacial history, seismicity and neotectonics of the Greater Yellowstone region. What is Jackson Hole, and how did it form? Is the Teton Fault active? Does it pose a risk to those living in Jackson? How much slip has occurred in the last 15,000 years? After a day of examining and measuring an offset moraine you'll come up with some answers.

### **DAY 15 (June 7)**

#### **Day Off, Grand Teton and Yellowstone National Parks – Drs. Helper and Marrett**

Two weeks into the class, your first full day off can be spent in either or both of these crown jewels of the National Parks system. Supplemental guidebook materials will allow you and fellow students to explore the volcanic and hydrothermal wonders of Yellowstone with some information in hand...

### **DAY 16 (June 8)**

#### **Travel to Canyon Ferry, Montana – Drs. Helper and Marrett – See Route Map 4**

A drive this day takes us north to west-central Montana along or near the leading edge of the Cretaceous Sevier fold-thrust belt. Along the way we enter the country explored by Lewis and Clark, with spectacular Big Sky vistas of isolated, snow-capped mountain ranges. Stops may include:

- Madison Canyon Landslide, Quake Lake and the scarp of the 1959 Hebgen Lake earthquake;
- The headwaters of the Missouri River at Three Forks, MT

Our destination is Kim's Marina and Resort at the foot of the Big Belt Mountains and the north edge of Canyon Ferry Reservoir, one of the largest reservoirs on the Missouri River. From there we begin to examine and map the geology of the Sevier Belt.

## **DAYS 17-21 (June 9-13)**

### **Structural geology of a fold-dominated portion of the Sevier Belt - Drs. Helper, Marrett and Horton**

Mapping, cross-section construction and description of a small area within the Big Belt Mt. salient of the Sevier Belt, a Late Cretaceous belt of thin-skinned deformation that extends the length of the northern Rocky Mountains.

- **Day 17:** Introduction to setting and stratigraphy
  - Compile a stratigraphic column of map units, recon. the field area, begin mapping
- **Day 18:** Continued mapping
  - Begin constructing cross section and stereonet
- **Day 19:** Finish mapping
  - Turn in map, cross section and stereonet
- **Day 20:** Field trip through the Big Belt Mountains
  - The Big Belts are a salient in the Montana portion of the Sevier belt. Mesoproterozoic sedimentary rocks (Belt Supergroup) here are overlain by a distinctive lower Paleozoic sedimentary sequence, both of which are exposed in folds and thrust sheets. On this day we discuss the Sevier and Laramide Orogenies, view cross section through the Big Belts as exposed in Beaver Creek Canyon, view and sketch geometries of folds and thrusts in Cambrian and Mississippian carbonate units, see folded thrusts, thrust folds, out-of-sequence thrusts, horses, and an antiformal stack.
- **Day 21:** Field Test
  - Individual, one-day mapping exercise

*This ends the first 3 week session; GEO660A*

## **GEO660B**

### **DAY 22 (June 14)**

#### **Travel to Cardwell, Montana - Drs. Helper, Marrett and Horton – See Route Map 4**

As we turn our vehicles south for the second half of the class, a short drive this day takes us through Helena, the state capitol, and south through the Boulder Batholith, part of the magmatic arc associated with Farallon plate subduction along the Cretaceous Pacific plate margin. We return to these rocks a week hence on a visit to Butte. At the little town of Boulder, we turn southwest and reenter the Sevier Belt to make our way south to a major re-entrant in the thrust belt along the Jefferson River. Lewis and Clark Caverns State Park sits in this re-entrant and is the base for our next four days of mapping slightly more complex fold-thrust geometries in the same lower Paleozoic sequence encountered in the Big Belts.

### **DAYS 23-26 (June 15-18)**

#### **Structural geometries of thin-skin fold and thrust belts - Drs. Helper, Marrett, Horton & Behr**

This 3-day project and accompanying field test allows mapping of somewhat complex folds and faults on one limb of an anticlinorium near the leading edge of the Sevier Belt. Mapping is within a small displacement transfer zone in the Elkhorn Mountains, where thrust faults become folds (or vice-versa!).

- **Day 23:** Precambrian-lower Paleozoic stratigraphy of the Elkhorn Mountains & first day mapping
  - Describe section and define map units for this project
  - Begin mapping
- **Day 24:** Continue mapping
  - Begin constructing cross section and stereonet
- **Day 25:** Finish mapping
  - Turn in map, cross section and stereonet
- **Day 26:** Field Test
  - Individual, one-day mapping exercise

## **DAY 27 (June 19)**

**Day Off - Drs. Helper, Marrett & Behr**

## **DAY 28 (June 20)**

**Travel and ore deposits Intro.: Field trip to Butte, Montana; travel to Hecla, near Melrose - Drs. Helper, Marrett, Meckel & Behr – See Route Map 4**

We travel an hour west to Butte, MT to see what remains of "the richest hill on earth". Discussions on giant porphyry copper deposits, EPA superfund sites and mining in the west. After buying supplies, we drive south into the Pioneer Mountains, where we establish a camp near the ghost towns of Lion City and Hecla, once the center of the richest silver mining district in Montana. With published maps and reports already in hand, we will spend four days documenting and unraveling field relationships among deformation, plutonism, contact metamorphism and mineralization within facies equivalents of the same strata mapped in the previous two projects.

## **DAYS 29-32 (June 21-24)**

**Hecla Project: Ore deposit geology and geologic processes - Drs. Helper, Marrett, Meckel & Behr**

This project integrates different geological disciplines to unravel the geological history of this late-1800's silver-zinc mining district. Field data will be collected over a period of four days to understand the sedimentary, structural, metamorphic, magmatic and hydrothermal history of this area and produce a concise report that synthesizes this information. In addition to introducing new concepts (for 660) in metamorphic and ore geology, this exercise offers a unique chance to integrate different types of data to understand the geological history of an area – a common exercise for any earth scientist.

## **DAYS 33 (June 25)**

**Travel South to Price, UT – Dr. Helper – See Route Maps 3 and 4**

- Lunch: Flood basalts at Snake River Plain visitor's center
- Afternoon: Great Salt Lake, Wasatch Mountains and Wasatch Mountain Fault

## **Day 34 (June 26)**

**Travel from Price to Molas Lake, CO – Drs. Helper and Kerans See Route Map 2**

We return to Grand Junction this day to purchase supplies before heading south into the high San Juan Mountains to establish a camp at Molas Lake, perhaps the most beautiful city park (city of Silverton) in the country! Our route retraces a segment of the drive on Day 7, as we ascend the San Juans. Near Molas Lake, the Oligocene to Miocene San Juan volcanic field locally rests upon a little deformed, ancestral Rockies (Pennsylvanian) sequence of cyclical sediments, variably exposed beneath the volcanic cover. These are our subject of study. To get there we first traverse a spectacular sequence of Mesoproterozoic quartzites and slates and their thinner Paleozoic cover near Ouray. These create some of the steepest and highest slopes in the San Juans. Waterfalls and avalanche chutes abound. Farther on and higher up, we enter the volcanic field, a large complex of nested calderas, and pass through ash flow tuffs, volcanic breccias, silic flows and felsic intrusions. The southern-most "fourteeners" in Colorado are here, most capped by these volcanic rocks, visible when not covered in snow. Caldera-related hydrothermal activity is evident from the rusty red hues of many mountain sides, and precious and base metal mining in this region has clearly left its mark, visible in many places along the drive.

## **DAYS 35-37 (June 27-29)**

**Pennsylvanian cyclical mixed carbonate-clastic strata - Drs. Kerans, Helper and Zahm**

These three days focus on study of the sedimentology and stratigraphy of mixed carbonate-clastic cyclical sequences, with perhaps an emphasis on the carbonate components. Like the Book Cliffs, this part of the class involves logging and interpretation of sedimentary strata, facies

analysis, correlation of logged sections, and the application of sequence stratigraphic concepts in an outcrop setting.

#### **DAY 38 (June 30)**

##### **Travel to Ghost Ranch Conference Center, near Abiquiu, New Mexico - Drs. Helper and Kerans – See Route Map 2**

The drive this day to our final field destination is a beauty, taking us out of the San Juan Mountains and along the upturned northeastern edge of the San Juan Basin to the very eastern edge of the Colorado Plateau at Ghost Ranch near Abiquiu, NM. The “San Juan Skyway” from Molas Lake south to Durango traverses the southern flank of the La Plata Dome, descending from 10,000’ through first Mesoproterozoic crystalline rocks at the highest elevations into south dipping Paleozoic and then Mesozoic sediments as it follows the glacial Animas River valley to Durango. Turning east toward Pagosa Springs, we drive between hogbacks of the Mesozoic section upturned by the La Plata Dome, then wind our way southeast between the edges of the San Juan Basin and San Juan Volcanic Field to cross a drainage divide near Chama, NM. From Chama we descend a glacial valley through yellow and black, then gray, white, yellow and red Cretaceous, Jurassic and Triassic strata to arrive at Ghost Ranch. Here we camp in the canyon country made famous by Georgia O’Keefe. These colorful cliffs of the Mesozoic Colorado Plateau sequence will be the focus of our final project.

#### **DAYS 39-41 (July 1-3)**

##### **Aeolinites and evaporites – sedimentology and stratigraphy of the Jurassic Morrison, Todilto and Entrada Formations – Drs. Mohrig and Kerans**

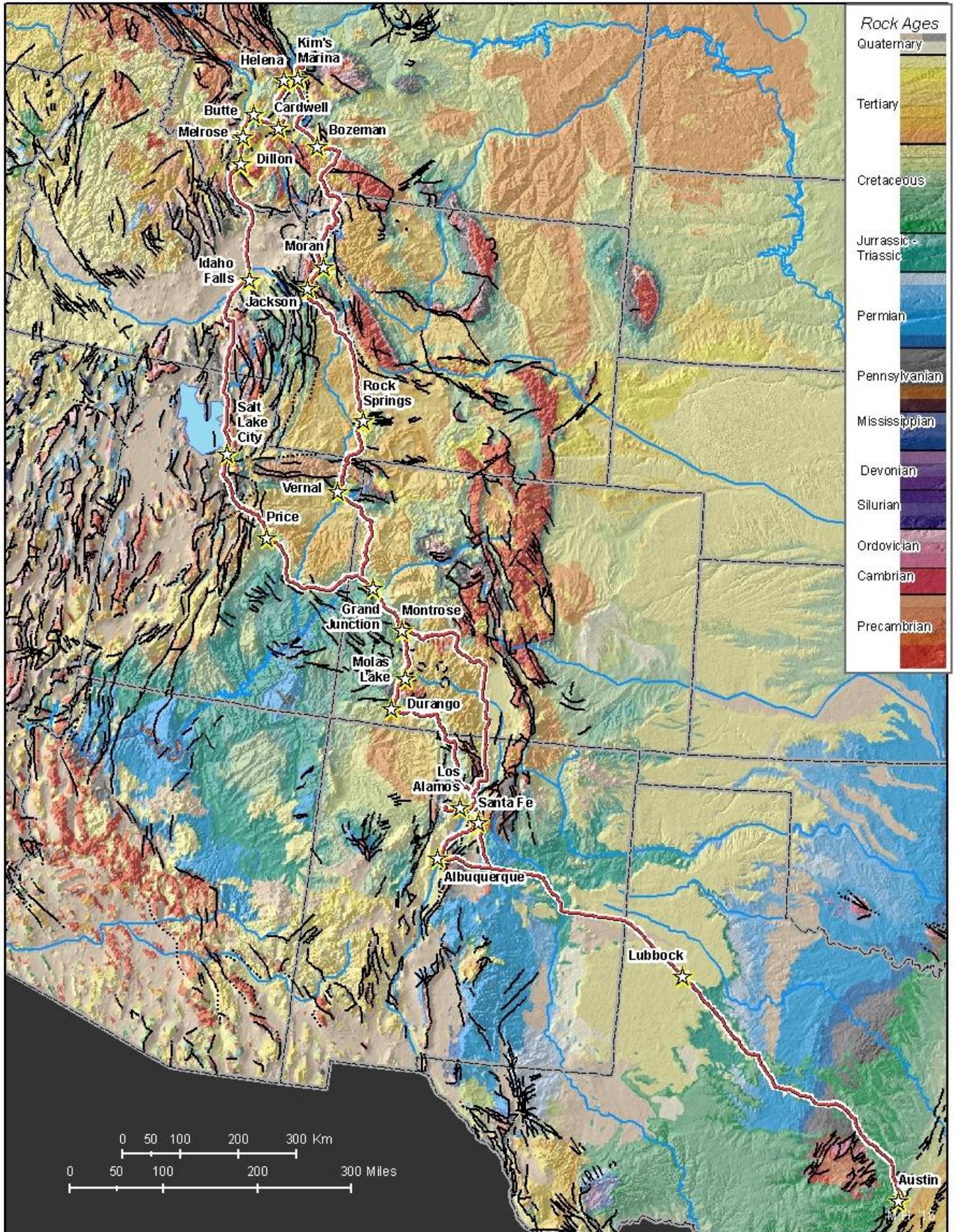
Here we measure, describe and interpret the stratigraphic and depositional contrasts between aeolian dune sandstone of the Entrada Formation and overlying gypsum beds of the Todilto Formation, as exposed in the walls of the canyons surrounding our campground.

#### **DAY 42 (July 4)**

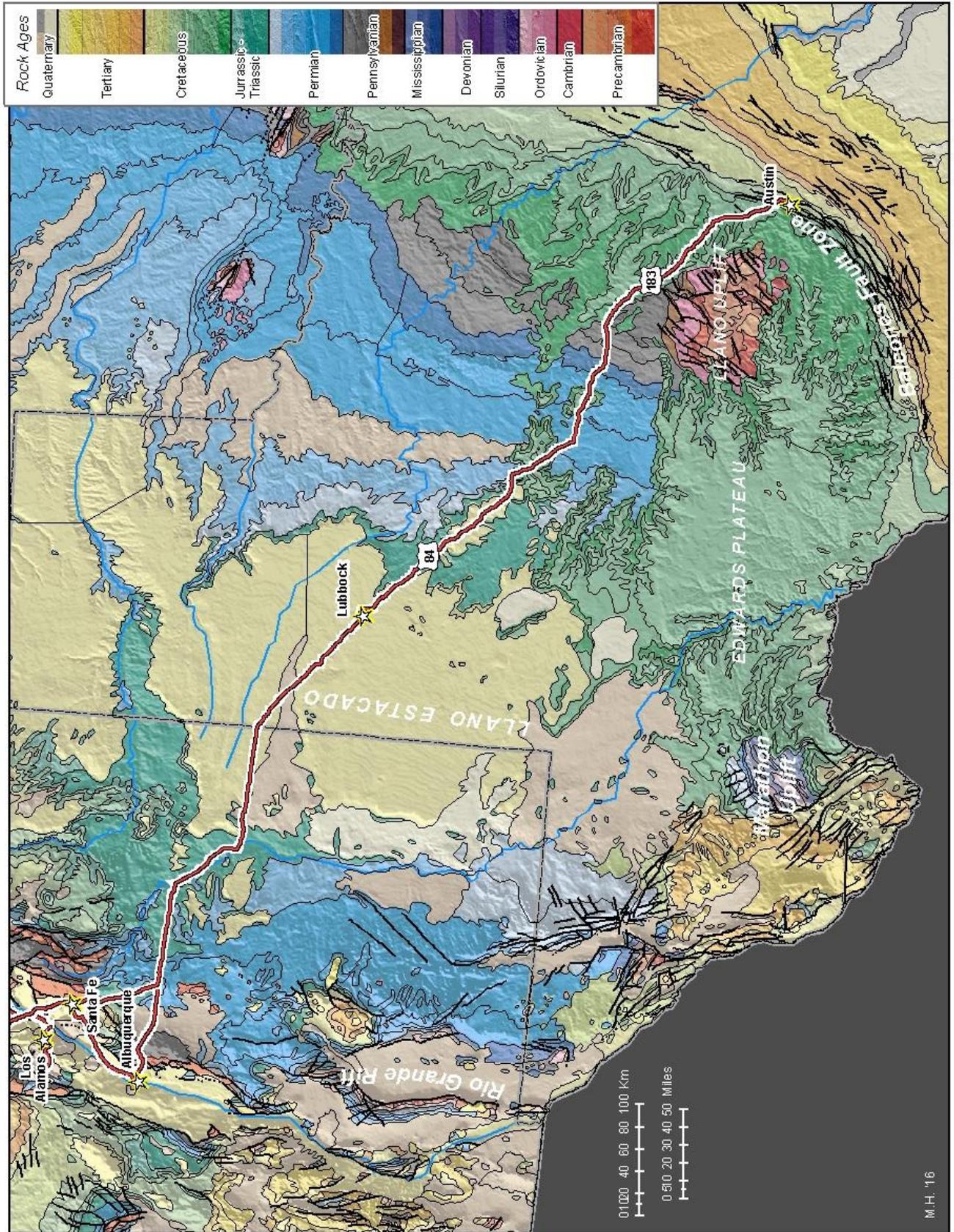
##### **Travel to Austin - Drs. Mohrig and Kerans – See Route Map 2 and 1**

An early departure and very long drive this day once again takes us across the Rio Grande Rift to Santa Fe, retracing from there much of the route of Day 1 across the eastern rift shoulder, the high plains of the Llano Estacado and the Edwards Plateau as we near Austin. It’s been 5700 miles of geologic immersion, with memories of experience to last a lifetime - what a class, what a trip!

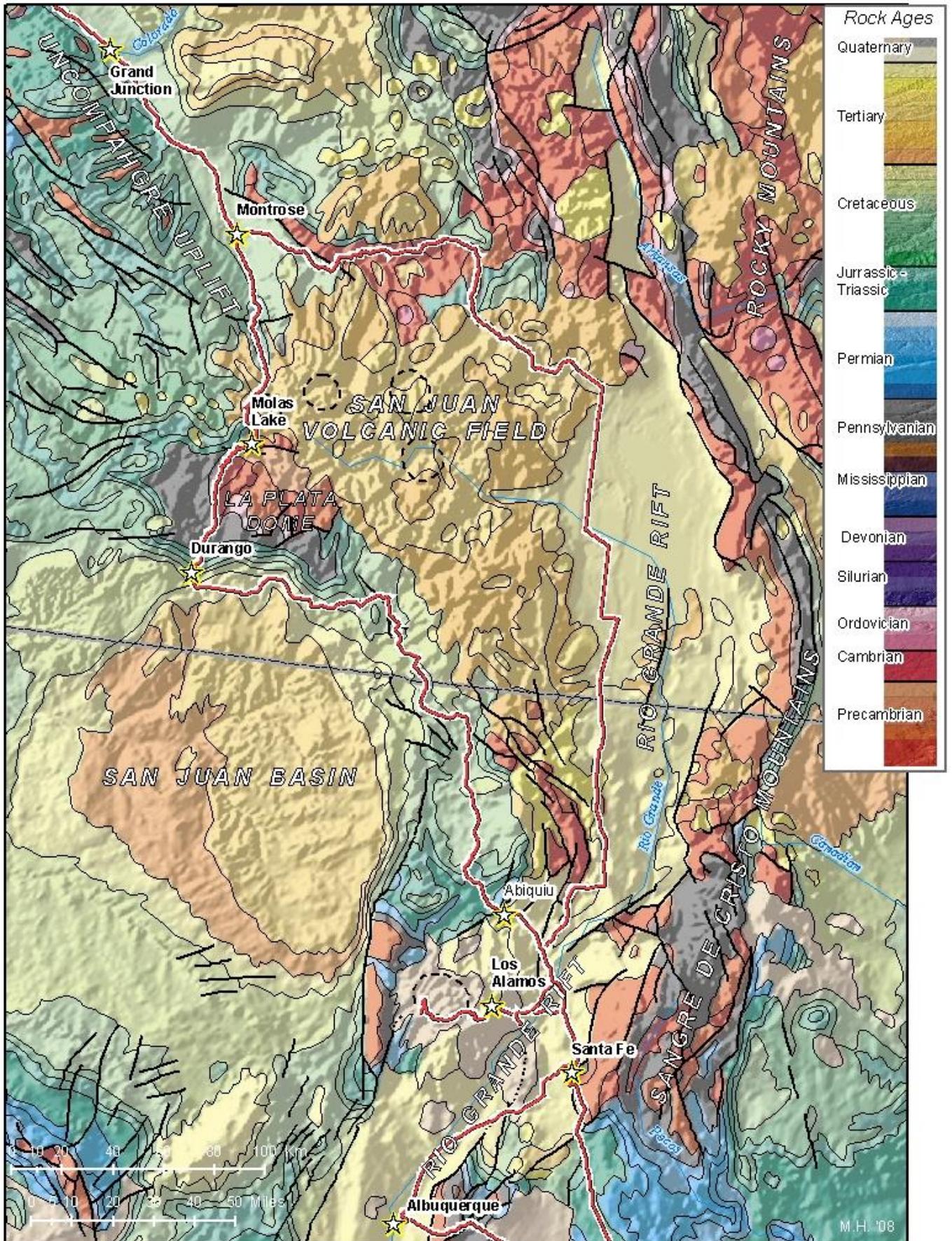
# Geo660 Summer 2016 Geological Route Map



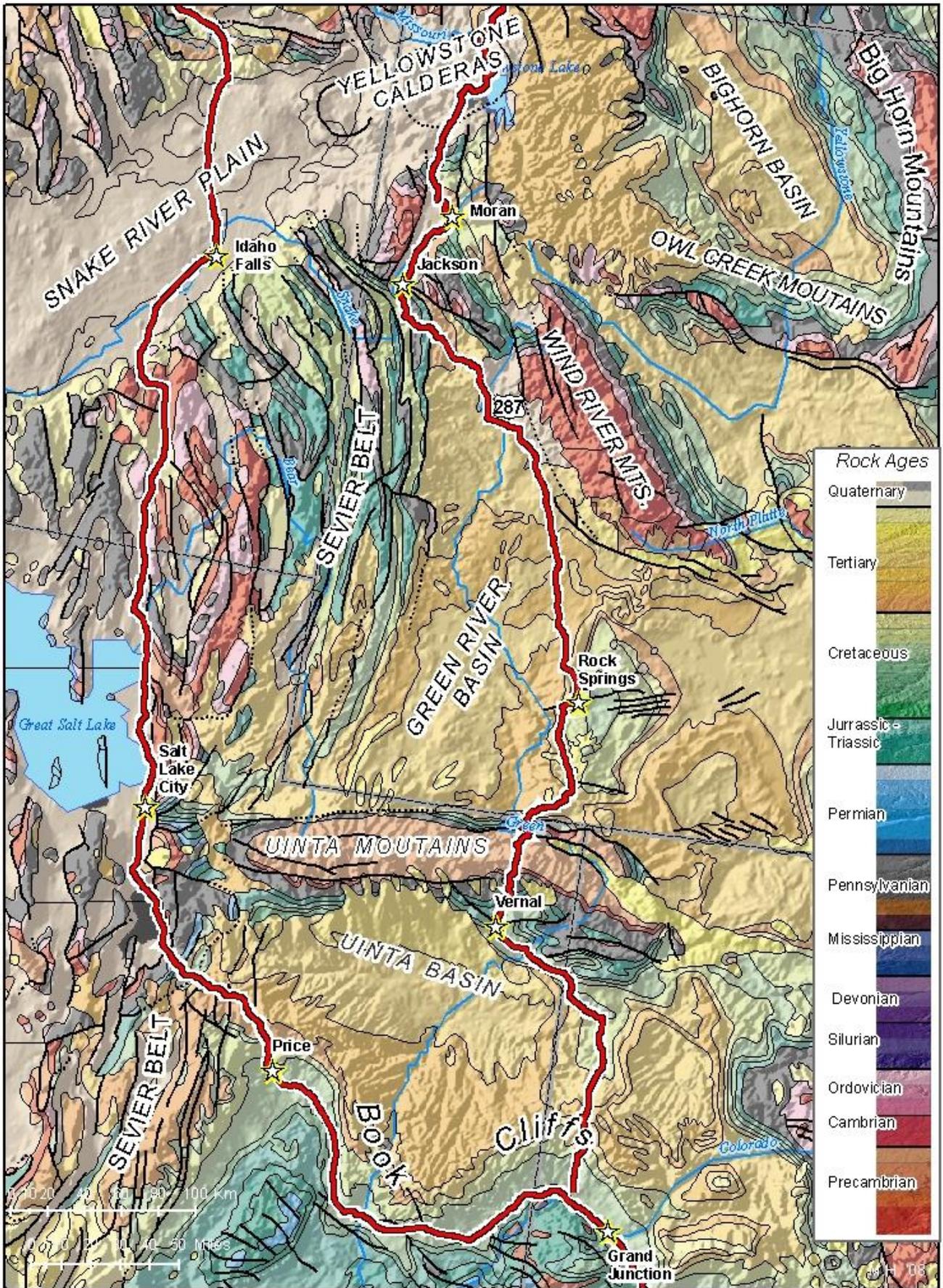
Route Map 1 – Austin, Texas to Albuquerque, New Mexico



Route Map 2 – Albuquerque, New Mexico to Grand Junction, Colorado



Route Map 3 – Grand Junction, Colorado to Yellowstone National Park, Wyoming





# Being Academically Prepared

## Sedimentary Geology

Below are listed some general aspects of sedimentary geology that you will be expected to have mastered by the time you leave for Geo 660. All of this material was covered in Geo 416M and Geo 420K. The best sources for your review are your notes, the text, and the web sites for these courses.

### **1. Classification of rocks and sediment by texture**

You must be able to classify terrigenous sediments and rocks by texture (e.g., poorly sorted, immature, fine-grained sandstone). This means that you must be able to identify the mean grain size, estimate the grain sorting, recognize the four stages of textural maturity, and recognize grain shape and roundness. You should be able to tell if the sorting reflects a unimodal, bimodal or polymodal grain distribution. Impact scars on pebbles and larger grains are important to identify. Rock color also reflects important aspects of the rock. You must have an understanding of the factors that control these sediment/rock characteristics. For sandstones and conglomerates be able to estimate the abundance of framework grains, matrix, cement, and porosity using your hand lens.

You must be able to distinguish those rock aspects that are depositional in nature from those that result from weathering. For example, weathering commonly results in the oxidation of pyrite and other ferrous minerals, differential dissolution of minerals, hydration, oxidation, and case-hardening of joints. Precipitation of travertine crusts and soluble white salt crusts (efflorescence), as well as Liesegang bands, are post-depositional products. In addition, it is usually possible on outcrop to recognize basic lithology (e.g., sandstone, limestone, shale) by weathering habit.

Be able to classify carbonate rocks according to the Dunham classification, including identification of major grain types. Know the major taxonomic groups of invertebrate fossils and their environmental significance. Know the marine evaporite mineral sequence.

### **2. Classification of rocks and sediment by mineralogy**

Be able to classify sediment and rocks by mineralogy (e.g., arkose). For sandstones be able to estimate the type of common cements (quartz, calcite, dolomite, siderite, iron oxides, kaolinite), the abundance of QFR components, and clan name using the Folk classification. Understand the relationship between mineralogy, source area, and other controls such as climate, tectonism and nature of transport.

### **3. Sedimentary structures**

You must be able to identify sedimentary structures and understand under what conditions they form. Be able to identify common fossils, know their age ranges, and environmental significance. Below are listed some common sedimentary structures and other features of sedimentary rocks. You should be able to recognize these, understand how they form, and interpret their genetic significance.

Laminations	Breccia
Wind-ripple laminations	Paleokarst
Trough cross-strata	Evaporite molds
Tabular cross-strata	Inter vs. intraparticle porosity
Current ripple and climbing ripple cross-strata	Boundstone
Wave ripple cross-strata	Geopetals
Hummocky cross-strata	Fenestral fabric
Textural mottled bedding	
Structureless (massive) bedding	
Graded and reverse graded bedding	
Contorted bedding	
Nodular bedding	
Flaser and lenticular bedding	
Herringbone cross-strata	
Scour-and-fill structures	
Channel walls and channel-fills	
Cryptalgal laminations, stromatolites (laterally linked and stacked hemispheres)	
Bouma sequence	
Wave and current ripple marks	
Trace fossils: burrows, tracks, and trails	
Flute casts, groove casts, load casts	
Parting lineation	
Mud cracks	
Stylolites	
Liesegang bands	
Chert and other nodules, calcite-cemented concretions (and other types)	
Cone-in-cone structure	
Adhesion structures	

#### 4. Depositional and diagenetic environments and processes

You must be able to make a basic interpretation of environment of deposition (e.g., deep-sea turbidite sequences, meandering fluvial channel). You should be able to determine whether the seafloor was well oxygenated, suboxic, anoxic. Clues are TOC (reflected in rock color), presence of absence of trace fossils, abundance of pyrite, etc. Most information is derived from the larger-scale geometry of the strata. You should always scan an outcrop for the continuity of beds, the overall strata arrangement, faults, channel structures, and vertical trends before studying the rock up close.

For carbonate and evaporite environments, review the shelf-to-basin facies tract, the environmental factors important for carbonate/evaporite production, the different styles of carbonate shelf architecture as a function of changes in sea level, climate, time in geologic history. Review the principal mechanisms proposed for (1) changing sea level, (2) dolomitization, (3) subaerial and subaqueous evaporite deposition, (4) cyclic sediment deposition.

## **5. Field methods**

You must be able to perform basic field procedures including (1) measuring a section with a staff and Brunton compass or similar instrument, (2) identifying textures and mineralogies with a hand lens, and (3) using a Brunton compass or similar instrument to measure bedding and foreset orientations, (4) operate a hand-held GPS instrument.

## **6. Data presentation**

You must be able to display geological information in various formats including (1) vertical sections, (2) scaled field sketches, (3) cross-sections, (4) neatly drafted maps, (5) stereonets.

## **7. Basin-scale processes**

You must have a basic understanding of (1) tectonic basin types, (2) the types of environments associated with these, and (3) the types of sediments characteristic of the different types of basins and source areas.

## **8. Global-scale processes**

You must have a basic understanding of the depositional architectures and their scales as a function of cycles of sea level, climate and tectonism. Know the general history of Earth change (e.g., greenhouse/icehouse periods, first-order sea-level curve), and the basics of higher order processes such as orbital forcing of Earth's climate.

## **Structural Geology & Mapping**

The topics and the skills outlined below were covered in GEO428, 426P, 420K, 416K and 401/303, particularly in labs and/or field trip exercises. Notes, texts, old labs and web sites for these courses are particular valuable resources for review.

- 1) Be able to read a topographic map, construct a topographic profile along a line of section, and have the ability to accurately locate yourself with a topographic map.
- 2) Have a good understanding of strike lines (structure contours), 3-point problems, the rule of V's, and how these are manifest on geologic maps by unit contacts, fault traces, fold axial traces.
- 3) Be able to correctly use a Brunton compass to measure the attitudes of linear and planar features.
- 4) Be able to construct stereographic projections of the attitudes of lines and planes, and determine a fold axis from attitude measurements of folded layers.
- 5) Be able to appropriately label maps and cross sections (and where these items belong on a finished product): title, author, date, north arrow, scale bar, contour interval, stratigraphic symbols, explanation of symbols, location of cross section; endpoints of cross section, orientation of cross section, vertical scale, and vertical exaggeration.
- 6) Be able to draw a structural cross section; know how to project data from a map into the plane of a cross section.

- 7) Know fold terminology and map symbols: fold axis, axial surface, hinge line, axial trace, plunge, fold limbs, cylindrical, overturned vs. upright, parallel vs. non-parallel, angular vs. curved.
- 8) Know fault terminology and map symbols: thrust, normal, strike slip, footwall, hanging wall, displacement, dip and strike separation, fault tip, fault ramp, detachment, listric, thin-skinned vs. thick-skinned, releasing and restraining bends.
- 9) Be able to interpret a geologic map, including relative ages from superpositional or cross-cutting relationships, dip directions from map patterns, anticlines vs. synclines and directions of plunge, axial trace symbols, up vs. down sides of faults from map patterns.

### **Igneous Geology**

- 1) Know how to classify igneous rocks using compositional criteria (intrusive rocks: granite, granodiorite, gabbro, peridotite; extrusive rocks: rhyolite, andesite, dacite, basalt) and textural criteria (tuff, welded tuff, vitrophyre, etc.), and apply appropriate adjectives (porphyritic, aphanitic, phaneritic, etc.).
- 2) Be able to identify common minerals in igneous rocks with a hand lens. These include, but are not limited to, quartz, plagioclase, k-feldspar, biotite, muscovite, clinopyroxene, amphibole (hornblende) and olivine.
- 3) Have an appreciation for the geological settings in which different igneous rocks might be found.

### **Metamorphic Geology**

- 1) Know how to classify metamorphic rocks (slate, phyllite, schist, gneiss, hornfels) and apply appropriate adjectives (granoblastic, porphyroblastic, foliated, etc.).
- 2) Be able to identify common metamorphic minerals with a hand lens. These include, but are not limited to: i) minerals common to most metamorphic rocks: quartz, plagioclase, k-feldspar, biotite, muscovite, chlorite, ii) pelites: garnet, aluminosilicates (andalusite, kyanite, sillimanite), staurolite, iii) metabasites: clinopyroxene, orthopyroxene, amphibole (hornblende, tremolite/actinolite), and iv) metacalsilicates/metacarbonates: calcite, dolomite, talc, tremolite, wollastonite, diopside.
- 3) Have an understanding of the concepts of metamorphic facies, P-T and T-X grids and isograds, including an appreciation of the dependence of mineral assemblages on rock composition, temperature, pressure and fluid composition/availability.
- 4) Understand the relationship of fabrics defined by metamorphic minerals to minor and major folds and faults/shear zones.
- 5) Know metamorphic index minerals for pelitic and mafic rocks.