DALHOUSIE UNIVERSITY

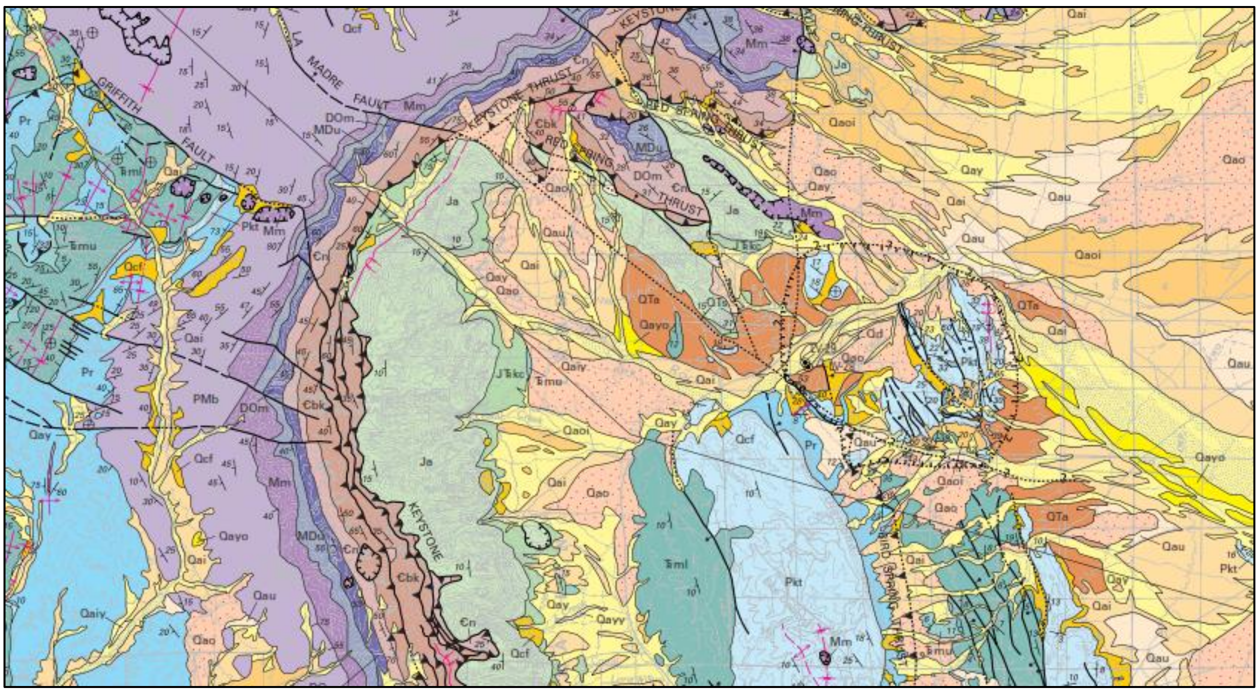
ERTH 4004: ADVANCED FIELD GEOLOGY

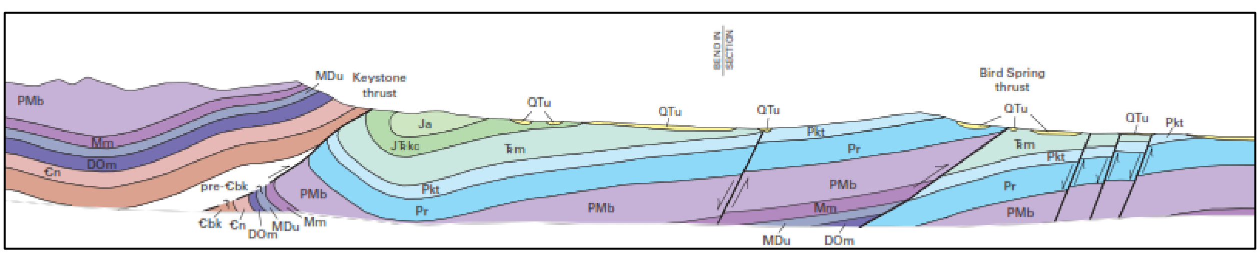
APRIL 25 – MAY 22, 2024

SOUTHERN NEVADA AND EASTERN CALIFORNIA

Instructors	**TAs**
Mike Young	Erin Hilliard
John Gosse	

"*Beneath all the wealth of detail in a geological map lies an elegant, orderly simplicity*" -- Tuzo Wilson





Excerpt from: Page, W., Lundstrom, S., Harris, A., Langenheim, V., Workman, J., Mahan, S., Paces, J., Dixon, G., Rowley, P., Burchfiel, B., Bell, J., Smith, E., 2005. Geologic Map of the Las Vegas 30'x60' Quadrangle, Clark and Nye Counties, Nevada, and Inyo County, California: U.S. Geological Survey Scientific Investigations Map 2814, 1:100,000

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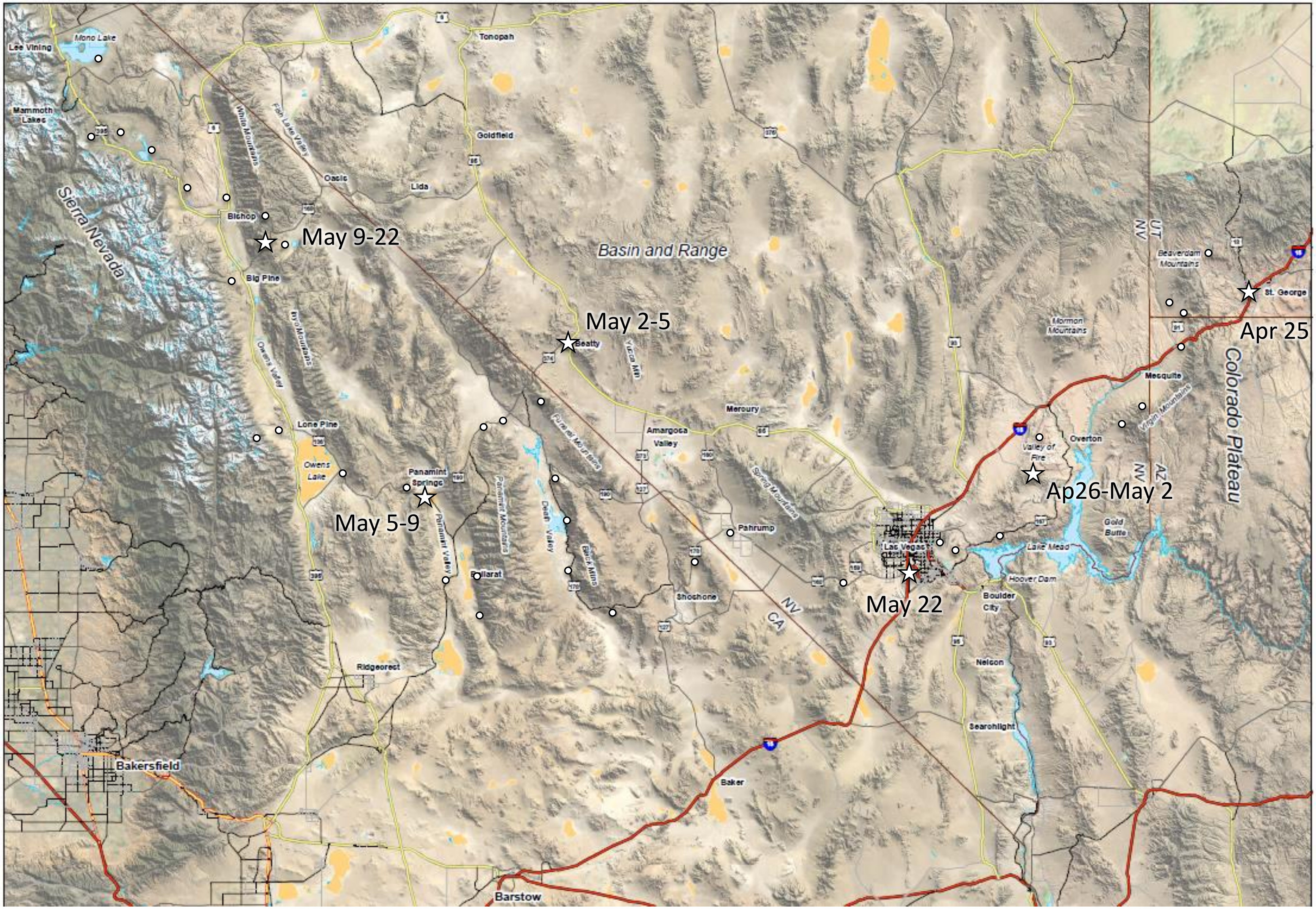


Location map of ERTH 4004: Advanced Field School 2024. Campsites indicated by stars and field locations by dots.

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
April 21 MDY and TAs arrive in Vegas Stay: Travelodge	22 Stay: Travelodge	23 Shopping – non-perishables and equipment Last day of exams Pickup SUVs at 10am Stay: Travelodge	24 Pack Trailer AM More shopping - PM (VoF Check-in 2pm) Stay: Travelodge	25 (Day 1) **Field School starts**; ~7:30am depart for St George, Utah Walmart, Frenchman Mtn, Virgin Gorge Stay: Rodeway Inn	26 (Day 2) Field Trip: Basin & Range. Castle Cliff Detachment, Muddy Creek Fm, Horse Spring Fm, Stay: Valley of Fire	27 (Day 3) Field Trip: Cabin Canyon & Precambrian rocks Shopping Mesquite - perishables Stay: Valley of Fire
28 (Day 4) Intro to Rainbow Gardens exercise Stay: Valley of Fire	29 (Day 5) Rainbow Gardens exercise Stay: Valley of Fire	30 (Day 6) Rainbow Gardens exercise Stay: Valley of Fire	May 1 (Day 7) Write up morning. Field Trip to Lovell Wash Canyon? Stay: Valley of Fire	2 (Day 8) Camp Move Day Death Valley, Turtlebacks? (VoF checkout 11am) Stay: Beatty Motel	3 (Day 9) Monarch Canyon Stay: Beatty Motel	4 (Day 10) Monarch Canyon Stay: Beatty Motel
5 (Day 11) Camp Move (5-6 hours). Field Trip: Soils, Fans, Wildrose Graben Stay: Panamint Springs	6 (Day 12) Manly Fan: Find the faults Stay: Panamint Springs	7 (Day 13) Manly Fan: Map the fan Stay: Panamint Springs	8 (Day 14) Manly Fan: Displacements and interpretation Stay: Panamint Springs	9 (Day 15) Camp Move (5-6 hrs) Whitney portal, Alabama Hills (Ferguson booked) Stay: Westgard Pass	10 (Day 16) Manly Fan: Write-up Bristlecone Pine Forest Stop at Owens River Stay: Westgard Pass	11 (Day 17) Poleta Stratigraphy (Little Poleta sections) Showers, laundry Stay: Westgard Pass
12 (Day 18) Little Poleta Mapping Stay: Westgard Pass	13 (Day 19) Long Valley Field Trip Stay: Westgard Pass	14 (Day 20) Big Poleta Mapping Guided Tour: Canoe to Black Hole Stay: Westgard Pass	15 (Day 21) Big Poleta Mapping: Stay: Westgard Pass	16 (Day 22) Big Poleta Mapping Interviews #1 Stay: Westgard Pass	17 (Day 23) Big Pine Skarn Stay: Westgard Pass	18 (Day 24) Big Poleta Mapping: Scissors Field Trip Stay: Westgard Pass

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
19 (Day 25) Big Poleta Mapping: Interviews #2 Stay: Westgard Pass	20 (Day 26) Big Poleta Mapping Last Day in the field Stay: Westgard Pass	21 (Day 27) Poleta Maps due at 5pm Stay: Westgard Pass	22 (Day 28) Break camp; drive to Vegas (5 hrs) **Field School ends** Stay: Travelodge	23 Most students depart Pack storage locker. return SUVs by 10am Stay: Travelodge	24 Camp Manager departs Stay: Travelodge	25 MDY departs
26	27 Memorial Day (US)	28	29	30	31	June 1

April 24: Dalhousie students arrive in Las Vegas; meet at **Days Inn, 5075 Koval Ln;** depart for St George, UT;

April 25-27: Intro to Basin & Range, detachment faults, growth faults and syn-tectonic basins; field trip days
Stay at Quality Inn Apr 25th and Valley of Fire campsite Apr 26th. Each person will be responsible for their own food

Apr 28-May 1: Rainbow Gardens exercise; stay at Valley of Fire campground, Nevada
Potable water at campsite, pit toilets, no showers, no laundry

May 2-4: Monarch Canyon exercise; stay in motel in Beatty, Nevada
Toilets/water/showers/laundry. We will provide breakfast and lunch supplies. Each person will be responsible for dinner

May 5-9: Panamint Valley and Manly Fan exercise; stay in Panamint Springs Resort (camping)
Potable water and electricity at campsite, flush toilets, showers, no laundry

May 9-22: Sierra Nevada, Owens Valley & White Mountains; includes Poleta Folds and Big Pine exercises; stay at Camp Ferguson in Cedar Flats Group Campground in the White Mountains, California
Pit toilets at camp, no water/showers/laundry. Swimming/showers/laundry 20 min drive away in Big Pine

May 22: Return to Las Vegas; stay at **Days Inn, 5075 Koval Ln**

Cell phone service is unreliable in most places. No service at any of the camps and expect to get to town or a gas station once every 3-5 days. Roaming charges can add up quickly, so plan on a US travel add-on from your cell provider if you wish to text/call/internet.

Welcome to the 2024 Advanced Field School
Southern Nevada and eastern California

DALHOUSIE UNIVERSITY
Inspiring Minds

The Advanced Field School mixes remote wilderness camping and rigorous geological training in the desert of southern Nevada and eastern California. During the four-week field school, students will study spectacular geology, see amazing scenery and build long-lasting relationships.

Field geology is the science and technique of recognizing, describing and interpreting geologic features in the field. It comprises more than just putting lines on a map, although lines on a map are necessary, and we will spend a good deal of time doing this. Field geology involves working out

- Stratigraphy, the sequence and conditions of formation of rock units;
- Structure, the three-dimensional geometric arrangement of rock units; and
- Geologic history, the "interpreted story" of geologic events that produced the observed stratigraphy and structure.

The three are closely interrelated, and in the very interesting cases are completely inseparable.

The most successful field geologists are those with a broad knowledge of all aspects of geology and the ability to apply it to specific situations. Field geology teaches a multitude of field techniques and draws upon the skills learned in practically every course in your undergraduate geology curriculum.

The objective of this course is for the student to gain experience in the techniques of field geology by constructing geologic maps, reports and supporting diagrams. The interpretation of the features that are recorded on maps, cross sections and stratigraphic sections are as important as the construction of these diagrams. The field report is the vehicle for expressing interpretations of the origin and evolution of the geology studied.

Watch the 2014 field school videos for more information: http://www.dal.ca/faculty/science/earth-sciences/programs/experientia_learning/field-schools/advanced_geologic_mapping.html

Health & Safety: ***Safety is top priority***

- Please read the entire Rules, Regulations and Safety document. Each person will be required to acknowledgement that they have read and agree to the Rules, Regulations and Code of Conduct
- Any risk you take can endanger the lives of your mapping team or other people in camp. Be very cautious in everything you do. You should not perform any task that you feel you are not qualified to complete or attempt.
- We will begin each day with a safety briefing. Every mapping exercise will be done in at least groups of two. Members of a mapping team must not separate or lose visual contact. Remember to always be checking your surroundings for safety hazards.
- We will ensure everyone knows where the vehicles will be parked, and keys will be hidden near the vehicle. Extra first aid equipment and drinking water will be left in the vehicles.
- We will be conducting safety training and practice at the beginning of the field school and provide ongoing updates/refreshers.
- You must wear safety glasses or goggles when sampling an outcrop.
- Sun protection and hydration are the most important safety conditions. It is essential to have and use sunscreen, large brim sun hat, bandana, and at least 3 litres of water in the field. It is very hot and very dry in the desert. We recommend field boots, pants, and a light long-sleeve collared shirt for every day.
- Next to heat, snakes and cacti are significant hazards, as is working around cliffs and hiking on uneven ground.
- Days often start before 6:00 am and there will be lectures on many nights. Use your downtime wisely to optimize sleep time.
- Check that all appropriate vaccinations are up to date (eg., Tetanus, Diptheria etc…)
- Everyone will have to read and sign a few documents which will be distributed and explained separately
    - A Student Commitment to Study Abroad form. Created by Dalhousie's International Centre
    - Rules, regulations, code of conduct, and safety procedures for Advanced Field School. Separate copies will be made available
    - An Acknowledgement of Risk form
    - A Code of Conduct form
    - A Health and Safety form
    - An individual information form including relevant medical conditions
- Further Reading:
    - PDAC Field Safety Guide: http://www.pdac.ca/pdf-viewer?doc=/docs/default-source/public-affairs/health-safety---health-safety-field-guide---eng.pdf

A few other points and recommendations as per the University's International Travel Policy and best practices for the Advanced Field School:

1. Registering travel (under Before you Go)
    a. Send your flight itineraries to the email listed (DalhousieTravel@itinerary.internationalsos.com) and cc me (mike.young@dal.ca)
    b. Register with the Canadian Government through Registration of Canadians Abroad. Citizens of other countries should register with the foreign office of your home country.
    c. Register your Emergency Information (https://www.dal.ca/campus_life/ile/travel_abroad.html)
    d. Register for the General Pre-Departure course through Brightspace.

e. Arrange for out-of-country health insurance (check on your status with the DSU plan) and trip interruption and cancelation insurance.
f. Record this information on our Google Docs travel itinerary spreadsheet.

- Each person must download a number of apps to your smart phone
  - International SOS app. Install the app and register. We are to liaise with International SOS in case of an emergency. They can be contacted directly through the app or by calling 1-215-942-8478.
  - A GPS app that displays in UTM WGS 84 and Lat/Long. I recommend Gaia Maps or GPS Status & Toolbox. Many others available.
  - FieldMove Clino app for collecting geological information. And it displays GPS coordinates in Lat/Long on dashboard page. First responders will need this if called.
  - Google Maps App. You will need to download offline maps for the area between St George, UT and Mono Lake, CA. You will need ~160 Mb of space for the offline maps. Click on each link below and "follow" the Google Maps pins. Organized by date, most field school localities are listed including camps, emergency services and medical centers. Once you download the offline maps and "follow" the pins below, the location and contact information will be available even without cell service or wifi.
    - Emergency Services: https://goo.gl/maps/EbuKY1aoDGq
    - Apr 25: https://goo.gl/maps/fnUmZsBuqPy
    - Apr 26: https://goo.gl/maps/X9WeXyPEtTP2
    - Apr 27: https://goo.gl/maps/a1LJY3sWBU7Pt5caA
    - Apr 28-May 1: https://goo.gl/maps/cGzAo1vMhx72
    - May 2: https://goo.gl/maps/inTdP1B9evR2
    - May 3-4: https://goo.gl/maps/sLHs3BuzEDu
    - May 5-8: https://goo.gl/maps/ceuw1tAhgES2
    - May 9: https://goo.gl/maps/UcPHLF22wUG2
    - May 10-22: https://goo.gl/maps/JBXLzTu7FGL2
    - Big Pine Skarn: https://goo.gl/maps/dZWMkQWkatT2
    - Long Valley Trip: https://goo.gl/maps/3RNAZQ4yWsp
- Missing or incomplete paperwork and/or not following or completing the safety procedures as outlined above and below in the Rules, Regulations, Code of Conducts & Safety Procedures section may result in denial of participating in field school.

Gear to Bring:
We will not have much spare time to go shopping. Please plan accordingly and bring the gear listed below with you. The field school does provide communal gear for the kitchen and office.

In addition to a daypack, you are allowed 1 medium-sized duffle bag for personal gear and 1 other duffle bag shared with another student for a tent and sleeping bags/pads. Your daypack must be large enough for your geology kit, hiking equipment, raingear, and 3-4 liters of water. Note that the maximum size of checked luggage for US bound flights is 50 lbs.

When hiking, you will need to carry a fair bit of this equipment in your day pack. Choose a pack with this in mind. The following is a list of gear that you do need to bring:

What we provide:

- Base maps and aerial photos
- Good quality tracing paper (vellum) in several sizes
- Acetate or Mylar overlay sheets
- Other paper for cross sections, etc.
- Brunton compasses
- Well-stocked first aid kids with each field camp vehicle
- Lecture tent with tables and chairs
- Electricity (generator) to charge your gizmos
- Food and a well-equipped kitchen

Geological Field Gear

____ **Hand lens**: Belomo ($30 USD on Belomo website) and lanyard (Bookstore)

____ **Hand lens lanyard**: Belomo ($4 USD on Belomo website). Other lanyards are acceptable, but they must be high quality and rugged. Break-away features tend to wear out. 32" boot shoelace works well in place of a lanyard. Lens and Lanyard are sold as a kit at Bookstore

____ **Compass**: Brunton and/or Suunto. Sign out from department.

____ **Hammer**: Estwing Long Handle 22 OZ (Bookstore) or Estwing Standard Handle 22 OZ ($50). We need a few hammers but not necessarily one each.

____ **Safety Glasses:** (Bookstore). Sunglasses ok.

____ **Notebook:** Orange Forestry notebook (Bookstore). Or, Rite-in-the-Rain ($19 USD; 370F-M, yellow 4.25"x6.75" or 970F-M, green 4.25"x6.75"; 540F for ERTH 3001)

____ **Plastic Acid Bottle:** (Bookstore**).** BAP equipment ($2.50). Optional.

____ **Pen magnet with Scriber**: (Bookstore). or Deakin ($16). Optional.

____ **Field Sheets Manual**: (Bookstore). custom made by Earth Sciences;

Other Required Field Equipment

____ Supply of 0.5 mm mechanical pencils

____ Extra erasers or eraser pen

____ Fine-tipped ball point pens (black and blue)

____ Technical Pens: Pigma pens by MICRON seem to be best. Bring 2-3 “01” pens for general linework and lettering. Bring 1-2 “03” black (red optional) for fault traces (black). Ink unfortunately tends to outlast the fine tips. Available at Bookstore or DeSerres

____ Medium-point marking pen (eg., sharpie)

____ Pencil crayons (set of 24 is great; a set of 12 will work fine).

____ Pencil sharpener

____ White out

____ Masking tape (1 roll)

____ Clear plastic ruler (Grain size ruler will suffice)

____ Belt (required) and/or hammer loop No. 23 or other gear pouches (optional)

____ Clipboard; a folding covered clipboard works best. Flimsy clipboards do not work well, and map will degenerate rapidly. (8.5x11 minimum; but 8.5x14 is better)

____ Watch (not just your smartphone)

____ Personal first aid kit with tweezers, bandages, moleskin, alcohol wipes, pain medication (eg., acetaminophen or ibuprofen), and comb for removing cacti

____ Plastic sandwich box (lids that latch and seal are best)

Camping Gear

____ Waterproof (and wind resistant) tent; extra/stronger tent pegs recommended; 50’ paracord

____ Sleeping bag (rating of -10C or better recommended)

____ Sleeping pad (very important to keep you comfortable and warm); patch kits

____ Backpack (30L or larger)

____ Wide-brimmed hat (with straps – it’s windy)

____ Water bottles and/or water bladder (minimum 4 litres)

____ Sunscreen (sunblock with zinc and/or titanium oxide recommended). 30 SPF min. Tinted recommended

____ Pocket knife (multi tools are best)

____ Headlamp/flashlight

____ Camera

____ Toiletries: towel, washcloth, soap, shampoo, deodorant, baby wipes, tweezers, nail clippers, scissors, etc…

____ Prescribed medication to last the entire duration of camp

Field Clothes and Personal Items

- ____ Sturdy hiking boots. These should be over the ankle, with stiff soles and uppers. These MUST be broken in before camp. We recommend waterproof, breathable boots with good ankle support. Pack spare laces.
- ____ Shoes or sandals other than boots to give your feet a rest when you are not in the field
- ____ Several pairs of Smartwool or similar hiking socks
- ____ Rain jacket. Ponchos are not recommended.
- ____ Work/field pants - 2 pair
- ____ Work/field shirts – 2 long sleeved, 2 short sleeved; several T-shirts
- ____ Hiking shorts – 1 pair
- ____ Sweatshirt or sweater
- ____ Warm jacket (it will get cold in the evenings)
- ____ Underclothes (minimum 8-10 complete sets including hiking socks)
- ____ Winter (toque) and summer hat and/or bandanas
- ____ Swim suit
- ____ Wet wipes, face/moisturizing cream, lip balm, diaper cream or similar
- ____ Work gloves/winter gloves. Be prepared for rain AND snowstorms in the field.
- ____ Wide brimmed hat with chin strap for sun protection, bandanas, buffs
- ____ Sunglasses

General Tips: Don't pack too many dressy clothes. We'll spend most of our days outdoors -- people who are sun-sensitive should dress accordingly. Don't over pack – we don't have the space for stuff not on these lists. Laundry will be available about *once a week*.

Note that we will experience extreme temperature variations. From below freezing at night in some camps to above 40^{0}C in the middle of some days. In fact, we may experience these variations in the same day. Plan accordingly and bring hot- and cold-weather clothing.

Medication: If you require any type of medication (allergies or any other type of medical condition, i.e., an effective pain reliever, topical creams for rashes, other prescription medication, etc...) bring what you need for the field school with you.

Please inform the Instructors if you have a medical condition that requires immediate or constant medication. Also inform the Instructors and TAs if you have food allergies or other dietary preferences.

Travel:

Everyone requires a valid passport to travel to the US. Please check that your passport will not expire within 6 months of your expected return date.

Dalhousie students and staff must book and pay for their own flights. We will meet at Days Inn, 5075 Koval Ln at 7:00 AM on April 25th, 2024. Rooms for everyone will be reserved at Days Inn the night of April 24th. We will arrive back at Days Inn, 5075 Koval Ln on May 22nd by ~4:00PM. Motel rooms are booked for everyone the night of May 22nd. If booking return flights on May 22nd, ensure it departs no earlier than 10pm in case we are delayed arriving back to Las Vegas.

During Field School, we will travel between field sites and camps using one rental SUV, a pickup truck which will tow a cargo trailer. Only field school staff are permitted to drive these vehicles. Personal vehicles are not permitted at field school.

Camp Setup:

Camp life is an integral part of field school. We expect everyone to contribute to a vibrant and well-functioning camp community. To encourage this, we have designed a mobile, fully-equipped camp including an office tent, kitchen tent, generator and water pump system.

Kitchen tent and equipment:

The kitchen tent includes a 10x20 ft awning tent with two 3-burner propane stoves, one upright fridges, one cooler/fridge, a BBQ, and a double sink equipped with running (hot & cold) water. We have a generator which powers lights, electrical outlets, the fridges, and a water pump system. The water pump system includes a ¾ hp pump and pressure tank hooked up to two 70-gallon water tanks and a water heater. We want to ensure a high standard of sanitation for meal preparation and clean up.

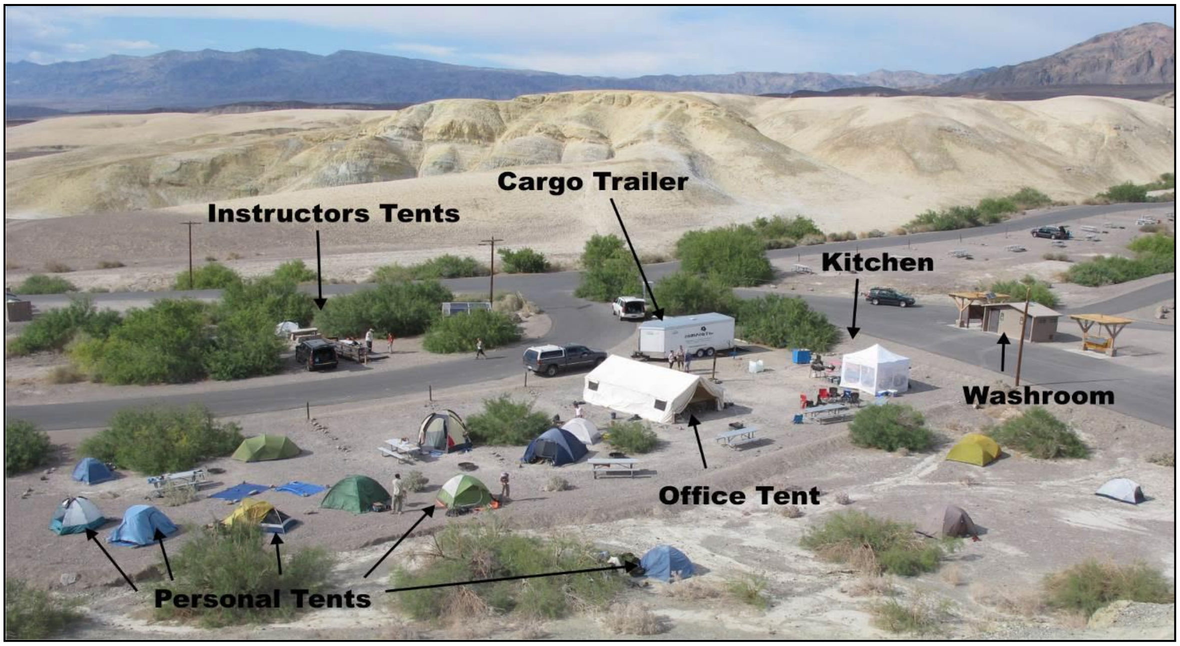
Under the supervision of an instructor or camp staff, students will take turns with dinner preparation for the entire group, breakfast and lunch preparation, and clean up. Students will divide themselves into groups and a rotating schedule will be posted. The camp manager will do the grocery shopping, but the cooking groups are encouraged to work with them to set menus and quantities.

Office and Lecture Tent:
The office tent is a 14x24 ft heavy duty canvas long house. Folding tables and chairs are provided as well as lights so that students can work on their maps, cross sections and reports each evening.

Communal areas:
At each campground, there will be designated areas for socializing including fire pits, picnic tables and shade umbrellas. We will provide folding camp chairs for everyone. We will start early and end early in order to work in the cooler part of the day leaving the afternoon prior to dinner for down time. Some students choose to do their work during this time, others will relax and socialize. At some of the campsites there are lakes, rivers or swimming pools will be available to go swimming. Also, some campsites or nearby towns have shower and laundry facilities. After dinner and cleanup, we will often have a campfire.

All campgrounds have toilet facilities. Some are rudimentary outhouses while others have flush toilets and running water.

Personal Tents:
Personal sleeping tents, sleeping bags and sleeping mats are not supplied and must be brought by each individual. In order to reduce weight, we ask that students arrange to share a tent with at least one other person. This will reduce the number of tents and therefore luggage. As mentioned earlier, we will experience extreme temperature variations, so it is important to bring a warm sleeping bag and a sleeping pad. Check your tent and other equipment before departing to make sure all of the pieces (poles, pegs, ropes) are included. A lightweight ground sheet/tarp will help prevent rips in the tent when set up on sharp rocks.



Camp setup in Death Valley 2013

Daily Routine:

5:00-5:30am – wake up.

The breakfast crew will prepare coffee, hot water, porridge, and lay out breakfast and lunch material

6:00am – breakfast and lunch preparation

Porridge and cereal for breakfast; each person will prepare their own lunch. Dinner leftovers will be available for those who get up early.

7:00am – depart in vehicles for field work

Mapping pairs or groups will be assigned. Base maps and assignments will be provided and explained. Vehicles will be parked for the entire day in the same location with keys hidden nearby. Extra water and first aid equipment will be left in the vehicles.

7:30am – arrive at field site

Introductory lecture and safety briefing at field site. Mapping pairs or groups will conduct field work. Instructors and TAs will attempt to visit each group while in the field. Each mapping group will pace themselves during the day including breaks and lunch. Ensure you have enough food and water.

3:00-4:00pm – assemble at vehicles and drive back to camp

4:30-6:00pm – cooking group prepares dinner; downtime for others

At some camp sites, laundry/shower/swimming shuttles will be organized during this time

6:00-7:00pm – dinner

7:00-7:30pm – clean up crew does dishes and puts away leftovers

7:30-10:00pm – homework, evening lectures, camp fire

Most evenings students will have homework to do as well as planning for the next day. Usually there is a short lecture in the office tent from 8:00-8:30pm.

9:00-10:00pm – bedtime.

Check chore rotation list for the next day prior to going to bed in case you are on breakfast duty.

During camp move days, we will wake and have breakfast at the usual time and then as a group we will tear down camp and pack the cargo trailer. Usually this takes 1.5-2 hours. There will be number of field trips usually linked with camp move days. We plan to arrive by mid-afternoon at the next camp in order to set everything up and prepare dinner.

EMERGENCY CONTACT NUMBERS
APRIL 25TH TO MAY 22ND 2024

Name	**Cell Number**	**Alternate**	**Office**
Mike Young	902-789-7519	US#: 212-913-2884	902-494-2364
John Gosse	902-430-0684		902-494-6632
Erin Hilliard	867-993-3432		
Garmin inReach for emergencies			
Earth Sciences Office		fax: 902-494-6889	902-494-2358
Mladen Nedimovic (Chair)			902-494-2355
International SOS	**1-215-942-8478**	**Able to contact International SOS through App**	
Tom Duffett	902-478-2909	902-443-3355	902-494-3777
National Rent-A-Car	833-315-5902 (Roadside)		Vegas: 702-263-8411
Days Inn 5075 Koval Ln, Las Vegas	(April 21-25; May 22-25)		702-736-3600
Quality Inn, St George	(April 25-26)		435-673-6181
Valley of Fire Campground	(April 26-May 2)		702-397-2088
Death Valley Inn, Beatty, NV	(May 2-5)		775-553-9400
Death Valley National Park	(May 2-5)	760-786-2441;	760-786-3249 (or 3280)
Panamint Springs Resort, Darwin, CA	(May 5-9)		775-482-7680
Bristlecone Pine Forest Manager	(May 9-22)	877-444-6777;	760-873-2514
Inyo National Forest, Visitor Information	(May 9-22)		760-873-2523

Emergency Response Form, Department of Earth Sciences

SAFETY ITEM	INFORMATION FOR THE EXCURSION
Excursion Date and Time (departure / return)	April 25th to May 22nd (Staff will be at site April 21st to May 27th)
Location of Excursion	Southern Nevada and eastern California
Field Leaders	Mike Young: mike.young@dal.ca John Gosse; john.gosse@dal.ca
Designated Deputy Leaders (TAs)	Erin Hilliard; Hilliard.Erin@gmail.com
No. of Participants (including Leaders and Assistants)	Lindsey Burgess, Brighton Gaddes Bailey Grondin, Alyssa Jones Louis Lui, Grace Mombourquette Alex Parsons, Sarah Penttinen Emily Theben, Grayson Waldon
Emergency Equipment Present: First aid kit(s) available Other equipment (list)	Individual and group first aid kits and first aid kits in vehicles Benadryl, ibuprofen, sunscreen, water Each person is responsible for camping equipment including tents, sleeping bags, warm/cool clothing, personal first aid kit
Who has formal First Aid experience	Young, Gosse

Drivers with valid licenses and suitable license classification	Young, Gosse, Hilliard
Rental vehicle insurance coverage (collision, personal accident, theft)	Full liability coverage on each of the 2 rental vehicles
Local Emergency Telephone Numbers	911;
Other Emergency Numbers: Also available through our Google Maps pins: Emergency Services: https://goo.gl/maps/EbuKY1aoDGq Apr 25: https://goo.gl/maps/fnUmZsBuqPy Apr 26-27: https://goo.gl/maps/X9WeXyPEtTP2 Apr 28-May 1: https://goo.gl/maps/cGzAo1vMhx72 May 2: https://goo.gl/maps/inTdP1B9evR2	 See below for medical centre contact info May 2-4: https://goo.gl/maps/sLHs3BuzEDu May 5-8: https://goo.gl/maps/ceuw1tAhgES2 May 9: https://goo.gl/maps/UcPHLF22wUG2 May 10-22: https://goo.gl/maps/JBXLzTu7FGL2 Big Pine Skarn: https://goo.gl/maps/dZWMkQWkatT2 Long Valley Trip: https://goo.gl/maps/3RNAZQ4yWsp
Weather Forecasts	Marine forecast is checked every few days.
Tidal information	Not applicable
Nearest Medical Facilities and other contacts: Las Vegas (April 22-May 2 & May 22-25; <50 miles) • *www.northvista**hospital**.com* - 1409 E. Lake Mead Blvd., North Las Vegas (NE) - (702) 649-7711 • *www.springvalley**hospital**.com* - 5400 South Rainbow Boulevard, Las Vegas (SW) (702) 853-3000 • *www.valley**hospital**.net* – 620 Shadow Ln, Las Vegas, NV 89106 (Central) (702) 388-4000 • *www.mountainview-**hospital**.com* - 3100 North Tenaya Way, Las Vegas (NW) (702) 255-5000 • *www.summerlin**hospital**.com* - 657 Town Center Drive, Las Vegas (W) - (702) 233-7000 Mesquite, NV (April 25 – May 2) • *www.mesaview**hospital**.com* - 1299 Bertha Howe Ave, Mesquite - (702) 346-8040	 Beatty, NV (May 2-5) • http://www.nvhealthcenters.org/ - 702 Irving St, Beatty, NV – (775) 887-1590 Ridgecrest, CA (May 5-9) • Ridgecrest Regional Hospital 1081 N China Lake Blvd, Ridgecrest, CA 1 (760) 446-3551 Lone Pine, CA (May 5-22) • Southern Inyo Hospital; *www.sihd.org* - 501 East Locust Street, Lone Pine (760) 876-5501 Bishop, CA (May 9-22) • Northern Inyo Hospital; 150 Pioneer Lane, Bishop, CA, United States 760-873-5811
University Contact Numbers	Dalhousie Security: 902-494-6400

ACADEMIC MATTERS

Text Books (all are optional)

1. Chersterman, C.W. and Lowe, K.E. 1978, **The National Audubon Society Field Guide to North American Rocks and Minerals**, Knopf Publishing. Or other rock and mineral field guide
2. Stow, D, 2005, **Sedimentary Rocks in the Field, A Colour Guide,** Elsevier, Academic Press.
3. Coe, Angela L. 2010. **Geological Field Techniques.** Wiley-Blackwell, 336 p.
4. McClay, K., 1987, **The Mapping of Geological Structures,** Wiley and Sons.
5. ERTH 2110/3001/4002 Field School Manuals

All books are optional and some have been used in other ERTH courses.

All material submitted by you for a grade will be your independent work. This is not as simple as it sounds, in part because you will be working with at least one field partner during all exercises and projects. We do encourage the free exchange of ideas in the field and back at camp. In practice, "independent work" distills down to this: ***All data on your maps and in field notes was observed by you, and all work submitted for a grade was done by you.***

Example #1: Suppose that during a discussion with another group in the field, you and your partner(s) become aware of an important structure that you had missed in your mapping. On that basis alone, it would not be appropriate to enter that structure on your map or submit your map with that structure shown. However, it would be appropriate to enter the idea in your field notebook and to acknowledge the source of the idea. You and your partner(s) could then return to the area in question, see the structure, collect your own data, and enter your data on your map (in fact, you may decide that the other group is completely wrong!) What you submit as your work must in fact be your work. We encourage the sharing of ideas and observations (not data) with one another. This is part of the learning experience and process.

Example #2: Suppose that you encounter some students measuring the strike and dip of an outcrop. You plan to measure the strike and dip of this formation, but as you approach you hear one partner say to the other, "*Strike 238, Dip 72*". **What do you do?**
Answer: You do not enter that measurement in your field notes. You inspect the outcrop yourself and make your own measurements. They might have measured a joint instead of bedding, or they may have got the dip in the wrong direction.

GRADING CRITERIA

From Seminar Class	5%
Poster Presentation: 5%	
Quiz & photos	5%
Quiz: 3%	
Posting photos & captions: 2%	
Field Projects	75%
Bunkerville: 5%	
Rainbow Gardens: 12%	
Monarch Canyon: 8%	
Manly Fan: 20%	
Poleta Folds: 30%	
Field Grade**	15%

A+	A	A-	B+	B	
90-100	85-89.9	80-84.9	75-79.9	70-74.9	
B-	C+	C	C-	D	F
65-69.9	62-64.9	58-61.9	55-57.9	50-54.9	<50

****FIELD GRADE CRITERIA**

Field courses are challenging. It is especially tricky to have so many students working together under stressful conditions. In this course you will live in close quarters with a lot of others, work together in various groups for various tasks, and be challenged in many ways. It is essential that we all strive to make our own experience a rewarding and positive one. It is also important to work hard to make and maintain a constructive group experience. A single, consistent irritation to an otherwise positive group environment hurts everyone. In a similar way, a single act of cooperation, generosity or kindness can lift the entire group. Because your own actions heavily determine your ability to master the subjects of the course as well as influence everyone around you, a field grade will be part of your evaluation in the course. Here are the main subjective criteria used to determine your field grade.

- Independence: shows “attack”, self-motivation and initiative in problem solving
- Attitude: does not complain, helps others, exhibits a positive attitude at all times
- Participation: is punctual, follows directions, demonstrates safety in the field
- Competence: proficient, careful and respectful with field equipment
- Professionalism: respectful of yourself, fellow students, TAs and instructor
- Preparedness: is ready and willing for any situation or changes the field environment and class contingencies may pose

DEADLINES AND MISSED COURSE TIME

We work hard to make the grading in this course fair. In the professional world, "there are no finished products, there are only deadlines." So, we require everyone to turn in their reports at the imposed time. To be fair to all, if for any reason you are late in turning in your project, the following criteria will be imposed:

- Late, by any amount of time: deduct 20% of the grade on that exercise.
- Each additional hour late: deduct an additional 15% of the grade on that exercise.

Students are paired for most of their projects. It is expected that each student contributes equally to the field work and maps/reports due for each project. If a student misses more than ~20% of the field school (field work time and/or deliverables), they may be asked to withdraw from the course.

AUXILLARY FEES

Students must pay an auxiliary fee of $2000. The auxiliary fee covers food, transport, and lodging expenses while at field school. Students will be responsible for some meals (up to 6 dinners) during field school. Transportation to and from the field school location is the responsibility of each student.

ACCOMMODATION POLICY FOR STUDENTS

Students may request accommodation as a result of barriers related to disability, religious obligation, or any characteristic protected under Canadian Human Rights legislation. The full text of Dalhousie’s Student Accommodation Policy can be accessed here:
http://www.dal.ca/dept/university_secretariat/policies/academic/student-accommodation-policy-wef-sep--1--2014.html
it is the student’s responsibility to make an accommodation request under that Policy if they have previously met with the Accommodations Office and have an accommodations advisor, or if they believe there is a barrier to their participation in the Program that is due to a characteristic protected by human rights legislation. Students should also understand that the assessment of accommodation requests in relation to international field courses can be more complex and therefore they should make any necessary accommodation requests as early as possible. More information and the ***Request for Accommodation*** form are available at www.dal.ca/access.

ACADEMIC INTEGRITY

Academic integrity, with its embodied values, is seen as a foundation of Dalhousie University. It is the responsibility of all students to be familiar with behaviours and practices associated with academic integrity.
The Academic Integrity website (http://academicintegrity.dal.ca) provides students and faculty with information on plagiarism and other forms of academic dishonesty, and has resources to help students succeed honestly. The full text of Dalhousie’s ***Policy on Intellectual Honesty*** and ***Faculty Discipline Procedures*** is available here:
http://www.dal.ca/dept/university_secretariat/academic-integrity/academic-policies.html

STUDENT CODE OF CONDUCT

Dalhousie University has a student code of conduct, and it is expected that students will adhere to the code during their participation in lectures and other activities associated with this course. In general: “The University treats students as adults free to organize their own personal lives, behaviour and associations subject only to the law, and to University regulations that are necessary to protect:

- the integrity and proper functioning of the academic and non-academic programs and activities of the University or its faculties, schools or departments;
- the peaceful and safe enjoyment of University facilities by other members of the University and the public;
- the freedom of members of the University to participate reasonably in the programs of the University and in activities on the University's premises;
- the property of the University or its members.”

The code can be found here: http://www.dal.ca/dept/university_secretariat/policies/student-life/code-of-student-conduct.html

SCENT-FREE PROGRAM: https://www.dal.ca/dept/safety/programs-services/occupational-safety/scent-free.html

RULES, REGULATIONS, CODE OF CONDUCT, AND SAFETY PROCEDURES FOR ERTH 4004: ADVANCED FIELD GEOLOGY

Last updated 7 March 2023

INTRODUCTION

The principal objective of Earth Sciences field trips is to expose students to geology in the natural setting and to teach them to make accurate observations and interpretations based on field relationships. These rules and regulations are designed to maximize the learning environment and maintain the highest safety standards possible for yourself and others. Our field trip rules and guidelines have evolved over a period of many years and we maintain that there are sound reasons for all of them. The instructor(s) will be happy to explain the reasoning behind any of the rules should you have any questions. While we have no wish to unnecessarily limit your personal freedom and/or enjoyment of our field excursions, one of our goals is to maintain a high level and safe field school program for decades to come. Please try to remember this when a rule seems arbitrary, unreasonable or inconvenient. Students who violate rules can be dismissed from field trips or field camp and may face disciplinary action at Dalhousie University upon return. While on a field trip you are bound by all the rules and regulations in the "Dalhousie University Calendar" and by the rules below which are more specifically formulated for field trips in general and ERTH 4004 Advanced Field Geology in particular. Because a number of people will be traveling in close quarters, special efforts must be made to exercise due regard for the rights and feelings of others. As long as everyone uses a reasonable amount of common sense, there will be no problems.

All rules and regulation apply to both students and staff of Dalhousie / Earth and Environmental Sciences field trips.

Failure to comply with the rules, regulations and code of conduct may result in immediate dismissal from field school. Less severe infractions will result in verbal warnings. Multiple verbal warnings will indicate a lack of compliance and may result in dismissal from field school. If dismissed, all travel arrangement and costs will be the responsibility of the dismissed party.

All field school participants (faculty, staff, TAs, students) are required to acknowledge, in writing, that they have read and agree to the rules, regulations, code of conduct, and safety procedures

PROCEDURES IN THE EVENT OF AN EMERGENCY

If you are involved in an emergency of any kind, you are to:

1. Stop what you are doing.
2. Check / clear the situation.
3. Call for help, use 911 if a phone is available. Field school will have a satellite phone to make out-going calls. We cannot leave the phone on to receive incoming calls. Begin a chain of communication that moves both ways from the individual, passed next to your partner, passed next to a TA, then finally to the supervising faculty. During an emergency, you should remain in the same geographic location to allow information to pass efficiently along this chain.
4. If you are qualified or have been trained by the Red Cross or similar accrediting organization, apply appropriate medical treatment. At the very least, keep the victim comfortable, warm, and conscious.

GENERAL RULES

1. Smoking in Dalhousie owned or rented vehicles or lecture tents is not permitted.
2. Everyone must make a special effort to be prepared to leave for the field and other destinations at the appointed time. One person who opts to sleep in, grab a last-minute sandwich, or makes a long phone call will hold up the group or possibly get left behind. You should always ride in your assigned vehicle so it will be obvious if you are missing when we leave stop or outcrop.
3. Radios, CD players, iPods, MP3 players, bull sessions, song feasts, and the like are permitted only as long as they don't infringe upon the rights of others to study, sleep, etc. or impair the concentration of the driver to operate the vehicle safely. CD players without earphones are not allowed in the vans--they block out instructions or geology descriptions

given and limit meaningful conversations. CD/MP3 players (even with earphones) should not be used during active instruction.

4. Efforts should be made to ensure that all equipment is properly cared for. Careless treatment of tents, trailers, electrical and plumbing equipment, personal gear, etc. can result in other members of the group becoming cold, wet, or inconvenienced in some other manner.
5. At all times you should respect the ecology of the areas we visit and show a respect for nature. Do not intentionally damage vegetation or other natural features. Do not pollute lakes and streams and do not deface natural or manmade objects. Do not throw stones or roll boulders down hillslopes. If you have permission to walk through a gate, leave the gate as you found it (closed, locked, or open).
6. During free time you are welcome to pursue your personal interests and activities. Reading, hiking, jogging, fishing (if licensed). However, if you leave camp during free time you do so under your personal responsibility and at your own risk. Always leave notice with some of the staff regarding where you are going and consider the safety of your environment, especially if you are conducting your activity alone. You must be back on time for the next planned activity. The Field School will not wait for you so plan accordingly.

RULES OF CONDUCT

1. Rules of personal conduct are designed to foster a healthy and prosperous educational environment. Violation of any of the rules listed below constitutes grounds for immediate dismissal from a field trip or field camp.
2. Belligerent- intimidating- or harassment-type of activity will not be tolerated. Any violation of this rule should be reported immediately to a member of the staff. Again, we, as a Dalhousie class, are bound by all the rules and regulations concerning harassment laid out in Procedures Rules & Regulations. This includes joke-telling, name-calling, or other verbal abuse which may not be intended to be racially or sexually demeaning but which could generate an uncomfortable environment or cause a student to feel insulted. We rely on the morals and values of the group to challenge and cease any such activity. If peer pressure does not prevent a repetition of the activity, use the chain of command to report the event.
3. As a co-educational group we must be particularly careful to avoid any behavior or activity that might be considered sexual harassment. Even though such behavior may be unintentional or offered in jest, it cannot be tolerated. A jest for one person can be a deep injury to another. If anyone feels that such a situation is developing or has occurred, they are asked to report it immediately to a faculty or staff member. If it involves a staff member, report it to one of the faculty members. We ask that you err on the side of caution.
4. No means no. There are no exceptions. No only needs to be said once and there is nothing to explain. No means no.
5. The use of illegal drugs is strictly forbidden; this includes recreational drugs. All controlled substances are forbidden in camps, hotels or in the field. Anyone caught using drugs will be dismissed from the course.
6. Fireworks are not permitted on field trips
7. Students may not possess firearms of any type; violators will be dismissed from the program.

POLICIES CONCERNING ALCOHOL

1. Dalhousie does not encourage the use of alcoholic beverages by students. It recognizes that students need to make individual choices concerning the use of alcohol. The university supports the choice not to drink and actively discourages the misuse of alcohol. Intoxication in no way releases a student from full responsibility for their behavior and its consequences.
2. Alcohol consumption is not allowed during instruction.
3. Alcohol consumption is not allowed during the work day seven days a week. Alcohol consumption is allowed after the workday is complete. At no times either within or outside of the normal workday hours when a student or staff is conducting trip or camp activities (like running the kitchen or erecting camp equipment) is alcohol to be consumed.
4. No hard liquor including hard cider, vodka, whiskey, etc. is allowed – in vehicles, in our camps, in hotels, or in town.
5. Beer and wine are the only alcoholic beverages that are allowed to be consumed by those who are of legal age in the state or province we are camping, and then only in moderation and only at appropriate times and places. Public

rowdiness and/or drunkenness will not be tolerated. When in camp, beer can only be consumed in the evening, after dinner, and in the area designated for social gathering.

6. Mixed drinks, shots, chugging, and drinking games are not permitted at any time during field trips, <u>even during free time in town.</u>
7. Students and staff are allowed to buy and consume beer and wine only in moderation. Students are limited to a maximum possession of six 12-ounce cans of beer or 1 bottle of wine. Pooling resources to purchase beer for a larger group is not allowed. Students or staff may not provide alcohol to others – whether they are of legal age or not.
8. Consumption of beer or wine in the vehicles, even when parked, is strictly forbidden.
9. <u>Beer or wine can only be transported in the rear of the vehicle</u> in unopened and unbroken units (6 pack, 12 pack, etc.). Broken units in a vehicle will be considered as evidence of consumption in the vehicles and violators will be dismissed. Transportation of broken units must therefore be in a trailer or the pickup bed.
10. Failure to comply with these rules will have consequences. If a student is considered to be intoxicated by a field school instructor or fails to comply with these rules more than once, the student can be dismissed from ERTH4002 Advanced Field School and sent home as soon as possible. Any costs involved in transportation home are the student's responsibility.

SAFETY IN CAMP

1. Propane lanterns, stoves, kitchen gear etc. can be a serious hazard.
    a. Proper usage, care, and maintenance of the stoves and lanterns will be presented to everyone during the early days of field camp; however, using common sense will be the most important accident prevention policy.
    b. NEVER take a lighted lantern into your tent.
    c. If a lantern or stove is not working properly, inform a staff member immediately.
    d. Only the staff members will operate the gasoline-powered generators.
2. For reasons of safety and insurance, only staff members are permitted to operate gas-powered equipment (vehicles, generators, heaters).
3. At times, large quantities of firewood must be prepared:
    a. A staff member must approve any student use of firewood cutting equipment (hand saws and axes). Always exercise extreme caution when using these tools.
    b. Do not chop wood in an area where there are people nearby who might be struck by an axe, flying wood, or dislodged axe head.
    c. If you have never had any experience with an axe, check with a T.A. prior to using one.
    d. Do not saw or chop into the ground, rocks, nails, etc., a dull axe can be dangerous.
    e. Make every effort to maintain a neat woodpile. Tripping over an outlying log or branch (common at night) may lead to serious injury.
4. <u>Never go barefoot in camp.</u> Rusty nails, broken glass, cacti, etc. are a hazard in any campground and a geologist who can't walk, can't map.
5. Open-toed shoes or sandals are not allowed in the camp kitchen.
6. Ground squirrels and other animals occupy our campsites– Do not keep food in your tent – animals will eat through your tent to get "treats". Unless absolutely necessary, do not trap or kill animals as they can carry disease.

SAFETY IN THE FIELD

1. Always wear boots in the field. <u>Tennis shoes and similar footwear are not recommended for fieldwork, as they do not provide adequate ankle support.</u>
2. Use extreme caution in, and when possible stay out of, particularly precipitous areas. Climbing in dangerous areas is not permitted. If you have doubts about whether working/visiting an area could be potentially dangerous "don't do it" (no area, however interesting and/or spectacular, is worth placing your safety at risk). The staff will attempt to identify dangerous (forbidden) areas but you must use good judgment.
3. When climbing, be careful to avoid dislodging loose materials. A rolling rock can be extremely dangerous to the people below.

4. Avoid climbing directly above another person or group. If you must pass above them on a slope, always warn the people below of what you intend to do and wait until they get out of the way. If you dislodge a rock, yell, "rock, look out below". If you are below, seek shelter and look upslope for the projectile.
5. Do not place yourself in jeopardy by moving directly below another person or group. If you must traverse a slope below another person, ask them to remain still until you are safely out of the way.
6. DO NOT ROLL BOULDERS; there could be other people, animals, etc. out of sight down slope and a rapidly moving boulder can be fatal.
7. Exercise extreme caution if you smoke in the field. Forest or sage brush fires are an ever-present hazard. Make doubly sure that matches and cigarette butts are extinguished. Better still - don't smoke. This is an opportunity to cut down on a bad habit. There may be times during drought when public lands are posted prohibiting fires of all kinds including smoking. You must honor these special regulations and not smoke.
8. If you become lost when in the field, do not wander looking for the group; that will just make you more lost. Stay where you are. Position yourself near a path or open ground. Do not stay near a raging stream as the noise makes it difficult to hear and be heard. A search party will find you. Take the time to find or acquire the appropriate shelter and water for a night's stay should that be necessary.
9. You should never be alone when in the field. If you or your partner becomes injured when in the field, do not panic. Check the scene; ensure there is no further chance for injury. Determine the extent of the injury. Call for/find help. Do not offer to treat the injury unless you have been trained to do so. Do not move an injured person, especially if the injury involves broken bones. The best course of action is to find help in the form of an instructor or TA as quickly and efficiently as possible.
10. Be careful when crossing fences that you don't break them down (bad for the fence) or cut yourself on the barbed wire (bad for you). Also, ALWAYS leave gates as you found them. If they are open, leave them open. If they are closed, make sure they are closed after you pass through.
11. When you leave for the field be certain you have: 1) a raincoat, 2) warm clothing, and 3) dry matches properly housed. If you have to spend a night in the mountains, even in a desert, these materials are critical.
12. The chain of communication in the field begins with the individual, passed next to your partner, passed next to a TA, then finally to the supervising faculty. During an emergency, you should remain in the same geographic location allowing information to pass efficiently along this chain.

WEATHER SAFETY

1. Field work is to end and students are to seek shelter when extreme heat, cold, precipitation, or wind descends.
2. Lightning is a particularly serious danger when working at high elevations and in exposed regions. Students are to exercise NO DELAY in seeking shelter and moving from high, exposed regions when thunderstorms are approaching.
3. Hypothermia is a serious life-threatening condition. Students are to dress appropriately for weather conditions, but if faced with hypothermia, are to stop working and do what is necessary to conserve heat. This includes removing wet clothing, seeking shelter, and curling up in a ball to retain body heat.
4. Heat stroke is a similarly serious life-threatening condition. Students are to always have not less than 2 liters of water when they depart for a day in the field. At least 4 L is recommended. Seeking shelter from the sun, allowing the body to periodically cool off, and being continually hydrated are the best defenses against heat stroke.
5. Sun poisoning occurs all too often, particularly on fair-skinned people. Stay covered with clothing and 30 SPF sun block during field work. Always wear a hat in the field.
6. Become aware of the signs of heat stroke and dehydration in yourself and your field partner. Early signs of dehydration include dark yellow urine, chapped lips, and no desire to void in a 4-hour period during the day. Dehydration prevents a person from properly sweating and therefore from regulating her temperature. This can lead to heat stroke. Heat stroke is a form of hyperthermia and is a medical emergency condition. Signs of heat stroke include cool, pale, clammy skin, muscle cramps, headache, nausea, fatigue and weakness, dizziness or lightheadedness, possible fainting. Stop any physical exertion, immediately get the person to shade, and try different methods to slowly but efficiently cool the person.

HEAT STROKE: SYMPTOMS AND TREATMENT

Heat stroke is the most serious form of heat injury and is a medical emergency. If you suspect that someone has heat stroke -- also known as sunstroke -- you should call 911 immediately and render first aid until paramedics arrive. Heat stroke can kill or cause damage to the brain and other internal organs. Although heat stroke mainly affects people over age 50, it also takes a toll on healthy young athletes. Heat stroke often occurs as a progression from milder heat-related illnesses such as heat cramps, heat syncope (fainting), and heat exhaustion. But it can strike even if you have no previous signs of heat injury.

Heat stroke results from prolonged exposure to high temperatures -- usually in combination with dehydration -- which leads to failure of the body's temperature control system. The medical definition of heat stroke is a core body temperature greater than 105 degrees Fahrenheit, with complications involving the central nervous system that occur after exposure to high temperatures. Other common symptoms include nausea, seizures, confusion, disorientation, and sometimes loss of consciousness or coma.

Symptoms of Heat Stroke

The hallmark symptom of heat stroke is a core body temperature above 105 degrees Fahrenheit. But fainting may be the first sign. Other symptoms may include:

- Throbbing headache
- Dizziness and light-headedness
- Lack of sweating despite the heat
- Red, hot, and dry skin
- Muscle weakness or cramps
- Nausea and vomiting
- Rapid heartbeat, which may be either strong or weak
- Rapid, shallow breathing
- Behavioral changes such as confusion, disorientation, or staggering
- Seizures
- Unconsciousness

First Aid for Heat Stroke

If you suspect that someone has a heat stroke, immediately call 911 or transport the person to a hospital. Any delay seeking medical help can be fatal. While waiting for the paramedics to arrive, initiate first aid. Move the person to an air-conditioned environment -- or at least a cool, shady area -- and remove any unnecessary clothing. If possible, take the person's core body temperature and initiate first aid to cool it to 101 to 102 degrees Fahrenheit. If no thermometers are available, don't hesitate to initiate first aid. You may also try these cooling strategies:

- Fan air over the patient while wetting his or her skin with water from a sponge or garden hose.
- Apply ice packs to the patient's armpits, groin, neck, and back. Because these areas are rich with blood vessels close to the skin, cooling them may reduce body temperature.
- Immerse the patient in a shower or tub of cool water, or an ice bath.

If emergency response is delayed, call the hospital emergency room for additional instructions.

After you've recovered from heat stroke, you'll probably be more sensitive to high temperatures during the following week. So, it's best to avoid hot weather and heavy exercise until your doctor tells you that it's safe to resume your normal activities.

Risk Factors for Heat Stroke

Heat stroke is most likely to affect older people who live in apartments or homes lacking air-conditioning or good airflow. Other high-risk groups include people of any age who don't drink enough water, have chronic diseases, or who drink excessive amounts of alcohol.

Heat stroke is strongly related to the heat index, which is a measurement of how hot you feel when the effects of relative humidity and air temperature are combined. A relative humidity of 60% or more hampers sweat evaporation, which hinders your body's ability to cool itself.

The risk of heat-related illness dramatically increases when the heat index climbs to 90 degrees or more. So it's important -- especially during heat waves -- to pay attention to the reported heat index, and also to remember that exposure to full sunshine can increase the reported heat index by 15 degrees.

If you live in an urban area, you may be especially prone to develop heat stroke during a prolonged heat wave, particularly if there are stagnant atmospheric conditions and poor air quality. In what is known as the "heat island effect," asphalt and concrete store heat during the day and only gradually release it at night, resulting in higher nighttime temperatures.

Other risk factors associated with heat-related illness include:
Age. Infants and children up to age 4, and adults over age 65, are particularly vulnerable because they adjust to heat more slowly than other people.
Health conditions. These include heart, lung, or kidney disease, obesity or underweight, high blood pressure, diabetes, mental illness, sickle cell trait, alcoholism, sunburn, and any conditions that cause fever.
Medications. These include antihistamines, diet pills, diuretics, sedatives, tranquilizers, stimulants, seizure medications (anticonvulsants), heart and blood pressure medications such as beta-blockers and vasoconstrictors, and medications for psychiatric illnesses such as antidepressants and antipsychotics. Illegal drugs such as cocaine and methamphetamine also are associated with increased risk of heat stroke.

People with diabetes - who are at increased risk of emergency room visits, hospitalization, and death from heat-related illness - may be especially likely to underestimate their risk during heat waves, according to a recent study presented at the Endocrine Society's annual meeting by researchers from the Mayo Clinic in Arizona, the National Ocean and Atmospheric Administration, and the National Weather Service.
Check with your doctor to see if your health conditions and medications are likely to affect your ability to cope with extreme heat and humidity.

Preventing Heat Stroke
When the heat index is high, it's best to stay in an air-conditioned environment. If you must go outdoors, you can prevent heat stroke by taking these steps:

- Wear lightweight, light-colored, loose-fitting clothing, and a wide-brimmed hat.
- Use a sunscreen with a sun protection factor (SPF) of 30 or more.
- Drink extra fluids. To prevent dehydration, it's generally recommended to drink at least eight glasses of water, fruit juice, or vegetable juice per day. Because heat-related illness also can result from salt depletion, it may be advisable to substitute an electrolyte-rich sports drink for water during periods of extreme heat and humidity.
- Take additional precautions when exercising or working outdoors.The general recommendation is to drink 24 ounces of fluid two hours before exercise, and consider adding another 8 ounces of water or sports drink right before exercise. During exercise, you should consume another 8 ounces of water every 20 minutes, even if you don't feel thirsty.
- Reschedule or cancel outdoor activity. If possible, shift your time outdoors to the coolest times of the day, either early morning or after sunset.

Other strategies for preventing heat stroke include:

- Monitoring the color of your urine. Darker urine is a sign of dehydration. Be sure to drink enough fluids to maintain very light-colored urine.
- Measuring your weight before and after physical activity. Monitoring lost water weight can help you determine how much fluid you need to drink.

Avoid fluids containing caffeine or alcohol, because both substances can make you lose more fluids and worsen heat-related illness. Also, do not take salt tablets unless your doctor has told you to do so. The easiest and safest way to replace salt and other electrolytes during heat waves is to drink sports beverages or fruit juice.
Check with your doctor before increasing liquid intake if you have epilepsy or heart, kidney, or liver disease; are on fluid-restricted diets; or have a problem with fluid retention.

ILLNESS OR INJURY

1. Only the individuals involved can make a rational decision about their physical condition and whether or not they should seek medical help. Several courses of action are available.
2. For minor illnesses or injuries such as colds, blisters, minor sprains, etc. the individual must decide whether to "tough it out" or to stay in camp for the day and recover. It should be kept in mind that if you are unable to continue your work in the field, your entire group must stop mapping in order to get you back to camp since mapping groups are not permitted to split up. This must also be weighed against the loss of mapping time you yourself suffer if you choose to remain in camp.
3. Some injuries (e.g. twisted knees, sprained ankles and the like) make it impossible for you to keep up with your group. In this case a decision must be made about whether one or two days' rest will get you back on your feet, whether you require medical attention, or whether you will be unable to continue with Field School.
4. Any student who feels that he or she should take a "sick day" should report this to the staff. Students are encouraged not to "malinger", but will never be forced into the field. In general, treatment of minor injuries such as small cuts and blisters is the responsibility of the individual.
5. If you need medical attention, every effort will be made to get you to a doctor as quickly as possible. It should be kept in mind that in some cases the nearest doctor could be more than 100 kilometers away and decisions to get medical help should not be postponed until the situation is critical.
6. In the event of serious illness or injury in the field, the following procedure should be followed <u>if the victim can move under his/her own power:</u>
   a. Use your VHF radio or phone to report the problem to other groups and to the staff.
   b. The entire group is to leave the field along the easiest route available.
   c. Once the group has reached a road, it may be necessary for the group to split up (the only conditions under which this is permitted).
   d. The injured person should be made as comfortable as possible and at least one person should remain with him/her.
   e. The remaining person(s) should proceed as quickly as possible to a van (if one is available) or to camp.
   f. If a van is available in the field, return to camp with the victim unless common sense dictates that you should go directly to the hospital (e.g., very severe bleeding). A road map and driving instructions to local health clinics will be left in the center console of each vehicle. Google Maps localities will be available for everyone. Install the Google Maps App, download the offline maps for the field school area, and follow the pins listed in the emergency contacts on page 15. Keys will be left near the vehicles and the location will be made clear to everyone each day.
   g. DO <u>NOT SPEED</u>! An accident only compounds an emergency.
7. In the event of serious illness or injury in the field, the following procedure should be followed <u>if the victim is immobile</u>
   a. Use a VHF radio or phone to report the problem to other groups and to the staff
   b. Make the victim as comfortable and warm as possible. At least one person should remain with the victim.
   c. Part of the group should return to camp for help as quickly as possible (Again: DO <u>NOT</u> <u>SPEED</u>! If you don't make it to camp you are no help to anyone).
   d. <u>NOTE</u>: If there is a suspicion of a back or neck injury, <u>DO</u> <u>NOT</u> <u>ATTEMPT</u> <u>TO</u> <u>MOVE</u> <u>THE</u> <u>VICTIM</u>.
8. Because there is an assumed responsibility of the individuals and partners to keep safe and aware of unsafe conditions and to conduct proper first aid treatments, we recommend (but do not require) that all students take standard and emergency first aid training prior to field school. We will also review some common safety issues that may be encountered on Field School in the first few days of field school.

OPERATION OF VEHICLES IN THE FIELD

1. In general, only staff members will drive the field school vehicles (owned or rented by Dalhousie). The driver of a vehicle is responsible for the safety of at least 7 individuals. For this reason, special efforts will be required to maintain safe driving habits. Reckless or inept driving should be reported to one of the field school faculty members.
2. Any non-staff person who operates a university-owned vehicle must receive permission (each time) from a faculty member.
3. At all times, vehicles are to be driven at reasonable speeds as dictated by road, weather, and traffic conditions, etc. AT NO TIME are vehicles to be operated in excess of existing speed limits. Speeding tickets and any other violations are the responsibility of the driver-neither Dalhousie University nor the field camp will pay fines resulting from violations.
4. No open or broken-unit alcoholic beverages or other drugs are permitted in the vans--violation will result in dismissal from the course. This regulation will be enforced!
5. No one is allowed to operate a vehicle if their blood alcohol content exceeds the state or provincial limit.
6. Even if this limit is not exceeded, no one is permitted to operate a vehicle after having consumed more than one alcoholic beverage (glass of beer or wine) or other intoxicating substance (legal drugs) within 5 hours of driving.
7. Vehicles are to be kept neat and in good repair. (Throw out trash at each opportunity.) Report all mechanical problems immediately and treat the vehicles with respect. Do not force or slam doors and keep your feet on the floor.
8. No activity is permitted in the vans that could interfere with, or infringe on, the rights of other passengers.
9. The person to the right of the driver (co-pilot) is to stay awake and alert at all times. This person is the assistant driver and should handle map reading, tolls, etc. for the driver.
10. No driver is permitted to drive to the point of fatigue.
11. When traveling, all vehicles are to maintain a reasonable spacing--do not lag behind--do not tailgate. Except under emergency conditions, no vehicle is EVER to pass another vehicle in the caravan. If you want to report a problem, use the radio. If it is inoperative, flash your headlights until the caravan pulls over.
12. It is the driver's responsibility to check oil, water, tires, etc. at each gas stop.
13. Drivers should ALWAYS show the credit card to the station attendant before gassing the van to make certain that it will be accepted. If the tanks are filled and the credit card is rejected, you will have to "front the bill" until you can be reimbursed at a later date.
14. The two-way radios are for business communications only. No excessive chatter and no CB jargon are permitted. The radio must be left on at all times so that you can be contacted in the event of an emergency. The AM/FM stereo or other noise in the van must be kept low enough so that any radio transmission can be heard.
15. The western states in particular are overrun with a rodent population such as ground squirrels, prairie dogs, etc. Drivers should NEVER jeopardize the lives of your passengers by swerving or braking to avoid one of these small animals.
16. Always ride in your assigned vehicle. Always check to make certain your vehicle has all its passengers when we leave stop so that we don’t drive off and leave someone.
17. Do not ride in the trunk of any car or van. If a van is full, wait for the next one.
18. Vehicles are never to be run or idled to provide music, heat, or air conditioning unless directed to by a staff member.

CARE OF EQUIPMENT

1. In an effort to minimize the cost of field camp and ensure safety, we provide equipment that must be used year after year. You are responsible for its safekeeping and proper use.
2. Students are provided with a Brunton compass and carrying case, and other expensive equipment. When issued, the equipment is in perfect working condition (do not accept it if it's not). We expect to receive the equipment in good shape at the end of the course. Normal wear is expected. If you lose equipment you will be charged its fair market value for replacement. If you damage it due to carelessness, you will be charged the cost of its repair. Always check to be certain the belt strap on the case is secure for any equipment you carry that way.
3. During each project, each mapping group is issued imagery coverage of the area, a map board and mylar overlay. Often, these field copies will be used for your final submission. Commonly, there are no extra copies.

4. Care of your own equipment is also critical to your comfort. Never leave your sleeping bag where it can get wet or blow away. Remember that afternoon wind and thunder storms are common even on the nicest days. If your gear gets wet, take action as soon as possible to dry it.

COOKING, CLEANUP, and MEAL ETIQUETTE

1. Early on field camp you will be assigned to a cook crew. Each cook crew will have a crew leader who is responsible for the smooth operation of that cook crew. The camp manager will ultimately be in charge of cooking related details.
2. The time for breakfast and dinner will be established by the camp manager and may vary depending on the camp site, weather, daily schedule, or type of food.
3. On normal days, the crew leader is responsible for waking his/her crew early enough to have breakfast finished by 6:30 AM sharp. This will allow the cleanup crew one half hour for cleanup prior to our 7:00 AM departure for the field. The details of cooking and cleanup are too extensive to review here. They will be reviewed in detail early in the program; however, a few important points are reviewed next.
4. The cook-crew leader will ring the dinner bell when the meal is ready to be served. The cook crew dishes out food to each student and serves themselves after the others are served. The COOK CREW announces "seconds" after THEY have finished eating.
5. Unless you are cooking, stay out of the cooking area. No one is allowed to eat in the cooking area.
6. Reasonable table manners and rules of etiquette are expected of all persons at all times.

HONESTY

1. ERTH 4004 is a formal University class and you are bound by all rules pertaining to academic honesty. This includes exams and map preparation. Published geologic maps of the study areas (including copies and photos of same) or student’s maps from previous years are not to be brought on field camp, doing so will likely result in dismissal.

A TRANSITION

DESERT WASH

The Mojave, driest of all North American deserts, gets less than 10 inches of rain a year. Snaking across this arid landscape, scoured desert washes carry the runoff after monsoon rains. Desert tortoises actively forage after these refreshing storms. Deep-rooted plants grow along the edges and on islands in the washes, providing black-tailed jackrabbits with shady hiding places.

JOSHUA TREE FOREST

Joshua trees are characteristic Mojave Desert plants that grow up to 40 feet tall. Haphazard, prickly branches give many animals shelter, a food source, or nesting materials. As many as 25 bird species nest in Joshua trees: Scott's orioles hang nests from branches; other birds build nests in foliage; and northern flickers peck nest holes in the trunks. Toppled trunks house insects that provide a food source initiating a complex food web.

MOJAVE DESERT SCRUB

This community's spiny, succulent plants denote *desert* to most people. In rainy periods barrel cacti store water in their vault-like bodies, safe under myriad spines. Surviving long periods of no rain, they live up to 130 years. Rock-dwelling chuckwalla lizards also use their bodies as canteens—and as larders—during wet periods. They can also wedge themselves into rocks and puff up so much that predators can't pull them out.

Grand Wash between Pakoon Springs and Tassi Ranch

A Joshua tree in Pakoon Basin
NPS / TOM PATTERSON

Upper Whitmore Canyon

1 PRICKLY PEAR CACTUS

2 CREOSOTE BUSH
NPS / TOM PATTERSON

3 JOSHUA TREE
NPS / TOM PATTERSON

4 BEAVERTAIL CACTUS

5 DESERT PAINTBRUSH

6 BARREL CACTUS

ROADRUNNER

DESERT TORTOISE

BLACK-TAILED JACKRABBIT

GAMBEL'S QUAIL

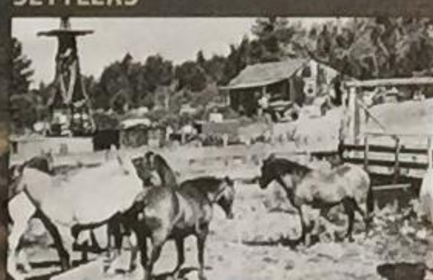
CHUCKWALLA

ANTELOPE GROUND SQUIRREL

INDIANS

The 1776 Dominguez-Escalante expedition found Southern Paiutes gardening, hunting, and gathering. In rabbit skin robes, this circle dance ceremonial group celebrates their ties to the land and animals.

SETTLERS



Beginning in the 1870s Mormon settlers, miners, loggers, and ranchers built homes here and struggled to raise families and survive in this remote country. Their descendants still ranch in the monument.

LOGGING

Local stands of ponderosa pine provided building materials for early settlers' cabins and homesteads and for Mormon building projects. No economically significant lumbering began until 1876.

◄1800 1825 1850 1875

AL LANDSCAPE

SAGEBRUSH STEPPE

Typical Great Basin communities are sagebrush steppe—a semi-arid plain—and pinyon-juniper woodland *(right)* that cover much of the national monument. You will drive for miles through this multi-hued landscape of sagebrush, shrubs, and short grasses. Big sagebrush is most common, but there are several other species, too. The adaptable coyote hunts rabbits and other small animals that hide in the shrubs.

PINYON-JUNIPER WOODLAND

Pinyon pines and junipers grow on mountainsides and plateaus above the steppe. Although junipers can live 300 to 400 years, they only grow 20 or 30 feet tall. Slow-growing pinyon pines germinate beneath a nurse plant and when mature produce nutritious seeds that were once a vital food source for native people. Birds and rodents like these tasty pine-nut seeds and help to plant new trees when they cache them in the ground for winter food.

PONDEROSA PINE FOREST

Cooler, higher, and with more rain, the Colorado Plateau ecoregion supports ponderosa pines with associated Gambel oak, New Mexican locust, and serviceberry—home to turkeys, Kaibab squirrels, mule deer, and goshawks. Ponderosa pines live to 600 years and can grow over 90 feet tall. Their orange-brown bark smells like vanilla. Periodic burning is essential to maintaining the health and vigor of ponderosa pine forests.

Steppe country east of Mount Trumbull

Pinyon-juniper growing on lava flow outcrops

Ponderosa pine forest on Mount Logan

7 RABBITBRUSH

COYOTE

8 BIG SAGEBRUSH

GREAT BASIN RATTLESNAKE

9 PINYON PINE

COMMON RAVEN

10 CLIFF ROSE

STELLER'S JAY

11 LUPINE

MULE DEER

12 PONDEROSA PINE

MOUNTAIN LION

COPPER MINING

After an abortive gold rush, copper mining took hold in 1873. Of several mines, the Grand Gulch was most important. Mules packed in tools and supplies until a wagon road opened to St. George, Utah, in the 1870s.

CATTLE RANCHING

Livestock grazing has been part of Arizona Strip culture since the 1850s. It is still part of the monument's multiple-use management where authorized. Few full-time residents live in this remote area today.

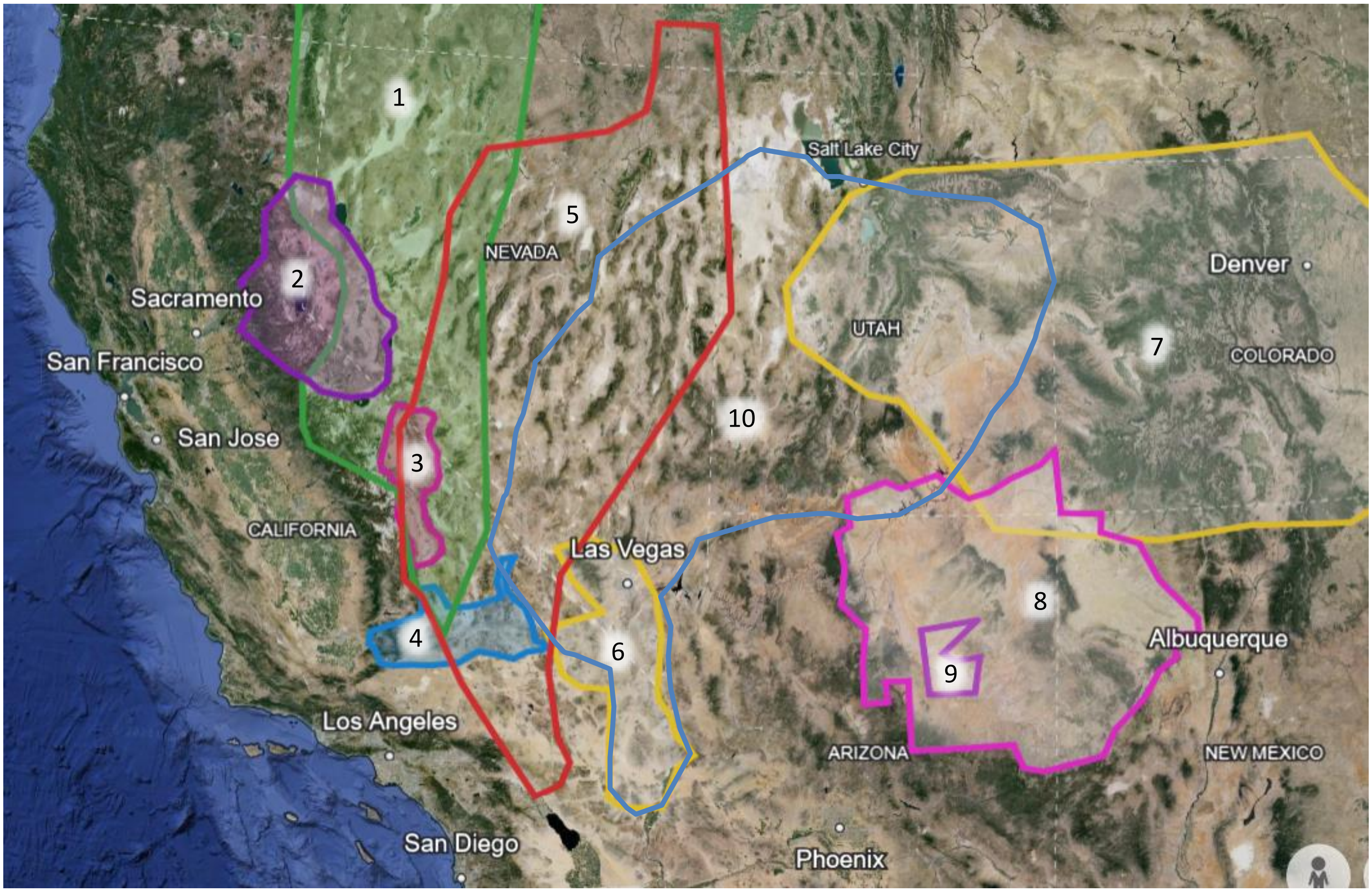
PRESERVATION

Established by presidential proclamation in 2000, this remote national monument includes an array of scientific, natural, cultural, and historic features and opportunities to experience rugged recreation.

1900 1925 1950 1975 2000▶

INDIGENOUS TERRITORIES OF SOUTHERN NEVADA AND EASTERN CALIFORNIA

Compiled by ERTH 4004 students: Lindsey Burgess, Bailey Grondin, Brighton Gaddes, Alyssa Jones, Louis Liu, Alex Parsons, Sarah Penttinen, Emily Theben, Grace Mombourquette, Grayson Waldon



Native American Territories

1. Southern part of Nuumu (Northern Paiute)
2. Washoe
3. Nüümü Witü (Eastern Mono/Monache)/ Kootzaduka'a
4. Kawaiisu
5. Newe Sogobia (Western Shoshone)
6. Chemehuevi
7. Ute
8. Navajo
9. Hopi
10. Nuwuvi (Southern Paiute) Territory

Sites:

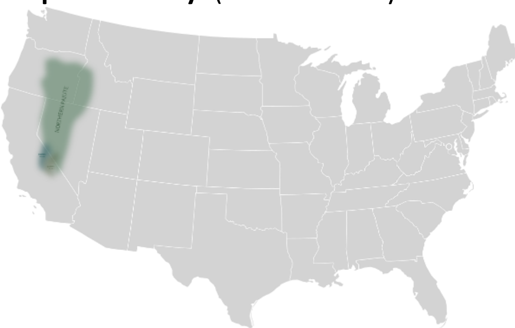
Mono Lake: Mono lake is one of the oldest lakes in North America. Mono is a terminal lake meaning it has no outputs and the only way water leaves the lake is through evaporation, leaving behind all dissolved material. This causes the lake to be hypersaline and has been a source of salt for the indigenous peoples of the area for thousands of years. The Kutzaduka'a people settled in the area around the lake as it offers many natural resources. The saline lake does not have any fish, but is teaming with brine shrimp which attract thousands of birds during migration seasons.

Chidago Petroglyphs: Believed to be between 1000-8000 years old, these petroglyphs are remnants of the Nuumu and Paiute peoples of this region. Often used as markers for annual migrations, these petroglyphs show images of groups of people, as well as animals and crops. Other instances of petroglyphs can be found throughout Owens Valley.

Nuumu Poyo: Known today as the John Muir Trail, this ancient trade route predates the American Conservation movement by centuries. The Nuumu Poyo or "Peoples trail" was used in annual migrations through Owens valley and over the Sierra Nevada by numerous Indigenous Tribes. Today it makes up a large portion of the Pacific Crest Trail and is hiked by thousands of nature lovers every year.

1. Southern part of Nuumu (Northern Paiute) – Brighton Gaddes

Map of territory: (include nearby field school sites)



History & Traditions: (brief history/timeline, food, languages, dwellings, traditional place names, trade routes)

The territory currently inhabited by the northern Paiute has generally expanded over the last 2000 years. Their first interactions with fur trappers and explorers occurred around the 1820s. The discovery of gold in California in the mid-1800s led to increased immigration from western colonizers, further encroaching upon the northern Paiute territory and resulting in the establishment of reservations, which are not very self-sustaining. Traditionally, the Paiute people were hunter-gatherers who utilized local watering resources for fishing. Variations in settlement patterns occurred due to territorial boundaries. They had fixed camps during winter and temporary camps in spring and summer, with settlement sizes averaging about 50 people. Housing types varied by season, with cattail homes over Willow pole frameworks in winter and mostly outdoor sleeping arrangements with windbreaks in summer. Post-colonization in the late 1800s, traditional dwellings transitioned to the homes seen today. Trading occurred within the northern Paiute people and in Nevada throughout the year, although relations with other indigenous groups were sometimes hostile, limiting trading options.

References:

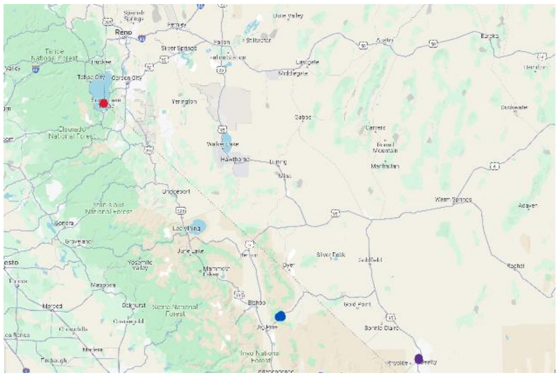
Northern Paiute. eHRAF World Cultures. (n.d.). https://ehrafworldcultures.yale.edu/cultures/nr13/summary

Paiute Indians of Utah. Utah History Encyclopedia. (n.d.). https://www.uen.org/utah_history_encyclopedia/p/PAIUTES.shtml

Paiute Indians. History to Go. (2016, April 22). https://historytogo.utah.gov/paiute-indians/

Images: (eg., petroglyphs, people, dwellings, etc)

2. Wa She Shu: "The Washoe People" – Lindsey Burgess



Territory: The Washoe territory surrounded Da ow aga (Lake Tahoe), which splits the border of California and Nevada. When necessary, they would venture to the broader surrounding area which was shared with other tribes, mainly the Paiute, Shoshone, Maidu, and Miwok. The Washoe say they were placed at lake Tahoe by their Creator along with the rest of the environment. Respect for the land and its resources has always been one of the defining values of the Washoe community. The map to the right shows Lake Tahoe (represented by the red dot) to the North-East of the Poleta Folds project (blue dot) and Beatty campsite (purple dot).

Language: The Washoe language is very distinctive from the languages of any neighboring tribes and was previously believed to be the sole representative of its language group. Researchers now recognize Washoe as its own branch of the Hokan language group, developing independently over thousands of years without contact with other Hokan speakers.

Food: The Washoe had a diverse diet that was seasonally dependent. Food was accessed through hunting, fishing, gathering, and foraging. Most notable food sources were fish, sheep, wild vegetables, and pine nuts.

Washoe women equipped with burden baskets and other tools for the tah gum harvest.

Washoe petroglyph of a hunter and a bighorn sheep.

Traditions: The Washoe considered the nearby pine nut forest sacred, as it was a staple food source through the winter. Each year they would host a festival in tribute of this resource. Each spring, a new fishing season was celebrated with large gatherings around the lake with socializing, games, and competitions like races and archery.

Modern History: Gold and silver were "discovered" on Washoe land by white settlers in 1848, who began to mine the land. Within 10 years, Washoe resources were exhausted. Colonizers did not delegate any land to the Washoe, thinking the population not survive long enough for it to be necessary. Because of this, many Washoe people chose to adapt by living and working in white communities. In 1924, the Washoe were officially recognized as citizens under law but weren't a formally recognized tribe until 1937. Some of the ancestral land was returned to the Washoe in 1970, and since this time, the community has been working to rebuild the community through re-learning traditions, beliefs, and language. It is estimated that the original population was close to 3000, and is now close to 1550. A large portion of the population resides on ancestral territory, and around 1/3 live off reservation. The tenacity of the Washoe community is a long-held value, and this value continues to drive the community to rebuild. "Our elders tell us we have been here since the beginning, and we are still here in our lands."

Reference:

Washoe Tribe of Nevada and California. "Wa She Shu: 'The Washoe People' Past and Present." *Wahoe Tribe of NV & CA*, 2021, washoetribe.us/aboutpage/4-Page-washoe-history.

3. Nüümü Witü (Eastern Mono/Monache) – Grace Mombourquette

History & Traditions:

The Eastern Mono people spoke a language called Nim an called themselves either *Nüümü*, which means "People" , or *Nün'wa Paya Hup Ca'a' Otuu'mu* "Coyote's children living in the water ditch". There is not much information available on Mono civilizations and customs, and records are not detailed. They are also known as the Eastern Mono/Monache and the Owens Valley Northern Paiute.

The Nuumu were mostly sedentary and settled along rivers and springs. The more arable land would enable them to grow and store more food and feed larger groups. The Eastern Mono would bury their dead, and burn the belongings and property of the deceased over their grave, and would return the following year to burn what was left. The ritual number was four. They organized their territory in different districts, and each was under the command of a headman. For example, the are around Bishop, CA was known traditionally as Pitama Patü or Pitana Patü, meaning south place, and the area around Big Pine, CA was known as Tovowaha Matii, or natural mound place.

Map of territory:

Figure 1: Nuumu Witu Traditional Territory, and nearby Field School sites.

The Owens Valley Paiute were also known to be aggressive and unfriendly towards neighboring tribes. From 1862 to 1863 they fought the Americans in the 'Owens Valley Indian War", and were allied with Shoshone, Kawaiisu and Tubatuabal.

Images

Figure 2: Eastern Mono diagonally weaved basket.

Figure 3: A Mono couple, 1920 (Wikipedia)

Modern History:

According to US Census, there are approximately 2300 enrolled Mono people. Population surveys include the Western Mono, so realistic numbers of Eastern Mono are unknown. There are several reservations with enrolled Mono people, including Big Pine Paiute Tribe of Owens Valley, Fort Independence Indian Community of Paiute Indians, Lone Pine Paiute-Shoshone Tribe, Bishop Paiute Tribe, and Utu Utu Gwaitu Paiute Tribe of the Benton Paiute Reservation.

Big Pine Band of Owens Valley Paiute Shoshone Indians was established in 1912 and is a federally recognized tribe of Mono Indians in California. The reservation is relatively small at 279 acres, but it includes a primary to 12th grade school and a decent sized library. The Band has a very successful Environmental Department, with focuses to maintain and environmental planning program and be involved and protect the land, water and air.

The Mono language (Nim) is very endangered, with few active speakers. There is estimated only 30 active speakers of the Eastern Mono dialect.

Sources:

https://native-land.ca
https://en.wikipedia.org/wiki/Mono_people
https://www.yosemite.ca.us/library/kroeber/paiute_mono_koso.html
http://mojavedesert.net/mojave-desert-indians/map.html

4. Kawaiisu Indigenous Territory – Bailey Grondin

Introduction

Based on artifacts and knowledge of other indigenous groups, the Kawaiisu occupied the Tehachapi Valley, the southern regions of the Sequoia National Forest, and southern Death Valley region for no more than 1,500 years (**Figure 1**). However, most artifacts in the area are only 500 years old. This timeframe may represent the movement of the group into the Southern Sierras from the Mojave Desert after a small ice age 3000 years ago, with warming occurring 700 to 800 years ago (California Department of Parks and Recreation, n.d.).

Culture

The Kawaiisu referred to themselves as the Nuwa, which means "The People". Their culture was mainly bound by family. Very little social structure occurred outside of family groups. Families that had relations to other families or tribes would often work together to gather food and supplies (California Department of Parks and Recreation, n.d.). Births marked an important occasion where tribes and families would celebrate, often for several days (mojavedesert.net, n.d.).

Food and Trade

The diet of the Kawaiisu consisted of greens, seeds, berries, and meats. Some foods were eaten raw, and some were cooked. Deer meat was made into jerky which was a trade product to other groups. Other native groups nearby knew of the resources available in the Kawaiisu land. This indicates that there was likely a well-developed network of trade within the area (mojavedesert.net, n.d).

Pictographs, Artifacts, and Legacy

Like other native groups, the Kawaiisu created pictographs. It is difficult to interpret the meaning of the pictographs as they typically only contain abstract shapes and symbols. **Figure 2** shows a pictograph of what is believed to be celestial objects such as the Sun and Moon (svchistory.com, n.d.). Clothing was made from skins, pelts, and bark. In the winter, fur was used for a warm poncho like garment (mojavedesert.net, n.d).

Today, the population of the Kawaiisu is about 60 (U.S Census Bureau, 2010). This is down from the maximum of roughly 1000 during their peak (California Department of Parks and Recreation, n.d.). A 20th century Kawaiisu family is highlighted in **Figure 3**. The Kawaiisu Territory is currently under the treaty cessions 284, 286, and 562.

Figure 1. Map of the Kawaiisu Territory (Native Land Digital, n.d.)

Figure 2. Pictograph depicting possible celestial objects (scvhistory.com, n.d.)

Figure 3. A 20th century image of a Kawaiisu Family (Mereu, 2019).

References

California Department of Parks and Recreation, n.d., The Kawaiisu Culture: https://www.parks.ca.gov/?page_id=24579 (accessed February 2024).

Mereu, 2019, There's Something About the Kawaiisu People: https://savethelandmarks.org/library/f/there%E2%80%99s-something-about-the-kawaiisu-people (accessed February 2024).

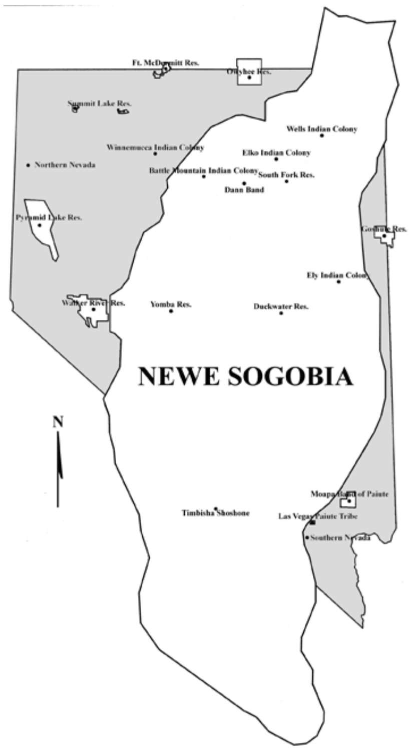
Mojavedesert, n.d., Kawaiisu Indians: https://mojavedesert.net/kawaiisu-indians/ (accessed February 2024).

Native Land Digital, n.d., Territories Kawaiisu: https://native-land.ca/maps/territories/kawaiisu/ (accessed February 2024).

SCVhistory, n.d., Burham Canyon Pictographs: https://scvhistory.com/scvhistory/lw3302.htm (accessed February 2024).

United Sates Census Bureau, 2010, 2010 Census CPH-T-6. American Indian and Alaska Native Tribes in the United States and Puerto Rico: 2010: https://web.archive.org/web/20141209093630/http://www.census.gov/population/www/cen2010/cph-t/t-6tables/TABLE%20(1).pdf (accessed February 2024).

5. Newe Sogobia (Western Shoshone) Territory – Sarah Penttinen



Western Shoshone were once part of the four groups that made up the Shoshone Territory, which is now known as Newe Sogobia – as of the 1820's (Admin et al., 2012). The four groups, north, south, east and west are all in different areas with distinct hunting and gathering resources (Te-Moak Tribe of Western Shoshone). As the bands were not close together and the Shoshone were quite independent, socializing with other families in the band was not common. Small activities such as rabbit hunting would be considered a friendly outing. Out of the four areas, the Western Shoshone were known as the 'unmounted'- as horses were not used until after they were brought by colonial settlers. The western Shoshone were also called the 'Grass House People'. This is because the most common housing was mainly huts made from tall, native grasses such as sosoni which is where the name Shoshone came from.

Image showing the cone shaped grass homes and their residents.

In the Newe Sogobia region, the languages spoken are Shoshoni, which is a Uto-Aztecan language as well as English. Newe in Shoshoni translates to 'The People". Some examples of these people would be the bands that also connect to the food eaten by the Shoshoni. The bands were all named based off the main food eaten, such as salmon eaters (Agaidika), buffalo eaters (Kutsundeka), pine-nut eaters (Tubaduka). With animals such as long horned sheep, buffalo, deer, rabbits, being eaten, the skins, horns and antlers were used for the making of clothing, accessories and tools. A couple examples of the repurposing of these animal products from the Shoshone would be deerskin dresses and archery bows made from antlers.

Between the Gold Rush and Fur Trade, the attractions brought many new people and industry down the California Trail and started to claim the land for themselves. Because of this, there became some tension between Shoshone and the visitors on the trails. While the visitors claimed land, the Western Shoshone raided back. One raid lead to the Swamp Cedar Massacre, where an army captain killed over 50 indigenous in Spring Valley, NV in 1863. Approaching the American Civil War and to protect the gold, the U.S. started negotiating terms and treaties. In October 1863, the Treaty of Peace and Friendship was signed, and the US was to trade $5000 annually for twenty years in livestock and other similar commodities, for the Shoshone to allow access to the territory and all its own commodities. As the U.S. only paid the first $5000 and still took advantage of the land, 1985 Supreme Court Case U.S. v. Dunn (two Shoshone sisters) resulted in the government willing to pay for the 19 years of missing payments. The Shoshone tribes did not and will not accept the money.

References

Admin, Knaus, D., miller, H., & Mueller, L. (2012, March 17). *The great basin tribes*. Native American Netroots. http://nativeamericannetroots.net/diary/1300

Moak tribe of Western Shoshone. Te. (n.d.). https://www.temoaktribe.com/history.shtml

Western Shoshone - Settlements. Settlements - Western Shoshone. (n.d.). https://www.everyculture.com/North-America/Western-Shoshone-Settlements.html#:~:text=The%20usual%20winter%20house%2C%20holding,in%20use%20during%20the%20summer.

Western shoshone | california trail interpretive center. (n.d.). https://www.californiatrailcenter.org/western-shoshone/

6. Chemehuevi - Louis Liu

Map of territory:

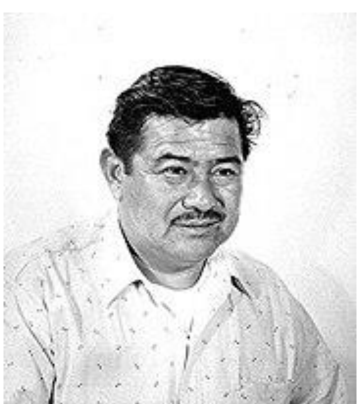
History & Traditions:

The Chemehuevi originated as a desert tribe within the Southern Paiute cluster. Following initial contact, they primarily inhabited the eastern Mojave Desert and later settled in Cottonwood Island, Nevada, and the Chemehuevi Valley along the Colorado River in California. Their lifestyle was nomadic, living in small groups due to the limited resources of the desert terrain. Carobeth Laird notes that their traditional territory extended across the High Desert from the Colorado River in the east to the Tehachapi Mountains in the west, and from the northern regions encompassing the Las Vegas area and Death Valley to the southern areas including the San Bernardino and San Gabriel Mountains (Laird 1976). They are predominantly associated with the Great Basin Indians and are recognized as relatives of the Kawaiisu tribe among others.

Chemehuevi baskets on display at local cultural centers

Name

The term "Chemehuevi" holds various interpretations. Some suggest it could derive from Mojave, translating to "those who play with fish," while others propose it originates from Quechan, meaning "nose-in-the-air-like-a-roadrunner." Alternatively, the Chemehuevi refer to themselves as Nüwüwü (The People) or Tantáwats, signifying "Southern Men." (Press 1979).



McKinley Fisher, local Chemehuevi man working for the Colorado Agency, 1957

Populations

The estimated pre contact populations of the native groups located in California varied greatly. The Chemehuevi population, specifically, was reported to be 350 in 1875, then later estimates puts the population at around 355 in 1910. Lastly, as of 2016, the Chemehuevi population is estimated to be in the thousands.

Languages

The Chemehuevi language belongs to the Colorado River Numic language group within the broader Numic branch of the Uto-Aztecan language family. Initially documented by John P. Harrington and Carobeth Laird in the early 1900s, it underwent further study in the 1970s by linguist Margaret L. Press. Unfortunately, the language is now on the brink of extinction. According to a documentary from 2008, there are believed to be merely three remaining native speakers of Chemehuevi (Anderson 2008).

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7. Ute – Grayson Waldon

History & Traditions: (brief history/timeline, food, languages, dwellings, traditional place names, trade routes)

The Ute people originated from the Great Basin region. The Ute Nation once covered much of modern-day Utah, Colorado, and Northern New Mexico. Their language is called Ute and is of the Uto-Aztecan language family. Historically, the Utes consisted of nomadic bands of hunter gatherers, who relied on the natural resources of their surroundings for sustenance. The Ute diet centered around large game such as elk deer and antelope, various small game animals, and wild plants such as berries, fruits, roots and seeds. Limited fishing was also done where streams were available. Ute dwellings were dependent on both season and location. During warmer months Ute bands, predominately consisting of greater family units, would move into the mountains where their dwellings consisted of maneuverable tipi like structures made from wood and animal hides. In the colder months the Ute bands would move down from the mountains into more sheltered areas where their dwellings would sometimes consist of more insulated mud huts which provided more protection from the cold. The Ute also produced many goods and tools such as hides, baskets, bows, arrows, knives and clothing. The Ute people traded these goods for things such as pottery which they could not produce themselves.

Images: (eg., petroglyphs, people, dwellings, etc)

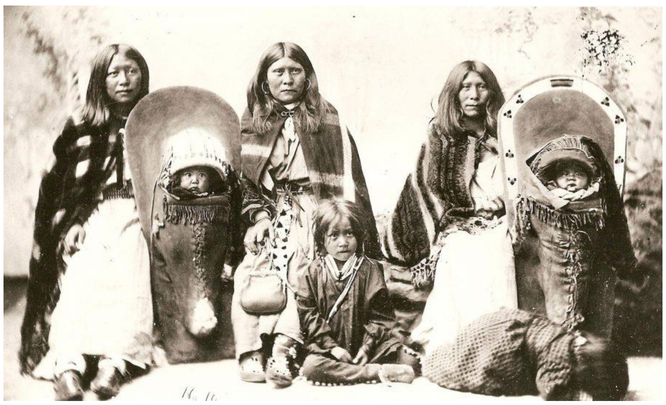

Image of Ute people in traditional Ute clothing.

This petroglyph near "Wolfe Ranch" is thought to be of Ute origin due to the depiction of horses, as the Utes quickly mastered riding horses when they were introduced to the continent by Europeans.

Modern History: (reservations, population, languages, other information)

The Ute tribe today is primarily located on several reservations in Utah, Colorado, and New Mexico. They consist of the Northern Ute Tribe, the Southern Ute Tribe and the Mountain Ute Tribe. Today the Ute population is estimated to be around 10,000 individuals. The Ute language is still spoken today, but there are a dwindling number of fluent speakers. Sadly, due to the small size of the modern day Ute reservations, the traditional lifestyle of the Ute people is no longer possible. Thankfully, an active effort is being made to preserve the Ute culture in further generations.

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8 and 9. Navajo and Hopi – Emily Theben

Navajo Nation

Brief History

Navajo Nation traditionally called Diné Bikéyah or Navajoland is the largest Native American tribe in the United States extending into Utah, Arizona, and New Mexico. The nation spans over 27, 000 square miles and is larger than 1/5th of the 50 states (Navajo Nation). Hopi is a sovereign nation which is located within Navajo Nation. The two nations had several land disputes in the 19th and 20th century because the Navajo encircled the entire Hopi Nation. Early Navajo were mobile hunters and gathers but after migrating to the Southwest between 1100 and 1500 CE they began to adopt practices such as farming from the Pueblo Nations they settled nearby.

The "Navajo religion is widely practiced and notable for its intricacy" (Brittanica) with many traditions relating to emergence of the first people from worlds beneath the surface of the Earth and many other stories explaining the origins and purposes of ceremonies and rites. The rites where traditionally used for curing physical and mental illness and ceremonies include prayer, song, and dry panting's made of pollen and flower petals. Many of these practices continue today.

Navajo women traditionally wear long, loose fitting dresses called biil. They are often colored and adorned with beads, sequins, and other decoration (Navajo clothing). They also wear pleated velvet skirts, blouses, long-sleeved tops, and moccasins. Men traditionally wear breechcloths and knee-length moccasins, as well as shirts and jackets. There clothing is also often decorated with beadwork or quillwork. Like many other Native American tribes, the Navajos believe that everything has spirit, and this is reflected in the way they dress. There is a strong belief that how they look on the outside reflects how they feal on the inside (Navajo clothing).

Language

Navajo speak an Apachean language routed in their Canadian origin. The language was used to create a secret code during World War 2. Navajo men were chosen to create codes and serve on the frontline delivering messages. Today they are recognized as the Navajo Code Talkers, "who exemplify the unequal bravery and patriotism of the Navajo people" (Navajo Nation).

Crown Canyon Petroglyphs

The Crown Canyon Petroglyphs are in Dinἒtah the traditional homeland of the Navajo people. The site contains ruins and rock art from the 16th to 18th century including not only extensive Navajo petroglyphs but also earlier ancestral Puebloan images. Depicts include animals, humans, supernatural beings, and other images (Bureau of Land Management).

Recent history

The current population of Navajo surpasses 250, 000. This nation is known to have the largest and most sophisticated form of American Indian government. Oil discovered on Navajoland in the 1920's promoted a need for a systematic form of government leading to the formation of a Tribal government in 1923. Then in 1991 the government was reorganized into a three-branch system (Executive, legislative, and judicial) with a council chamber hosting 88 council delegates. During council sessions delegates carry on the tradition of speaking in Navajo, just one example of how the nation retains is cultural heritage.

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10. Brief History of the South Paiute People – Alex Parsons

Brief History
The Southern Paiute people are a Native American tribe residing in the Colorado River basin across southern Nevada, northern Arizona, and southern Utah. They consist of bands living in various locations within this territory. "*The first European contact with the Southern Paiute occurred in 1776 when Spanish explorers encountered them while attempting to find a route to the missions of California. Before this contact, the Southern Paiute faced slave raids from the Navajo and Ute tribes. The arrival of Spanish and later Euro-American explorers increased slave raiding by other tribes.*" In 1851, Mormon settlers occupied Paiute water sources, establishing a dependency relationship. However, the presence of Mormons brought an end to the slave raids, resulting in generally peaceful relations. "*Mormon missionary Jacob Hamblin played a diplomatic role. The introduction of European settlers and agricultural practices, especially large herds of cattle, disrupted the Southern Paiute's traditional lifestyle by driving away game and reducing their ability to hunt and gather natural foods.*"

Map of territory for the Nuwuvi (Southern Paiute)

Foraging and Food
The Southern Paiute people relied on various foods for sustenance. Bitterroot, wild carrot, wild onion as well as chokecherries were a staple for their diet Chokecherries served multiple purposes, as their stems were brewed for a sweet drink, and their berries were crushed and dried for later use. Southern Paiute women collected nectar droplets from cane plants by beating the stalks and separating the dried droplets for sweetness. Waada seeds, ground into meal, were another important food source. In regions with sufficient water, they cultivated corn, squash, and wheat using ditch irrigation. Men primarily hunted waterfowl, rabbits, bighorn sheep, and other mammals as they traversed the land. The basket weaving skills of Paiute women were highly significant, utilizing red-stemmed willows for weaving. These skills were integral to their daily lives and are thought to have been transmitted from mothers to daughters for millennia. When gathering and foraging, they carried large conical baskets on their backs to collect items.

Hat woven by a Southern Paiute women

Languages and Culture
"Traditionally spoke Colorado River Numic, which is now a critically endangered language of the Numic branch of the Uto-Aztecan language family and is mutually intelligible with Ute" The Southern Paiute traditionally had 16 to 31 subgroups, bands, or tribes. As of Dec 31, 2021, there are 920 people among the five constituents' bands. The name Paiute originates from "paa Ute," which translates to "water Ute," reflecting their inclination to reside close to water sources.

Sources:
CHAT GPT was used as a co-editor for this summary paper

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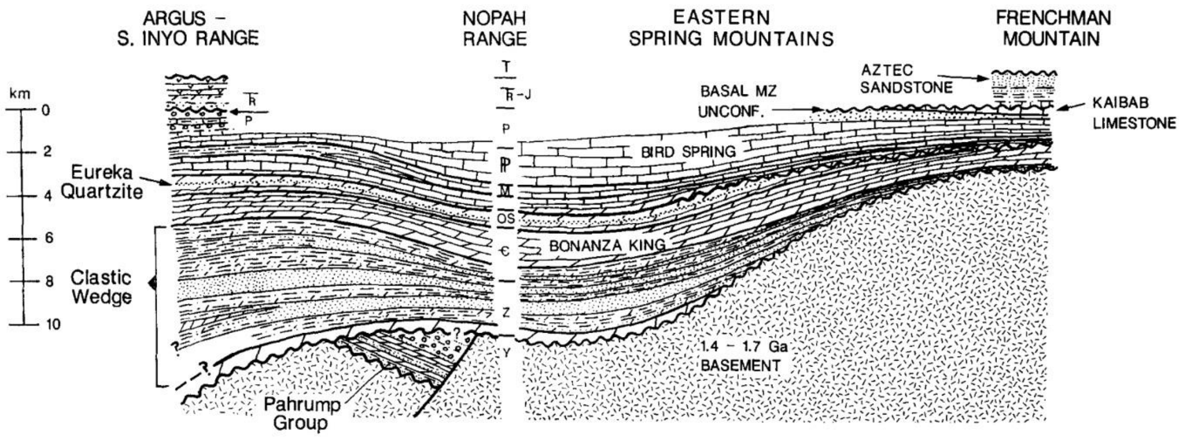
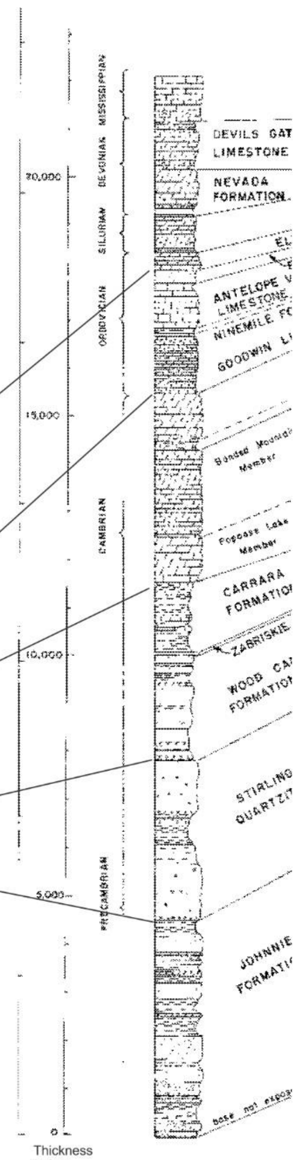
GEOLOGY OF THE SOUTHWEST US



Simplified stratigraphic cross section of Mesozoic and older rocks exposed in the region. See map below for locations. Y: Mesoproterozoic; Z: Neoproterozoic; C: Cambrian; OS: Ordovician-Silurian; M: Mississipian; P: Pensylvanian; P: Permian; Tr-J: Triassic-Jurassic; T: Tertiary. From Wernicke, Axen & Snow, 1988.

NORTHWEST SPRING MOUNTAINS



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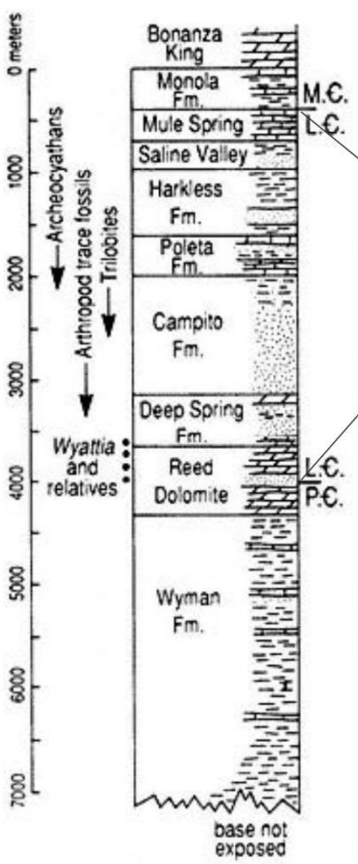
White Mtns & Inyo Range



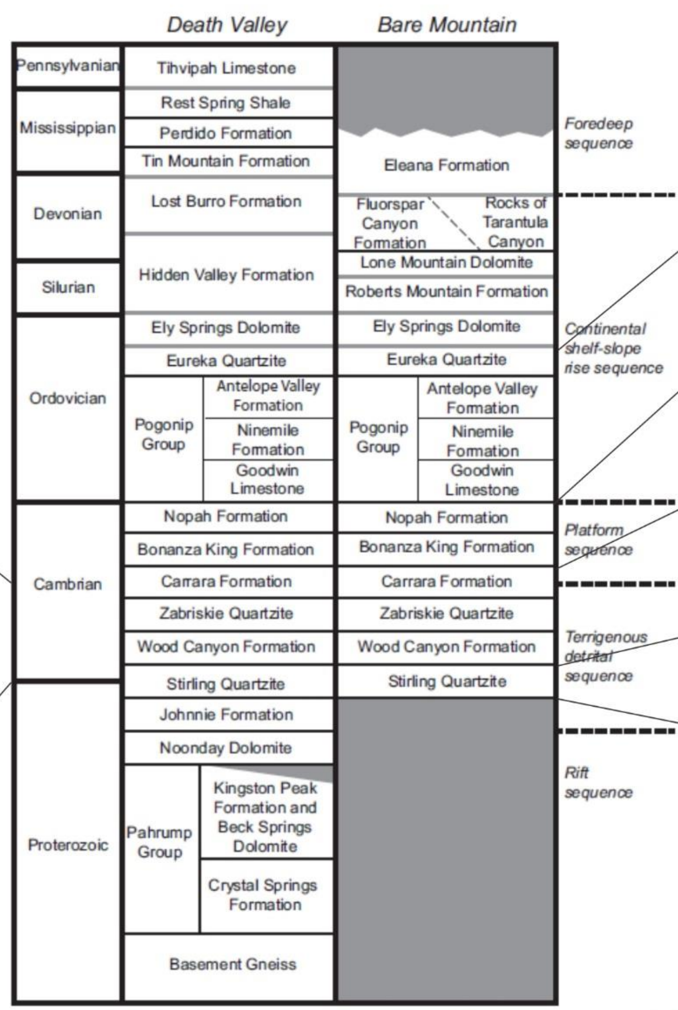
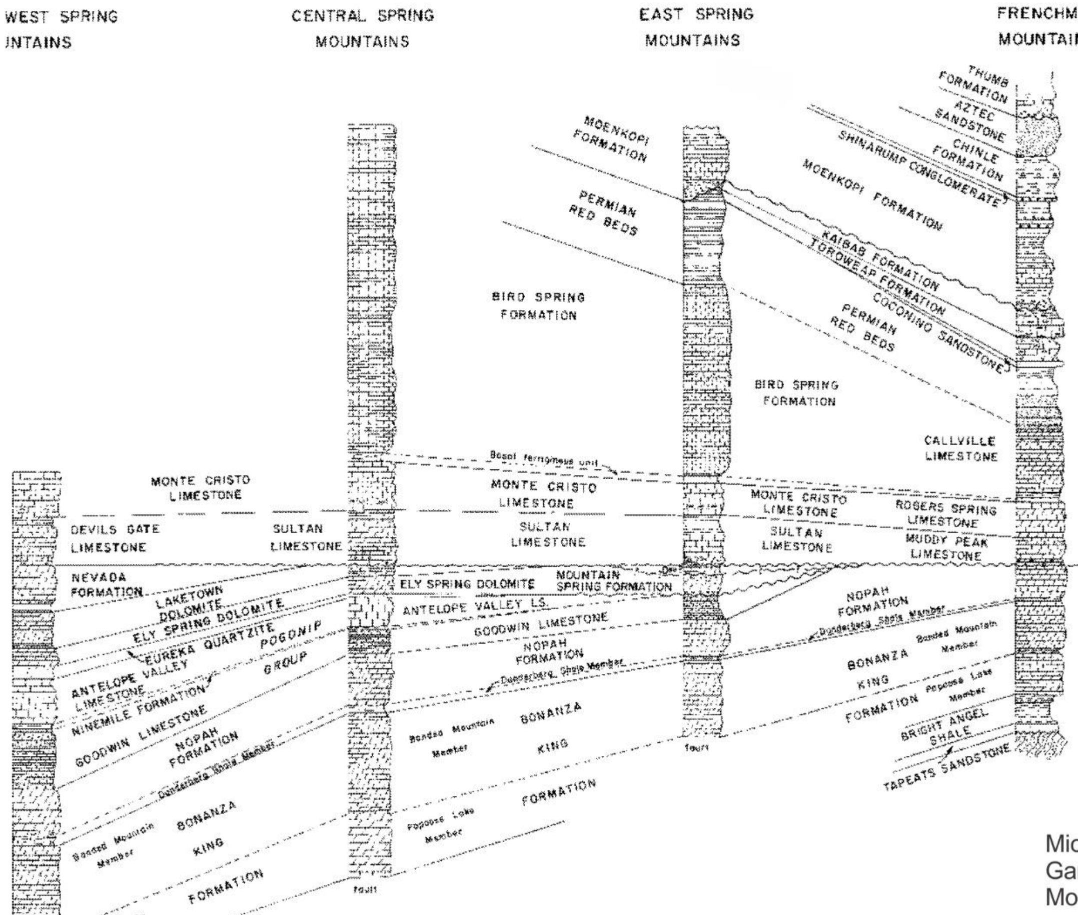
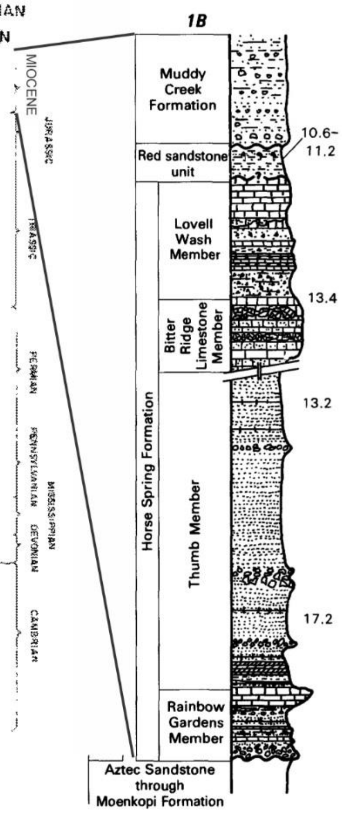


Figure 3. Generalized chart showing stratigraphic position of Paleozoic units exposed at Bare Mountain, Nevada; Death Valley, California; and the surrounding area (after Poole, 1974; Poole et al., 1992; Monsen et al., 1992). Gray areas show gaps in the geologic record due to nondeposition, faulting, or erosion.





Miocene section in the Rainbow Gardens area east of Frenchmans Mountain. From Bohannon, 1984

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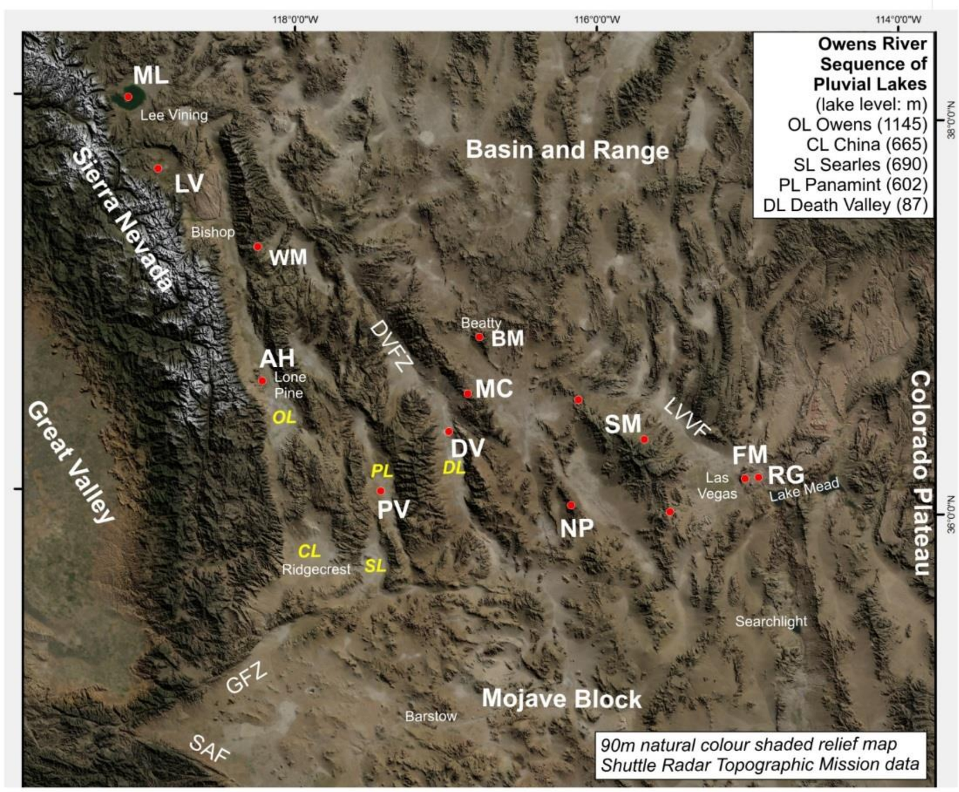
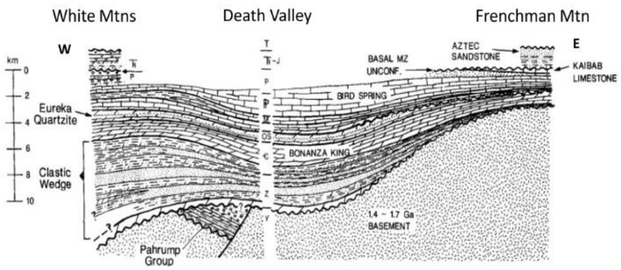
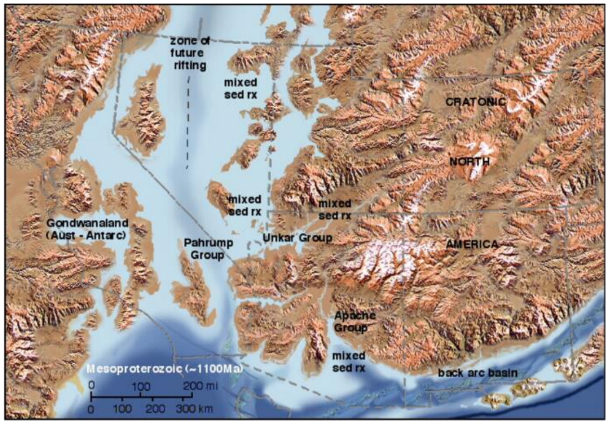


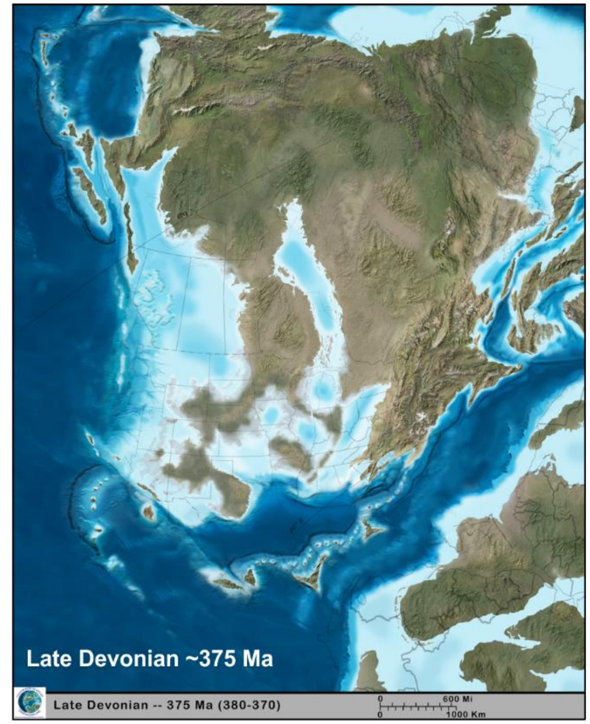
Days and Locations: FM: Frenchman Mountain; RG: Rainbow Gardens; SM: Spring Mountains; NP: Nopah Range BM: Bare Mountain; MC: Monarch Canyon; DV: Death Valley; PV: Panamint Valley; AH: Alabama Hills; WM: White Mountains; LV: Long Valley Caldera; ML: Mono Lake

GFZ Garlock Fault Zone; SAF San Andreas Fault; DVFZ Death Valley Fault Zone; LVVF Las Vegas Valley Fault

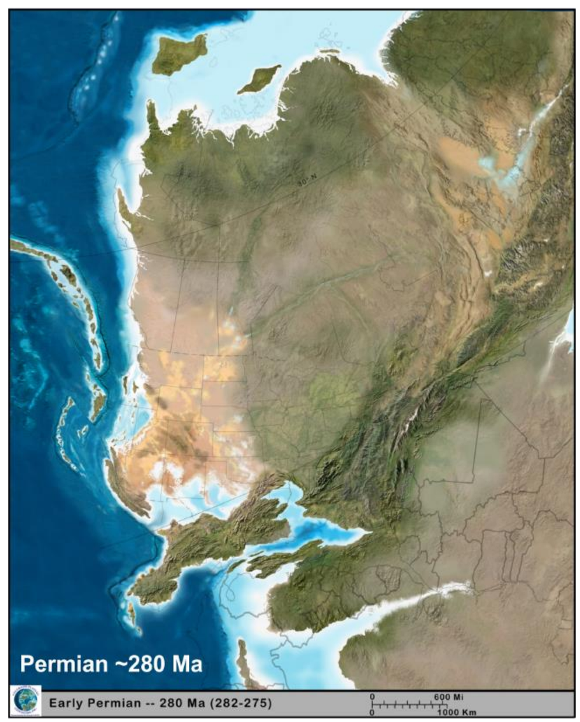

White Mtns
Death Valley
Frenchman Mtn
W
E
km
0
2
4
6
8
10
Eureka Quartzite
Clastic Wedge
Pahrump Group
BASAL MZ UNCONF.
AZTEC SANDSTONE
KAIBAB LIMESTONE
BIRD SPRING
BONANZA KING
1.4 - 1.7 Ga BASEMENT

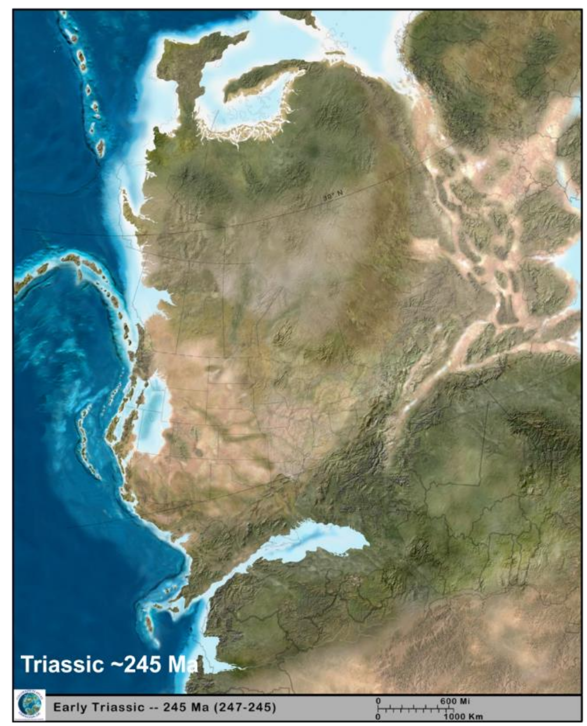

zone of future rifting
mixed sed rx
CRATONIC
NORTH
AMERICA
mixed sed rx
mixed sed rx
Gondwanaland (Aust - Antarc)
Pahrump Group
Unkar Group
Apache Group
mixed sed rx
back arc basin
Mesoproterozoic (~1100Ma)
0 100 200 mi
0 100 200 300 km


Late Cambrian ~500 Ma
Late Cambrian -- 500 Ma (505-495)
0 600 Mi
0 1000 Km

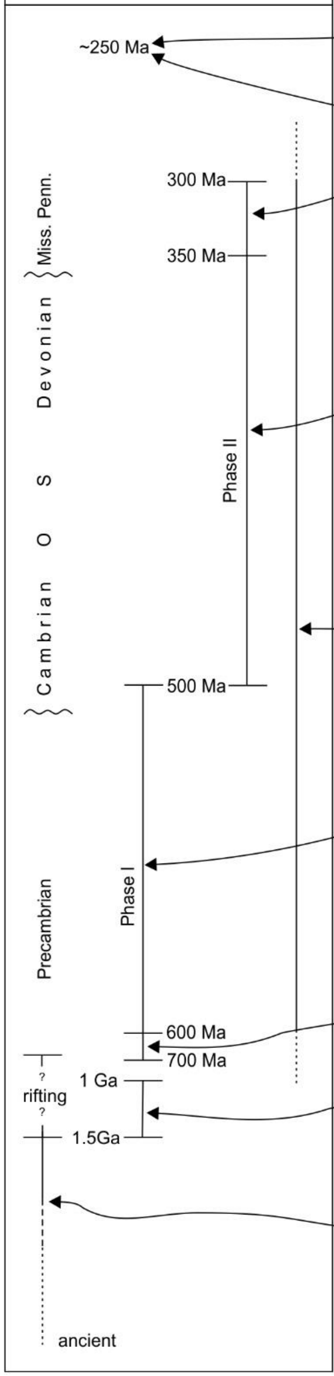

Late Devonian ~375 Ma
Late Devonian -- 375 Ma (380-370)
0 600 Mi
0 1000 Km


Pennsylvanian ~308 Ma
Middle Pennsylvanian -- 308 Ma (311-307)
0 600 Mi
0 1000 Km


Permian ~280 Ma
Early Permian -- 280 Ma (282-275)
0 600 Mi
0 1000 Km


Triassic ~245 Ma
Early Triassic -- 245 Ma (247-245)
0 600 Mi
0 1000 Km

TIMELINE	EVENTS



left-lateral displacement of passive margin truncates facies continuity in SW California

oldest age of oceanic crust in ocean basin; oceans are transient, continents are record keepers

Antler Orogeny: continental margin switches from passive to subduction as island arc impinges on NA, driving W-dipping subduction and east-vergent thrusting of deep water shales and silts over passive margin seds. Topography created by thrust results in flexural basin (foredeep), thus switching sed delivery direction. Compare: Maritimes Basin (Windsor-Morien Groups), terminal collision during Alleghanian O. at 320-310 Ma

Shallow marine sedimentation on passive margin. Subsidence and sedimentation rates slow as rifted margin cools, becomes more rigid. Still thickening to the west. Mostly carbonate seds. Changes in sea level move shoreline well inland at times, building stratigraphy with different depositional environments. Compare: Taconic-Acadian-Alleghanian Orogenies (420-315 Ma) along with Maritimes Basin (Horton-Windsor; 350-320 Ma)

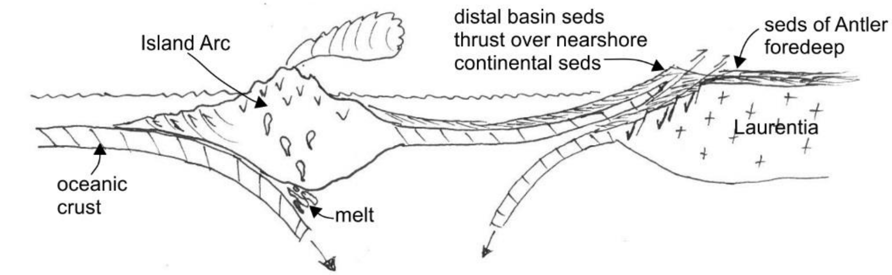
Island Arc Volcanism: active over extended period. Island Arcs local to western NA as they share the same fossil assemblage as in continental NA seds from the same time. None accreted onto NA during this period, though one was involved in the Antler Orogeny (above). Compare: numerous episodes of arc development in the Iapetus during similar time period.

Post-rift non-marine sedimentation on rapidly subsiding, weak, warm passive margin. Seds thicken rapidly to the west (up to 12 km!). Hingeline near present Las Vegas. Sedimentation kept pace with subsidence, and seds are consistently shallow, nearshore facies. Compare: C-O Meguma, Paleozoic of Avalon - deposited in Iapetus Ocean

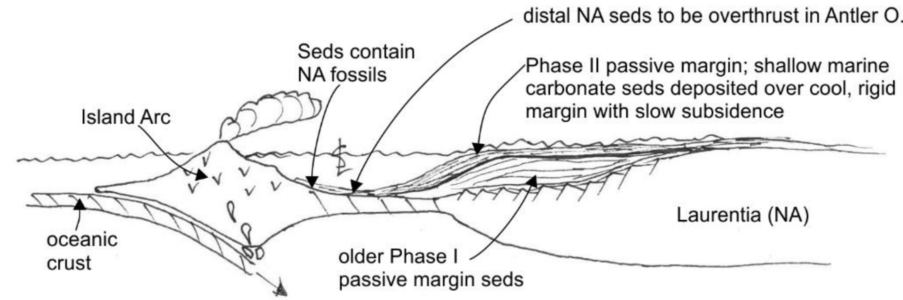
First seds on new passive margin are basal conglomerate and glacial diamictite (Snowball Earth).

Pahrump (&Belt) Group: Thick seds (clastic and carbonate) deposited on weak, thin crust, possibly in early failed rift (5-12km thick). Compare: synchronous with Grenville Orogeny.

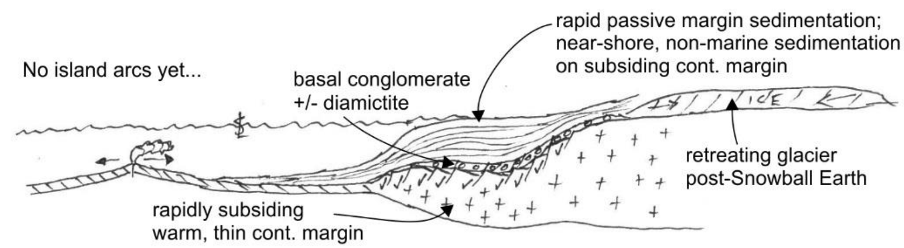
Precambrian basement of Laurentia records history of continent rifting and assemblage with younger rocks in sutures between older continental blocks. These younger sutures were ancient mtns but are now eroded away to flat. Compare: ca. 1.4-1.3 Ga anorogenic plutonism - Voisey's Bay in Nfld, Carbonatite REE in California



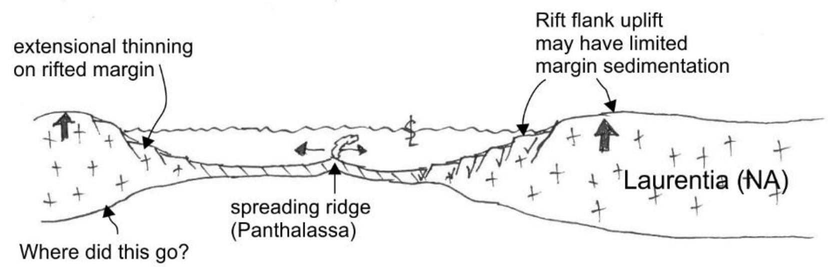
ANTLER OROGENY - ~350-300Ma



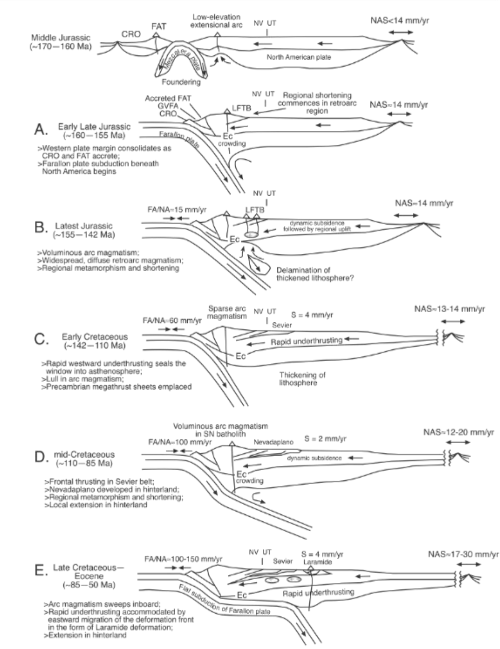
PASSIVE MARGIN - PHASE II ~500-350Ma



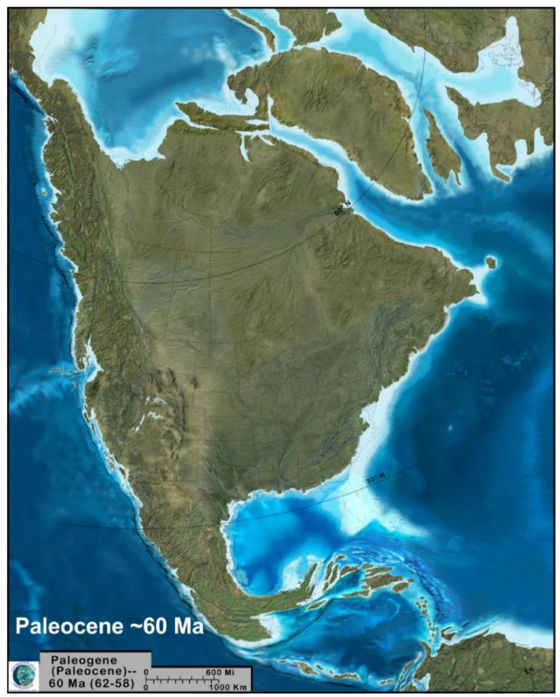
PASSIVE MARGIN - PHASE I ~750-500Ma

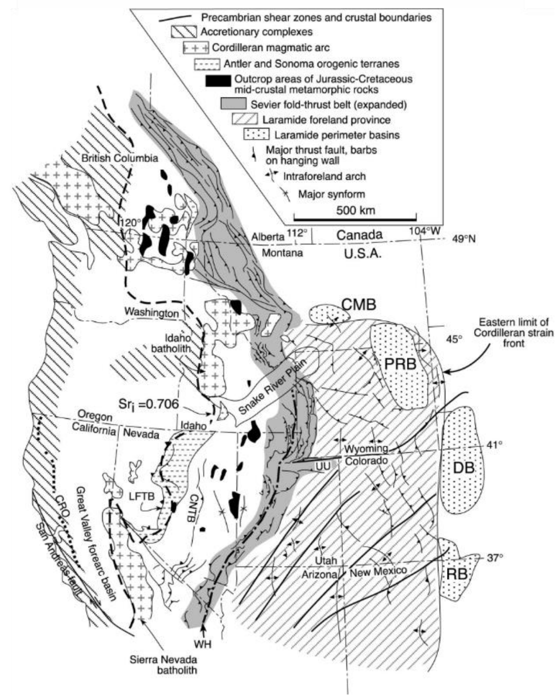


CONTINENTAL RIFTING ~1.5-1.1 Ga; 850 - 650 Ma

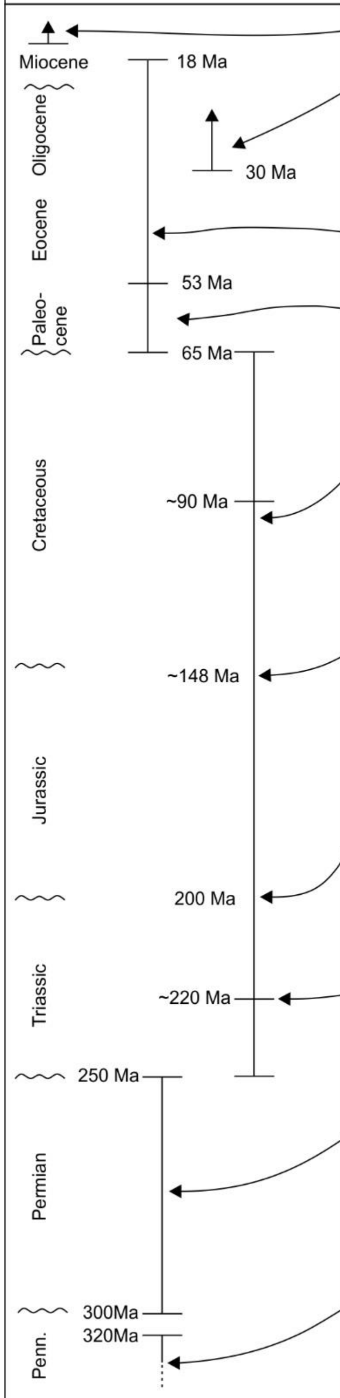


DeCelles, 2004





TIMELINE	EVENTS



EVENTS

Yellowstone hotspot

Sudbduction of spreading centre. Farallon-Pacific spreading ridge is subducted leading to 1) mantle window and upwelling of asthenosphere, 2) transcurrent motion along new plate margin b/w Pacific and NA plates, and 3) switch from compressional to extensional tectonics in the Basin and Range Province.

Rollback of flat slab. Initiation of extension begins in Canada and northern US

Laramide Orogeny (Flat Slab). Deformation and magmatism (mantle wedge) sweeps eastward beyond Colorado Plateau due to flattening of the subducting slab. Compare: continued onshore erosion and offshore passive margin deposition.

Sevier Orogeny. Continued subduction of the Farallon Plate leads to voluminous arc magmatism (2nd and larger phase of SN Batholith) and classical fold-and-thrust belts along the length of the North American Cordillera. Western Interior Seaway foredeep forms due to loading on the lithosphere (dynamic topography). Compare: Offshore deposition, deep weathering onshore, Chaswood Fm.

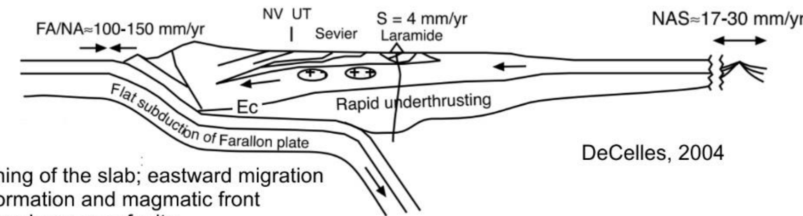
Arc magmatism, deformation, and continental sedimen-tation. First phase of Sierra Nevada Batholith including Independence Dikes (155 Ma), thrusting and synchronous terrestrial sedimentation including aeolian dunes of the Jurassic Aztec Formation. Compare: rifting of Atlantic Ocean well underway; offshore deposition

Western Pacific style to Andean style. Transition from arc accretion and basement-involved deformation & magmatism to "Andean-style" subduction, foreland fold-and-thrust, and arc magmatism. Compare: rifting of Pangea on east coast NA beginning at ~200 Ma results in plate direction and velocity change.

Truncation. left-lateral strike-slip faulting segments Antler and Sonoma structures. Compare: early rifting (failed) along east coast - red beds, conglomerates, breccias, and aeolian dunes of Fundy Group.

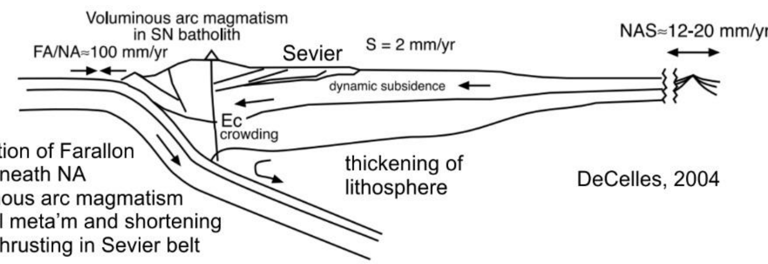
Island arc accretion (Sonoma Orogeny). A series of island arcs were thrust up onto the continental margin (preserved in western NV). Basement was involved during deformation thus distinguishing this phase of orogeny from the later Sevier Orogeny. Compare: NS in center of Pangea which is stabilizing by this period.

Ancestral Rocky Mountains formed. western NA was rising and the development of the extensive passive margin sequence is largely over by the beginning of the Permian. Compare: minor deformation and deposition related to the Maritimes Basin.



-flattening of the slab; eastward migration of deformation and magmatic front
-high angle reverse faults
-lack of deformation in NV & CA

LARAMIDE OROGENY - ~85-30 Ma



-subduction of Farallon Plate beneath NA
-voluminous arc magmatism
-regional meta'm and shortening
-frontal thrusting in Sevier belt

SEVIER OROGENY ~ 160 - 85 Ma

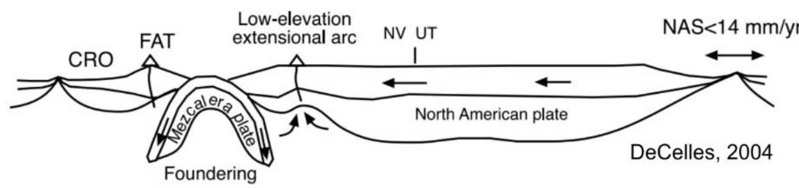
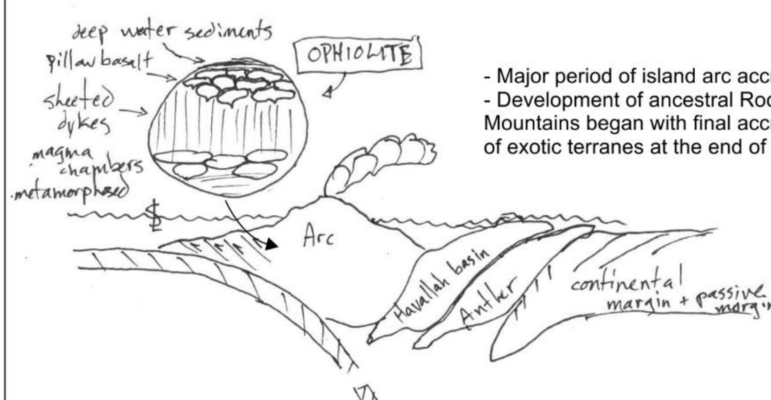
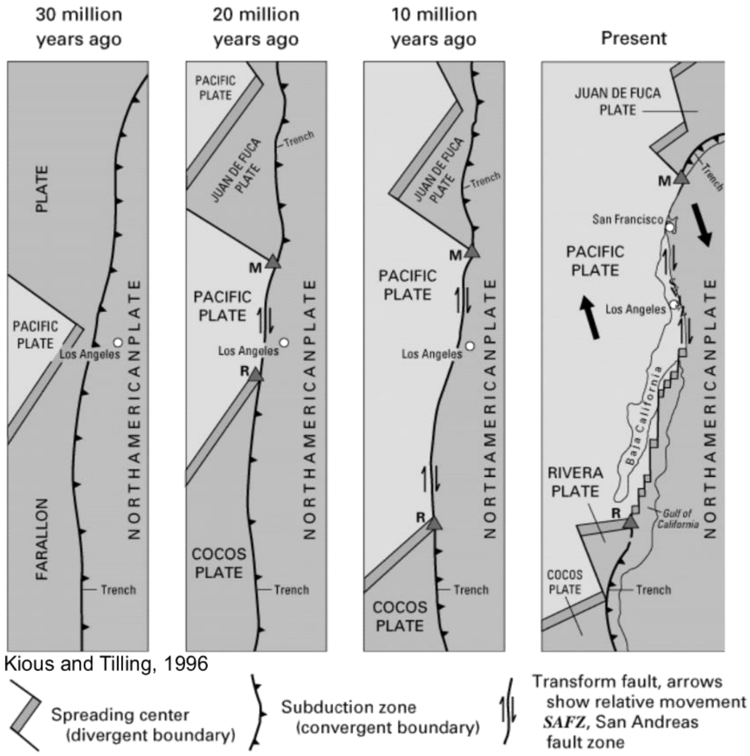


PLATE REORGANIZATION ~ 170 - 160 Ma



- Major period of island arc accretion
- Development of ancestral Rocky Mountains began with final accretion of exotic terranes at the end of the Permian

ISLAND ARC ACCRETION ~250 - 300 Ma



Kious and Tilling, 1996

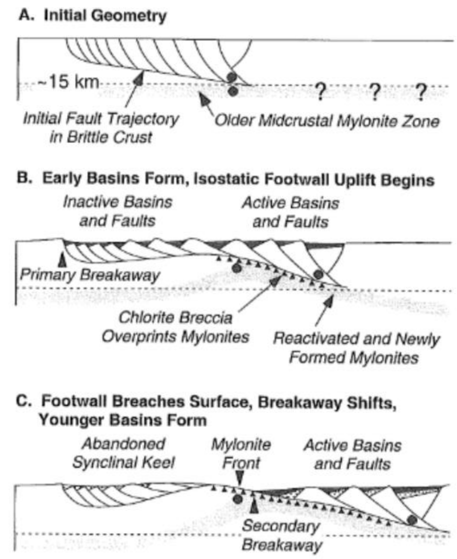
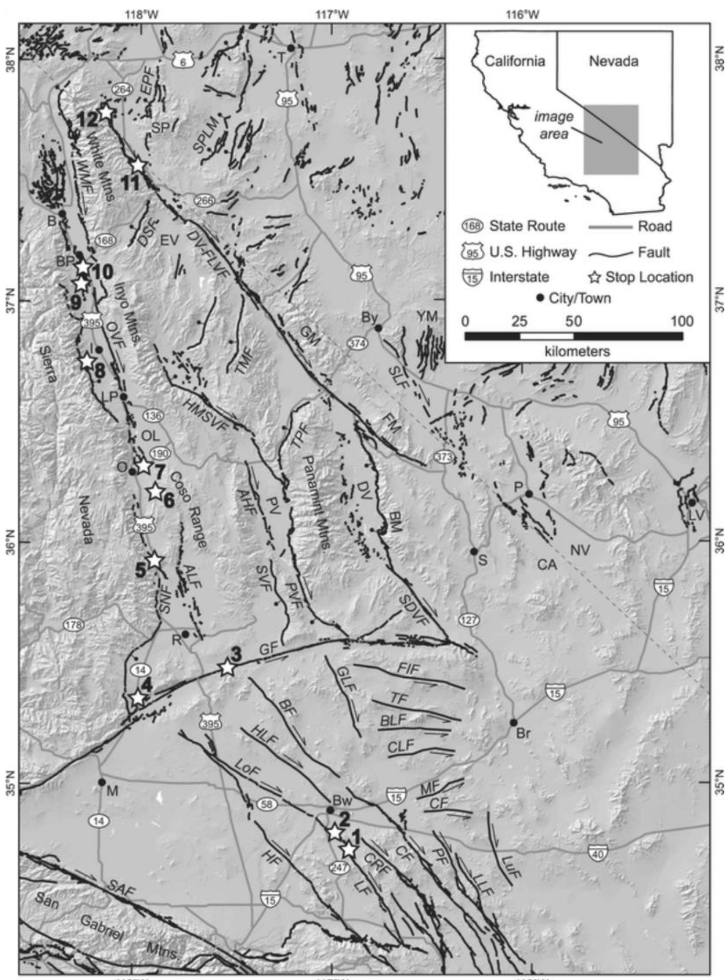


Figure 3.1 Evolutionary scheme of typical Cordilleran metamorphic core complex through normal shear on a ductile-brittle detachment system (e.g., Whipple Mountains, California). See figure 3.2 for aerial distribution of tectonic elements shown here in cross section. Low cut-off angle between syntectonic strata and the detachment would be expected above the secondary breakaway. After Spencer (1984). Axen, 2004



Frankel, 2008

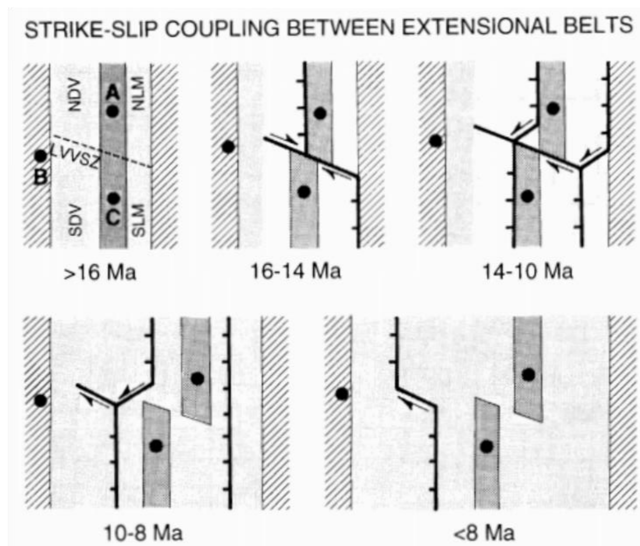


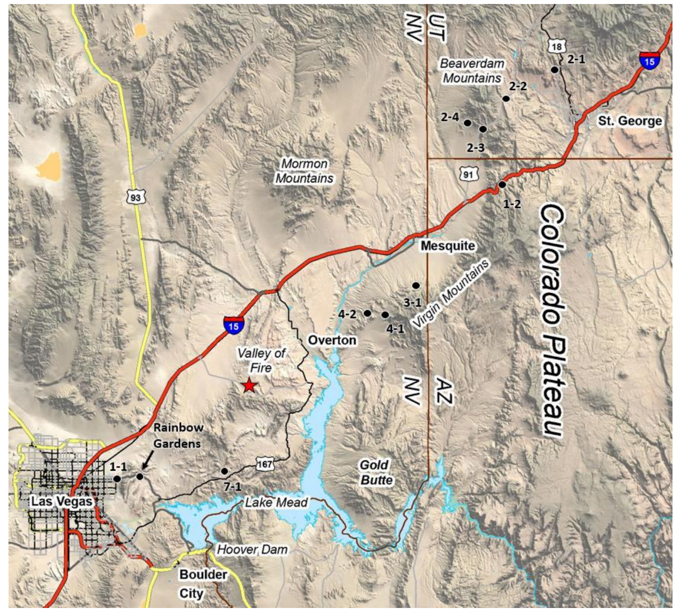
Fig. 10. Schematic geometry of Basin and Range extensional belts (light shading) and disruption of medial stable terrane (dark shading) between the Colorado Plateau and Sierra Nevada (diagonal ruling). Stepwise relative motion between points A (Sheep Range), B (Sierra Nevada), and C (Spring Mountains) during extension is shown in figure 7. From 16 to ~10 Ma, extension in the southern Lake Mead belt (SLM) is *kinematically* coupled by transform faulting through the Las Vegas Valley shear zone (LVVSZ) to extension in the northern Death Valley belt (NDV).

Snow & Wernicke, 2000

Day 1 - Field Trip through Frenchman Mountain and Rainbow Gardens

Logistics: We will meet at Travelodge by 7:00am on Thursday, April 25th. Your luggage (tent, sleeping, etc) will be loaded into the trailer and you will not see it until we arrive at the Valley of Fire camp on Friday evening

Safety: Hiking boots, 2L water, snacks for the day, sun screen, collared long sleeve shirt, pants are recommended but shorts are tolerable, wide brim hat, sun glasses, change of clothes and toiletries for 2 days. **Hazards:** dehydration, sharp rocks, cacti. **Other: bring cash/cards for dinners and stops at Walmart (we will have a modest selection of food in the cooler).**



Map of Lake Mead region showing field trip stops on Days 1-4, 7 as well as the site of the Rainbow Gardens exercise. We will be camping at Valley of Fire (star)

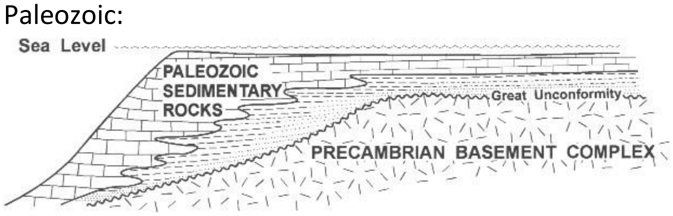
Stop 1-1: Frenchman Mountain basal nonconformity

(modified from Wernicke et al, 1989)

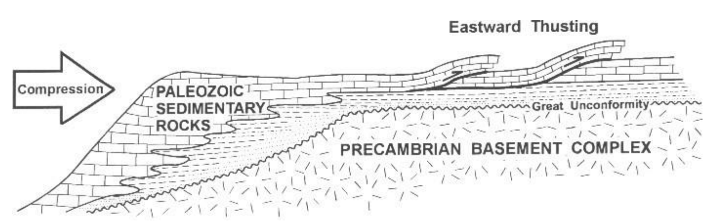
Here, lower Cambrian Tapeats Sandstone rests unconformably on Proterozoic crystalline rocks that are a mixture of 2.1, 1.7 and 1.4 Ga (Rowland et al., 1999). From the north side of the road looking southwest toward the summit of Frenchman Mountain, a complete cratonic section, ranging in age from Cambrian through Mississippian, is exposed (see figures below). As is typical of the craton, Silurian and Ordovician units are missing along a Devonian-on-Cambrian disconformity. Clastic rocks comprise the Lower Cambrian section, while carbonates dominate younger units; this transition from clastic to carbonate will be observed in other areas during the field school and lies near the boundary between Lower and Middle Cambrian units. A normal fault with apparent left-lateral separation lies beneath the road, forming a boundary between Upper Paleozoic exposed to the north and older rocks exposed to the south.

After a regional overview in the parking lot, we will walk up the path to the southeast for 100-150 m to look at the Precambrian basement in more detail. Along the path, take note of the brilliantly exposed unconformity (The Great Unconformity).

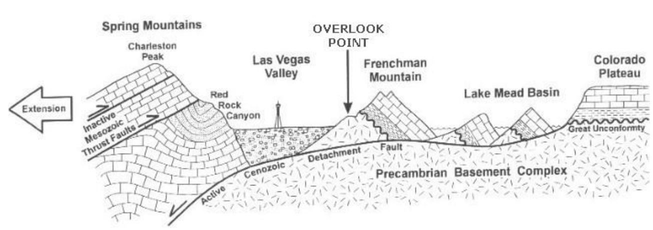
Paleozoic:

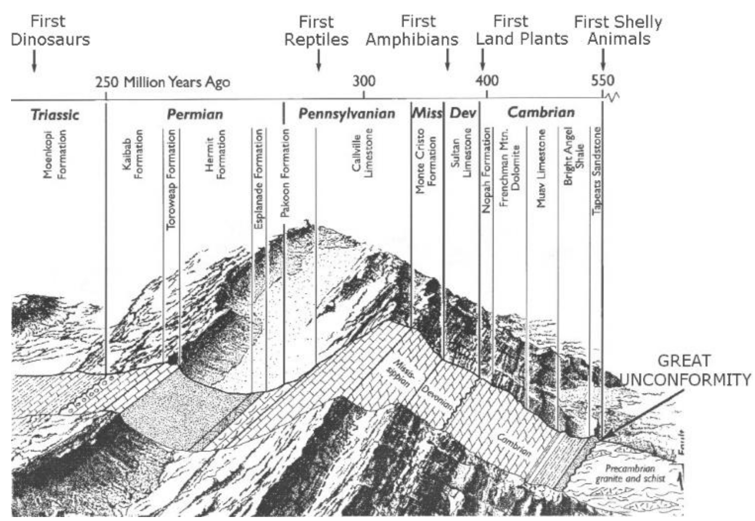


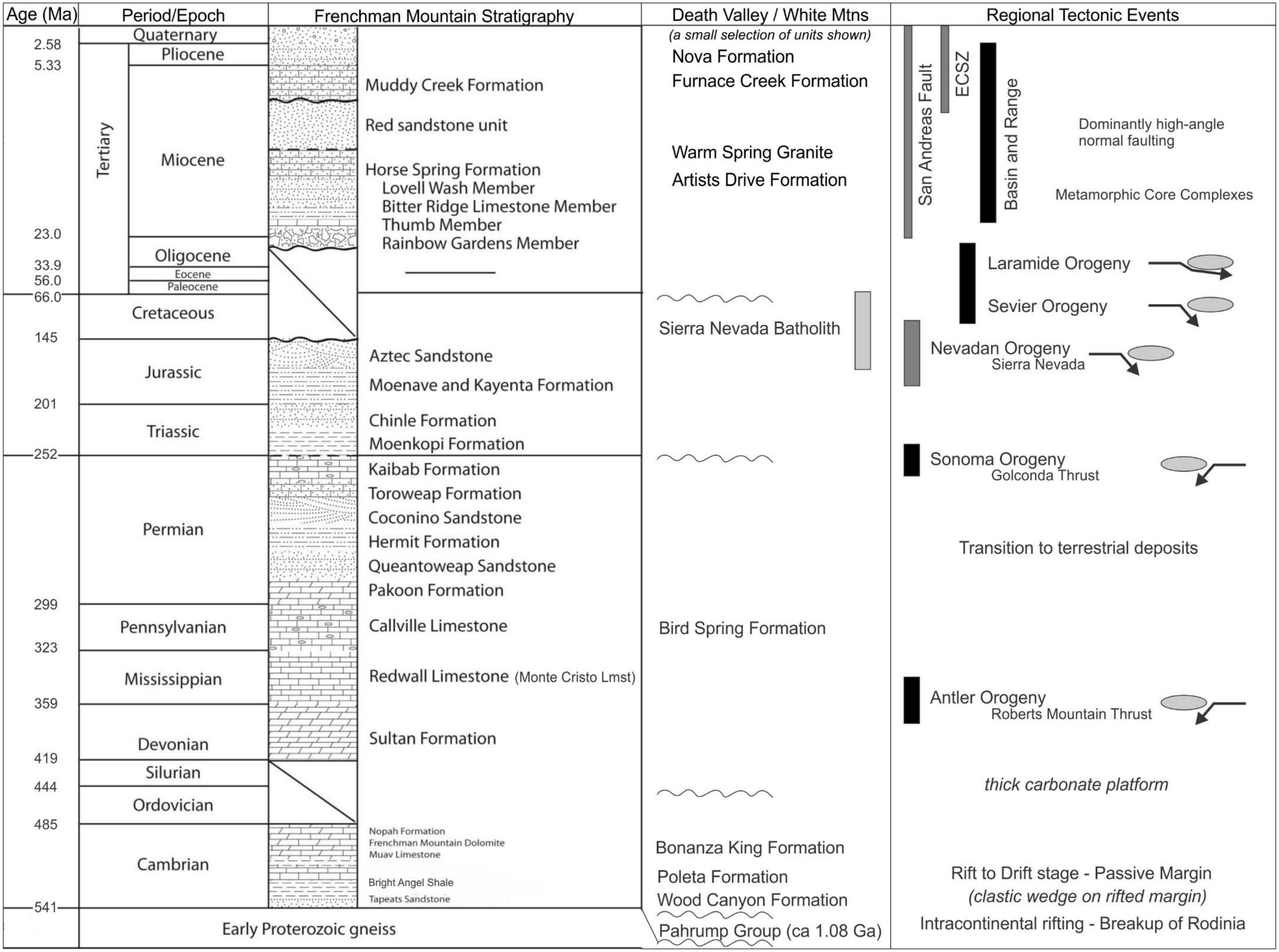
Mesozoic:



Cenozoic:







Stratigraphy of Frenchman Mountain and Rainbow Gardens. Compiled from Bohannon, 1984, Fryxell, 2005, Beard et al., 2007, Rowland, 1989

Stops 1-2: Colorado Plateau (modified from Wernicke et al., 1989)
As we proceed northeastward on I-15 from Mesquite, NV, the freeway enters the mouth of Virgin River Gorge where the canyon walls are composed of variably faulted and folded Paleozoic strata (Stop 1-2). The faulted and folded strata abruptly end against a steep fault zone about 3 miles from the mouth of the gorge. On the east side of the fault zone, flat lying Upper Paleozoic strata, including slope-forming red- and light-brown weathering Permian redbeds and ridge-capping Permian Kaibab and Toroweap Formations form the westernmost extent of the Colorado Plateau. At the mouth of the canyon, we are crossing the northeastern extension of the Virgin anticline – the core of which is exposed in Cabin Canyon.

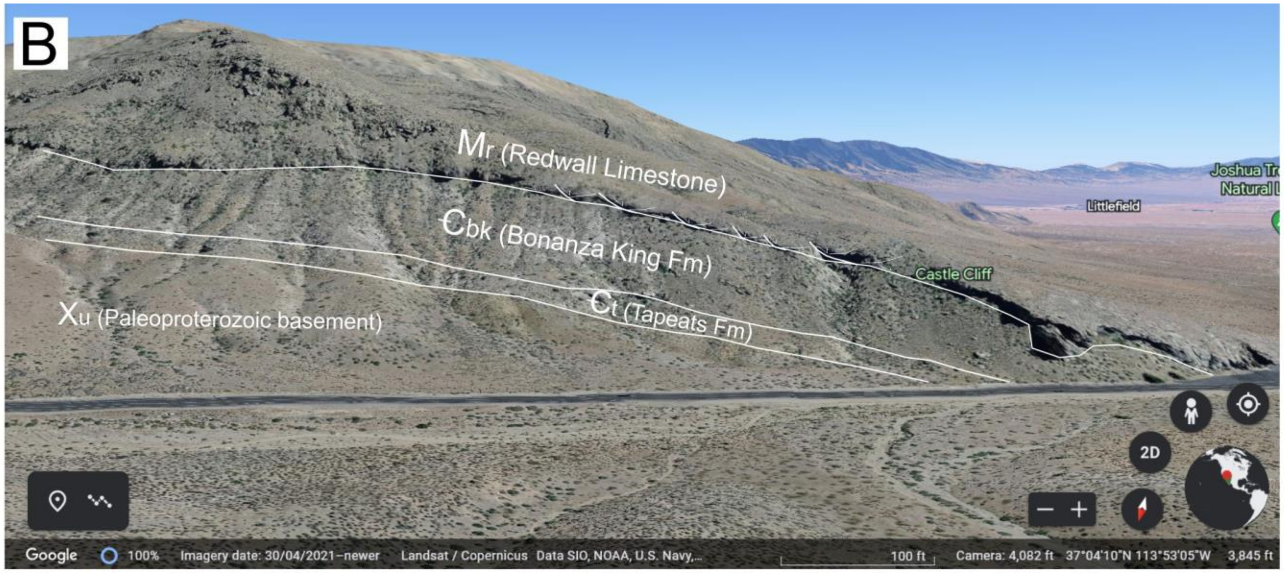
Day 2 - Field Trip Northern Virgin Mountains, NV and Beaverdam Mountains, Utah – see map on Day 1-3 stops.
Safety: Hiking boots, 2L water, snacks for the day, sun screen, collared long sleeve shirt, pants are recommended but shorts are tolerable, wide brim hat, sun glasses, change of clothes and toiletries for 2 days. **Hazards:** dehydration, sharp rocks, cacti. **Other: Continental breakfast is included with our stay at Rodeway Inn and we will supply cereal, fruit, snacks and light lunch supplies. We will stop at Albertson's or Walmart on our way to our first stop so you can buy food for lunch.**

This first full day of field school will serve as an introduction to the geology of the region with emphasis on 1) structural analysis of a Proterozoic shear zone, 2) examination of the breakaway fault (detachment) separating the Colorado Plateau from the Basin and Range, and 3) discussion of the tectonic significance of Miocene conglomerates and megabreccias.

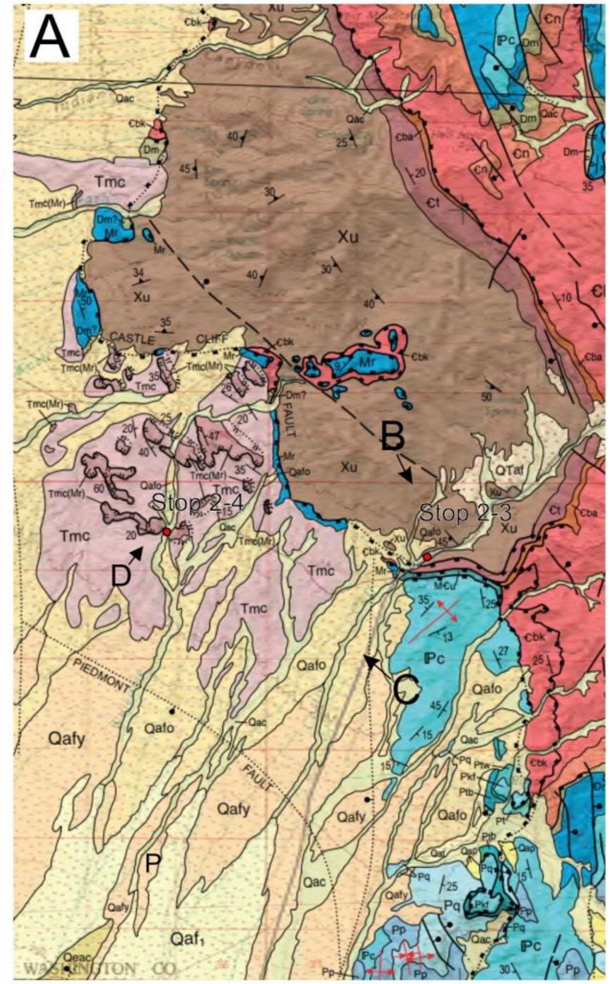
Stop 2-1: Snow Canyon State Park
The morning of Day 2 (April 26th) we will depart St George, UT and proceed north on UT 18 to Snow Canyon State Park. The park is on the western edge of the Colorado Plateau. The rocks include fluvial and minor aeolian deposits of the Jurassic Kayenta Formation, spectacular aeolian dunes of the Jurassic Navajo Sandstone (time equivalent to the Aztec Formation), and Quaternary basalt flows. The basalts tend to occur along fissures and linear vents which are fault-controlled. The faults are typically high-angle normal faults related to the Basin & Range extensional domain to the west. We will take a short hike to lava tubes in the Quaternary basalts.

Stop 2-2: Colorado Plateau and Beaverdam Mountains
Heading west toward Nevada on Old US 91 via UT 18 to a viewpoint before entering the Beaverdam Mountains. This stop is a pullout on Old US 91 and we can see a broad expanse of flat-lying strata of the Colorado Plateau, including the spectacular cliffs of Red Mountain to the northeast, composed of the Jurassic Navajo (Aztec) Sandstone. Looking northwest, the flat-lying strata turn up abruptly and dip eastward, such that a complete section of Paleozoic strata down to Precambrian basement is exposed in the Beaver Dam Mountains. The cliffs on the crest of the range to the west are underlain by Mississippian limestone.

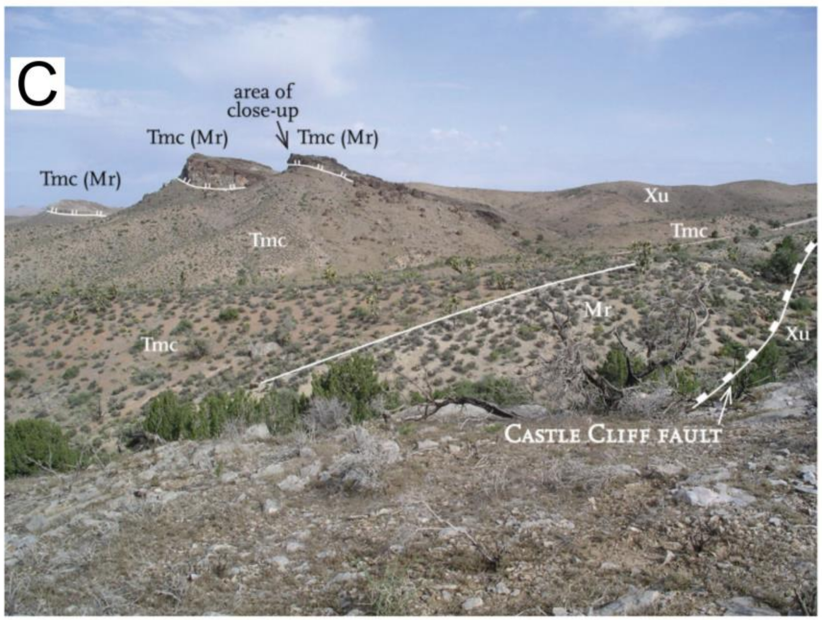
Stop 2-3: Castle Cliff detachment. (modified from Wernicke et al., 1989)
Continuing on Old US 91 through the Beaverdam Mountains, we will transect a complete Paleozoic section from Permian Kaibab Limestone at the top to Lower Cambrian Tapeats Sandstone at the base. We will stop just before the road leaves the Beaverdam Mountains near a steep cliff on the left (Castle Cliff). Walk up the slope southeast of the highway to observe exposures of brecciated Precambrian crystalline rocks overlain by a highly-attenuated sequence of fractured and brecciated Paleozoic clastic and carbonate rocks. Some key stratigraphic intervals are identifiable in the Cambrian Bonanza King and Nopah Formations (see strat column related to the Frenchman Mountain) allowing for thickness estimate of structurally thinned or missing parts of the sequence. The massive to thick-bedded cliff-forming rock capping the slope is the Mississippian Redwall Limestone, which generally dips eastward and is cut and repeated by several curved and planar west-dipping normal faults. These faults generally terminate downward at a major low-angle fault strand of the Castle Cliff detachment zone (see photographs, maps and sections on next 2 pages). The amount of stratigraphic attenuation between the Precambrian crystalline rocks and this fault strand is approximately 1.4 km. Some of the normal faults that cut the Redwall Limestone contain fault striae that are suggestive of structural transport of hangingwall rocks to the southwest.

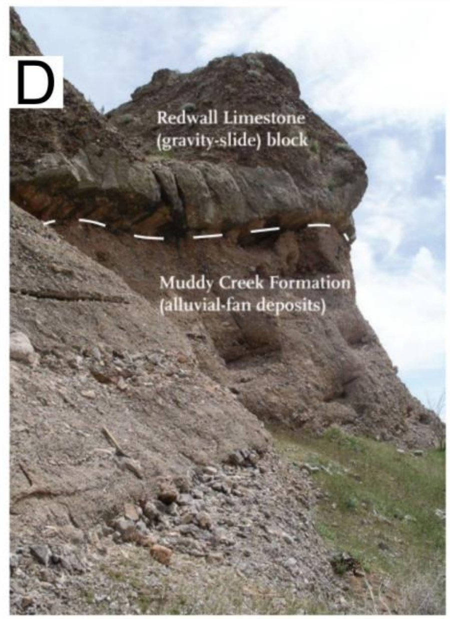


Oblique view of Castle Cliff. True thicknesses: Xu ~15,000m; Ꞓt ~100m; Ꞓbk ~600m; Mr ~250m. What's missing?

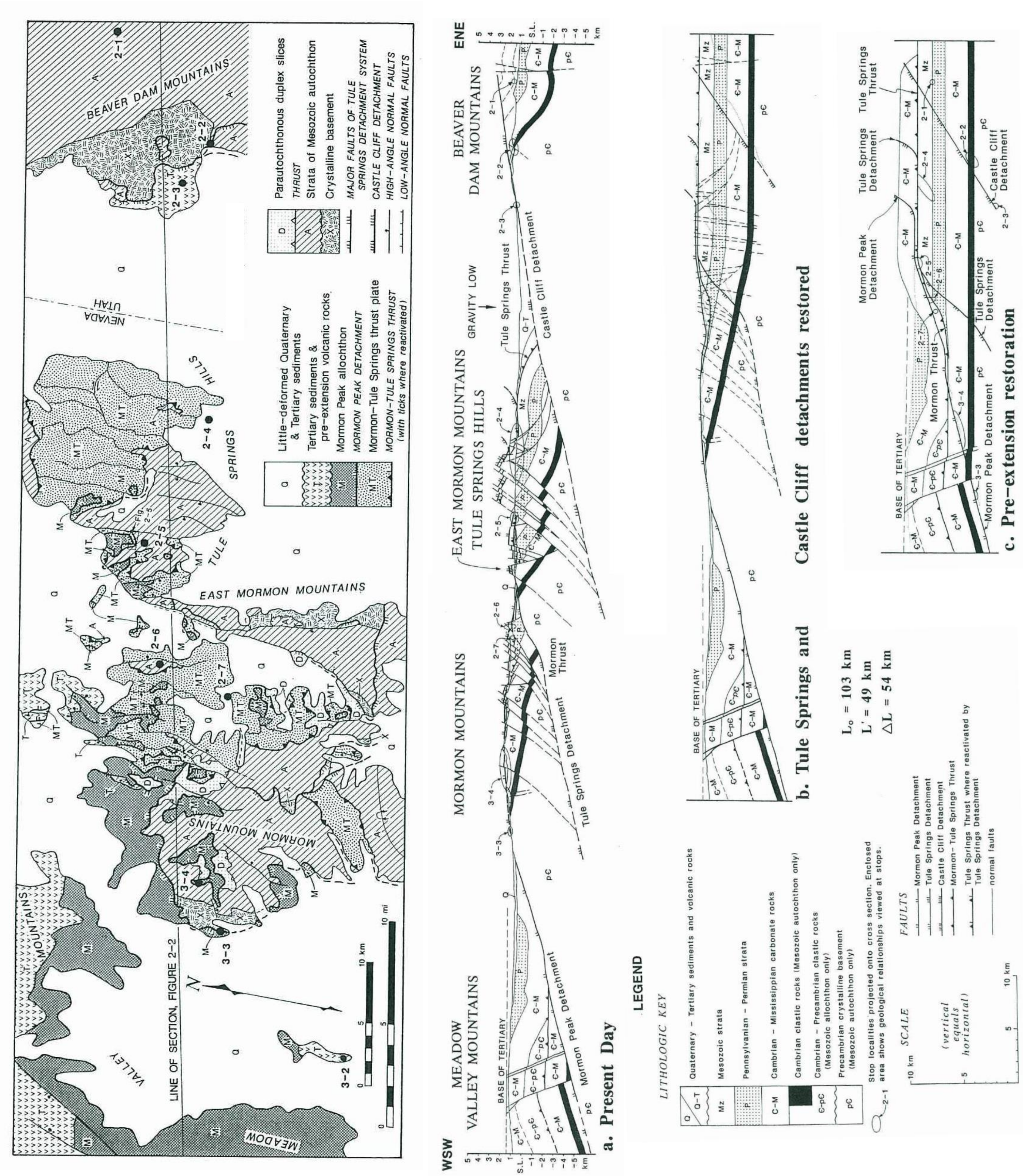


A. Part of the Geologic Map of the St. George and East Part of the Clover Mountains 30' x 60' Quadrangles, Washington and Iron Counties, Utah (Biek et al., 2009). Locations of the Castle Cliff Detachment (Stop 2-3) and field photos of the Miocene gravity-slide block (Stop 2-4) are shown. The arrows next to the letters indicate the direction of view in the images.





C. View north to Castle Cliff fault and large gravity-slide blocks of Redwall Limestone (Tmc[Mr]). The gravity-slide blocks and enclosing Muddy Creek (Tmc) strata are tilted to the east. The Castle Cliff fault dips gently west and places highly sheared Mississippian Redwall Limestone (Mr) against Precambrian crystalline basement rocks (Xu). The dirt road to Welcome Spring traverses the wash below the nearest gravity-slide block and is visible at the right of the photograph. D. Close-up view of gravity-slide block and underlying Muddy Creek Formation; rock hammer for scale. The coarse alluvial-fan deposits lack clasts of the Precambrian crystalline basement, now widely exposed in the Beaver Dam Mountains, showing that this and other gravity-slide blocks were emplaced prior to unroofing of the Beaver Dam Mountains in late Miocene time, 5 to 10 million years ago. Note brecciated nature of Redwall Limestone.
Biek, 2009

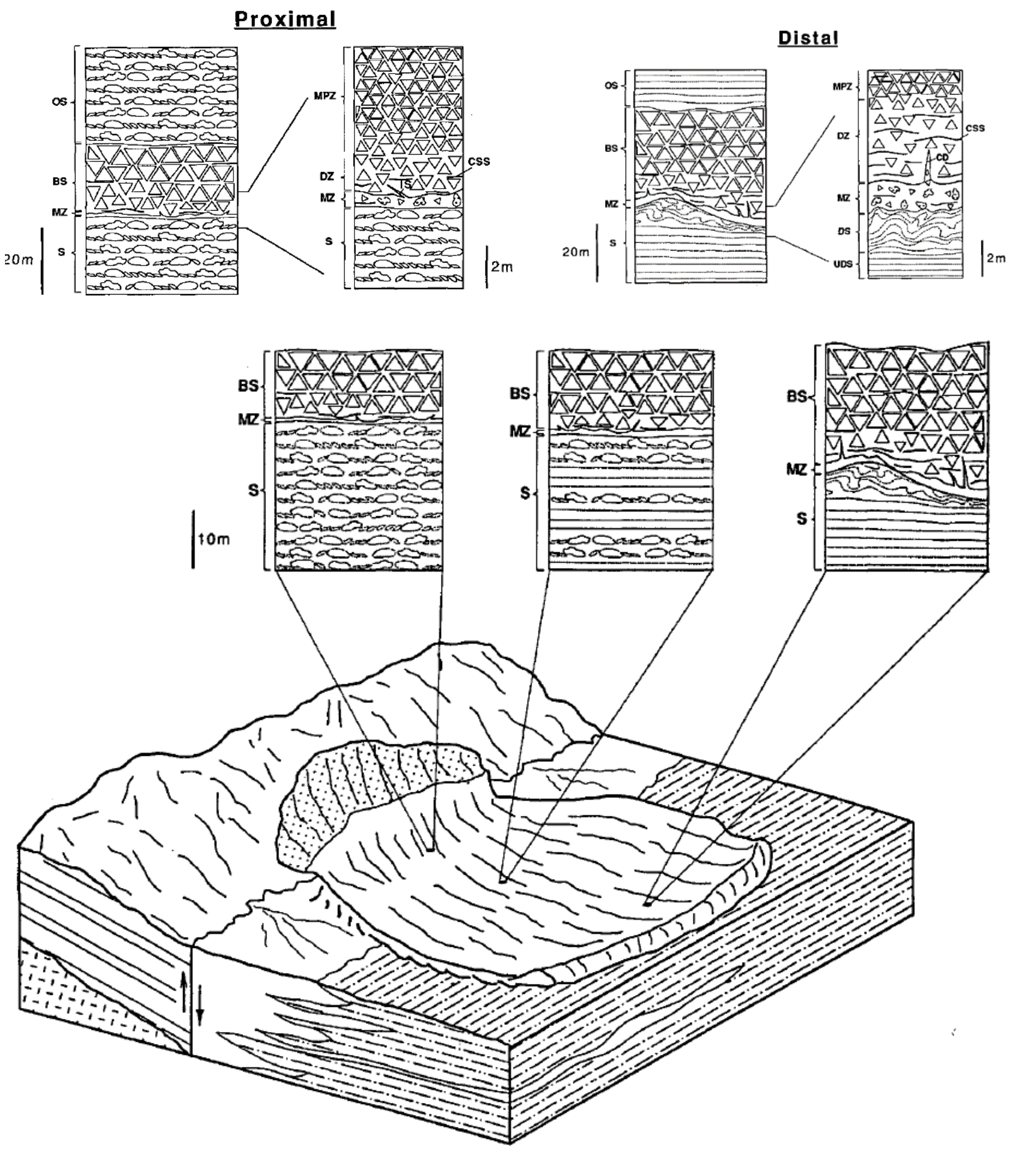


Tectonic map, cross sections and restored sections of the Mormon Mountains, NV to the Beaverdam Moutains, UT. Stops 2-1, 2-2, and 2-3 indicated in the Beaverdam Mountains. From Wernicke et al., 1989

Stop 2-4: Cenozoic (Miocene?) monolithologic breccias (modified from Wernicke et al., 1989)

This stop is 3 miles to the west from Stop 2-3 along a graded dirt road. This stop is an overview of landslide blocks of Mississippian rocks intercalated with basin-fill sediments that are have been correlated with the Miocene-Pliocene Muddy Creek Formation (Wernicke et al., 1989) or with the Miocene Horse Spring Formation (Beard et al., 2007). The slide blocks and the enclosing clastic sedimentary strata (which lack clasts of Precambrian rocks) dip gently to moderately northeast, probably reflecting back-tilting into the Castle Cliff detachment. Road cuts and a few natural exposures reveal small-displacement faults that cut the basin-fill strata and may be cogenetic with tilting. Striations on these faults are generally consistent with northeast-southwest extension.

If accessible, we will visit an exposure of a gravity slide block just southwest of Welcome Spring. Here, an east-dipping gravity-slide block of Mississipian Redwall Limestone overlies similarly dipping alluvial-fan deposits interpreted to be a coarse facies of the Muddy Creek Formation. These coarse alluvial-fan deposits lack clasts of the Paleoproterozoic crystalline basement, now widely exposed in the core of the Beaver Dam Mountains culmination, showing that this and other gravity-slide blocks were emplaced prior to unroofing of the Beaver Dam Mountains culmination, likely in late Miocene time.



Idealized morphology (not to scale) of large dry-climate rock-avalanche deposit showing internal features and associated substrate lithofacies in proximal, medial, and distal portions. Abbreviations are substrate (S); undisturbed substrate (UDS); disturbed substrate (DS); mixed zone of entrained substrate and comminuted breccia (MZ); disturbed zone (DZ) of the breccia sheet (BS) that displays comminuted slip surfaces (CSS), and is intruded by clastic dykes (CD) and intrusive stringers (IS; load structures and poorly-developed clastic dykes) derived from the mixed zone; matrix-poor zone (MPZ) of the breccia sheet; and overlying sediments (OS). In places, a discontinuous megabreccia cap occurs along the top of the breccia sheet. Approximate vertical scale is indicated for zonal stratigraphic columns. From Yarnold and Lombard, 1989.

Stop 3-1: Cabin Canyon, N Virgin Mountains; Precambrian geology (modified from Quigley et al., 2002)

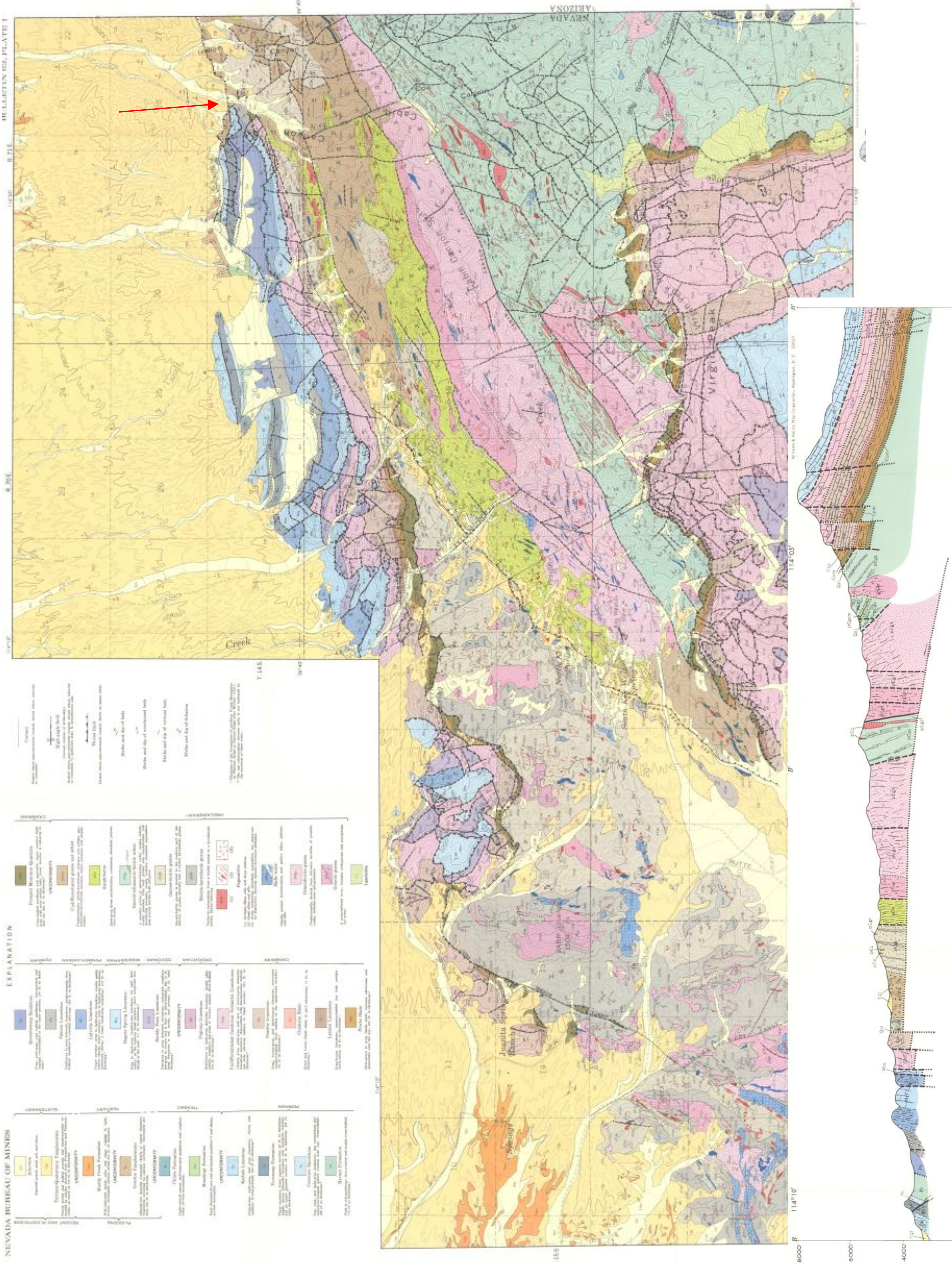
The crystalline core of the Northern Virgin Mountains (NVM) consists of Paleoproterozoic (ca 1,700 Ma) rocks that are part of the Mojave Precambrian province, an isotopically enriched, upper-amphibolite to granulite facies metamorphic terrain extending from west-central Arizona westward into the Basin and Range (map of cabin canyon below). The proposed boundary between the Mojave and the juvenile Yavapai province (Karlstrom and Bowring, 1988) is at least 40 kilometers east of the NVM at the Gneiss Canyon shear zone, or perhaps lies farther east at the Crystal shear zone of the Grand Canyon.

The early tectonic history of the Virgin Mountain crystalline terrain (VMCT) likely involved:

- **D1:** Burial to depths of 20-25 kilometers and complex bedding sub-parallel thrusting and contraction (**S1**). This first-generation fabric has been intensely overprinted, with the only remaining structural evidence being northwest-trending inclusion trails in pre-D2 porphyroblasts and weak fabrics in low strain domains south of the Big Springs segment.
- **D2:** Throughout the rest of the VMCT, intense E-W contraction resulted in formation of a penetrative N-S fabric (**S2a**), accompanied by high-temperature metamorphism and localized migmatization. This fabric was progressively reoriented into a NE-trend (**S2b**) during synchronous NW-side-up thrusting, continuing peak temperature metamorphism (upper amphibolite facies), and granitic magmatism.
- **D3:** This NE-trending fabric was strongly reactivated during continual deformation at shallower crustal levels (**D3**), resulting in formation of the **Virgin Mountains shear zone network** (VMSZ). The VMSZ is composed of structurally linked mylonitic shear zones displaying a wide variety of finite strain state geometries, including:
  - dextral strike-slip zones with spectacular structural asymmetry,
  - oblate (flattening) domains with conjugate shear bands and weakly developed vertical stretching lineations,
  - steeply lineated L>>S prolate (stretching) domains with poor asymmetry, and
  - obliquely lineated reverse and normal sense domains with excellent asymmetry. Deformation is most intense along pre-existing lithologic and structural heterogeneities, although almost all the Proterozoic rocks have been overprinted by this event.

An overall kinematic analysis of the VMSZ suggests that deformation was primarily dextral transpressive, with complexities arising due to variations in shear zone orientation and geometry, rheologic heterogeneities, and perhaps, timing of deformation. Regional deformation has been dated at circa **1,650-1,550 Ma** using U-Pb monazite geochronology, a broad time range suggesting either multiple movement histories or a protracted deformation continuum lasting over 100 m.y. Seemingly incompatible structures can be easily created during heterogeneously partitioned transpressive deformation and are correlated based on metamorphic conditions and deformation microstructures.

- **D4:** The latest movement on the Cabin Canyon Fault cuts across S3 mylonitic fabrics. The Cabin Canyon Fault has reverse and left-lateral motion on it and could be Laramide or Miocene age, or both.


NEVADA BUREAU OF MINES
EXPLANATION
SECTION B — B'
Creek

We will walk up the Cabin Canyon as a group to calibrate some of our observations. Eventually, we will separate and attempt to identify different rocks, metamorphic mineral assemblages, map units, and structures. Look out for cross-cutting relationships and attempt to determine a sequence of deformation-metamorphic events. You can check your work by consulting the full Quigley et al., 2002 field guide for this canyon on the proceeding pages.

Complete the partially redacted geological map on the opposite page using the map unit legend below. Measure and plot structural measurements of foliations and lineations. We will attempt to identify and distinguish different generations of structures.

The legend on the geological map includes several units that are defined by the combination of rock types. Below is a brief description of rock types and legend units.

Yl dikes, isoclinally folded, internally massive to mylonitized	Weakly to undeformed leucopegmatite (Yl) since it is younger. Young deformation could be related to Laramide Orogeny. Y = Mesoproterozoic (ca. 1.4 Ga).
Leucocratic quartz monzonite, weakly foliated	
Strike-slip ultramylonite zones	Mylonites are ductile fault rocks. Ultramylonites have experienced grain size reduction and consists of ~90% matrix (see pg 23 in field sheets)
Xa with numerous Yl, gneissic to mylonitic	Amphibolite gneiss (Xa) intruded by numerous weakly to undeformed leucopegmatites (Yl).
"Granulated" Yl mylonite and Xgdn	Leucopegmatites (Yl) intruded granodiorite gneiss (Xgdn) late- or post-D3. “Granulated” may refere to cataclasite texture.
Xpgn with Yl, mylonitic	Paragneiss (Xpgn) intruded by leucopegmatites (Yl)
Xpsgn and Xgdn, mylonitic	Gt-bt-sill paragneiss (Xpsgn) and bt-hb granodiorite gneiss (Xgdn). Paragneiss with abundant aluminosilicates is also called a pelitic gneiss.
Xgdn, gneissic to mylonitic	Bt-hb granodiorite (Xdgn); gneissic to mylonitic
Xgdn, Xpsgn and Xpgn, folded and mylonitic	Gt-bt-sill paragneiss & leucosomes (Xpsgn) and bt paragneiss & leucopegmatites (Xpgn) intruded by and interlayered with biotite-hornblende granodiorite gneiss (Xgdn); All rocks were metamorphosed and deformed multiple times. X = Paleoproterozoic (ca. 2.2-1.7 Ga).
Xps, crenulated and mylonitic	Pelitic schist (Xps). Lower metamorphic grade. Separated from the gneissic rocks to the north by the Cabin Canyon Fault. The fault has a long history including high-temperature D2, lower-temperature D3 mylonite, brittle Laramide reverse fault, and Miocene oblique strike-slip.

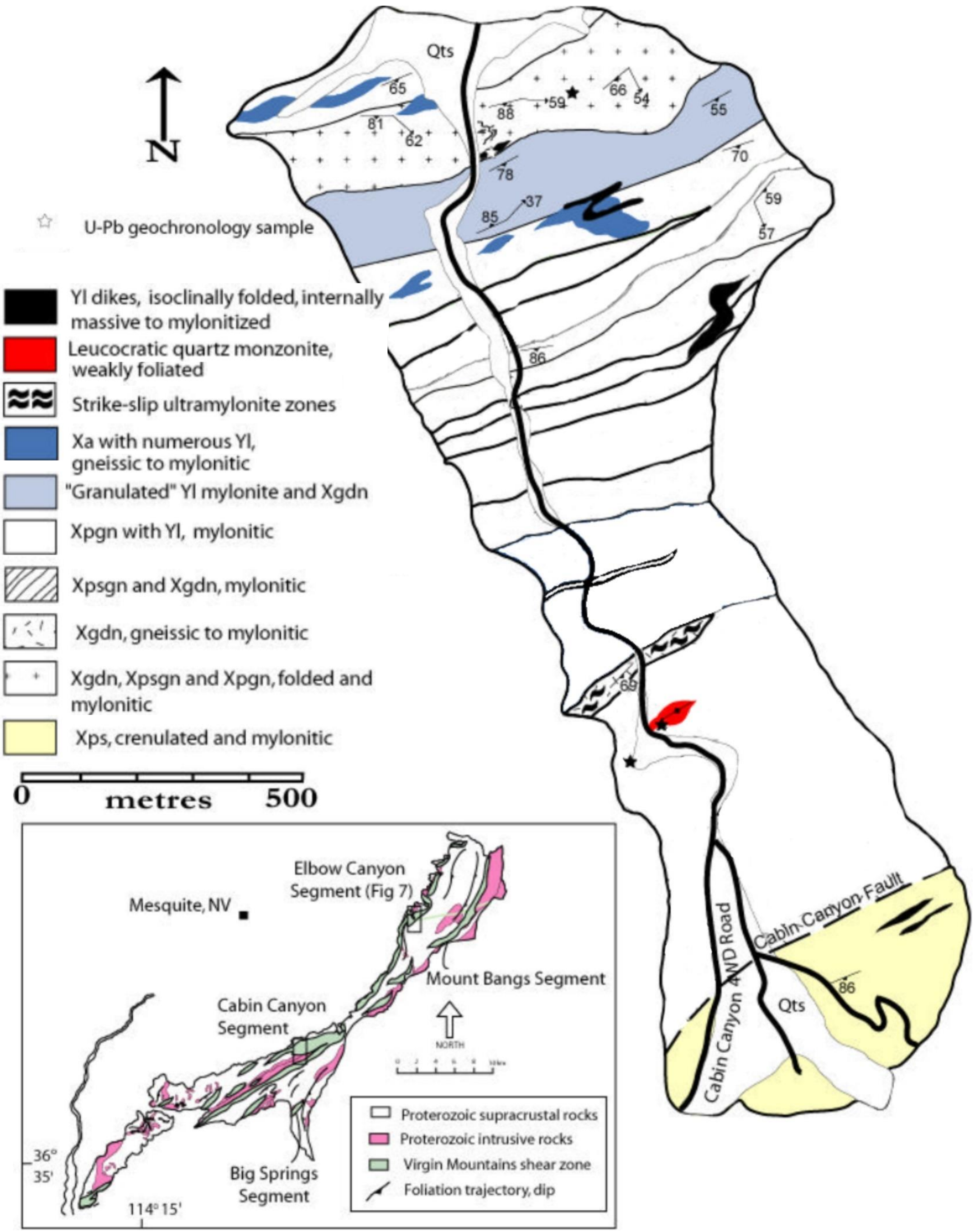
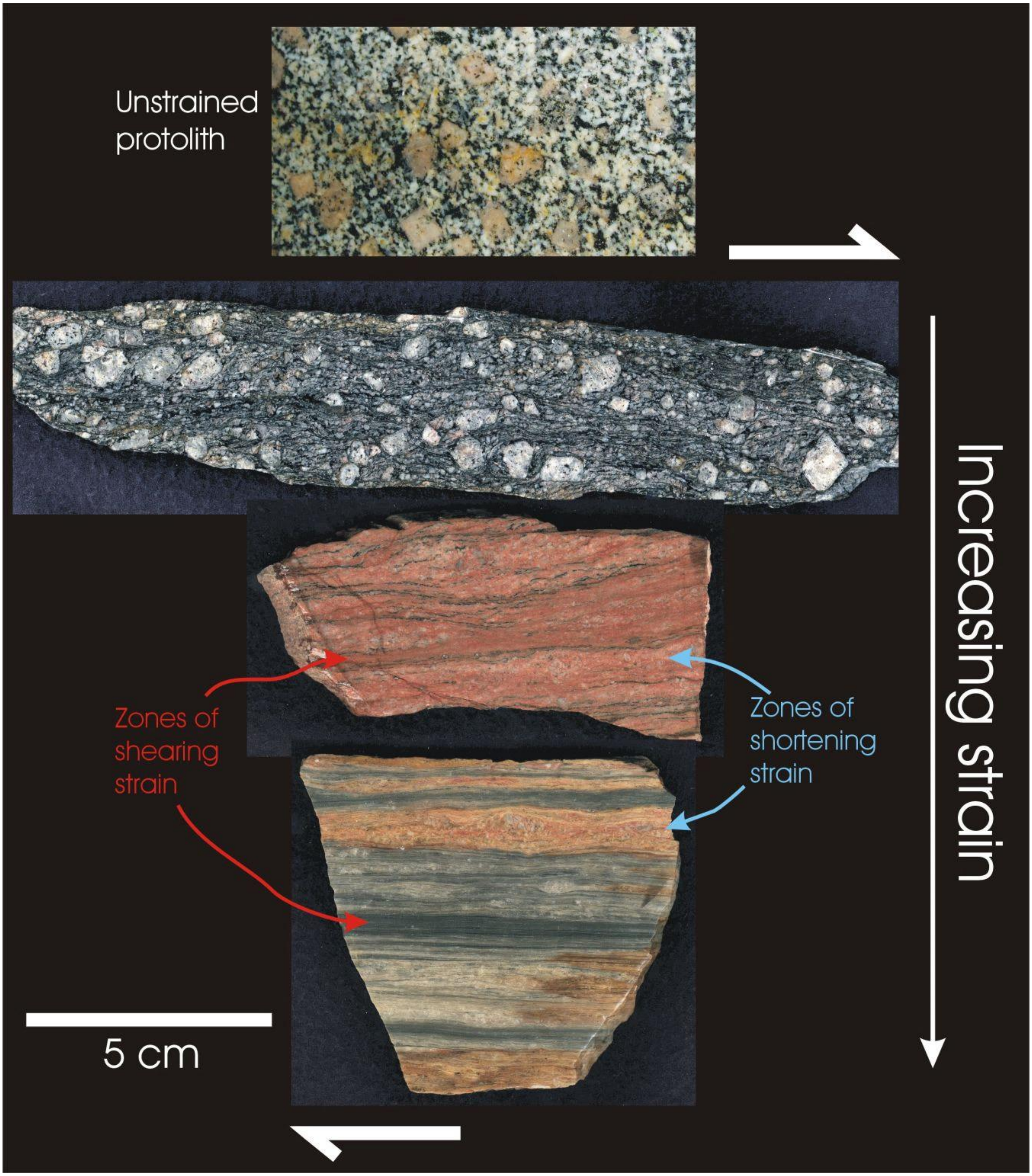


Figure 1. Geologic map of the Cabin Canyon segment, with location of U/Pb monazite and zircon samples. Inset. Virgin Mountain shear zone network, with location of Cabin Canyon segment (Quigley et al., 2002)



Examples of variably strained mylonites. Increasing percentage of matrix in shear bands and shear zones used as a proxy to indicate increase in strain rate. The three fault rocks are named protomylonite (10-50% matrix), mylonite (50-90%), ultramylonite (90-10%). Stop descriptions from Quigley et al., 2002. Locations are estimated on map on page 48

Stop 3-1A: Cross-cutting Leucopegmatite Dikes

The first outcrop reveals the complexity of the pre-mylonite, high-temperature S2a and S2b structural fabrics and associated plutonism of the VMCT. This biotite-hornblende granodiorite unit, interlayed with pelitic paragneiss and cross-cut by numerous leucopegmatite dikes and veins, preserves cross-cutting relationships that have been largely obliterated within the higher D4 strain domains in the core of the Cabin Canyon shear zone. The chronology of events was as follows:

D2a: High temperature metamorphism and development of compositional layering and strong S2 foliation, defined here by alternating layers of granodiorite and isoclinally folded syn-D2 migmatitic leucosomes (figure 2). This fabric was weakly crosscut by thicker late syn-D2 leucopegmatites (figure 2) that record slightly lesser degrees of D2 isoclinal folding (although they are still strongly deformed in this fashion).

D2b: Refolding of D2 leucopegmatites orthogonal to their axial planes by open F3 folds, associated with the progressive re-orientation of the N-S fabric (S2) into the NE-SW fabric (S3) during NW-side-up thrusting. "Syn-D3 leucopegmatites" (figure 2) intruded axial planar to F3 folds. The late-D2 leucopegmatites locally "bleed-into" the early-D3 pegmatites, and the formation of NW-side up shear fabrics associated with intrusion of these dikes and re-orientation of the S2 fabric. These dikes are relatively straight, although they have been folded locally. It is this generation of dike which we believe we have dated at Stop 3-1C (see below).

D3: All fabrics and intrusions are overprinted by a lower temperature mylonitic foliation associated with dextral transpressive deformation in the VMSZ. The mylonitic fabric (S3) weakly crosscuts the leucopegmatites, and likely records a retightening of the outcrop-scale F3 open fold, which would account for the slight splaying in the D2b pegmatites.

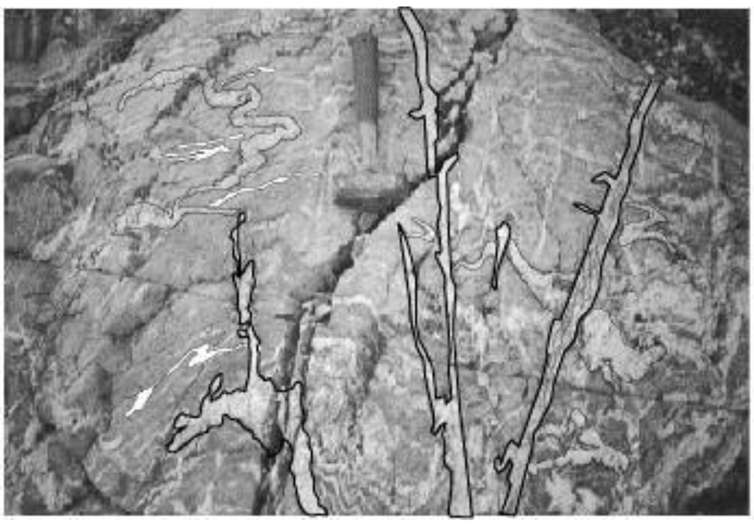


Figure 2. Crosscutting leucopegmatite dikes at the opening to Cabin Canyon. These excellent cross-cutting relationships are obscured in higher strain zones within the Cabin Canyon shear zone, and record the transition from migmatization and foliation development associated with D2 to the reorientation of this fabric into a NE-trend (D3) and synchronous plutonism. Cross sectional view, looking

Stop 3-1B: Oblate (pure-shear dominated) Mylonites

Pure-shear domains contain mylonitic, conjugate shear planes at roughly 30 degrees from the mylonitic foliation on vertical rock faces. Foliation planes contain large (>12 centimeter) "pancake-like" K-feldspar porphyroclasts, likely derived via the mechanical dismemberment of leucopegmatite dikes during deformation. The same crystals appear as highly flattened and dismembered leucosomes on faces perpendicular to the mylonitic foliation, resulting in aspect ratios of roughly 30:30:1. The combination of these oblate flattening strains, conjugate shear bands recording vertical extension parallel to the foliation planes, and development of a weak, vertical stretching lineation suggest that shortening in these domains was accommodated by intense vertical "extrusion", similar to that first predicted by the Sanderson and Marchini (1984) transpression model. While grain-sizes are coarser in these domains relative to the ultramylonitic strike-slip domains, the microstructures and metamorphic reactions are suggestive of similar tectonic conditions. The strike-slip domains are thus inferred to have recorded more intense finite strains than the oblate domains, as opposed to recording a different deformation event. Further evidence of increased strain in the strike-slip mylonites is that obliquely plunging fold axes in the wall rocks have been rotated into parallelism with the shallowly plunging lineation in the strike-slip domains.

Stop 3-1C: Folded Leucopegmatite Dike

This muscovite-biotite leucopegmatite dike is of early D2b generation in that it crosscuts all other intrusions and the strong S2a foliation, locally at high angles, but is tightly folded about an axis sub-parallel with those fabrics. It shows small domains of D3 mylonitization and associated retrogression, but for the most part is internally unfoliated.

Stop 3-1D: Dextral Strike-Slip Mylonites

The narrow (~15 meters maximum) dextral strike-slip ultramylonite zones contain a variety of shear sense indicators on faces paralleling the lineation, including sigma and delta porphyroclasts (figure 3), antithetic bookshelf-type structures, asymmetric myrmekite fabrics in K-feldspars, C-S fabrics, and shear bands. The subhorizontal lineation developed in these zones thus appears to represent the movement direction. Quartz microstructures indicate deformation occurred predominantly by subgrain rotation and climb-accommodated dislocation creep, whereas feldspars deformed by internal kinking and development of mechanical twins, brittle fracturing, and recrystallization-accommodated dislocation creep, together are suggestive of lower amphibolite, upper greenschist deformation conditions. Garnet is retrogressed and locally psuedomorphed by plagioclase + epidote +/- actinolite, often resulting in a "disaggregation" of originally euhedral garnet porphyroclasts during progressive strain. Hornblende has broken down to form actinolite. The microstructures and metamorphic relations thus suggest that deformation and metamorphism occurred under upper greenschist facies conditions.

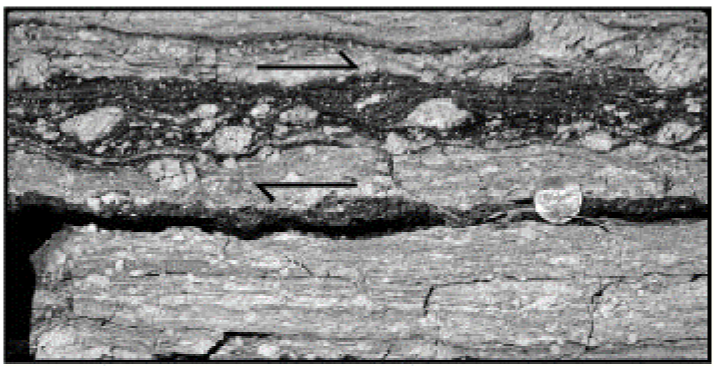


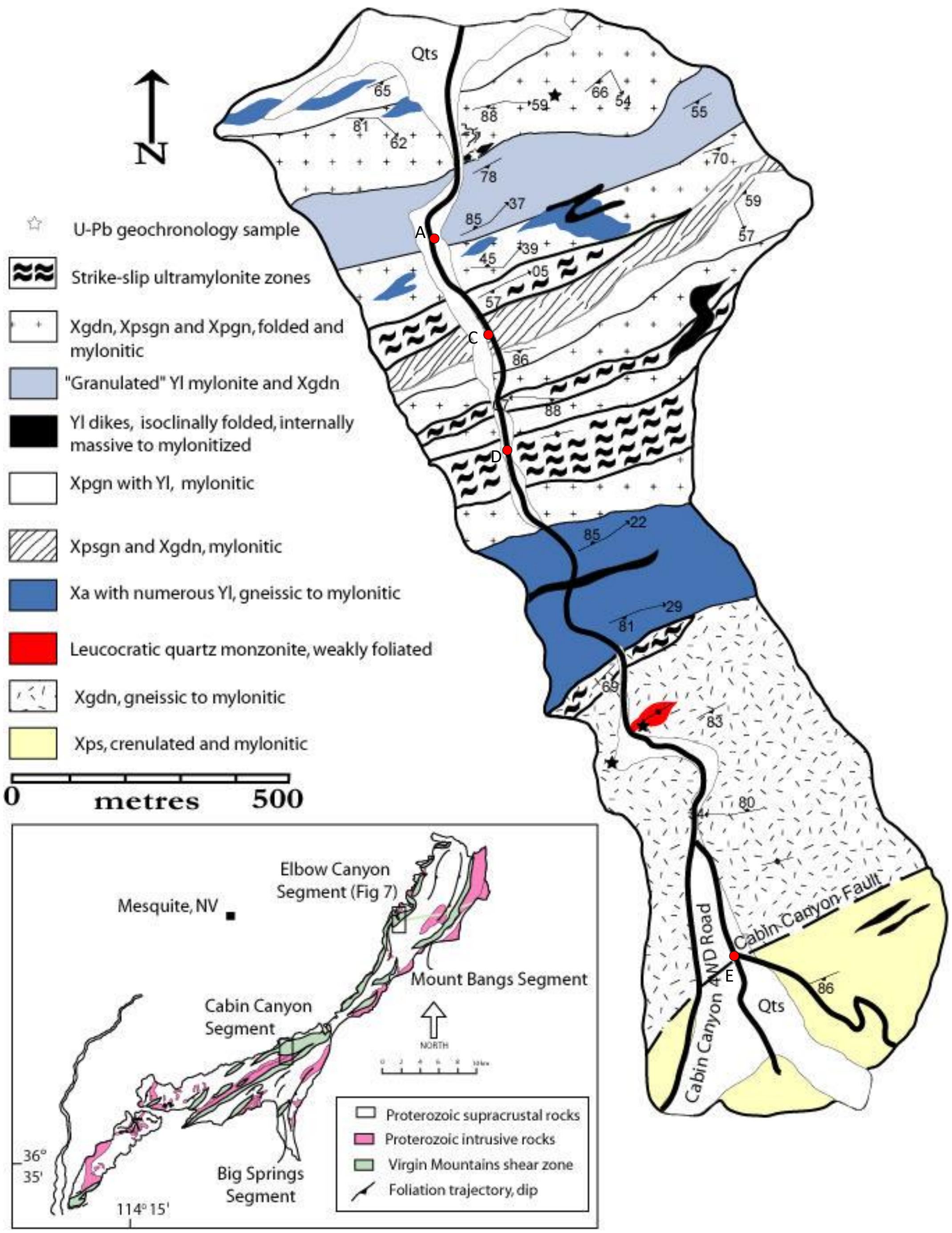
Figure 3. Sigma-porphyroclasts, and shear bands revealing dextral shear sense, ultramylonitic unit, Cabin Canyon shear zone. Plan view, NE is to the right.

As you walk up the canyon….

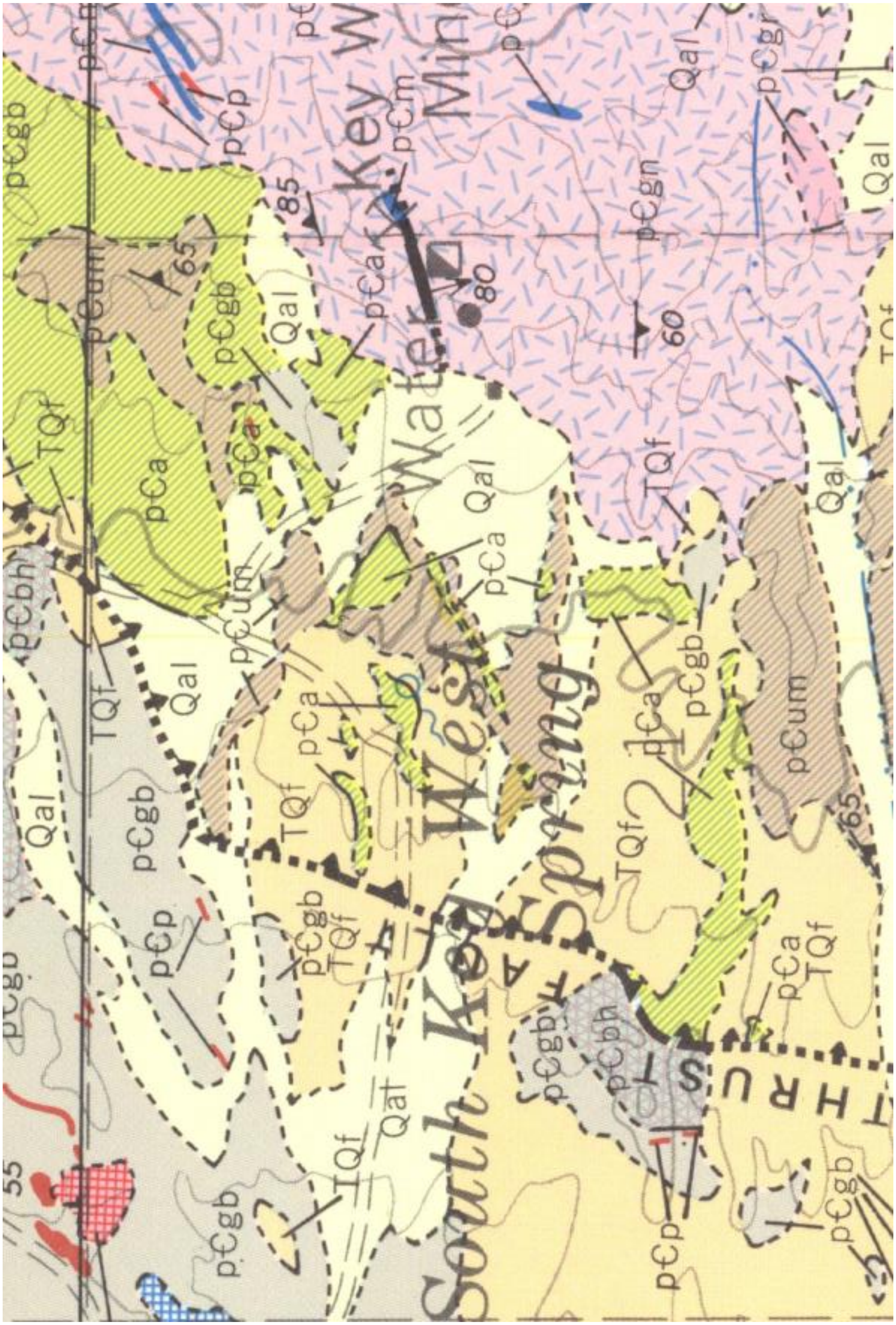
Interpreting the kinematic history in the strongly lineated, obliquely plunging domains is more complicated. Sinistral N-side-up indicators are present in some of the northern locations, although oblique dextral deformation still predominates. Lower temperature shear sense indicators such as shear bands and sigma porphyroclasts are present on faces non-parallel to the strong lineation observed in these units. The apparent conflict between opposing senses of shear is reconciled with the interpretation of early, high temperature NW-side up thrusting (D2b) and development of the stretching lineation, overprinted by the upper greenschist facies dextral transpressive deformation (D3), with some sinistral faults operating during D4 shortening to accommodate space problems, structural anisotropies, and heterogeneous transpression. The steeply plunging lineation is interpreted to be the result of the earlier event based on: 1) the differing character between it and the strike-slip and vertical lineations observed in the simple shear and pure shear dominated domains, respectively, 2) the obliquity of lower temperature shear sense indicators to this lineation, and 3) the apparent overprinting and reorientation of this lineation proximal to the strike-slip domains. To the east of Cabin Canyon in Lime Kiln Canyon, the mylonitic foliation is strongly folded and displays a combination of N and NE-trending, dextral-oblique strike-slip segments and N-trending, W-side-up reverse segments. This is interpreted as a partitioned, syn-mylonitic constraining bend in the Cabin Canyon segment (figure 1 inset), based on the presence of localized parasitic mylonitic folds with the same geometry, and lack of evidence that folding preceded the ductile deformation.

Stop 3-1E: Cabin Canyon Fault Trace

As you come southward out of Cabin Canyon, the trace of the sub-vertical Cabin Canyon fault is visible in the near saddle to the NE and the prominent valley and far saddle to the southwest. The fault separates granodioritic gneiss and semi-pelitic paragneiss to the north from a relatively thick package of pelitic schist to the south. Kinematic indicators are rare, but where observed, slickenlines plunge shallowly (10-20°) to the east. This fault zone has had a long movement history, as a high-temperature D2 deformation zone, a lower temperature D3 mylonitic shear zone, and most likely as a brittle Laramide reverse fault and Miocene oblique strike-slip fault. The nature of basement-penetrating faults is enigmatic because their age (Miocene vs. Laramide) is largely unknown, and they rarely show slickenlines. They are often recognized as continuous chloritic breccia zones along Proterozoic lithologic contacts. Although Miocene left-slip is likely (Williams and others, 1995), reconstructions of fault separation using Proterozoic lithologies are unreliable due to the extremely heterogeneous nature of the Proterozoic basement. Furthermore, it is likely that most basement-penetrating faults had both a Laramide and Miocene component of slip. Aside from the Hen Spring fault, basement penetrating faults predominantly follow the Proterozoic foliation, striking NE in S2b dominated domains, and striking N-S in S2a dominated domains. An important conclusion of our work is that the orientation of Proterozoic fabrics helped control the geometry of Miocene and Laramide faults, and uplift of the Virgin Mountain Anticline.



Optional Day 4 (April 28) - Key West Mine (Nickel)



Qal	Alluvium
TQf	Tertiary-Quaternary Fanglomerate
pCum	Undifferentiated gneiss and schist
pCa	Amphibolite (dark-gray, contains abundant pegmatites locally)
pCgb	Garnet-biotite gneiss
pCbh	Biotite-hornblende gneiss
pCp	Pegmatites
pCm	Mafic rocks (mainly hornblendite dikes)
pCgn	Granodiorite gneiss (mainly orthogneiss)
pCgr	Granite gneiss (ortho and paragneiss)

Exercise 1: Rainbow Gardens Stratigraphy

Days 4-7, April 28-May 1

Safety: Hiking boots, 4L water, snacks for the day, sun screen, collared long sleeve shirt, pants are strongly recommended because of the terrain, snakes, and sharp rocks, wide brim hat, sun glasses. **Hazards: dehydration**, sharp rocks, **loose gravel on steep slopes**, cacti, snakes, lizards, dust, lightning. Roads from the Valley of Fire to the parking lot are mostly paved but are a little bumpy. Ensure you buckle your seatbelts for these days and the rest of field school to avoid neck injury. 911 will work in the case of an emergency. Location: Drive east along East Mead Lake Boulevard from Las Vegas. We are on a dirt road 10.1 km east of Los Feliz Street. At the intersection of the dirt road, turn right (south) and drive 400 m into the parking lot. Latitude 36.184 N, Longitude 114.923 W. The nearest full-size hospital is on the same highway, about 20 km west of us: North Vista Hospital – Hospital, 1409 E Lake Mead Blvd, North Las Vegas, NV 89030, +1 702-649-7711.

Equipment: Verify before leaving the Hoover Dam Lodge that your 2-person group has a Jacob staff, hiking sticks, compass, hammer, handlens, field notebook, sharp coloured pencils, ruler, this field guidebook, and your field school field sheets booklet. Bring your own lunch for each day in the field. On Day 5 there may be an opportunity to swim, depending on weather and other factors, so bring your towel, swim suit, soap, and footwear for the beach which will either be very muddy or very cobbly.

Figure 1. Map of the outcrops of the Miocene Rainbow Gardens member of the Horse Springs Formation. "Rainbow Gardens" study area is situated just east of Frenchman Mountain. You will be measuring and interpreting a section near transect A.

PURPOSE

1. Describe in detail and measure a portion of the stratigraphy of Horse Springs Formation
2. Learn to use a wide range of observations (sedimentology, clast lithology, syn-sedimentary deformation, paleoflow direction) to interpret the depositional environment and tectonic processes that led to the stratigraphy.

EVALUATION

With few exceptions, all partners in a group will receive the same grade for this exercise. A draft version of the measured section with unit description is due by 9 pm on Day 6, worth 30%. A field presentation to other groups that describes your key findings (10%). A final version of your stratigraphic column with a report. There is one report per group, so please discuss the answers and your interpretations with your partner(s)). Members of each group will initial the questions for which they wrote answers in the report. Please do not discuss your answers with other groups.

Figure 2. Satellite image of the Kodachrome Wash of Rainbow Gardens area. The map has been rotated such that north points to the upper left. The Rainbow Gardens member is exposed in the western part of the map and the lower part of the Thumb member in the central and eastern parts of the map area. The paved road in the upper right is Lake Mead Blvd.

Day 4 (April 28): "Measure with pleasure"

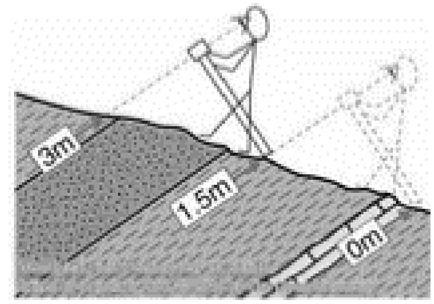


Figure 3. Proper Jacob staff use

- AM (arrive at Parking Lot by 8:30): walk through area, brief overview of regional stratigraphy, expectations
- AM: Guided description of portion of the stratigraphy; review how to measure/describe sedimentary rocks (Fig. 3)
- AM: Reconnaissance of the section you and your partner will describe in detail
- We'll have lunch between 11 and noon at the top of the hill for an overview of the regional geology.
- PM: Begin measured section at specified location (40-60 m of section filling in unmeasured portions)
  - Capture the measured section information in your notebook while in the field at a scale of **1cm=1m**. Set up your notebook using the example in the Field Sheets (**see pages 7-8**).
  - Ultimately, on the evening of Day 4, you will transfer your field notes onto graph paper at a scale of **1cm=2m**, see Figure 4 below.
- Evening: ***Notebooks will be checked***

Day 5 (April 29): "A stratigraphic column is worth a thousand words. We want 1500!"

- AM (arrive at Parking Lot by 8:30). Today you will add a description to your section.
- Review yesterday's progress, taking note of comments provided in your field notebook.
- You will spend most of the day completing your very detailed measured section. While you do this, you and your partner need to decide how to break your section into two to five sub-member 'units'.
- For each unit, you need to provide a detailed description that would enable any other geologist to visualize the section you have measured, or easily find it in the field anywhere along the exposure. See Figure 4 for examples.
- Lunch is on your own time.
- 3:00 pm: back at the vehicles
- Swimming: We may have the option to go for a brief swim on the way back to the campground.
- Evening: **By 9 pm we want the first draft of your section (on the supplied graph paper) that includes your unit descriptions like Figure 4, using the legends according to your Field Sheets booklet (p. 7-8). This is worth 30% of your grade in this project.**

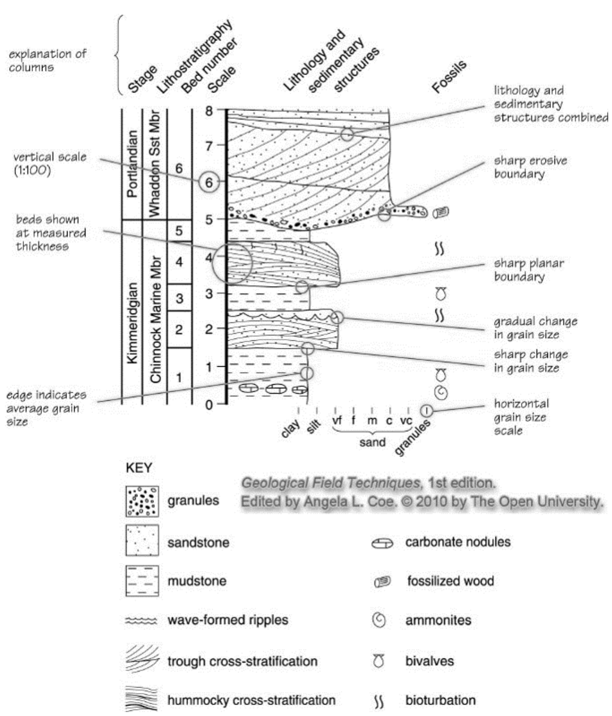
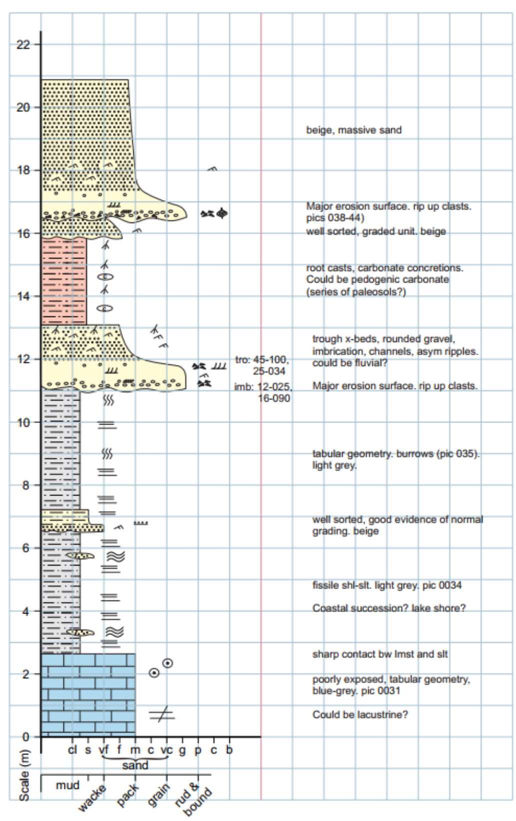


Figure 4a. Examples of a measured stratigraphic column that could be written in your field notebook (Coe textbook 2010).



Elements to include in unit descriptions:

Overall: rock type(s) and relative proportions in unit, overall thickness, nature of upper and lower contacts (gradational, sharp, erosional (evidence such as rip up clasts, etc), colour, lateral extent of unit and contacts, fining or coarsening upwards (individual bed, or member)

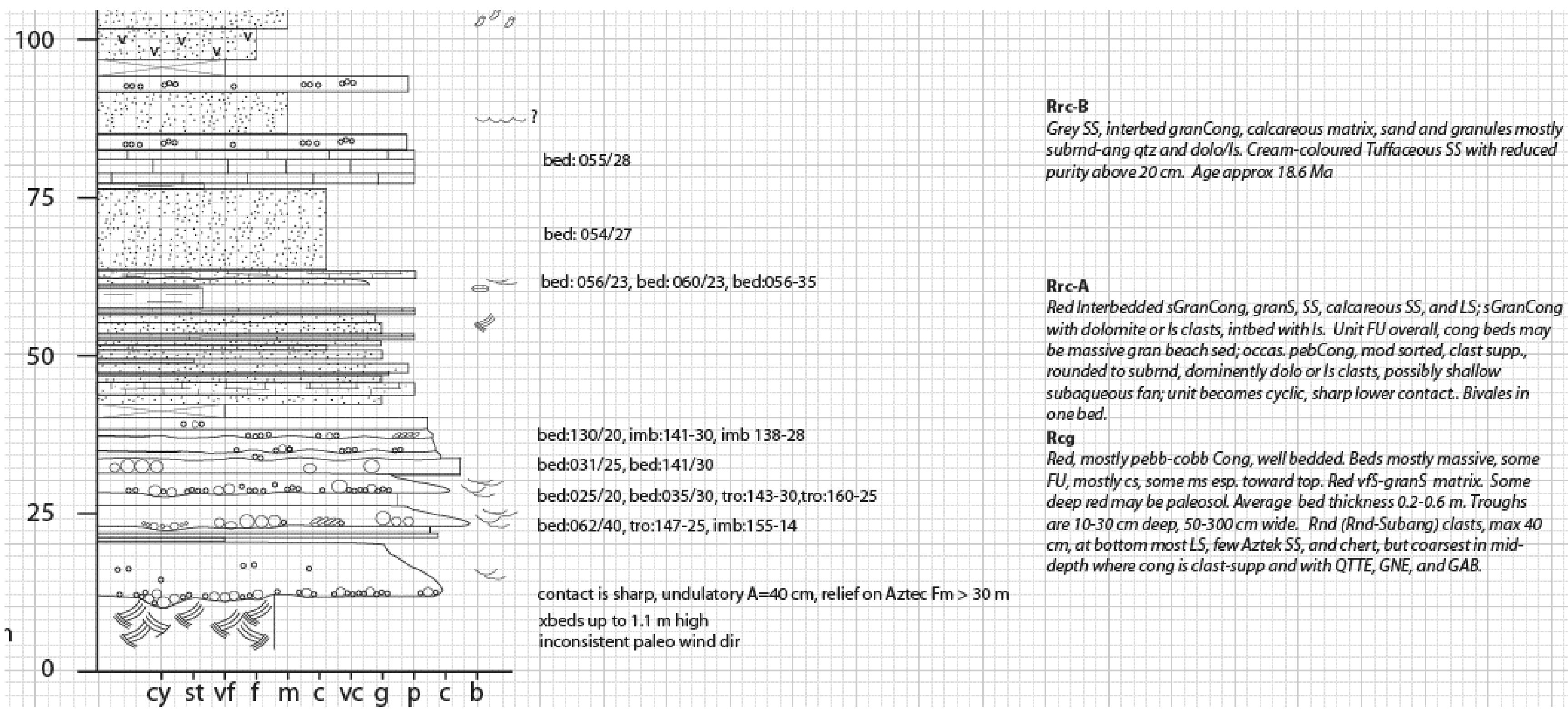
Clastic: colour, grain size (and variation), bedding or lamination thicknesses, shape of beds (lenticular, planar, tabular, height and length of lenses), sed structures (trough cross, planar cross, graded, laminated, burrows, mudcracks, convolutions, de-watering, syn-depositional deformation, heavy mineral layers, redox, concretions, fossils, etc…), paleoflow direction, way up,

Conglomerates: (see clastic, but also): rounding of clasts, elongation of clasts, average and maximum clast size, lithology and proportion of clasts, matrix composition and colour, matrix- or clast-supported, bedded or chaotic, imbrication (fabric analysis or describe), grading, cross stratification, pebble lithology

Carbonate: micrite or spar cement in carbonate, burrows, other fossils, clastic component, brecciation, colour
Other observables: deformation (determine if it is syn-depositional or post-depositional, measure stress directions and interpret the folds and faults); gypsum (in situ layers or fracture fills); paleosols; datable elements such as ashes, ignimbrites, lava; samples you collected

Unit X description example:
22 m total thickness. 0.5–2-m-thick bed, generally coarsening-upward, from rhythmically-interbedded finely laminated and finely bedded siltstone to massively bedded, matrix-supported, poorly sorted conglomerate. Conglomerate beds found throughout unit, tend to thicken upwards. Conglomerate clasts typically range in size from 10 to 50 cm. Conglomerate clasts are well-rounded to subangular and dominantly composed of Paleozoic limestones and dolostones; some clasts appear to be derived from the Jurassic Aztec Sandstone. Conglomerate matrix is composed of rounded, red to pink quartz grains with some carbonate lithic grains. Imbrication is common. Isolated, lenticular, pebble conglomerate within the sandstone show high-angle stratification and deep troughs with pebble lag. Basal contact is sharp; deposited on Jurassic Aztec and Paleozoic formations. No paleosols observed. Burrows noted in single sandstone bed at 11.5 m (see figure). No other fossils observed. Trough cross-beds in the sandstone beds (max. 20 cm thick) indicate paleoflow to 220°, but conglomerate imbrication indicates paleoflow to 340°. **Other notes:** Hydrothermal alteration with clays, fractured clasts, and slickenlines observed along a thin post-depositional fault with normal-offset (Flt Plane 84/350, down to east) at 16 m (see figure). Basalt clasts in conglomerate correlated with Buckboard Mesa Basalt (based on amygdaloidal content, dated at 7.4 Ma by biotite $^{40}Ar/^{39}Ar$).
Interpreted depositional environment: alluvial fan, minor debris flows, with provenance to the east

Fig 4b. Use this format for the final draft of your measured section (see Fig 4a for ideas for your draft/field notebook versions; use symbols from the ERTH 2110 Field Sheets)



Grain size fractions for sediments:
clay, silt, very fine sand, fine sand, medium sand, coarse sand, very coarse sand, granular gravel, pebble gravel, cobble gravel, boulder gravel

Data in the middle column
The data in the middle would include bedding orientation, information on clast size or bedding thickness, paleoflow direction, nature of the contact between strat units, or measurements regarding soil development (colour, Bt thickness, etc)

Comments on the right
The comments text on the right is meant to be mostly description of the highlights, or details that are difficult to depict in the section. You can also add a sentence or two that is a minor interpretation…BUT preface the sentence with “Interp:” to make it clear that these are ideas, and not observations

Day 6 (April 30): “Reading between the laminations”

- AM (arrive at Parking Lot by 8:30). Today you will add final observations to your measured section, incorporate the observations of the rest of the stratigraphy provided by the other groups, and interpret the data to address questions (see below). Before we start, we will provide you with copies of the draft version of the measured sections and descriptions by the other groups.
- We will conduct **a walk-through** of the entire section again, and each group will provide a 10-15 minute summary of their section, emphasizing the key aspects. Your group should be prepared to communicate these points. The better you communicate your section, the higher your score. [**10% of project grade]**.
- You will then have about an hour or so to make any final observations in your measured section.
- Lunch. Make sure you bring yours.
- PM We will use the afternoon to visit some key geological sites that will help provide more context for the geological history archived in the entire measured section (all groups). We will be back at camp well before dinner time.
- By 9:00 pm we expect a final version of your measured stratigraphic column, final unit descriptions (see above) and an interpretation of the depositional environments in that section as follows:

1. **[20%] Final copy of the detailed measured section of your designated ~50 m section**
2. **[15%] Unit descriptions for <u>units in your section</u>; include a couple of sentences on depositional setting (*see box below*)**
3. **[10%] Interpretation of the depositional environment.** CONCISELY provide the field evidence for your interpretation, include sketches or cartoons. For instance, you may write “*The combination of desiccation cracks and salt layers in Unit B, and sand dunes in the lowest beds of Unit C, suggests an arid depositional environment*”.
4. **Answers to these questions:**

   4.1 [5%] Calculate and describe the sedimentation rates (m/Ma) for your measured section, and how they compare to the rest of the Horse Spring Formation (see Figure 8). (250 wds). Discuss any tectonic or climate implications or causes of this sedimentation rate, and any caveats to your calculation. (100 wds)

   4.2. [10%] Provenance and paleoflow
   Comment on the provenance and paleoflow directions and describe any trends or variation that your section revealed and that you gathered from Rainbow Gardens and Thumb member units described by other groups. Be sure to mention what data were used to interpret paleoflow or provenance (250 wds)

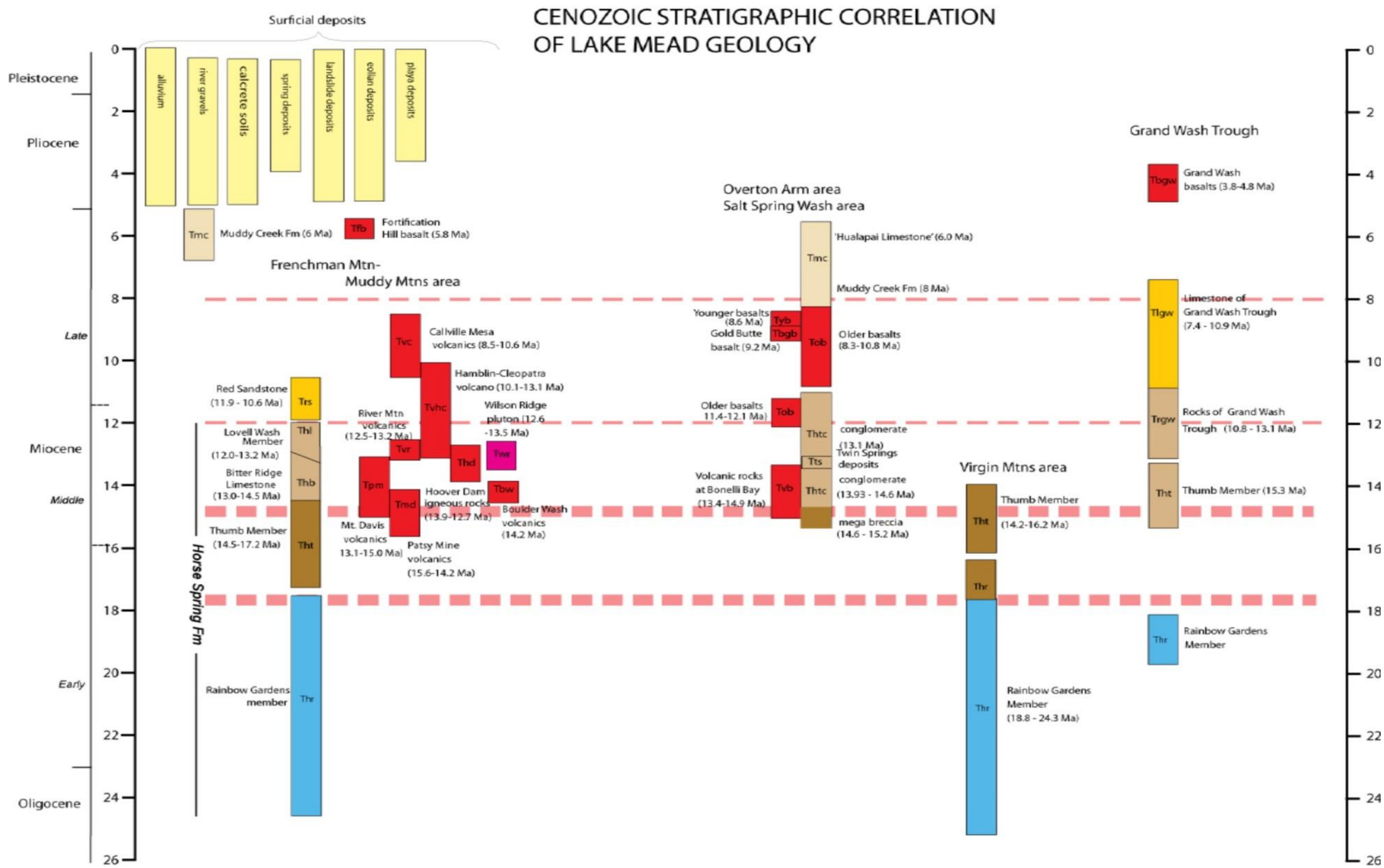


Figure 5. Regional chronostratigraphy. From Umhoefer et al., 2010

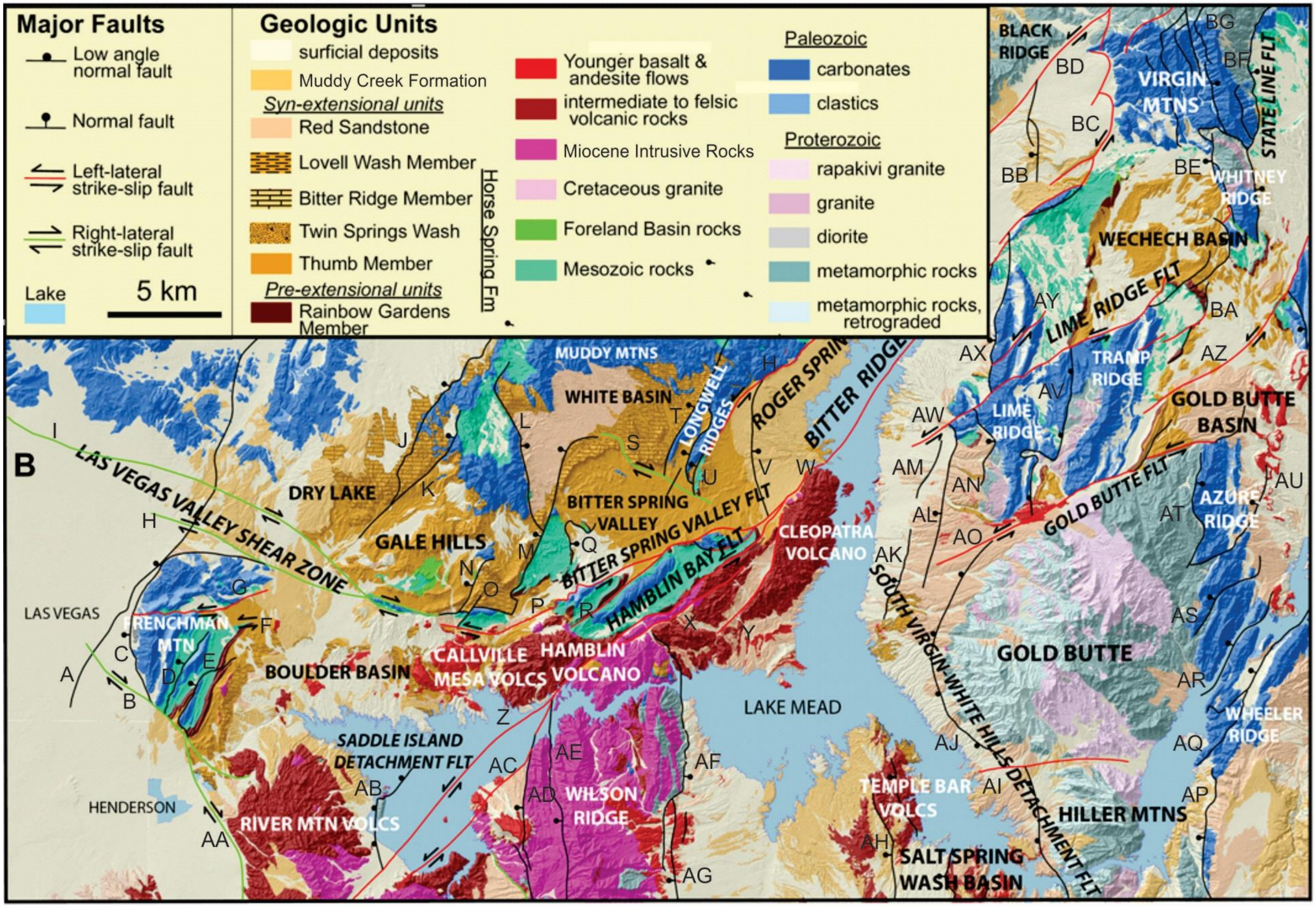


Figure 6. Regional geology map. From Wagner, 2010

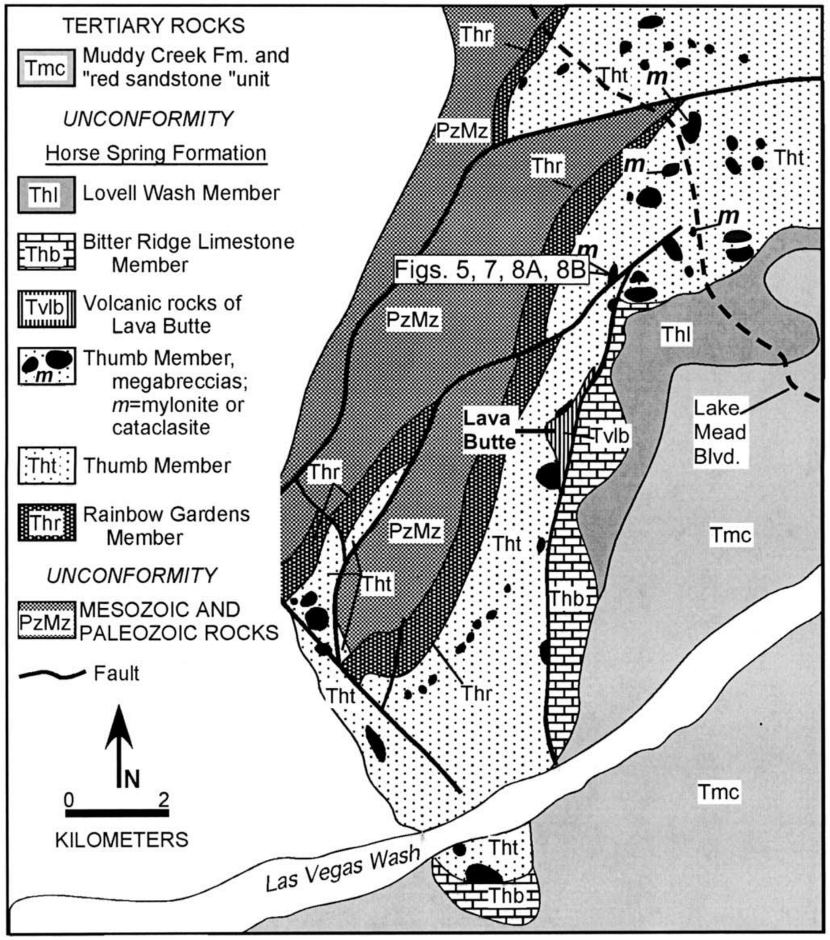


Figure 7. Geology of Rainbow Gardens. From Fryxell et al. 2005

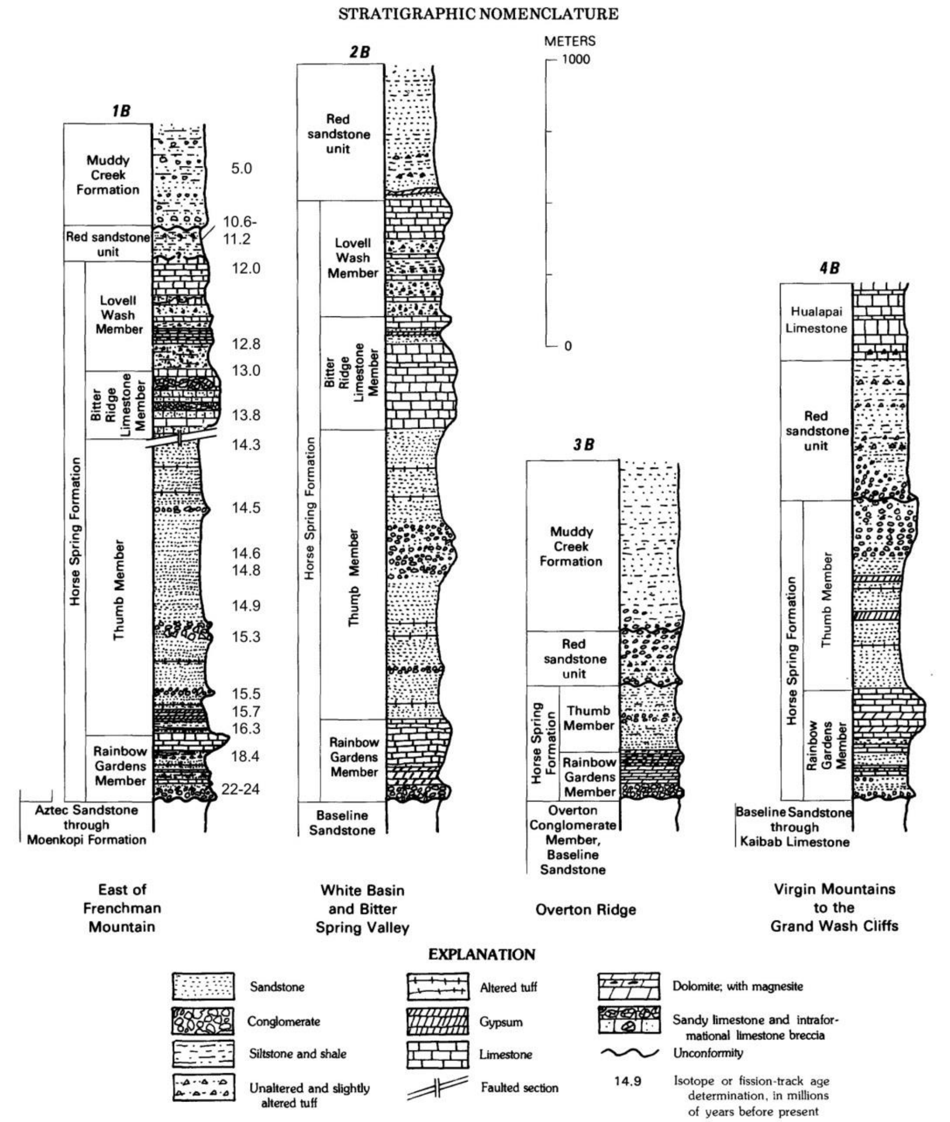
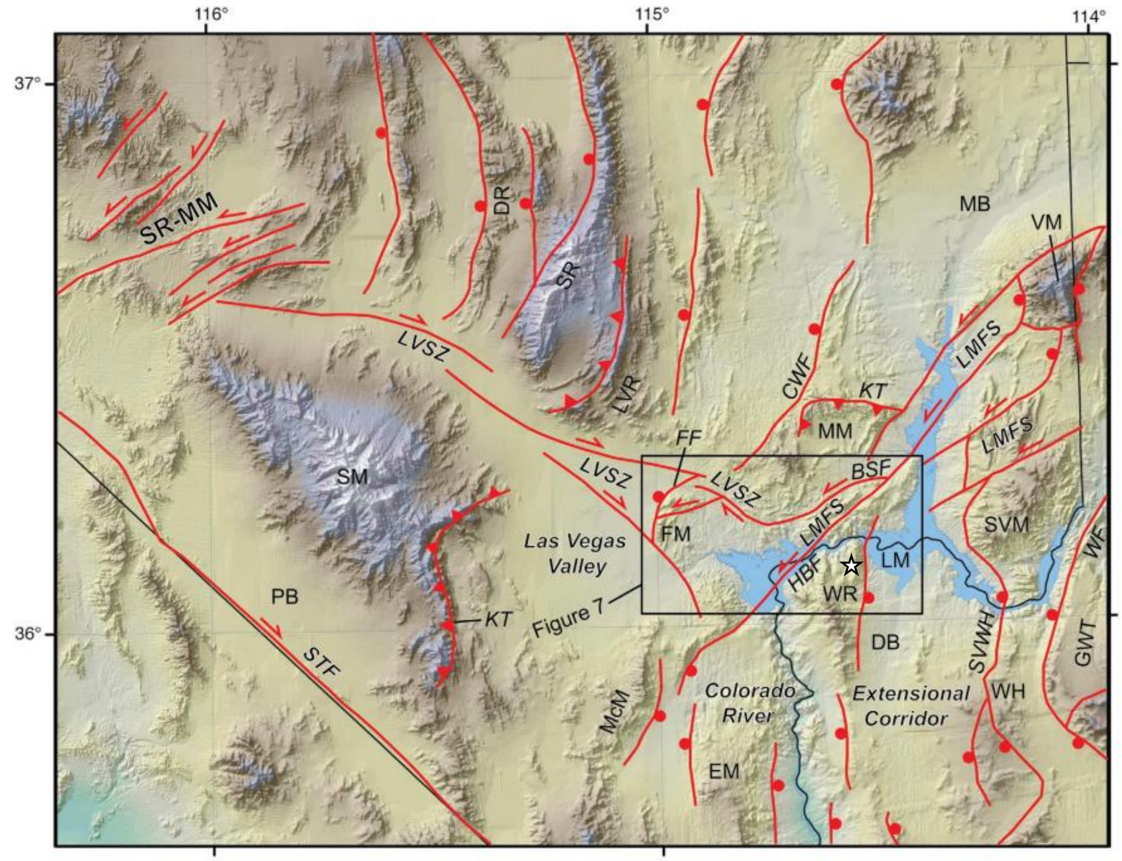


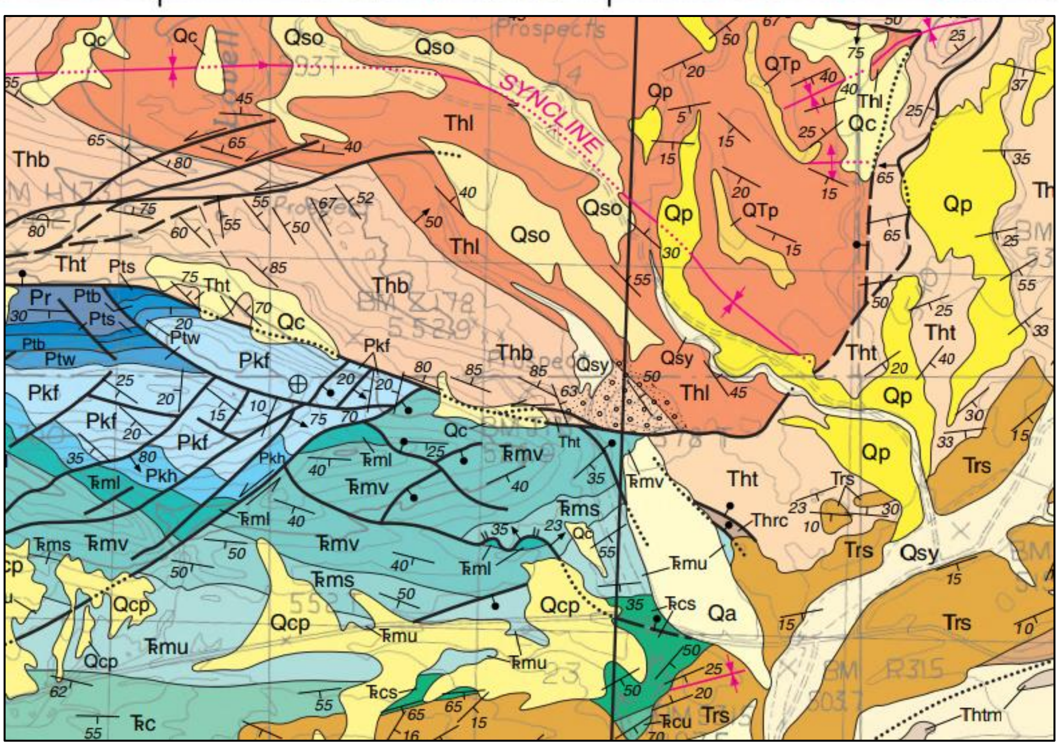
FIGURE 2—General lithology and stratigraphy, previous stratigraphic nomenclature (*A* column), and proposed stratigraphic nomenclature (*B* column) of the Tertiary rocks of the Lake Mead region. Ages of the rocks are generalized from tables 1 and 2.

Figure 8. From Bohannon, 1983.

Optional Day 7 (May 1) – Las Vegas Valley Shear Zone

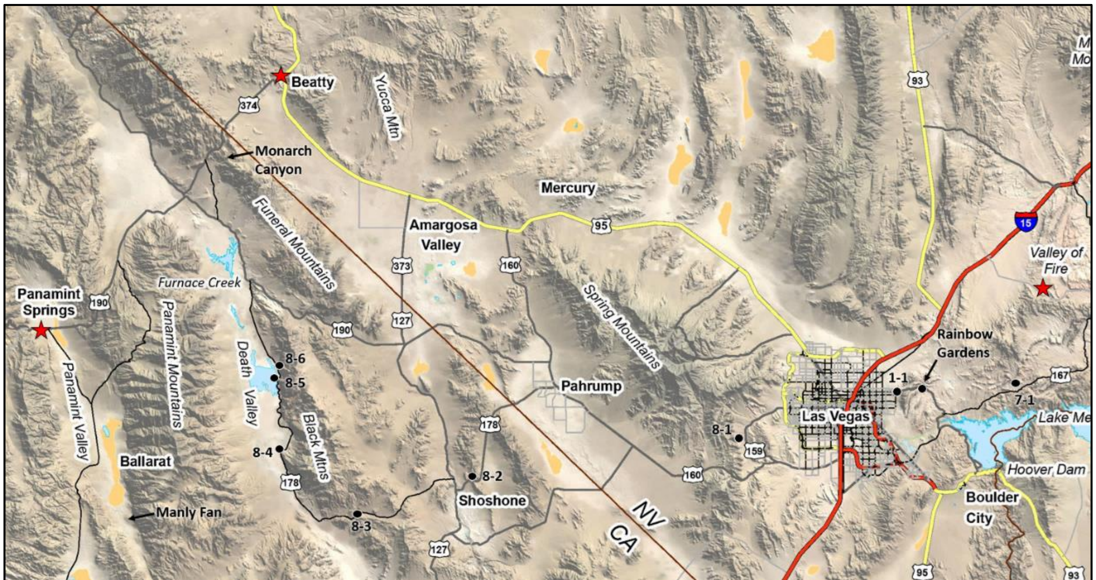
In the afternoon of May 1st, we may visit a site described as the eastern termination of the Las Vegas Valley Shear Zone. Lamb et al. (2010) reports abundant evidence of syn-deformation sedimentation and abrupt facies variations adjacent to the fault. Turko (2022) describes the site as an oblique-normal fault with extensive brittle fracturing and cataclasis in the footwall. In reviewing the geological map (Callville Bay Quadrangle, Anderson, 2003), it appears that the site we will visit may be part of the left-lateral and northeast-trending Bitter Spring/Lake Mead Fault System.





Day 8 (May 2) – Keystone Thrust (Red Rocks) and the Opening of Death Valley

On May 2nd, we will move camps from Valley of Fire to Beatty, NV via Death Valley. En route, we will make a roadside stop to look at the Mesozoic-age Keystone Thrust, a textbook-example of a foreland fold-and-thrust belt, and then several stops through southern Death Valley to examine features related to its opening including a hike into the Badwater Turtleback, a metamorphic core complex.



Road map with field trip stops on Day 8 (May 4th). Stars indicate campsites and motel. Days 9 and 10 will be mapping Monarch Canyon, and on Day 11 we will move to Panamint Springs.

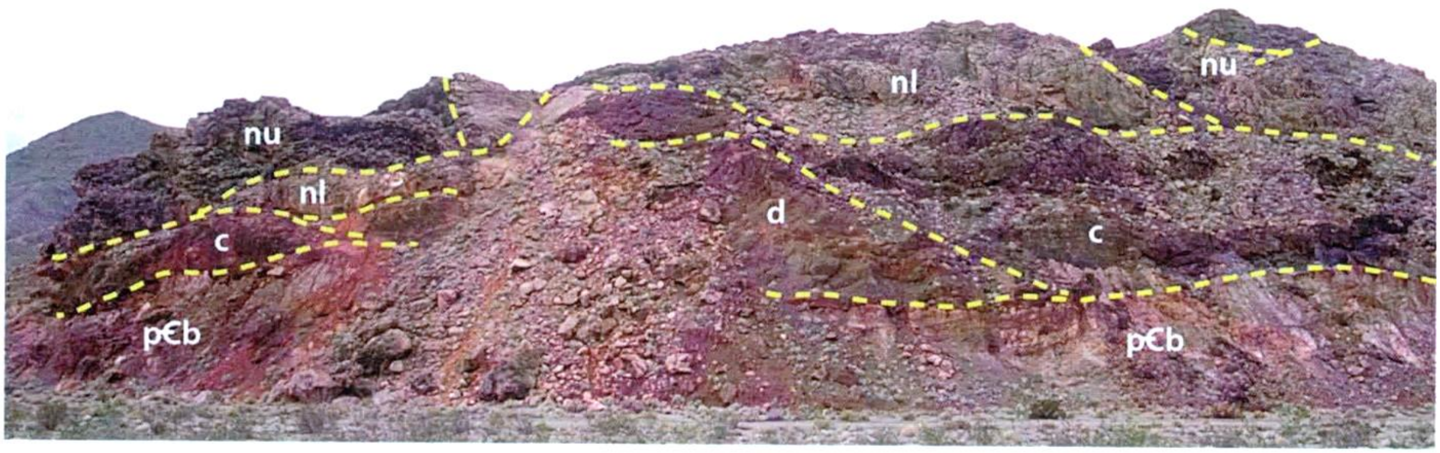
Stop 8-1: Keystone thrust in Red Rock (modified from Wernicke et al., 1989). This stop provides an overview of the major structural relations at La Madre Mountain. In the foreground are three northeast-tilted blocks of Paleozoic carbonates. On their southwest sides they are bounded by the Red Spring thrust, which dips about 30 to 35^0 to the northeast and places the Paleozoic strata above the red Jurassic Aztec Sandstone exposed in the valleys. The thrust plate and underlying parautochthon are cut by high-angle normal(?) faults striking north to northwest, which bound the Paleozoic blocks on their eastern sides (Davis, 1973; Axen, 1984, 1985). Therefore, bounding the prominent valley on the east (underlain by Aztec Sandstone) is the Red Spring thrust on the right, and a high-angle fault on the left.

The high skyline cliff in the rear is La Madre Mountain, which is composed of Paleozoic strata of the Keystone thrust plate. The high-angle faults continue into the Keystone plate, but their offset there is much less than in the Red Spring allochthon and parautochthon. Davis (1973) interpreted this to mean that one episode of movement on the high-angle faults tilted the Red Spring plate and predated emplacement of the Keystone thrust, and that later movement on the same faults cut the Keystone plate after is emplacement.

Stop 8-2: Resting Spring Range rotation. (modified from Wernicke et al., 1989). Here we see evidence for the relative timing of rotation of the Resting Spring Range block and see examples of syn-extensional volcanic rocks. The geology this roadcut was studied in detail by Troxel and Heydari (1982). Fanglomerate, tuff, and welded tuff in the outcrop were deposited following most of the rotation of the Resting Spring Range, and subsequently tiled an additional 10^0 eastward. The dip of strata on the west side of the outcrop, containing a prominent black vitrophyre, is interpreted to be largely primary by Troxel and Heydari (1982), with deposition occurring on a west-dipping topographic buttress, followed by a rotation of about 13^0 eastwards. The tuffs are some of the easternmost exposures of a large region of mid- to late Miocene synextensional volcanism centered in the Black Mountains area (Wright et al., 1983; 1984; Wright and Troxel, 1984). According to Wright et al. (1984), the older volcanic units in the Nopah-Resting Spring Range clock are steeply tilted and yield K-Ar ages of about 12 Ma while the younger, gently tilted tuffs are about 9 Ma, showing that the tilting of the range occurred between 9 and 12 Ma. However, Tertiary rocks to the west in the southern Black Mountains dated at 8-9 Ma are highly faulted and rotated, overlain by flat-lying basalts dated at about 4-5 Ma (Wright et al., 1984).

Stop 8-3: Amargosa Chaos (modified from Troxel and Wright, 1987; and Wernicke et al., 1989). The Amargosa Chaos consists of Precambrian, Paleozoic, and Tertiary strata arranged in subhorizontally elongated fault slices. The vertical ordering of the fault slices is younger rocks above older, such that part of the section is consistently omitted across the faults (Noble, 1941; Wright and Troxel, 1973; 1984). The mosaic of fault slices is localized structurally along the undersides of large, relatively coherent normal fault blocks, and apparently is a structural expression of relatively penetrative brittle shear strain where the normal faults merge into a common plane of detachment (Wright and Troxel, 1973; Wernicke and Burchfiel, 1982; Wright and Troxel, 1984). The chaos structurally veneers a large, domiform detachment system exposed throughout the southern Black Mountains.

The varicoloured outcrop on the south of the road where we will stop contains an exposure of the contact between the chaos (Virgin Spring phase) and the underlying crystalline basement. Lithologies include grey- and pink-weathering crystalline basement and a highly attenuated section of the basal formation of the Pahrump Group. The Crystal Spring Formation, the lowest formation of the Pahrump Group, is attenuated from approximately 1200 m thick down to a few tens of metres at this outcrop. A complete, relatively unfaulted section is present about 10 km to the west of this outcrop. The faulted slices above the basement contain fragments from all of the major subunits of the Crystal Spring, and include sandstone, dolostone, chert, and diabase. The cream-coloured unit at the top of the outcrop is a fragment of the overlying Noonday Dolomite, the oldest post-Pahrump unit in the miogeoclinal succession.



View of "Exclamation Rock," with fault contacts drawn to illustrate some of the structure of the Amargosa Chaos. Abbreviations as follows, pCb, Precambrian basement; c, Crystal Spring Formation; d, diabase; nl, Lower Noonday Dolomite; nu, Upper Noonday Dolomite. Note that the entire upper Crystal Spring Formation is missing beneath the Lower Noonday Dolomite. Absence of the Beck Spring Dolomite and Kingston Peak Formations, however, is probably because those units stratigraphically pinch-out in this vicinity. From Miller and Wright, 2007

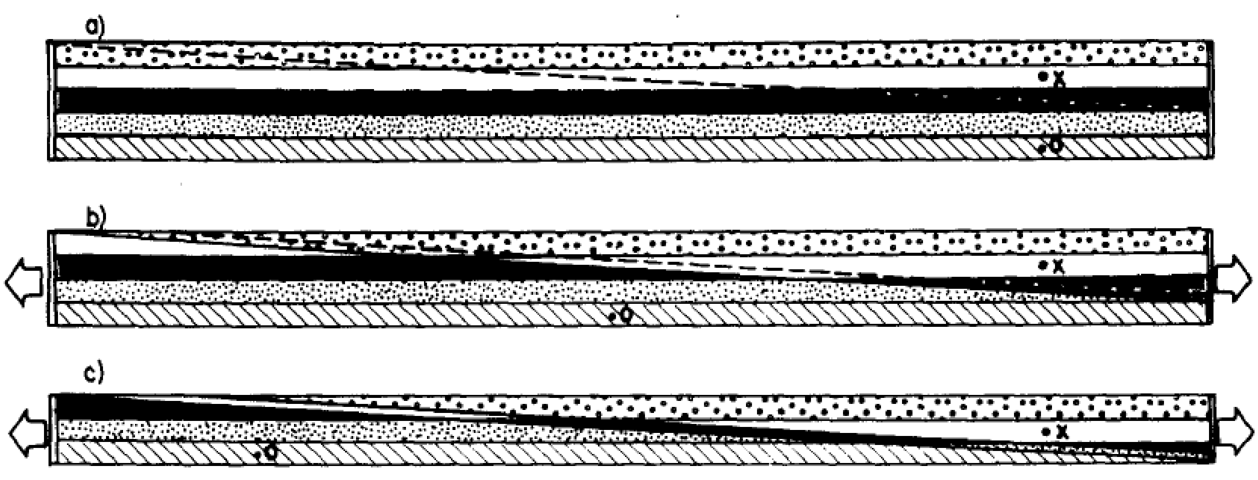
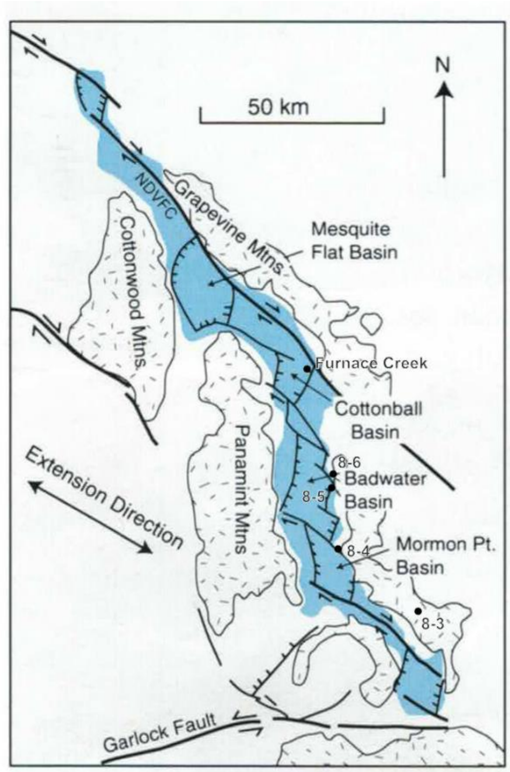


Fig. 14. Formation of *chaos* structure. (a) Unfaulted sedimentary sequence, with reference points marked × and ○. (b) Fault displaced one stratigraphic unit. (c) New fault with an additional offset of one stratigraphic unit.
From Wernicke, 1982

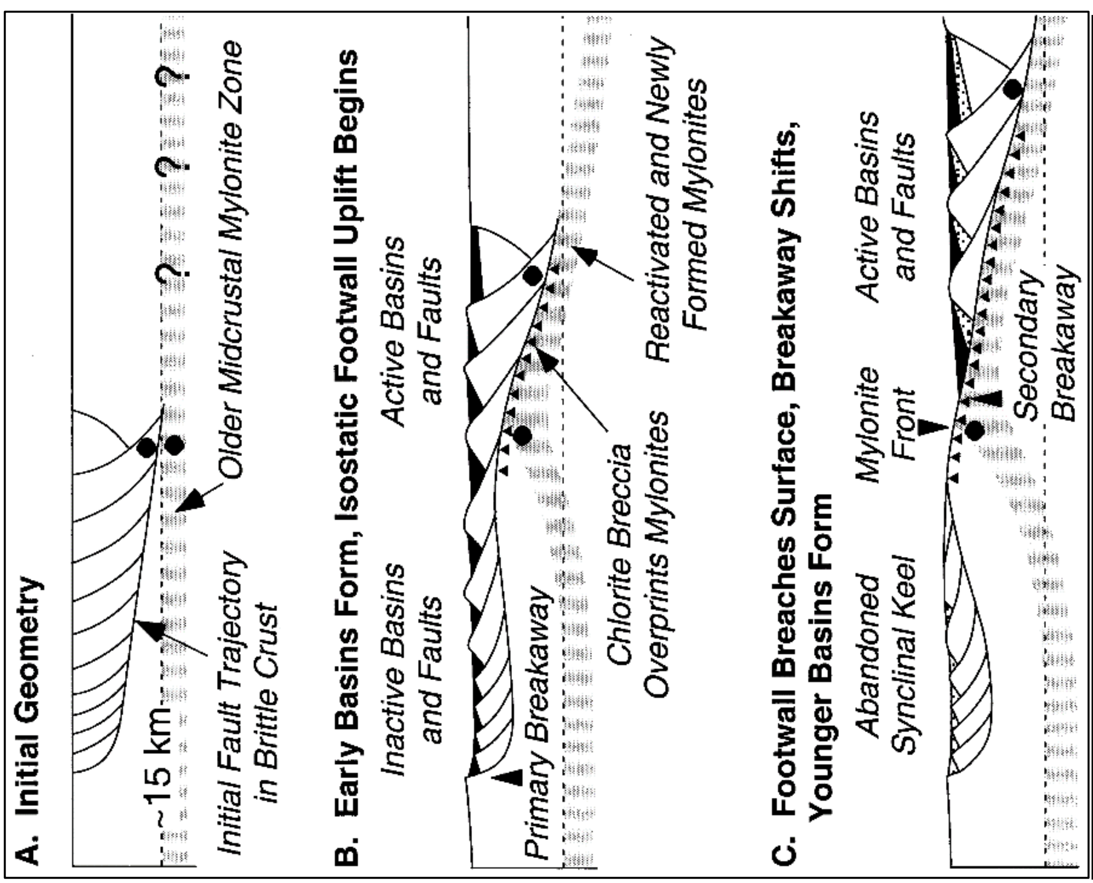
Stop 8-5: View of Copper Canyon Turtleback from Mormon Point (modified from Wernicke et al., 1989). The western boundary of the Black Mountains is affected by Quaternary faulting, with the large-scale topography controlled by the shape of the domiform turtlebacks. In this area, we are on the northwest 'toe' of the Mormon Point turtleback with an excellent vantage to the northeast into the Black Mountains and the Copper Canyon turtleback. The dark grey rocks of the turtleback are largely Precambrian metamorphic rocks and contain a strong mylonitic fabric that probably developed in the Cenozoic. Above the turtleback surface, tectonically resting on the crystalline rocks, are Miocene and Pliocene volcanics and sediments of the Copper Canyon Formation. The proximity of the salt pan to the Black Mountain front, and the narrow, locally developed alluvial fans contrast with the west side of the valley, where broad fans extend several miles out from the east flank of the Panamint Range. This difference reflects the rapid subsidence on the eastern side of the valley, which occurs much more rapidly than alluvial fans are able to prograde westward over the salt pan.

There is a strong component of right-slip in the opening of modern Death Valley, as the transport direction of the normal faults is to the northwest, parallel to the long axes of the turtleback domes. Death Valley is thus a pull-apart basin, connecting two major strike-slip fault zones, the southern Death Valley fault zone and the Northern Death Valley fault zone, both of which are northwest-striking and are nearly pure strike-slip faults in Quaternary time. The en echelon arrangement of the turtleback dome, including the Mormon Point, Copper Canyon, and Badwater turtlebacks could reflect the progressive right-stepping of the strike-slip displacement (Wright et al., 1974).



Sub-basins of modern Death Valley (after Blakey et al., 1999). Field trip stops for May 8th indicated in black dots.

We will spend time here discussing the architecture of a turtleback (metamorphic core complex) and the different types of fault rock and associated metamorphic mineral assemblages.



Conceptual model of the evolution of metamorphic core complex. Track the two black dots on either side of the detachment fault. Also note that the once normal fault can rotate during isostatic rebound such that the fault kinematics will appear to reflect reverse motion. Courtesy Axen, 2004.

Stop 8-6: Badwater Basin lowest point in North America at 282 feet (86 m) below sea level.

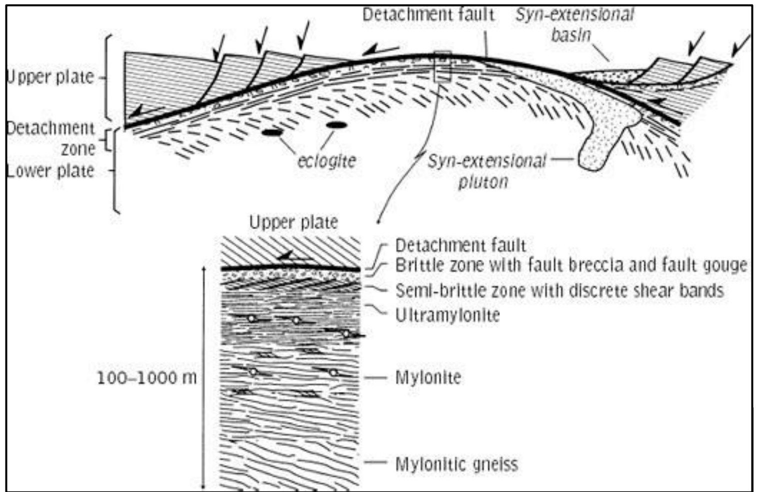
Stop 8-7: Badwater Turtleback (modified from Miller and Wright, 2015).

Park on the side of the road approximately 2.2 miles (3.5 km) north of the Badwater parking lot. Notice that the mountain front steps back from the highway at this spot. Hike 10-15 minutes to the mouth of the southernmost prominent canyon. The mouths of each canyon along this part of the Badwater turtleback reveal spectacular exposures of the Badwater turtleback fault and associated fault gouge, as well as some dramatic exposures of mylonitic rocks.

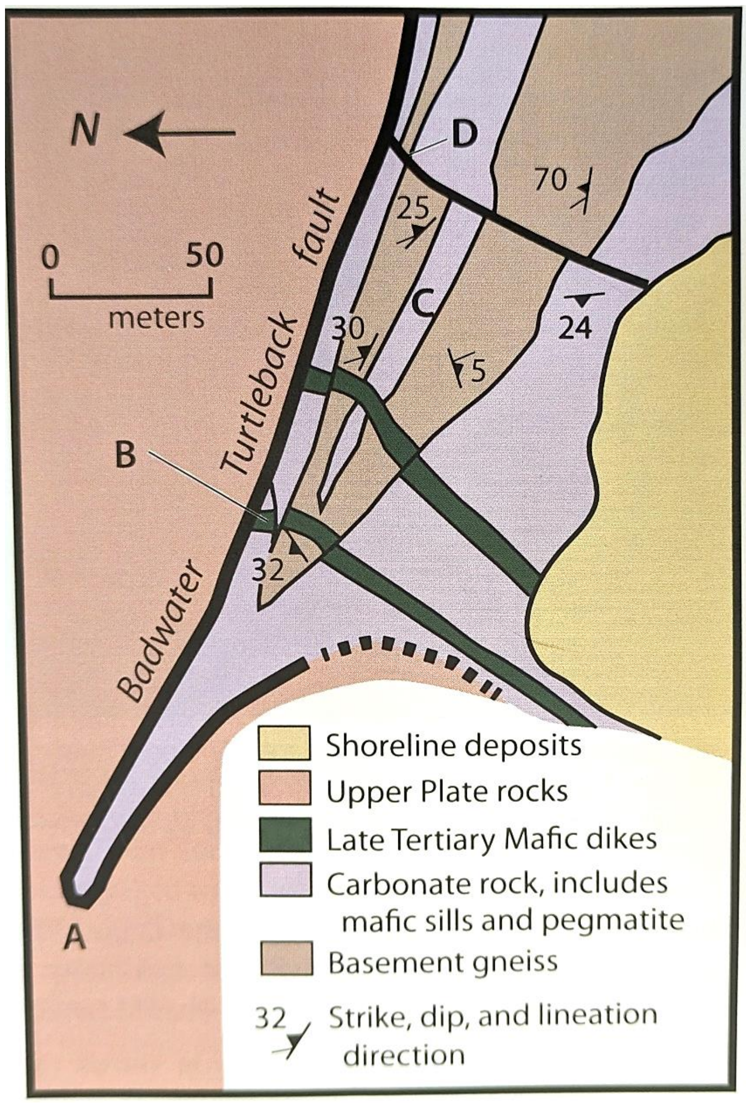
The first canyon displays ductiley deformed calcite marble with blocks of pegmatite and dolomite, sandwiched between sills of mafic igneous rock. These rocks are locally brecciated and are cut by a series of brittle faults, all of which lie in the footwall, beneath the turtleback fault (location A on map at right). Bypass the dryfall by scrambling up the steeply inclined bench on the south side of the canyon. At the top of this bench, carefully walk into the next part of the canyon to see a wide variety of ductilely deformed footwall rocks, brittle faults, and cross-cutting intrusive relations. The map at right is highly simplified. Capital letters indicate points of interest.

- A: Exposure of detachment fault at canyon mouth
- B: Mafic dykes with chilled margins and cross-cutting relations
- C: Good exposure of ductile shear zone in marble mylonite. Note that the basement gneiss here structurally overlies the marble.
- D: High-angle faults. The mis-match of unit thicknesses across this fault indicates an oblique component of slip.

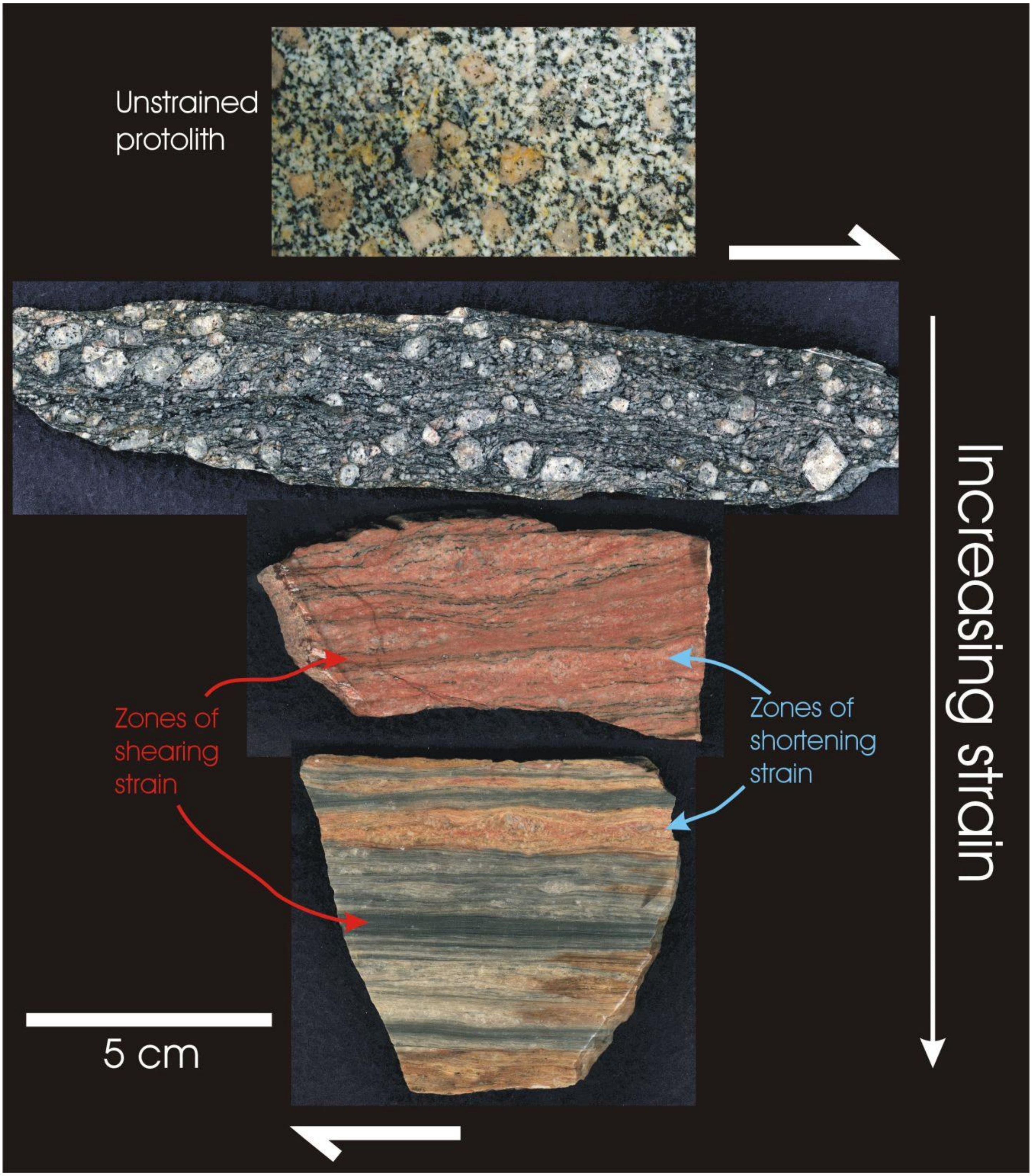
We will spend time looking for the features described above as well as discussing how to properly name the rocks, assess the metamorphic mineral assemblages, and work out the mineral-fabric relationships and chronology.



Anatomy of a metamorphic core complex. Shearing (brittle and ductile) can extend more than 1000 m beneath the detachment surface. The crystalline core will be overprinted by brittle and semi-brittle deformation at the detachment zone as exhumation progresses.



Sketch geological map of Death March Canyon (courtesy of Miller and Wright, 2015.


Unstrained protolith
Increasing strain
Zones of shearing strain
Zones of shortening strain
5 cm

<u>**Exercise 2: Monarch Canyon**</u>

Day 9-10 (May 3-4)

You will be given:

- Base maps: a satellite image with topographic contours at 1:4,000.
    - The section line, structural levels and selected unit contacts are drawn on the map.
- Google Earth images of the canyon to assist with mapping
- Geologic map and section of Monarch Canyon region. *Be wary of the structural measurements!*
- Thin section images
- Stereonets, thumb tacks, tracing paper and masking tape

Background:

The Monarch Canyon region of the northern Funeral Mountains in eastern California is in the hinterland (central part) of the Sevier Orogeny deformation front and the Basin and Range extensional domain. Here, you will examine structures related to both deformation events. There are thrust-related structures and metamorphism overprinted by an extensional fault system. Both the compressional and extensional deformation was ductile.

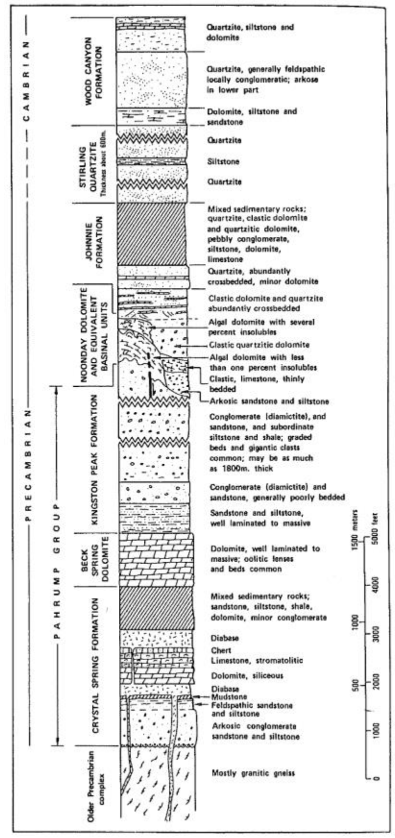


Figure 3. Generalized columnar section of Precambrian to Lower Cambrian strata, Death Valley region. Equivalent basinal units of Noonday Dolomite are now known as the Ibex Formation. From Wright and others (1974).

There are three structural levels in Monarch Canyon. The lowest exposed level consists of lower Crystal Springs Formation pelite, psammite and amphibolite which record well-developed L and S tectonic fabric elements. The middle structural level consists of mylonitized pelitic schists and marbles of the upper Crystal Springs, Beck Springs, and Kingston Peak, Formations. The uppermost structural level consists of undeformed dolostone and quartzite of the Stirling Quartzite.

The overprinting structures and mineral assemblages will appear quite complex upon first assessment. But, if you take a systematic approach and compartmentalize the structures and minerals with the events affecting the region, this canyon will yield a few 'eureka' moments. The metamorphic minerals present in varying proportions and locations include: garnet, staurolite, biotite, muscovite, kyanite, sillimanite, k-feldspar, plagioclase and quartz. Take time to consider whether the minerals are defining a foliation, overgrown by a later foliation, or if they grew over a previous fabric.

Day 8 (May 2):

- Camp Move and Field Trip Day
- Core complexes, badwater

Day 9 (May 3):

- Intro to Monarch Canyon
- AM: tour & mapping of canyon to look at rocks
- PM: structural geology
- Eve: maps checked

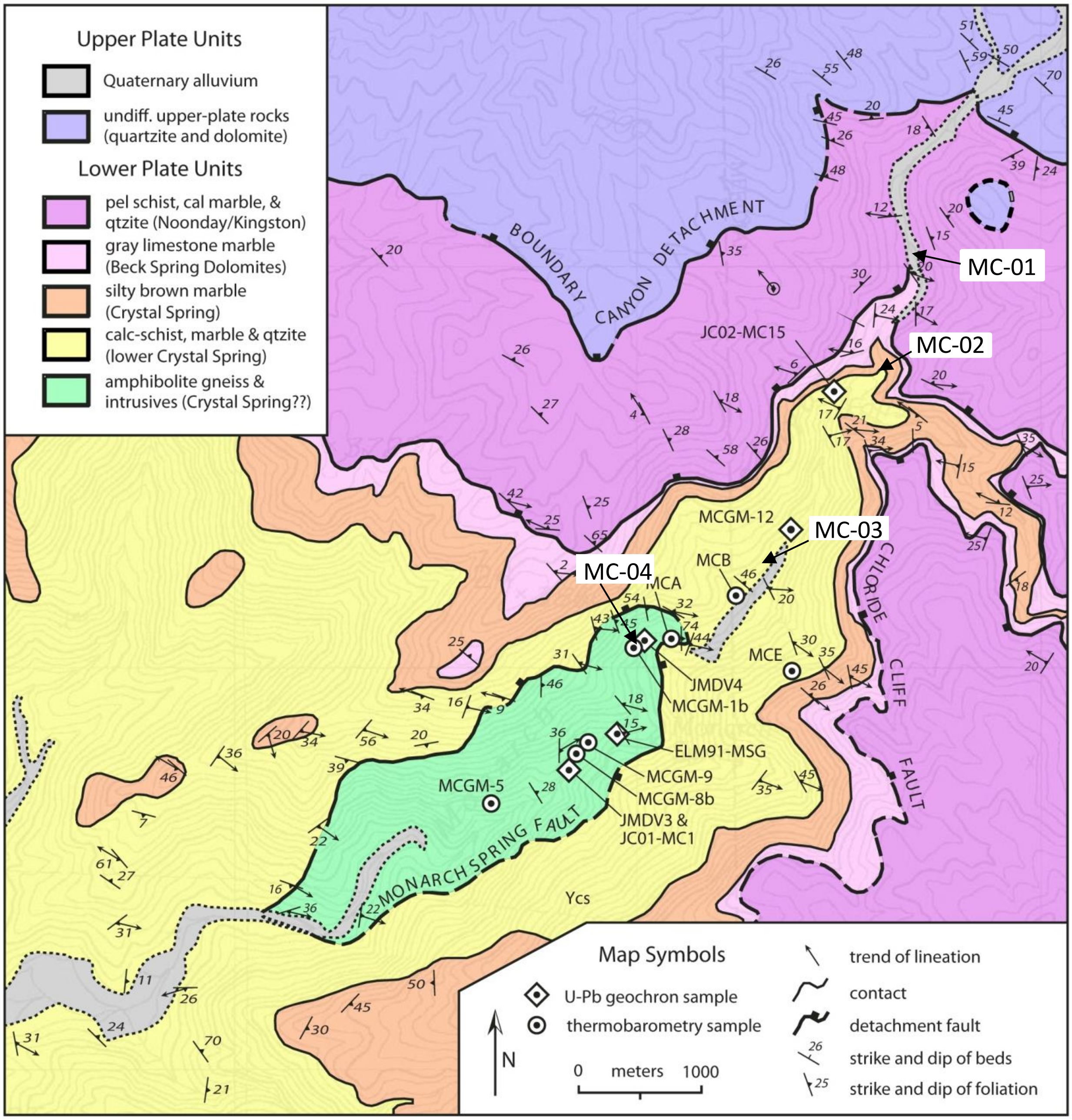
Day 10 (May 4):

- AM: intro to structure;
    - Visit S1/M1 & S2/M2, lower structural level, shear sense
- PM: identifying and mapping structural & metamorphic components
- Eve: answers to specific questions and stereonets due.

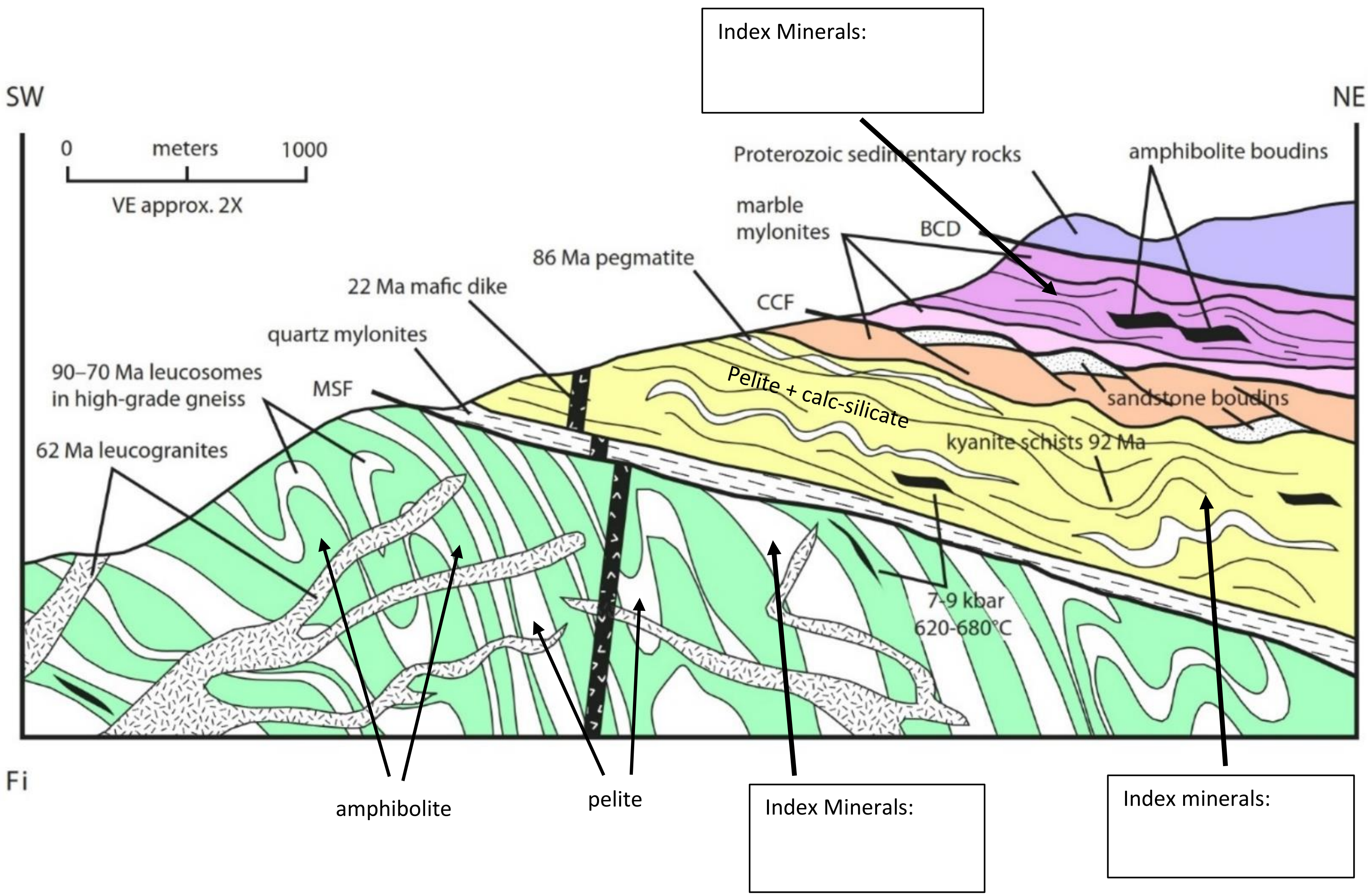
Your Job:

1) Individual: Using the base map provided, produce a map which includes: 1) lithological contacts as well as major faults clearly indicated, 2) structural measurements neatly and accurately plotted, 3) location of sketched shear sense indicators (ie., Sketch #1), and 3) key metamorphic mineral assemblages.
2) Individual: **Two** neat sketches of shear sense indicators in your notebooks. They must include scale, labels, orientation, shear sense, type of indicator based on the supplemental material. ***Locate each sketch on the map.***
3) In Pairs: Produce one stereonet. Plot planar (poles only) and linear fabric elements for each of the three structural levels (ie., below Monarch Spring Fault (MSF), Above MSF but below Boundary Canyon Detachment (BCD), and above BCD. Use different colours to distinguish between structural levels. Remember to clearly indicate the type of structures (eg., foliation, lineation, fold hinge, etc…) using a legend. Use different symbols for each fabric element (eg. dots, open circles, +, squares, triangles, etc).
4) In Pairs: Big picture considerations – answer the following questions.
    1) Deformation and metamorphic events
        a. Find evidence for D1. How is it defined (type of fabric, orientation, folds, etc)? How do you know it's the oldest Deformation?
            i. Any shear sense associated with it?
            ii. What are the Index Minerals defining M1? What are the approx. P-T conditions? It can be tricky to figure out if some minerals belong to one or another event.
        b. Find evidence for D2. How is it defined? How do you know it is 2nd? From direct observations of cross-cutting relationships or from indirect evidence such as plutonic rocks cutting one but not the other?
            i. Are the shear sense indicators consistently in the same direction? Which direction? Report with geographic direction; eg. Top down to the southwest.
            ii. What are the Index Minerals defining M2? Some of these overgrow M1, but it may not be completely clear…
        c. Any D3 structures? John will pay for the best examples… no limit on expense.
    2) Pegmatites (<100 words)
        a. What are the age relationships of the pegmatites and mafic dykes relative to D1 and D2?
    3) For discussion as a group: What regional processes caused each of the major deformation/metamorphic events? (<250 words, not including diagrams)
        a. Hint: this is meant to be a short summary of the geological history
        b. Hint: consider what process(es) led to the generation of the pegmatites
        c. Hint: consider the peak M1 mineral assemblage and how those rocks are now at surface
        d. Hint: locate Monarch Canyon on the Axen, 2004 diagram or the Anatomy of a Metamorphic Core Complex diagram

Timeline	Deformation	Metamorphism	Magmatism	Regional Event
~5 Ma				
~7 Ma				
~18 Ma				
22 Ma				
79 Ma				
86 Ma				
92 Ma				
100 Ma				
180 - 165 Ma				Arc magmatism (Sierra Nevada)
→	Paleozoic & early Mesozoic history summarized in Field Guide			←
750-600 Ma	Noonday, Johnnie, Stirling Quartzite			Rifting
1.08 Ga	Pahrump Group		Mafic dykes & sills	Rifting



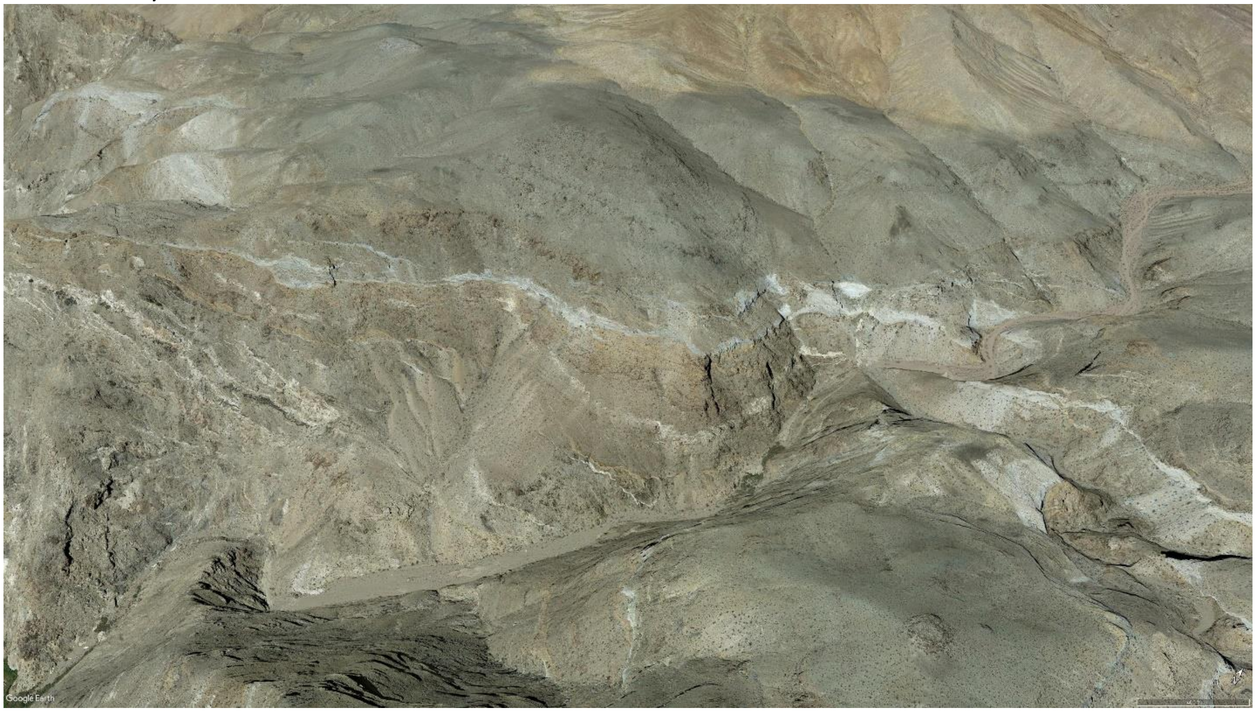
Geology map of Monarch Canyon, northern Funeral Mountains, showing rock units, major structures, and Mattinson et al. (2007) sample locations. MC-01 to MC-04 thin section photographs on pgs 86-88.


SW
NE
0
meters
1000
VE approx. 2X
Index Minerals:
Proterozoic sedimentary rocks
amphibolite boudins
marble
mylonites
BCD
86 Ma pegmatite
22 Ma mafic dike
CCF
quartz mylonites
90–70 Ma leucosomes
in high-grade gneiss
MSF
Pelite + calc-silicate
sandstone boudins
kyanite schists 92 Ma
62 Ma leucogranites
7-9 kbar
620-680°C
amphibolite
pelite
Index Minerals:
Index minerals:

Fi

Google Earth perspective images

1. lower canyon – overview. View to NW

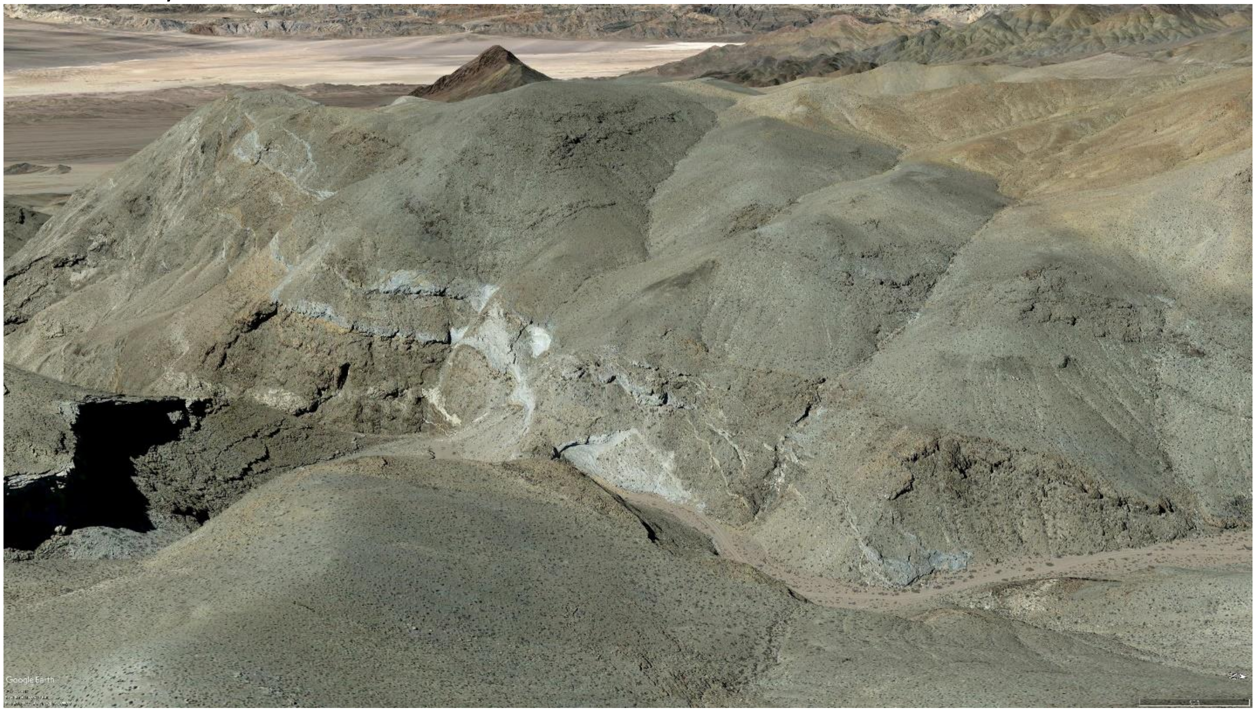


2. lower canyon – detail. View to NW

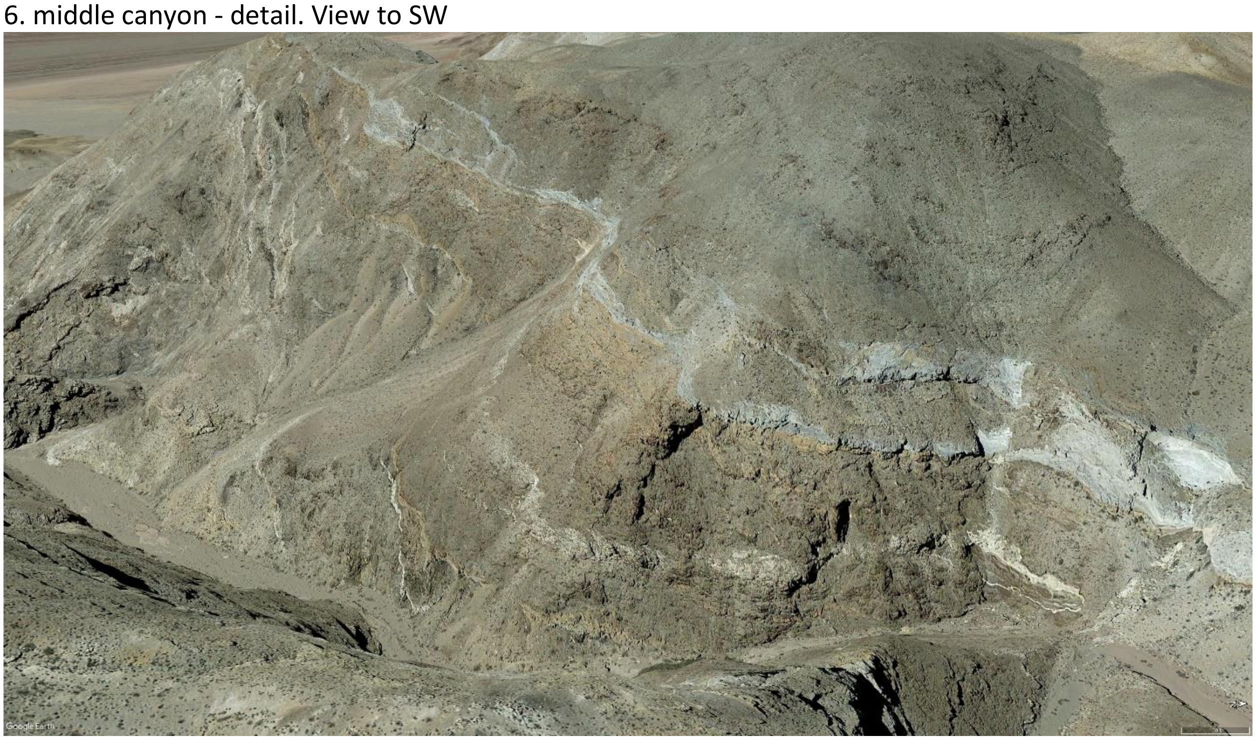
3. upper canyon - overview. View to NW.

4. upper canyon - detail. View to southwest.

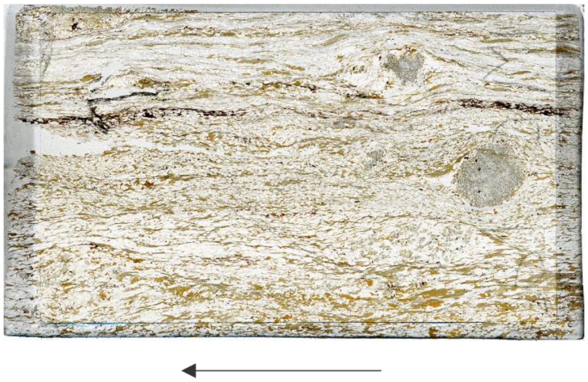
5. middle canyon - overview. View to SW

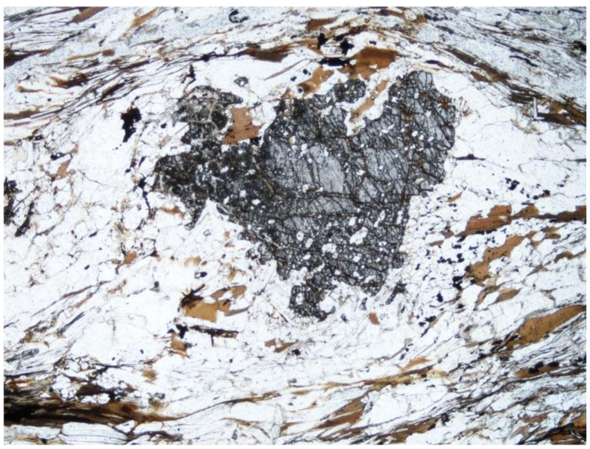


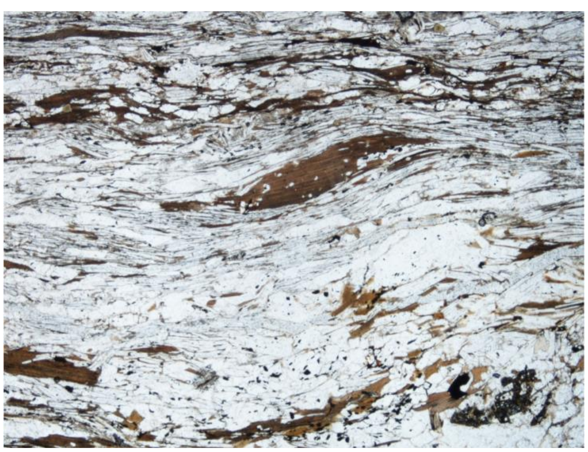
6. middle canyon - detail. View to SW

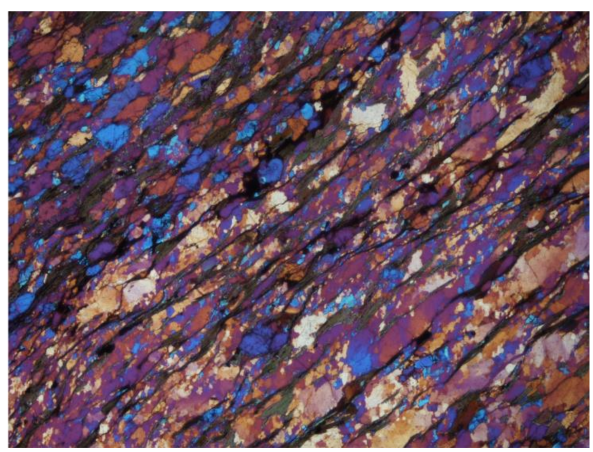


MC-01

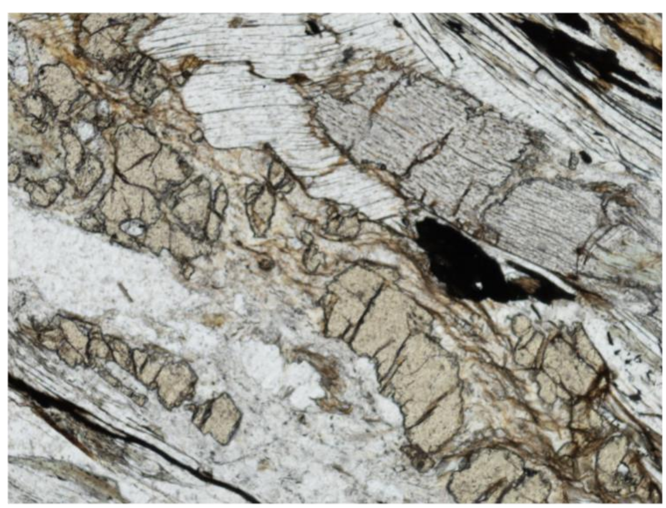




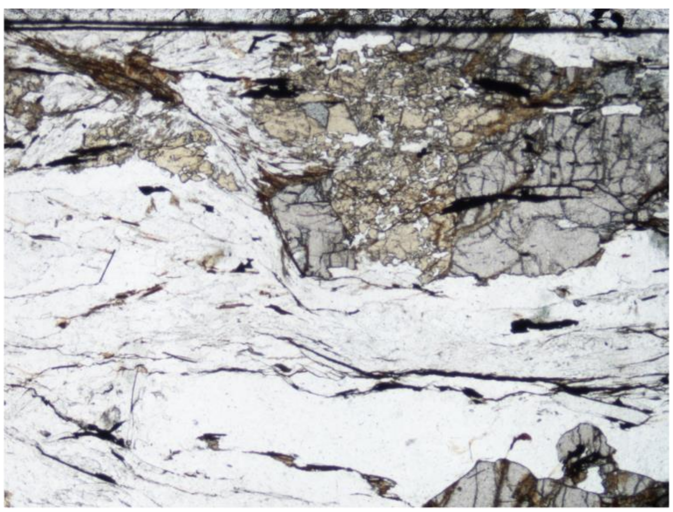


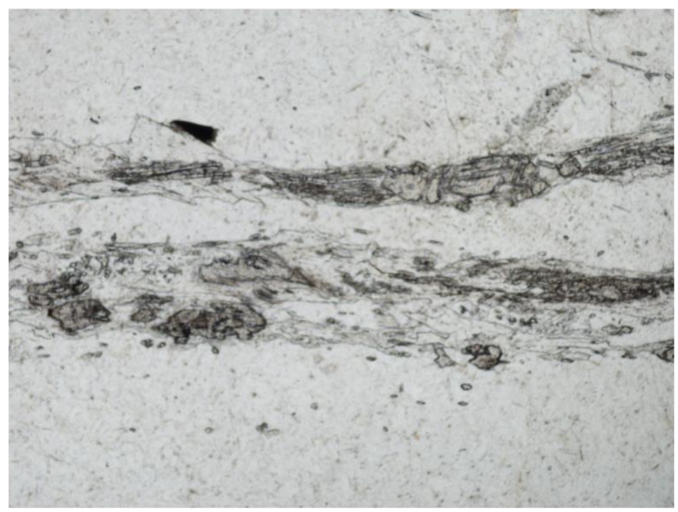


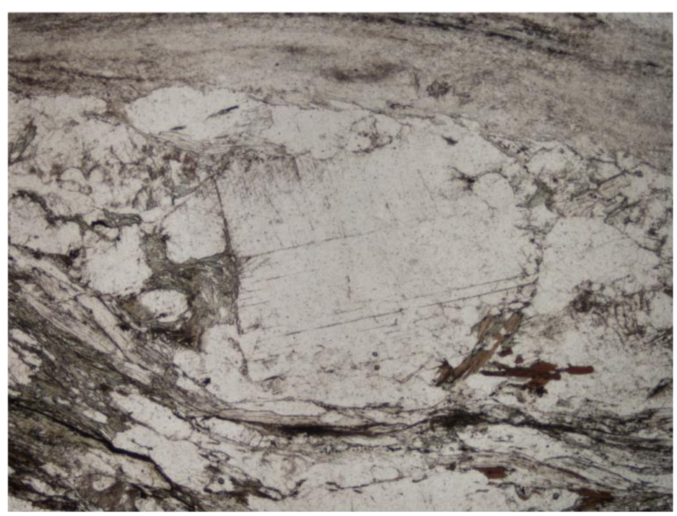
MC-02



MC-04







Exercise 3: Active Tectonics in the ECSZ – Panamint Valley

Overview

The *Eastern California Shear Zone* exhibits the best examples in North America of how strain can be partitioned along major faults. Currently, the main sources of stress are (i) the northward-directed movement of the Pacific Plate relative to eastern California/western Nevada, and (ii) the eastward movement of the Colorado Plateau relative to eastern California. Based on precise geodetic measurements of the relative movement of the Pacific Plate and western Nevada, it is clear that the dextral San Andreas Strike Slip Fault does not accommodate 100% of that motion.

Some of the underlying questions that geologists and geophysicists are attempting to address:
(a) How is the rest of the motion accommodated?
(b) If along discrete faults, which faults?
(c) What are the kinematics of the faults, and how is stress transferred between the faults?
(d) What is the strain rate, or slip rate, along these faults?
(e) Does the slip rate or strain vector change spatially or temporally?
(f) What are the earthquake recurrence intervals and magnitudes based on historic and pre-historic data, and how has this changed over time?
(g) Are there fault segments that appear locked?

Philosophy…an open mind is needed

It is unlikely that you have experienced this kind of mapping in your undergraduate training. **First**, you are being asked to map Quaternary sediments, soils, and geomorphological landforms. **Second**, you are expected to map faults that you will not likely see exposed. This means that you will need to interpret some information about the faults instead of measuring everything. How do you determine fault dip if the fault is not exposed? Does that mean there is no right answer? No. It means that you often may not be able to have direct 'smoking gun' evidence for some of the information you need to map the tectonic history of the region. **Third**, you will need to use new pieces of evidence. Instead of the strain markers and sense of shear indicators that you have used over the past three or four years, you will be learning new ones. **Fourth**, unlike pre-Quaternary mapping, the reconstruction of tectonic history from Quaternary records can significantly benefit from your knowledge of the current regional tectonic activity, seismicity, and modern stress field data. *It is no less precise than interpreting structures in the deeper past, but it requires some new experience, which we will provide in the next four days*.

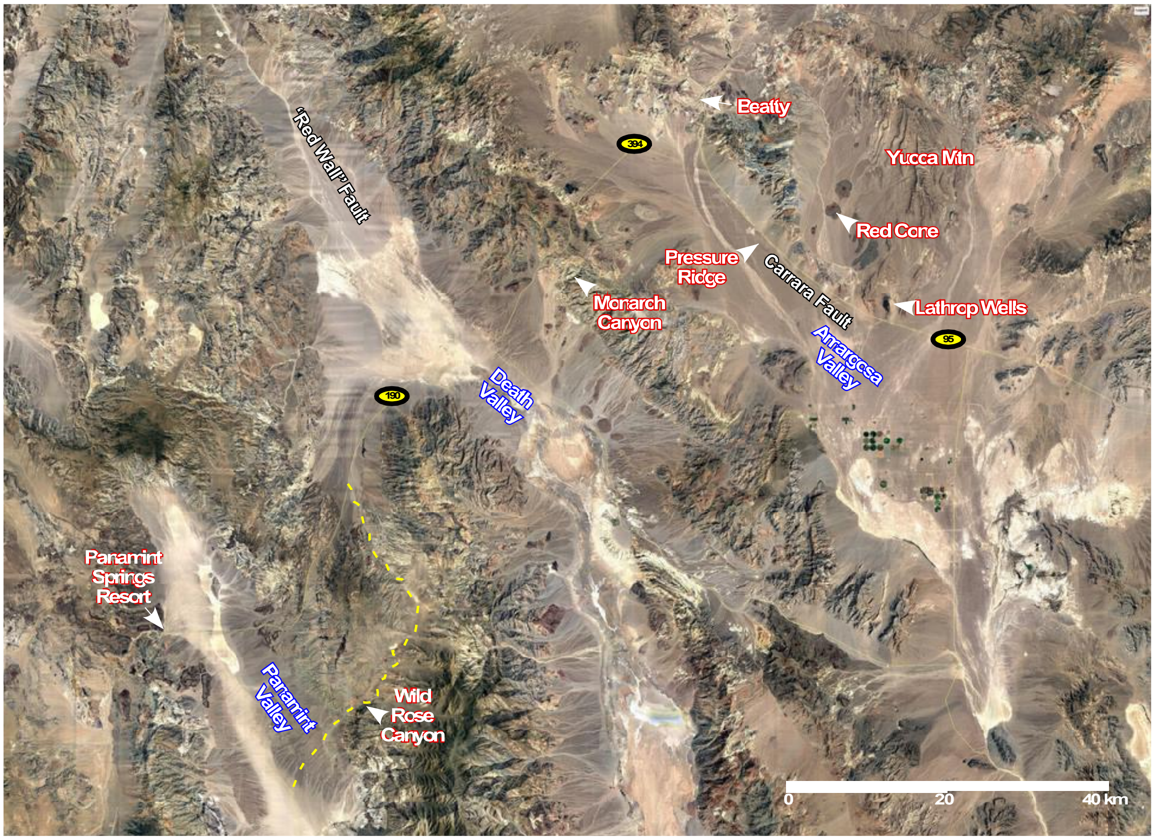
Purpose

The objective of this exercise is to have you practice some basic tectonic geomorphology. Specifically, for your final report, you will (1) map fan surfaces according to their relative ages; (2) map and interpret fault kinematics, fault length, and displacements/offsets of landforms; (3) estimate fault slip rates for faults you mapped in the map area; (4) compare your slip rates with other slip rates measured in the region; (5) interpret the strain and stress history; (6) appreciate the uncertainties involved in these tasks. Once you get calibrated to interpret the imagery made available to you, you can do much of the mapping from the images.
Details of the location will be provided on the day the exercise commences. You will be provided with imagery and 10-m topographical maps, GPS units, transportation to and from the mapping region.

Day 11, May 5: Overview of the Walker Lane Belt and Eastern California Shear Zone

Safety: Hiking boots, 2L water, snacks for the day, sun screen, collared long sleeve shirt, pants are recommended but shorts are tolerable, wide brim hat, sun glasses. **Hazards:** dehydration, sharp rocks, cacti. **Other: Take cash for lunch at a Subway in Beatty (or pack from the food in the cooler); and we will be at a gas station at lunch if you need to buy other things.**

As efficiently as possible we will pull pole on the Monarch Canyon camp, we will backtrack to the east a little, into Amargosa Valley. The ride will be one hour. We will hike (10 minutes) to the top of Red Cone volcano, to discuss the history of volcanism in the *Timber Mountain caldera* area, and discuss the geology of *Yucca Mountain* and why it was the top pick for USA's high *level nuclear waste repository*. We will discuss the local and active tectonics that represent the easternmost part of the Walker Lane Belt. We head to the old mining town of Beatty, now a tourist stop, for a late lunch, so pack snacks for the trip. From there we will cross Death Valley and drop into its scenic sister—Panamint Valley. On the east wall we will stop at a **key location** in *Wild Rose Canyon* to reveal an important clue to the history of the opening of Panamint and Death Valleys. At the last stop you will make some compass measurements to estimate the rate and direction of the opening of Panamint Valley. We'll then proceed to Panamint Valley to set up camp, have dinner, and an evening lecture.



Day 12, May 6: "Find the faults"

Safety for the next three days: Hiking boots, 4L water, you can refill at the vehicles, snacks and lunch for the day, sun screen, collared long sleeve shirt, pants (NO SHORTS), wide brim hat, sun glasses. **Hazards: HIGH HEAT**, dehydration, hyperthermia, exhaustion, sun stroke; sharp carbonate and volcanic rocks, uneven terrane, snakes, cacti. Windstorms, sand storms, thunderstorms with hail are common. You may hear loud engine noises from fighter jets practicing in Panamint Valley. This is normal.

Equipment for the next three days: field notebook and coloured pencils, compass on belt, handlens, hand tools, handouts (maps, instructions), camera/phone, tape measure, first-aid kit, group radios (check frequency), GPS (check batteries, verify your location). *NO INTERNET USAGE PLEASE.*

Early morning departure (6:30 am), with a 60-minute drive to the map site. Pickup time will be determined by temperature. Pickup location will be where we drop you off. It will be **HOT**.

Four groups of three. NO COMMUNICATION BETWEEN GROUPS, even to orient yourself on the fan…(we want you to learn to precisely navigate in regions with only a few markers…such as bushes; plus you have a GPS, maps, and compass).

Main field objective: You want to determine if it is worth mapping this area in detail. Based on your knowledge from yesterday, there may be faults here. Find the fault(s) on the Manly Fan (the many fan within the field area). Determine the fault(s) types…are they normal, thrust, or strike slip faults? Consider measuring fault displacement if you can, but the priority will be to identify and map the faults.

Submit a group **field-quality map** to John before getting into the suburbans, with the faults numbered, and a sentence for each fault that **describes how you interpreted the fault type**. (25% of your project grade)

Afternoon: We will visit other fans in the Panamint Valley to discuss the sedimentary framework of a fan, their soils, and how to map and date alluvial fans.

Evening: Group discussion of some of the faults found. Prep for tomorrow: decide where you want to get dropped off along the road in your field area. Begin mapping the fan surfaces in your field area using the imagery you have.

Day 13, May 7: "Map the fan surfaces"

Morning: Early morning departure (6:30 am), with a 60-minute drive to the map site. Pickup will be determined according to temperature. Same groups. NO COMMUNICATION BETWEEN GROUPS.

Main field objective: Map the fan surfaces in the entire field area on the lightly shaded topo sheet. Label the surfaces Qf1, Qf2, Qf3… with oldest being Qf1. Indicate the position and types of faults on the map that you found yesterday. You need to map fan surfaces that are in your mapping area to the south of Manly Fan. Note any faults and other geological features you see, but your main focus will be on mapping the fan surfaces.

Afternoon: A short (1.5 hr round trip) hike to help you visualize the movement of a fault. Return to camp. Submit a group **field-quality map, with legend, and a description of the map units** by 9 pm (25% of your project grade)

Evening: Brief discussion on the tectonics of Panamint Valley. Brief discussion on how to properly measure fault displacement. Decide where you want to get dropped off along the road in your field area.

Information to consider for your legends for each fan unit (note, you should also map and describe other surficial geology units as well, such as colluvium for instance):
(i) Sediment composition (sand, pebble gravel, etc)
(ii) Lithological composition
(iii) Soil attributes (horizons, development, Av thickness; Quality of desert pavement (% of overturned rubified clasts)
(iv) Presence of specific pedogenic elements (Bk horizons, petrocalcic horizon)
(v) Sedimentary structures (levees, disintegrated boulders, ponding structures)
(vi) Bar and swale topography (m)
(vii) Vegetation
(viii) Fan surface topography, erosion, gullying
(ix) Eolian components
(x) Ash components
(xi) Proportion of debris flow vs fluvial fan facies
(xii) Maximum grain size
(xiii) Geometry and other factors that helped determine relative age, or distinguish the fan unit from other fan units

Day 14, May 8: "Fault slip history of the field area and implications for the tectonics of Panamint Valley."

Morning: Sleep in! Departure at 7:30. Same groups. Pickup will be at 14:00.

Main field objective: Find pinning points, measure offsets (Determine the horizontal and vertical components) on as many faults or fault segments as possible. Read ahead so you can determine what data you need for the final report.

Afternoon and Evening. Each group will provide a series of maps, tables of measurements (include locations if pertinent), and schematic diagrams to describe the fault slip history recorded within your study area and place this into context with the deformation history of Panamint Valley (and adjacent regions if necessary). Due at 9:00 pm. (50% of your project grade). One report per group.

NOTE1: You will need to estimate the fault plane orientation to use trigonometry for this.

NOTE2: We will provide an estimate of the ages of certain fan surfaces this afternoon. Make sure you record them. You need to provide the RATES of slip (along the fault, plus the horizontal and vertical components)

NOTE3: Determine if there are sets of faults (fault systems) that operate together, concurrently. State your evidence for this.

NOTE4: Determine the relative ages of the faults. What is the evidence?

NOTE5: In your final interpretation of the regional tectonics, address things such as (i) relate the Manly Fan structures to other structures in Panamint Valley. (ii) what is the most significant strain direction (use a vector on your map)?; (iii) what is the overall rate of opening of Panamint Valley?; (iv) relate your fault history to the regional tectonics.

NOTE6: Include a schematic/cartoon to explain your tectonic interpretation

Grading criteria for Day 3
mapped units
units offset
fault location
fault sense
number of faults
criteria for mapping
fault kinematics
fault interrelationship
SS strain rate
Normal strain rate
Any other strain rate
Total strain in region
Uncertainty-max min
Orientation of total strain
Diagram local tectonics
Explain slip rates
Time variation in slip rate
Relationship to other faults
Regional tectonics
Spelling/grammar
Correct for erosion
Quadrangle
Total slip (horizontal, incl normal)


Image © 2013 DigitalGlobe
Image USDA Farm Service Agency
Google earth
Imagery Date: 7/16/2011 lat 36.085764° lon -117.325152° elev 467 m eye alt 52.75 km
10.6 km

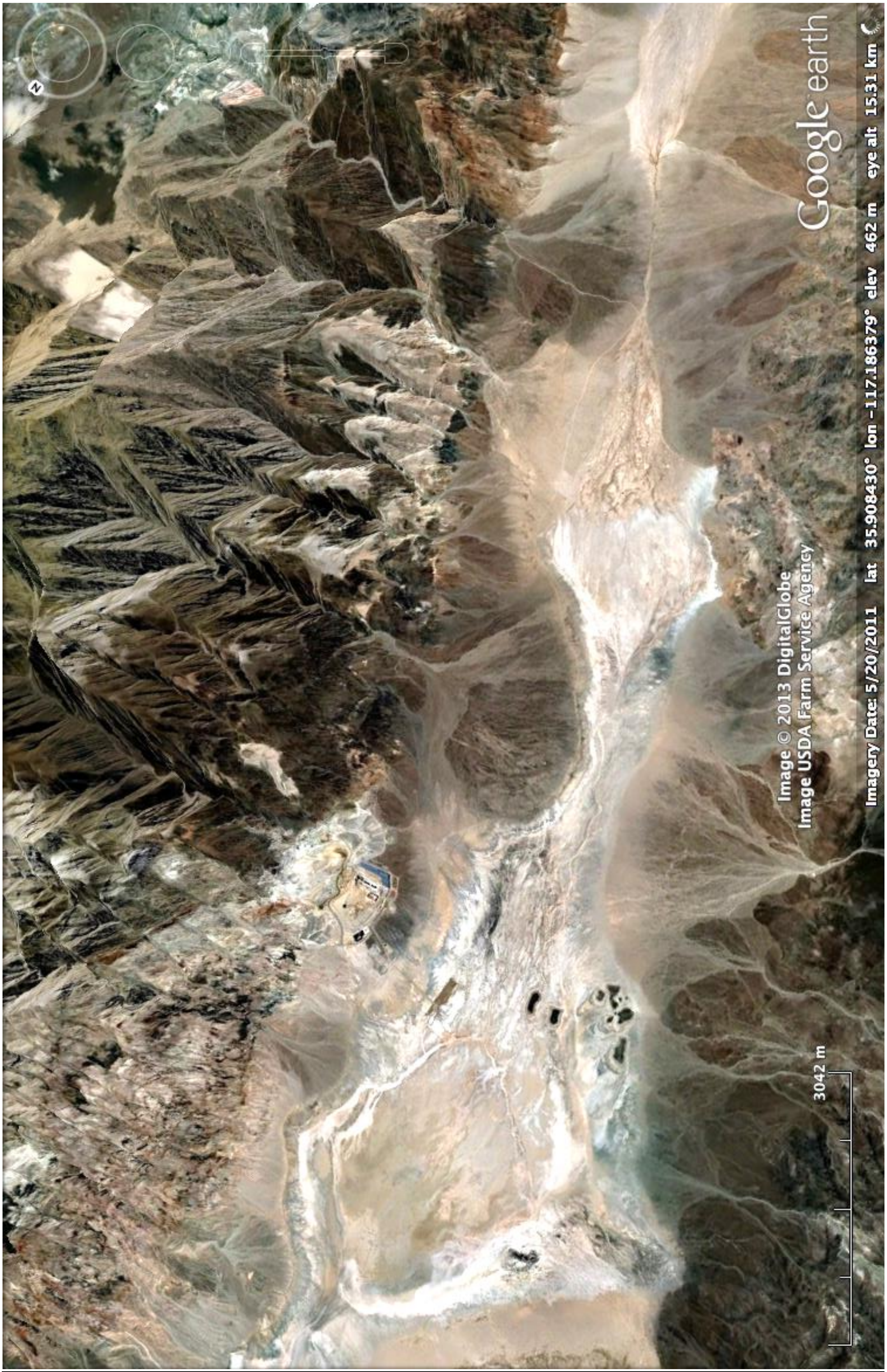


Image © 2013 DigitalGlobe
Image USDA Farm Service Agency
Google earth
3042 m
Imagery Date: 5/20/2011 lat 35.908430° lon -117.186379° elev 462 m eye alt 15.31 km


Google earth
Imagery Date: 8/30/2014 35°54'33.99" N 117°11'15.64" W elev 448 m eye alt 1.74 km
243 m
1995


Image © 2013 TerraMetrics
Image © 2013 DigitalGlobe
86 m
Google earth
Imagery Date: 8/14/2011 lat 35.904055° lon -117.184185° elev 441 m eye alt 1.56 km


Image © 2013 DigitalGlobe
212 m
Google earth
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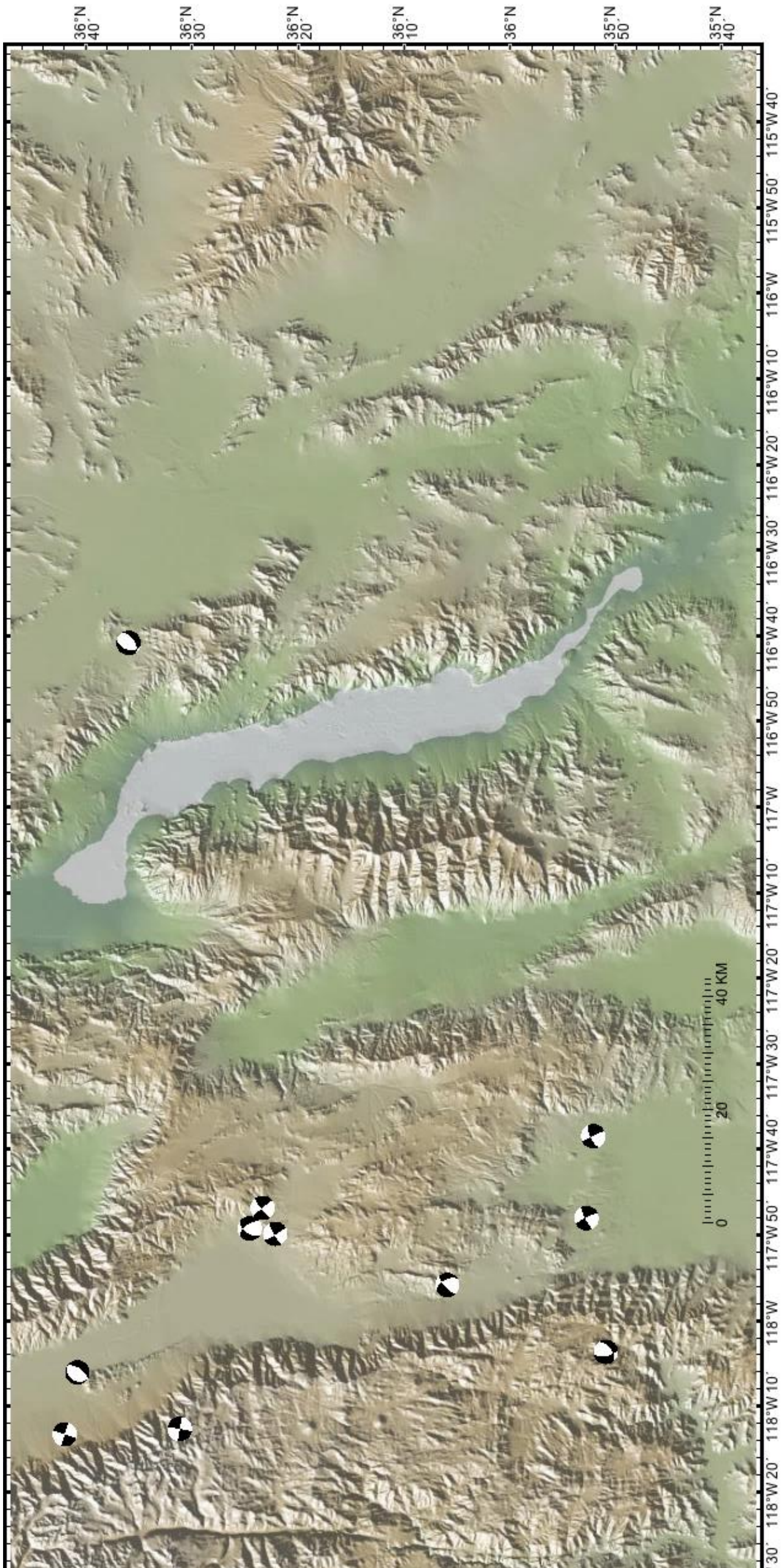
36°N 40'
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117°W 50'
118°W
118°W 10'
118°W 20'
118°W 30'
0
20
40 KM

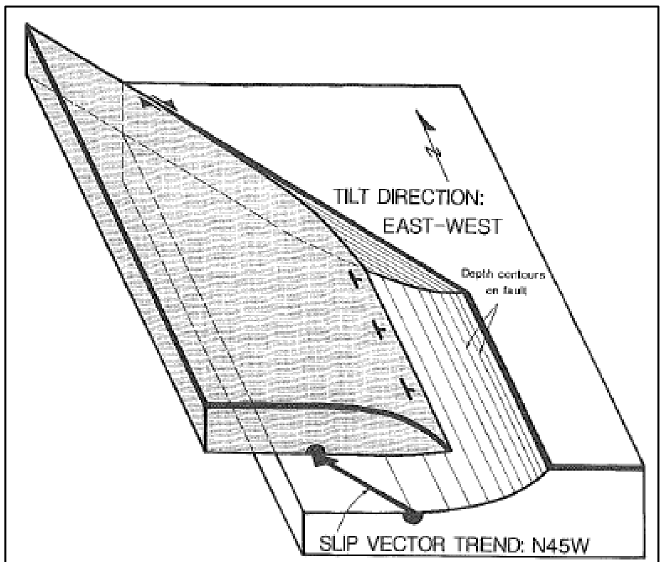
Day 15 (May 9) – Camp Move; Panamint Valley to the White Mountains

On May 9th, we will move camp from Panamint Valley to the White Mountains. En route, we will make stops at Darwin (ghost town), Mount Whitney Portal, Alabama Hills, and the Lone Pine Fault.

Road map with field trip stops on May 11th. Stars indicate campsites at Panamint Springs, and Camp Ferguson in the White Mountains.

Stop 15-1: Father Crowley overlook (modified from Wernicke et al., 1989). From this vantage, we can see some of the major features of the Tucki Mountain area. Due east of the overlook, we see the northernmost end of Panamint Valley. Like Death Valley, Panamint Valley is an asymmetric (rhombic) pull-apart basin. The principle growth fault for the northern basin is the Panamint Valley fault zone, which lies along the western foot of the Panamint Mountains. If the light is favourable, we may be able to see some of the fault scarps. The valley terminates to the north at the steep, dominantly strike-slip Hunter Mountain fault zone.

A small hill rising from the alkali flat, Lake Hill, is comprised of highly brecciated Ordovician and Silurian rocks. The large mountain behind it is Panamint Butte, which displays one of the oldest structures in the Tucki Mountain area, the Lemoigne thrust. The Lemoigne thrust places Middle and Upper Cambrian strata on top of rocks as young as Lower Permian. The trace of the thrust is exposed north of the northernmost tip of Lake Hill from this perspective. A recumbent syncline occurs in the Owens Valley Group beneath the thrust, about two-thirds of the way up Panamint Butte from the valley bottom.



Conceptual model showing interaction between detachments, strike-slip faults and tilt direction in oblique pull-apart basin such as Death Valley and Panamint Valley (Walker et al., 1986; Burchfiel et al., 1987). Tilt direction is controlled by the dip direction of the ramp in the detachment. Black layer represents basalts capping Panamint Butte, Hunter Mountain, and the Darwin Plateau area. From Wernicke et al., 1989.

North of the syncline, we can see a change from the rugged topography characteristic of the Paleozoic rocks to the smoother, grey-weathering slopes underlain by the Hunter Mountain batholith, a composite alkalic intrusion of Middle Jurassic age. From this vantage, the buff-weathering zone marking the transition between the carbonate and intrusive exposures is the contact aureole of the batholith. The aureole cuts smoothly across the trace of the Lemoigne thrust, establishing a pre-Middle Jurassic age for thrusting.

Capping Panamint Butte are a series of Pliocene basalt flows which are correlative with those beneath our feet. Geophysical surveys (including MIT field school data) indicate that these basalts do not lie beneath the floor of Panamint Valley. If the Panamint Butte and Darwin Plateau volcanic flows were once continuous, then the absence of volcanics beneath Panamint Valley indicates that the Panamint Valley fault zone must have been developed at a low-angle. This interpretation is supported by the fact that reconstruction of the kinematically linked Hunter Mountain fault zone completely restores the correlative volcanic flows exposed here and on Panamint Butte (Burchfiel et al., 1987). A geometrical model showing relations at the northern end of Panamint Valley is shown in the figure on the previous page. Despite the consistent eastward dips of rotated normal fault blocks, slip direction of the hanging walls is consistently northwestward.

The entire Nova Basin can be seen from this viewpoint; it consists of the light-brown or tan hills extending southward from Panamint Butte. The southern limit of these hills approximately coincides with Wildrose Canyon. Beyond lies the high backbone of the Panamint Mountains, which primarily consists of the footwall of the Tucki Mountain detachment system. The highest peak on the skyline is Telescope Peak (3360 m/11049 ft). The Hall Canyon monzogranite pluton forms the prominent white exposures at the foot of the range below Telescope Peak.

Stop 15-2: Darwin (from Steve Spear; accessed April, 2017 http://sgspear.com)
Darwin Canyon can be easily (but not quickly) reached by traveling west from Panamint Springs on CA 190 to the paved turn-off to the town of Darwin. This turnoff is about 18.5 miles west of Panamint Springs. 5.8 miles after the turn, you will arrive in "downtown" Darwin. A left turn (east) in the center of town and then generally keeping left up the hill will bring you to a summit on a semi-paved road. This will continue down a very steep hill into Darwin Canyon whereupon the road will turn to gravel. After 4.0 miles from the center of Darwin you will come to a pump house (Miller's Spring). The next several miles have numerous geologic features that are very closely spaced. Any vehicle with high clearance can get to these locations and then back out through Darwin. To continue on this road back to Panamint Springs is much shorter but is much steeper, rockier and requires four-wheel-drive (not the route for us!).

- Folds are located on both sides of the road 0.9 miles past the pump house.
- An angular unconformity is obvious on the north (left) side of the canyon 0.4 miles down canyon from the folds.
- A fault is located 0.2 miles further down the canyon from the unconformity. It is in the sediments in the left wall of the canyon.
- Miocene dykes and sills. From the faults continue down the canyon for 1.1 more miles. You will come to a junction. Keep left down the wash for 0.6 miles to China Garden Spring. Park near here and continue walking down the canyon for about 1/3 mile more, past the gate.

Stop 15-3: Whitney Portal
We will park in the uppermost parking lot. From here, we will make a short, but steep hike up the slope onto very well exposed "granite". It will be your job to properly classify and describe the rock using the Field Sheets and the modified IUGS Method outlined below:

Glazner, A.F., Bartley, J.M., and Coleman, D.S., 2019. A More Informative Way to Name Plutonic Rocks, GSA Today, vol 29, no. 2.
In this paper, Glazner et al. (2019) propose a revision to the traditional IUGS 'Streckeisen' QAPF classification scheme. In the traditional scheme, 27 fields on the diamond-shaped diagram are defined by varying proportions of Quartz (Q), Alkali-Feldspar (A), Plagioclase (P), and Feldspathoids (F). The revised diagram erases these hard boundaries, but still is meant to capture as much detail as the IUGS at the hand specimen or thin section scale (detailed mineral proportions). There are far fewer bins in which to put the overall rocks (9 vs 27). I would like us to experiment with this new scheme to see if it can help a field geologist efficiently capture the normal variations across a pluton, but also to drill down to the details at the hand specimen level.
Modified IUGS Method for Classification of Plutonic Rocks
The following procedure involves the same observations needed to classify a rock with the IUGS method, and thus the full IUGS name can always be applied. All percentages are modal (volume %).
Rocks with Quartz + Feldspars >10% (Upper Half of IUGS Diamond)
1) Estimate the proportions of quartz (Q), alkali feldspar (A), plagioclase (P), and mafic minerals (M), and the identities of mafic minerals and accessories (*example: 20,20,50,10; biotite, hornblende, titanite*).
2) Assign a root name based on where the QAP estimate, normalized to 100, falls on the upper triangle in the figure on the next page (*example: granodiorite*).
3) Prefix the rock name with unnormalized QAP; e.g., 20,20,50. The proportion of mafic minerals (colour index) is implicit in these numbers as 100 minus their sum (*example: 20,20,50 granodiorite; color index is 10*).

4) Prefix the resulting name with relevant mafic minerals, using defined abbreviations if desired. The prefix should list these in increasing abundance so that the most abundant is closest to the root name (Shelley, 1993, p. 7) (*example: hbl-bio 20,20,50 granodiorite*).
5) Important accessory minerals can be denoted by, for example, *titanite-bearing* or *ttn-bearing* (*example: ttn-bearing hbl-bio 20,20,50 granodiorite*).

Note that these steps are identical to the IUGS method except that there are far fewer bins in which to put the rocks (six versus sixteen). The bins simply indicate broad QAP proportions. For example, granites and granodiorites are quartz-rich and distinguished broadly by alkali feldspar > plagioclase or plagioclase > alkali feldspar, respectively. Syenites are rich in alkali feldspar and poor in plagioclase + quartz. Diorites are rich in plagioclase and poor in alkali feldspar + quartz, and so on. For map scale, nomenclature likely skips Step 3 because the modal variation at that scale is too variable for quantification.

Complications

There are many details. For example, it is common in granitoids that the feldspars are difficult to distinguish in the field; in such cases they can be lumped, with only two numbers reported, as *biotite 35,60 granite*. Modal data can be determined with varying levels of precision. Field estimates might be good to only the nearest 10%, whereas microscopic estimates can be good to a percent; the approximate precision should always be stated. A feldspathoidal rock might contain two or more important feldspathoids, as in 30,20,40 sodalite-nepheline syenite, indicating sodalite + nepheline = 30 and sodalite < nepheline.

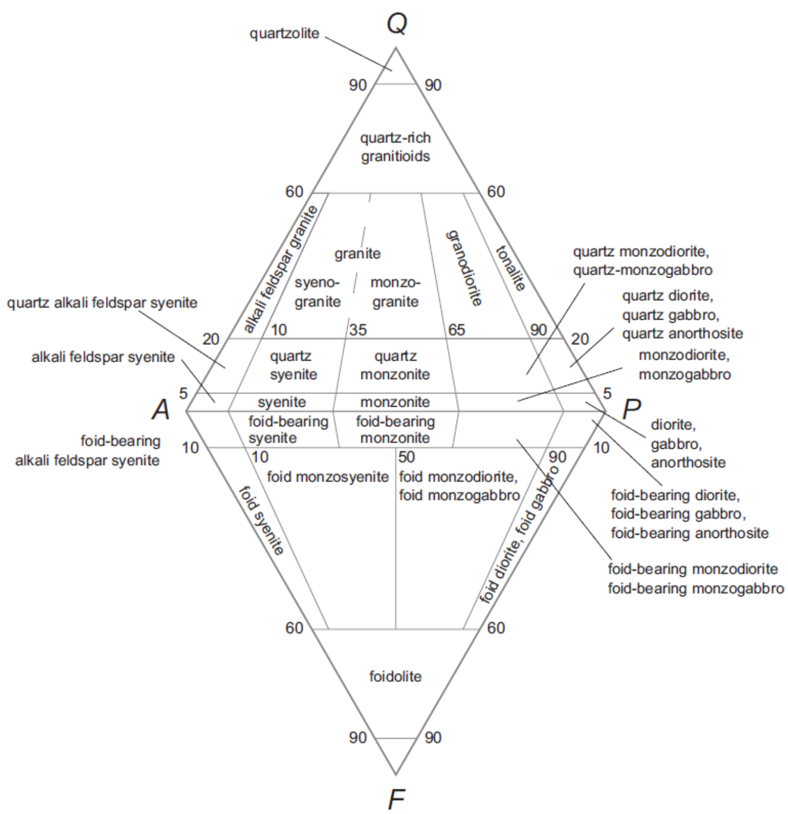


Figure 2. The International Union of Geological Sciences classification double triangle. Field boundaries are arbitrary and not designed to follow petrologic processes, so closely related rocks can scatter across several fields. The plethora of names and positions of boundary lines are difficult to remember, particularly because they mean little in terms of process. They also serve to carve up related rocks (e.g., one map unit) into several different rock types.

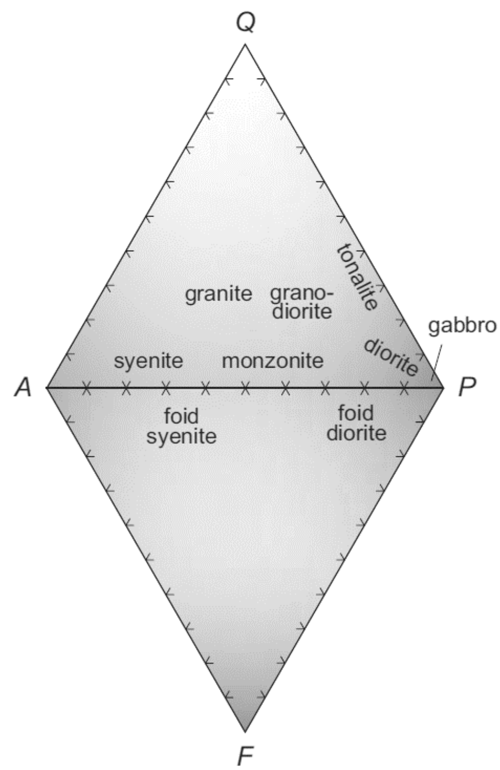


Figure 6. Proposed simplified names for rocks in the International Union of Geological Sciences (IUGS) diamond. Boundaries are fuzzy, fields overlap, and names are redundant of the numeric values, which can be converted into formal IUGS names if desired.

Stop 15-4: Alabama Hills (modified in part from Jessey, 2007)
The deeply weathered granites of the Alabama Hills are a fantastic study in jointing and weathering. Found just west of Lone Pine, California, the hills were once buried under a moist region covered with vegetation -- excellent condition for granite to weather. As joints formed in the rock, exposed surface areas were sculpted though spheroidal weathering. As the Sierra Nevada were uplifted in the Miocene-Pliocene, a rain shadow on the lee side of the mountains creating an increasingly arid climate that could no longer sustain the moist vegetation. As the rocks were exposed, further weathering of the joints sculpted the granite into ledges, spires and natural arches. These rocks form a countless variety of whimsical shapes and figures, giving the landscape its surreal quality.

The Alabama Hills and Diaz Lake lie to the west and north of U.S. 395 with the high Sierras in the distance. The Inyo Mountains lie to the east of the highway. For the next 45 miles, we will be in an area affected by the "great" March 26, 1872 Owens Valley earthquake (M=8.3). Surface breaks and scarps were common and many have survived to the present day. The main zone of faulting is along the east side of the Alabama Hills. Lake Diaz (to the northwest) was created when a graben formed between the Owens Valley fault and a small fault east of the lake.

The Alabama Hills are a block of Triassic/Jurassic metavolcanics intruded by Mesozoic granite of the Sierra Nevada Batholith. On the eastern side of the Alabama Hills, geophysical surveys suggest that the depth to bedrock is approximately 9,000', about the same as the elevation difference between the floor of Owens Valley and the summit of Mt. Whitney (14,495'). The base of the graben block thus sits nearly four miles below the crest of the Sierras. The fact that the Alabama Hills outcrop at all indicates fault motion must have been a combination of uplift of the Sierra Nevada Mountains with concurrent down dropping of the Owens Valley. The valley that lies between the Alabama Hills and the Sierra Nevada escarpment has been a very popular movie location. So many westerns were filmed in this locale that you can walk into almost any older restaurant in Lone Pine and find an autographed picture of John Wayne. Either he ate in many of Lone Pine restaurants or one of the locals forged his signature and got numerous free meals.

Stop 15-5: Lone Pine Fault, a fault scarp from the 1872 earthquake (modified from Jessey, 2007)
Eastward (300 m downhill) from Movie Road in Alabama Hills, there is a small pullout and parking area with interpretive signs. Park here and walk 150-200 m along a path to the north toward the fault scarp. This impressive scarp, on the Lone Pine fault, preserves some of the clearest evidence of slip during the great earthquake of March 26, 1872. Vertical offset is approximately 15 feet and right-slip 45 feet. While there is no general agreement on the magnitude of this earthquake many believe it to be the largest to strike California in the last 200 years. Twenty-seven residents of Lone Pine lost their lives in the disaster. The enterprising survivors buried the victims in a mass grave atop a pressure ridge uplifted during the earthquake. The cemetery, located just north of town remains today as a memorial.

Although historic accounts indicate the escarpment you are examining was created during the 1872 earthquake, recent exposure dating suggests that the vertical offset actually results from three separate earthquakes over the past 10,000 years. Slip from the 1872 quake was about four feet in the vertical plane and 18 feet in the horizontal plane. Examine the fault scarp carefully. Can you find any evidence to support three separate events? Despite numerous studies there is no general agreement on Holocene slip rates for the Owens Valley fault. Estimates vary from a low of 1.5 mm/yr to a high of 7mm/yr. Recurrence interval is thought to be 3000-4000 years, but this is only for the strand of the fault broken in 1872.

Exercise 4: Poleta Folds

Days 17-27 (May 11-21)

The Poleta folds of eastern California has been studied and mapped by literally thousands of students over the past 45 years. This area affords an opportunity to do stratigraphic analysis and mapping in classic Cordilleran orogen fold-thrust belt geology which is an archetypal collisional mountain belt formed by converging oceanic and continental plates. The fold-thrust belt here is part of a series of continuous contractional structures extending north-south through western North America Cordillera from Canada to southeastern California. It is characterized by thin-skinned tectonics, as opposed to thick-skinned deformation that characterized the Laramide province farther inboard. Cordillera fold-thrust belt structures are generally east-vergent, which means that thrust sheets appear to have moved from the west (hinterland) relative to the stable continental craton onto which the thrust sheets moved (foreland). Thrust belts commonly mark the outer edge of collision mountain ranges such as the Andes, Alps and Himalayas, and of course the North American Cordillera. Thrusts in this situation don't just appear on their own but in herds and can interact to make wonderfully complicated cross-sections. Understanding the regional context and significance of the rocks we're mapping is an important learning goal.

The White Mountains of east-central California are underlain by a thick (10-12 km) Neoproterozoic to late Paleozoic passive margin succession. In fact, the Precambrian-Cambrian boundary in this area is conformable and the faunal assemblages have been studied in detail. Jurassic to early Cretaceous granitic laccoliths and plutons intrude these rocks and are interpreted as apophyses of the massive Sierra Nevada Batholith. The rocks have been multiply deformed during the Antler, Sonoman, and possibly Sevier Orogenies resulting in complex fold interference patterns in some places. Extension in the Miocene resulted in numerous high-angle normal faults throughout the White Mountains and more recent strike-slip faulting has also affected the area.

Little Poleta:

Little Poleta is a two-day guided exercise designed to introduce you to the semi-independent Big Poleta mapping exercise. Little Poleta is a small area outside the main map area but is underlain by most of the mappable units in the area and displays the key structural elements exceptionally well. As a group, we will develop a measured stratigraphic column which you will use to map both the Little and Big Poleta areas.

- You will be given a 1:3,500 topographic base map with the map boundaries indicated and the cross-section line. Some of the geologic contacts and faults have been partially completed.
- You will also have a satellite image with the contours overlain at the same scale as the topo map.

As a group we will complete the map on the topographic base utilizing the satellite image. Some of the concepts we will practice together are:

1. Locating yourself on a topographic and satellite image
2. Drawing in contacts as you traverse paying attention to:
    a. Rule of V's – topography and geologic contacts
    b. Stratigraphic thicknesses – honouring the strat column and topographic effects
    c. Predictions based on bedding-cleavage-lineation relationships.

Your Job:

1. Produce a field quality geologic map by completing the map with symbolized linework.
    a. Include structural measurements, contact lines (observed, approximate, inferred), axial traces of folds, and faults. Use the map symbols in the Field Sheets.
    b. Produce a rudimentary legend
2. Produce a sketch cross section (facing southwest) using the red ticks as the bounds.
3. Produce a measured section for the map area (see itinerary below for details)

Big Poleta:

Big Poleta is designed to enhance and hone your mapping skills. It is intended to be an independent endeavor with minimal assistance from professors and teaching assistants. It is approximately 3 x 3 km area of rolling hills and nearly complete exposure. You will be partnered with a classmate for safety reasons and to bounce ideas off each other. However, each person must produce their own original map and cross sections. You will have 7 days to complete the Big Poleta exercise.

- You will be given a 1:5,000 topographic base map printed on mylar with the map boundary indicated.
- You will also be given a satellite image at the same scale.

Your Job:

1. Produce a coloured geologic map completely filling in the map area.
    a. Include structural measurements, contact lines (observed, approximate, and concealed), axial traces of folds, and faults. Use the map symbols provided in the Field Sheets.
    b. Ink in the linework using a fine-tipped black pen after you have finalized linework and colouring.
    c. Create a neat and inked legend for map symbols. Colour in the stratigraphic column which will serve as the map unit legend.
2. Produce two cross sections (three section lines and topo profiles will be provided. It will be up to you to choose 2 of the 3 sections to complete). Use the same map colours and symbols. Additional symbols may be required so consult the Field Sheets
3. Finalize your measured stratigraphic section by inking and colouring it in using the same map unit codes and colours as the map and sections.

Symbols and Colours (test these to ensure sufficient contrast). Each polygon requires code label.

Contact Lines	Black (0.2-0.25mm)			
Trace of bedding	Black dots/dashes			
Axial Traces of Folds	Black or red (0.2-0.25mm)			
Faults	Bold Black (0.35mm)			
Structure symbols/dip	Black (0.2-0.25mm)			
Alluvium (Q)	Light yellow		Poleta Fm (ЄP5)	Orange/red
Harkless Fm (ЄH)	Green (line for marker*)		Poleta Fm (ЄP4)	Light blue
Poleta Fm (ЄP8)	Tan/light orange		Poleta Fm (ЄP3)	Light Green
Poleta Fm (ЄP7)	Blue		Poleta Fm (ЄP2)	Grey
Poleta Fm (ЄP6)	Tan/light orange/brn		Poleta Fm (ЄP1)	Dark Blue

*carbonate markers in Harkless should also be drawn on map (dashed lines) and included in legend.

May 10: Field trip to Sierra Overlook (Stop 16-1) and another site (Stop 16-2; it's a surprise)

1. AM: Depart for Sierra Overlook – we will have a spectacular overview of the Sierra Nevada, Volcanic Tablelands and the sub-alpine of the White Mountains
2. PM: Complete Panamint report if not completed

May 11:

1. AM: Little Poleta measured section
    - setup notebook similar to Rainbow Gardens
    - notebook scale: **1cm=5m** (1:500); final draft: **1cm=10m** (1:1000; total ~200m)
2. PM: revisit to finish descriptions; redraft in notebook with interpreted depositional setting.
3. PM: begin mapping; find the skull marker
4. Eve: Complete strat column (leave room for ЄP1 (60m), ЄP2 (40m) and ЄP3 (12m total) at bottom
    - Follow templates in Field Sheets for final product (see below).
    - Set scale on paper prior to beginning
    - Include map unit codes (eg. ЄP1) and notes on diagnostic features of each unit
    - Choose colours as above – be sure the colours are dissimilar enough to distinguish units on the map

May 12:

1. 7:30-9:30 – sketch Little Poleta
   - review Google Earth perspective images
2. 9:30-3:00 – guided mapping tour of Little Poleta
   - Locating yourself – triangulation, points of reference, bearings, station #'s
   - Relief and rule of V's
     - Complicated map patterns; contacts may not be parallel to strike if on a slope
   - Strike ridges and dip slopes
   - Do across-strike transect first; draw contacts as you go; leave unknowns blank; move on; fill in later with along-strike transects
   - properly orient map to north – allows you to draw contacts by sighting
   - Map with cross section in mind – build it in your notebook
   - Plot strike & dips while in field – accurately. It's a good check
   - Use contours to your advantage; Note: Big Poleta will be done on contour map. Get used to finding yourself on a contour map
   - Before we depart parking lot, each person should sketch a cross section.
   - Rough copies of map and cross section checked; not marked.

May 13: Long Valley Caldera Field Trip – See below for Long Valley Field Guide

May 14: Big Poleta Groupie #1: 'Canoe' to Racetrack
As a group, we will traverse across the map area. Some of the concepts we will practice together are:

1. Finish measuring 1,2,3&4 at Big Poleta
2. Locating yourself on a topographic and satellite image
3. Drawing in contacts as you traverse paying attention to:
   - Rule of V's – topography and geologic contacts
   - Stratigraphic thicknesses – honouring the strat column and topographic effects
   - Predictions based on stratigraphic order
   - Building a cross section as you map

May 15-16: Big Poleta mapping
May 17: Big Pine skarn mini-project
May 18-20: Big Poleta mapping; including Field Trip through: 'Scissors'
May 21: Big Poleta map, cross sections and strat column due at 5pm. No late submissions.
May 22: pack up camp and travel to Las Vegas; arrive at Travelodge by 4pm.

Abbreviated notes for mapping: Guide for Constructing Geological Maps, Cross Sections, and Stratigraphic Columns (see field guide for more complete description of field/mapping techniques)

Geologic Maps

The following are required on all geologic maps. PLEASE PAY ATTENTION TO THESE CONVENTIONS.

a. Title based on project area. e.g. Geology of Rainbow Gardens, Nevada.
b. Location of the project area. e.g. northwestern Lake Mead region, southern Nevada.
c. Name of the geologist(s) and date(s) of project.
d. Scale, both ratio (e.g. 1:6000) and bar.
e. North arrows with declination.
f. Contour interval and datum, if appropriate.
g. Line of construction of cross-section, keyed to the map, e.g. A_A', if appropriate.
h. Explanation
    i. Rock Units - list them in chronological order, oldest are at the bottom, keyed to the map by boxes showing corresponding letter symbols, and colour or ornament. Put unit symbols both in boxes and on the map.
    ii. Symbols - for bedding, contacts, faults, folds, etc - list the symbols used, following the Field Sheets

The final maps and sections must be inked in with fine-tipped black or red pen. Do this after you have checked the map, made the legend and coloured in the units

Geologic Cross Sections

General Rules For Drawing Cross-Sections

Cross sections are interpretations of subsurface geology that are generally based upon a map of the bedrock geology exposed at the surface (while it is common to incorporate geochronologic, drilling and/or geophysical data, this will not be the case at camp). Thus, *the geology in the cross-section MUST agree with the data on the corresponding geological map*. Think of it this way, the data on your map are *primary data* in the same way that measurements made with a mass spectrometer are primary data. The interpretations you make in a cross section must be based on and faithful to those primary data. Downward extrapolation should be carried as far as is reasonable considering the complexity of the geology and amount of data available. This depth will be specified for each project. Below are some things to consider when drawing your sections. If you have concerns regarding constructing cross sections, especially with projecting strata and structures in the subsurface, please see an instructor as soon as possible.

1) Topography should be accurately drawn.
2) The title of a cross section must reference an accompanying geologic map. The sections should also include the location, name of geologist(s), and the date(s) of the mapping project. Indicate orientation by showing directions above each end of the section.
3) Scale(s) must be indicated. **Vertical and horizontal scales should be the same**, unless there is good reason for doing otherwise. Use regular intervals for the elevation scale (e.g., 5500, 6000, 6500) and write elevation (feet) on the ends to indicate what the numbers mean. Indicate the datum for the vertical scale (in most cases: feet above sea level)
4) Include the bearings of the line of section. If the cross-section changes direction, be sure to indicate with a vertical solid line. *Beware*, apparent dips will change across a bend in the section.
5) You will want to be concerned with apparent dips, as the section may not be everywhere (or anywhere) perpendicular to strike.
6) Be true to bedding thicknesses. Don't let thicknesses of stratigraphic units vary unless you have a good reason to do so.
7) Never use a straight edge for contacts or bedding. There are virtually no perfectly straight contacts in the real world.
8) Show bedding within each of the sedimentary units in a diagrammatic fashion on the section.
9) Use the same colours for units on the section that you use on the map. Colour LIGHTLY and evenly
10) Use fine or dashed lines (form lines) to highlight structures. Form lines may be extended above ground to show folding and overturning, but are not colored in. Form lines above ground may also be used to indicate overturned bedding.

Remember: These are interpretations tied to "ground truth" observations at the surface and should be guided by your geological wisdom and common sense.

Stratigraphic Columns

The following are required on all stratigraphic sections:

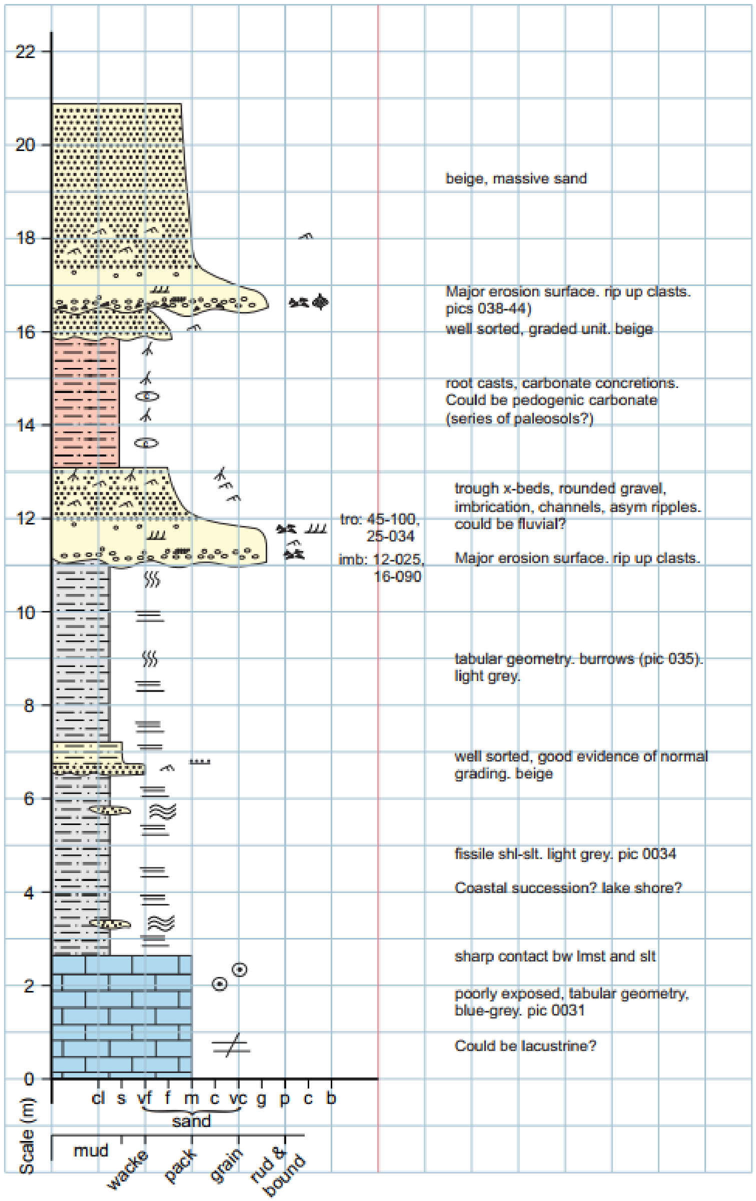
a. Type of column, title, location, method of data collection, name(s) of geologist(s) and date must accompany the section.

b Include columns for the age of units shown and for stratigraphic hierarchy (Group, Formation, Member, etc.)

b. Vertical scale must be shown. It may be useful to show both a continuous graduation of thickness and illustrate individual unit thicknesses.

c. Use patterns or cartoon drawings of exposures to illustrate your graphic column. Use relief on your graphic column to indicate either differential weathering and erosion or grain size.

d. Include a column for rock descriptions



Little Poleta. Looking Southwest from Hwy 168

Big Poleta – Google Earth Perspectives. Looking southwest. ‘Canoe’ is visible in upper middle part of image. Chevron Island in far upper left hand corner, Scissors upper left along prominent buff-blue-buff strata. Vale of Tears in middle to lower middle part of image.

Big Poleta – Google Earth Perspectives. Looking SW toward Canoe, Powell Ridge, and Racetrack

Big Poleta – Google Earth Perspectives. View to northeast of Sylvester's Incubus. Wegmann's Ridge at right and Black Hole at upper left.

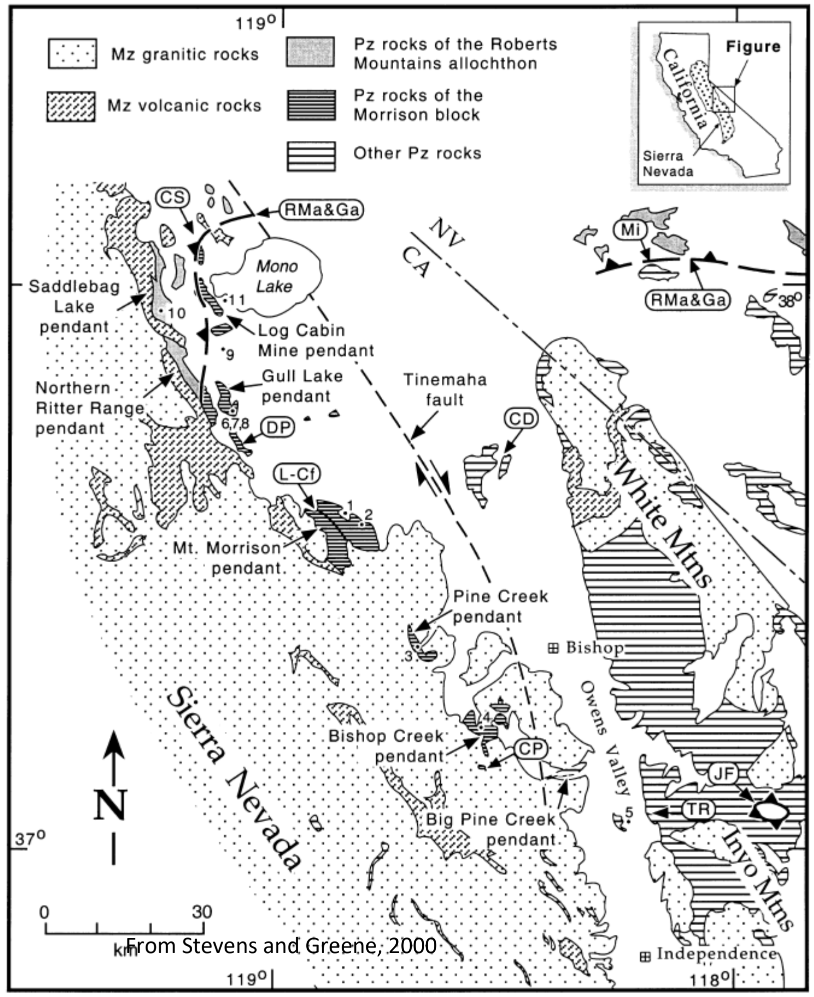
Big Poleta – Google Earth Perspectives. View to northeast of Powell's Ridge at left, Scissors in middle, and Black Hole at right.

Big Poleta – Google Earth Perspectives. View to northeast of Scissors

Exercise 5: Big Pine Skarn

Paleozoic metasedimentary rocks are present in numerous roof pendants and wall rock septa in the eastern Sierra Nevada Batholith (Jurassic to Cretaceous) of east-central California. These pendants range in size from a few 10s of meters to 10s of kilometers, and reflect a dominantly passive emplacement style of the granitic plutons. In some cases (Saddlebag Lake and Mt Morrison pendants in particular), thick stratigraphic sequences are still preserved and have not been reoriented by the emplacement of the plutons. Stoping and metasomatism are common at the margins of the pendants.

The Big Pine pendant consists of a series of Cretaceous granitic stocks and volcanic rocks with intervening septa, xenoliths and pendants of marble, quartzite, hornfels, gossan and calc-silicate rocks. These metasedimentary rocks have been correlated with the Cambrian Poleta Formation (Moore and Foster, 1980; paper included below).

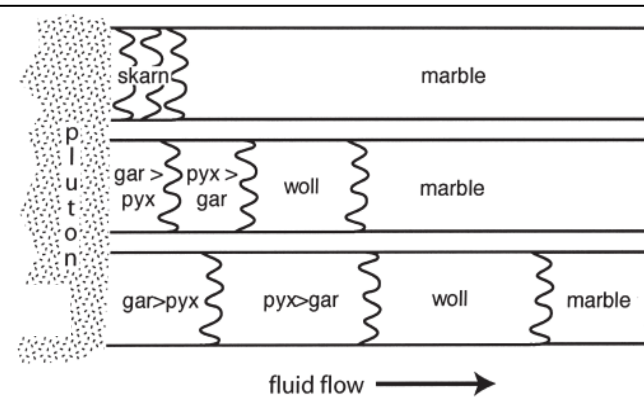


From Stevens and Greene, 2000

Regional index map (after Bateman, 1992). CD—Casa Diablo; CP—Chocolate Peak; CS—Conway Summit; DP—Deadman Pass pendant; JF—Jackass Flats; L-Cf—Laurel-Convict fault; Mi—Miller Mountain; Rma and Ga—interpreted margin of Roberts Mountains and Golconda allochthons; TR—Tinemaha Reservoir. Small numbers refer to field trip stops.

Skarn Mineralization

Skarn is a relatively simple rock type defined by a mineralogy usually dominated by calc-silicate minerals such as garnet and pyroxene. Most skarns occur at the interface between granitic plutons and carbonate host rock. They are typically zoned with a general pattern of proximal garnet and distal pyroxene (see right) and minerals like wollastonite, vesuvianite, or massive sulphide and/or oxides near the marble front. Skarns are divided into 7 types based on the dominant commodity elements: Fe, Au, Cu, Zn, W, Mo, and Sn. General correlation exists among igneous major and trace element composition and skarn type. Plutons associated with Fe and Au skanrs contain significantly more MgO and less K_2O/SiO_2. Au and Sn skarns are more reduced, and Cu, Zn, and Mo skarn plutons are more oxidized (Meinert et al., 2005). In terms of geochemical evolution, there is a fairly linear array from relatively primitive calcic Fe skarn plutons through Au, Cu, Zn, to W, Mo, to relatively evolved Sn skarn plutons.

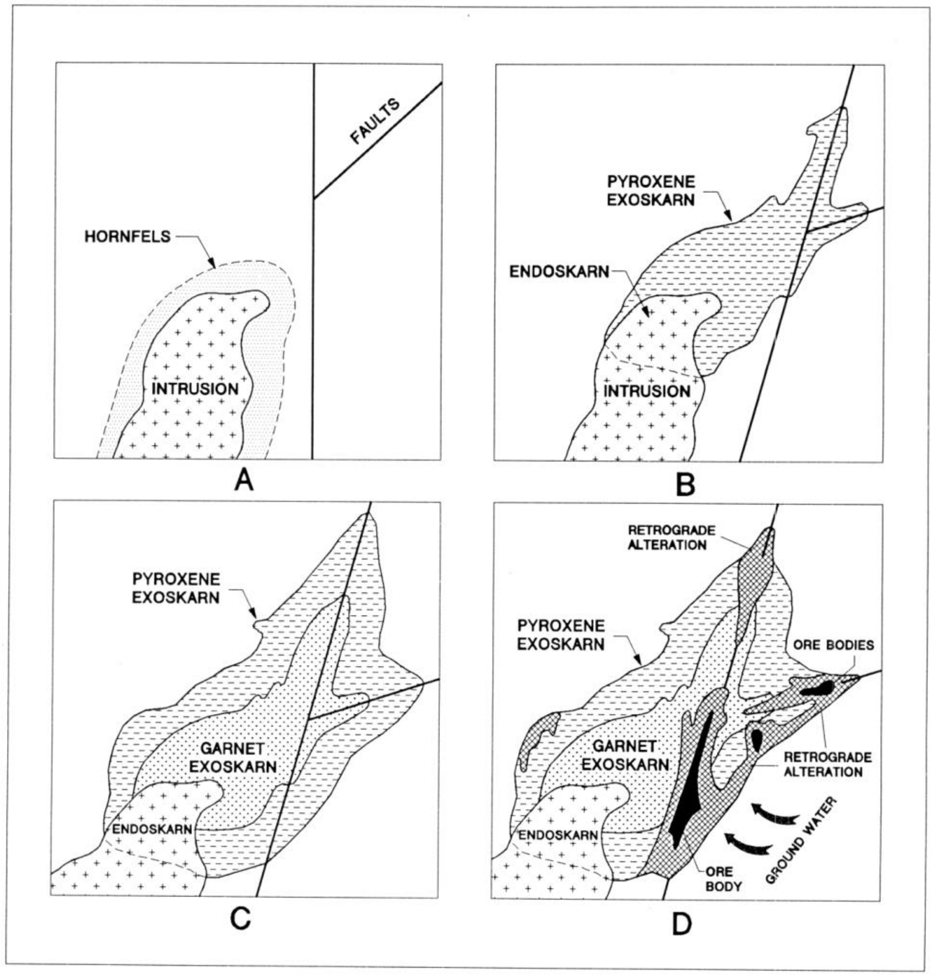


Schematic illustration of the propagation of multiple reaction fronts during progressive fluid flow. Note that all fronts originate from the fluid source. The separation between fronts increases during progressive fluid flow. Either the distance traveled or the distance between fronts can be used to constrain the amount of fluid flow as a time-integrated fluid flux. The wollastonite front corresponds to Si metasomatic reaction. Pyx > gar indicates metasomatism of Fe ± Mg. The gar > pyx front indicates Al transport.

From Meinart et al., 2005

Mapping the Big Pine pendant skarn

We will spend one or two days mapping a small portion of the Big Pine pendant. Our focus will be on the contact zone where alteration and mineralization are greatest. To do this effectively, we must characterize the unaltered plutonic and host rocks and then map the contact zone in detail. It may not be possible to be so systematic, but it is important to keep in mind.



. *Schematic evolution of a calcic skarn deposit:*

A. *Intrusion of magma into carbonate-rich sequence and formation of contact hornfels (hornfels not shown in B, C or D).*

B. *Infiltration of hydrothermal fluids to produce endoskarn and pyroxene-rich exoskarn.*

C. *Continued infiltration with progressive expansion of exoskarn envelope and development of proximal garnet-rich exoskarn. Skarn controlled partly by lithologies (e.g., limestone beds locally replaced by garnetite), bedding planes and fractures. Some mineralization may take place late in this stage.*

D. *Hydrothermal system wanes and cools accompanied by retrograde overprinting. During this stage metals may be introduced or scavenged and redeposited to form economic orebodies. The structural/lithological controls and influence of meteoric water may result in irregularly distributed orebodies that are notoriously difficult to delineate in skarn.* From Ray and Webster, 1991

Plutonic rocks:

- QAP name (symbol list from Monarch Canyon exercise)
    - Map boundaries between distinct phases
    - Accessory minerals listed next to symbol; consider significance for map boundaries.
    - There may be volcanic facies present – look for fragmental textures.
- Grain size & phenocryst variation
    - If systematic, indicate on map with labels or hatching
- Mineralogical variations toward margin: ms, bt, hb/amph, fluorite, endoskarn alteration.
    - Use mineral labels in regions or at stations
- Textures: miarolitic cavities, greisen, veins, brecciation, dykes (aplites and pegmatites)
    - More difficult to capture on a map, but could be very important. Line symbols for veins/dykes, hatching or other symbol for cavities & greisen.

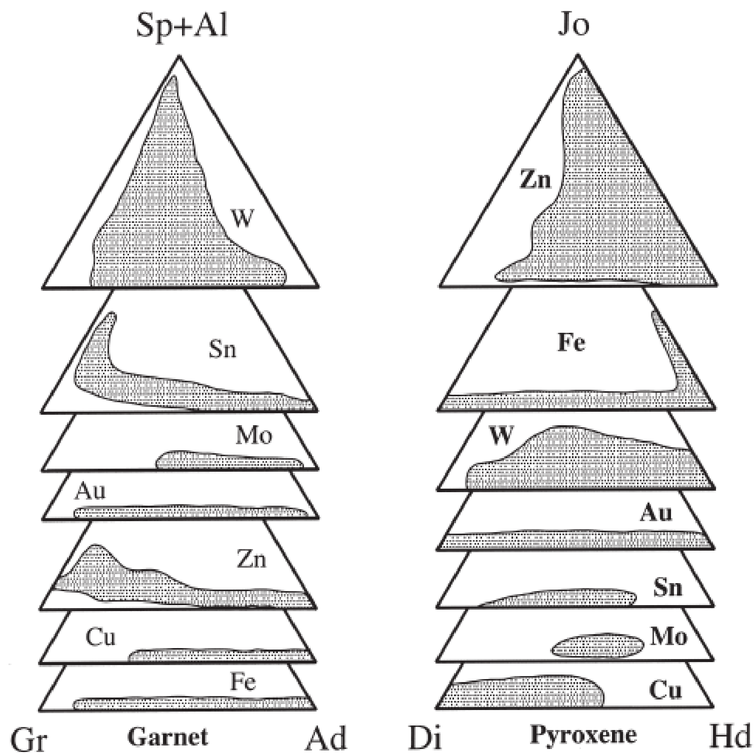
Host rocks:

- Recognize protoliths where possible; use rock type symbols as in Monarch Canyon exercise
- Develop a "stratigraphy" based on what you know of Poleta Formation; not necessarily in sequence, but of particular rock types – it will help to predict rock types through map area.
    - Some rocks that you may encounter: marble, quartzite, hornfels, calc-silicate rock, gossan. Do not use this as an exhaustive list – you may find more variation than this.
    - Map boundaries between these "stratigraphic" units
- Structure measurements – typically, this will be bedding but there may be a new foliation and/or lineation (deformation during pluton emplacement). Or a pre-existing foliation that has been overprinted. Faults or joint sets if present.

Alteration/mineralized zone (skarn):

- You will spend a great deal of time worrying about mineralogy in this zone. Pay particular attention to garnet, pyroxene, amphiboles, wollastonite and commodity minerals (see below).

- Map in the garnet:pyroxene ratio. In particular, grt>px and px>grt.
- Look for accessory minerals and their abundances
- And finally, look for ore minerals. See the diagram at right for commodity elements and their typical abundances relative to garnet and pyroxene compositions. Consider which minerals would host these commodity elements.



Ternary plots of garnet and pyroxene compositions from major skarn types. End members: Ad = andradite, Di = diopside, Gr = grossularite, Hd = hedenbergite, Jo = johannsenite, Pyralspite = pyrope + almandine + spessartine (from Meinert, 1992).

May 16:

Eve Lecture:

1. Outcrop mapping
2. Symbols, labels & hatching while mapping
3. Skarn mineralization

May 17:

AM:

1. Introduce everyone to the typical rock types
2. Techniques in outcrop mapping (different from traverse mapping)

PM: Mapping in pairs

Eve: "Rock Talk"; each group has 5 minutes to describe their observations

General group	End members	Abbreviation	Composition	Related names
Garnet	Grossularite	Gr	$Ca_3Al_2Si_3O_{12}$	Grandite
	Andradite	Ad	$Ca_3Fe_2Si_3O_{12}$	
	Spessartine	Sp	$Mn_3Al_2Si_3O_{12}$	
	Almandine	Al	$Fe_3Al_2Si_3O_{12}$	Subcalcic garnet
	Pyrope	Py	$Mg_3Al_2Si_3O_{12}$	
Pyroxene	Diopside	Di	$CaMgSi_2O_6$	Salite
	Hedenbergite	Hd	$CaFeSi_2O_6$	
	Johannsenite	Jo	$CaMnSi_2O_6$	
	Fassaite	Fas	$Ca(Mg,Fe,Al)(Si,Al)_2O_6$	
Olivine	Forsterite	Fo	Mg_2SiO_4	Monticellite
	Fayalite	Fa	Fe_2SiO_4	Knebelite
	Tephroite	Tp	Mn_2SiO_4	Glaucochroite
	Monticellite	Mc	Ca_2SiO_4	
Pyroxenoid	Ferrosilite	Fs	$FeSiO_3$	Pyroxmangite
	Rhodonite	Rd	$MnSiO_3$	Bustamite
	Wollastonite	Wo	$CaSiO_3$	
Amphibole	Tremolite	Tr	$Ca_2Mg_5Si_8O_{22}(OH)_2$	Actinolite
	Ferroactinolite	Ft	$Ca_2Fe_5Si_8O_{22}(OH)_2$	
	Manganese actinolite	Ma	$Ca_2Mn_5Si_8O_{22}(OH)_2$	
	Hornblende	Hb	$Ca_2Mg_4Al_2Si_7O_{22}(OH)_2$	
	Pargasite	Pg	$NaCa_2Mg_4Al_3Si_6O_{22}(OH)_2$	Hastingsite
	Ferrohastingsite	Fh	$NaCa_2Fe_4Al_3Si_6O_{22}(OH)_2$	
	Cummingtonite	Cm	$Mg_2Fe_5Si_8O_{22}(OH)_2$	
	Dannemorite	Dm	$Mn_2Fe_5Si_8O_{22}(OH)$	Subcalcic amphibole
	Grunerite	Gru	$Fe_7Si_8O_{22}(OH)_2$	
Epidote	Piemontite	Pm	$Ca_2MnAl_2Si_3O_{12}(OH)$	
	Allanite	All	$(Ca,REE)_2FeAl_2Si_3O_{12}(OH)$	
	Epidote	Ep	$Ca_2FeAl_2Si_3O_{12}(OH)$	
	Pistacite	Ps	$Ca_2Fe_3Si_3O_{12}(OH)$	
	Clinozoisite	Cz	$Ca_2Al_3Si_3O_{12}(OH)$	
Plagioclase	Anorthite	An	$CaAl_2Si_2O_8$	
Scapolite	Meionite	Me	$Ca_4Al_6Si_6O_{24}(CO_3,OH,Cl,SO_4)$	
Other	Vesuvianite (idocrase)	Vs	$Ca_{10}(Mg,Fe,Mn)_2Al_4Si_9O_{34}(OH, Cl, F)_4$	
	Prehnite	Pr	$Ca_2Al_2Si_3O_{10}(OH)_2$	
	Axinite	Ax	$(Ca,Mn,Fe)_3Al_2BO_3Si_4O_{12}(OH)$	

Lower Paleozoic metasedimentary rocks in the east-central Sierra Nevada, California: Correlation with Great Basin formations

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ABSTRACT

Rock type, stratigraphic sequence, and associated fossils in metamorphic rocks exposed in roof pendants near Big Pine and Bishop, California, allow, for the first time, detailed correlation of Sierran metasedimentary rocks with Paleozoic formations in the Great Basin. The Big Pine pendant rocks are correlative with the Lower Cambrian Poleta Formation and represent shelf facies. Rocks of the eastern Bishop Creek pendant also represent predominantly shelf facies, and correlate with Ordovician and Silurian strata of the Inyo Range. These correlations place the early Paleozoic shelf margin west or northwest of the Bishop Creek pendant; they indicate that major structural features do not exist between the Sierra Nevada and the Great Basin at this latitude and substantiate the model that depicts these rocks as Cordilleran miogeoclinal strata.

INTRODUCTION

Metasedimentary rocks exposed in roof pendants in the east-central Sierra Nevada have long been considered lateral equivalents of some part of the Paleozoic section of the Great Basin. However, metamorphism, complex structure, discontinuous outcrops, and facies changes in the Sierran pendants made stratigraphic comparison between the two provinces difficult. Ross and Berry (1963) made a generalized correlation of metasedimentary rocks in the Mount Morrison pendant with Ordovician rocks in the Great Basin, using graptolite assemblages, but detailed formation correlations have not been established between the Sierra Nevada and the Great Basin.

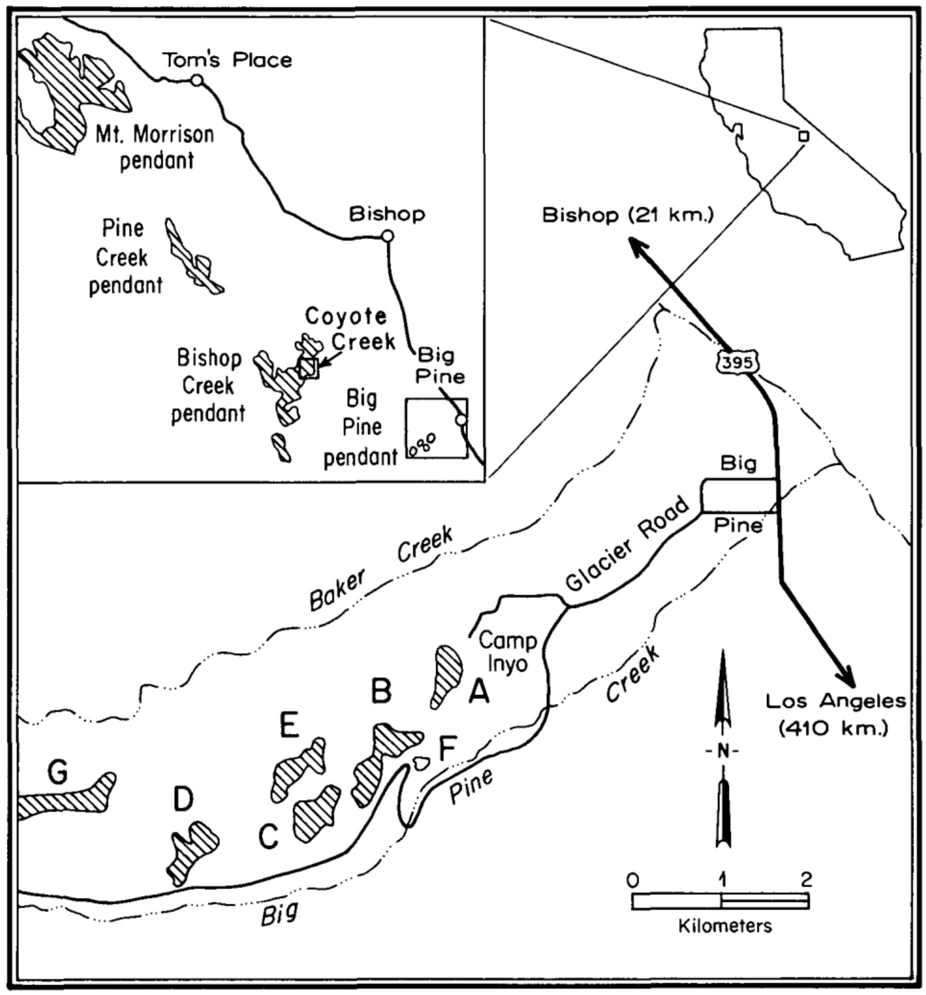


Figure 1. Spatial relationships of metamorphic rocks in the east-central Sierra Nevada (inset) and detailed map of metasedimentary bodies near Big Pine, California.

Lower Paleozoic marble and hornfels described by Bateman (1965) near Big Pine, California, and in the eastern part of the Bishop Creek pendant are similar to Great Basin formations which lie less than 15 km to the east in the White-Inyo Range (Walcott, 1895; Knopf, 1918; Nelson, 1962). This report summarizes the results of a detailed study of the metasedimentary rocks, including several significant new fossil discoveries, and correlates the rocks with specific Paleozoic formations of the Great Basin. These correlations extend the Lower Cambrian and Ordovician shelf facies of the Cordilleran miogeocline into the Sierra Nevada. The similar depositional environments in the eastern Sierra and western Great Basin rule out any major structural

Geological Society of America Bulletin, Part I, v. 91, p. 37–43, 7 figs., January 1980, Doc. no. 00108.

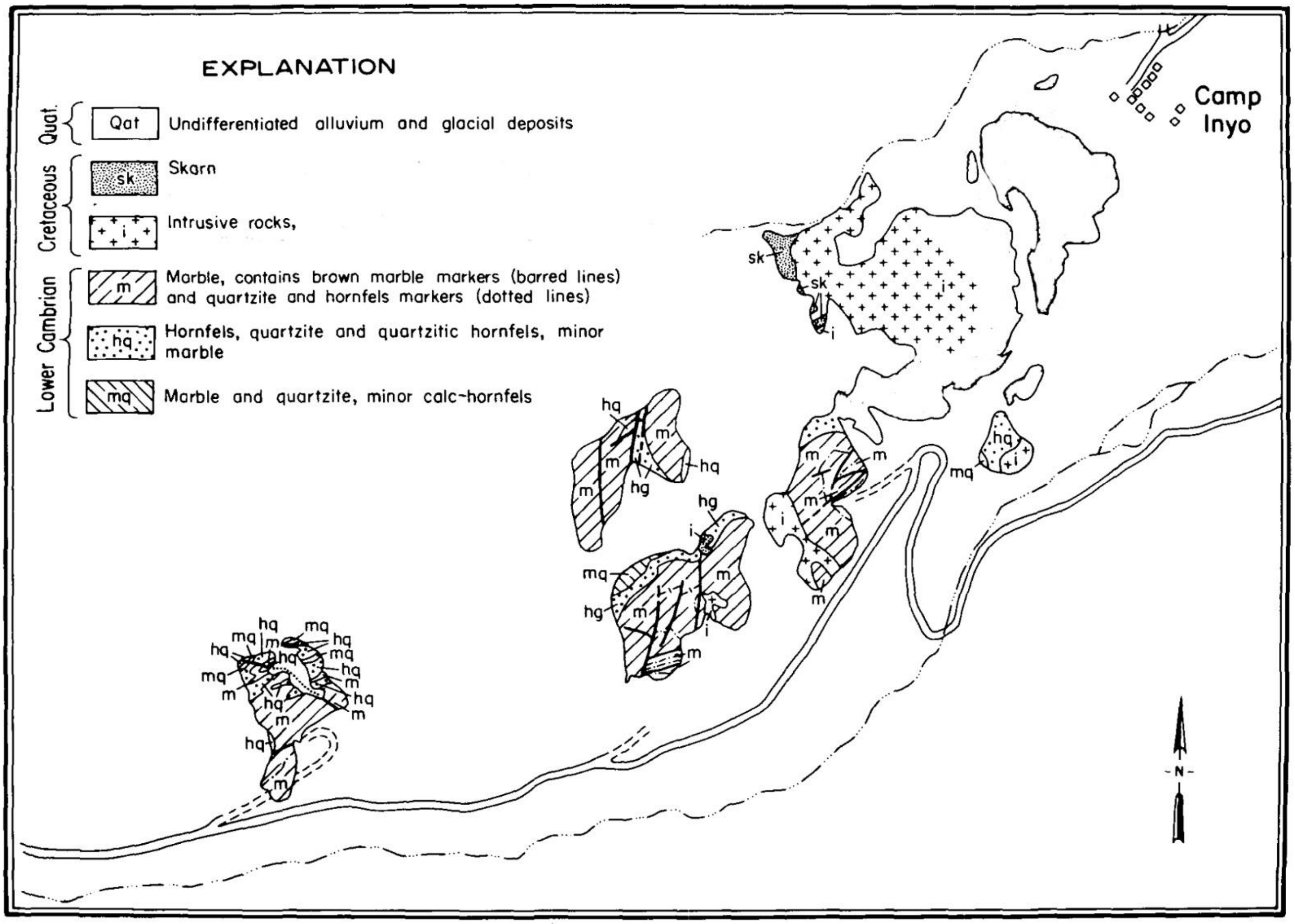


Figure 2. Geologic map of Cambrian metasediments near Big Pine, California.

break between the two provinces at this latitude, and place the position of the early Paleozoic continental margin to the west or northwest of the Bishop Creek pendant.

LOWER CAMBRIAN ROCKS NEAR BIG PINE

Cretaceous plutonic rock and Quaternary till separate small masses of metamorphic rocks west of Big Pine, California (Fig. 1, A through G; Fig. 2). Walcott (1895) first suggested that the rocks in one of these masses are similar to Lower Cambrian rocks in the White Mountains to the east. Our determination of the detailed stratigraphy in these masses allows correlation with the Lower Cambrian section in the White-Inyo Range described by Nelson (1962) and substantiates Walcott's original statement.

The original textures and lithologies of the metasedimentary rocks have been preserved despite contact metamorphism caused by nearby Mesozoic intrusives. Poorly preserved sedimentary structures and bedding are commonly present in the marble, hornfels, and quartzite units. Oolitic and pelletal textures and mottling are present in the marbles, whereas cross-laminae, burrows, and trails are preserved in the quartzite and hornfels. Correlation of strata between the masses permits the construction of a composite column for the metasedimentary rocks in the area (Figs. 3 and 4).

Metamorphosed oolitic and mottled limestone, mudstone, and quartz sandstone present west of Big Pine resemble lithologies of the unmetamorphosed Lower Cambrian section of the White-Inyo Range to the east, in particular, the upper Campito and lower Poleta Formations (Fig. 4). This correlation is supported by fossil assemblages present in the Big Pine rocks. Individual specimens of the trace fossils *Skolithos*(?) and *Cruziana*(?) are found in the quartzite units. *Cruziana* and *Skilithos* are common throughout the quartz sandstone and siltstone of the Lower Cambrian section to the east. Marble in mass A (Fig. 1) contains deformed and recrystallized archeocyathids. These lower Cambrian index fossils are found in the White Mountains only in the lower Harkless, upper Campito, and Poleta Formations (Gangloff, 1976). Abundant archeocyathids associated with mottled and oolitic limestones occur only in the lower Poleta Formation (Moore, 1976). The trace fossils, lithologies, and stratigraphic sequence of the Big Pine rocks best fit correlation with the upper Campito and lower Poleta Formations (Fig. 4). The only other mottled and oolitic limestone to the east which contains archeocyathids is the upper Poleta Formation, but the marble in the Big Pine mass is much thicker than this unit. Although large northeast trending folds deform the marble, distinctive internal stratigraphy (color, grain-size, and rock types) and original textures in the marble indicates there was no major structural thickening. Rock types in mass A are locally identical to limestone in the lower Poleta, and thicknesses are consistent with this correlation (Fig. 4).

Quartz sandstone and siltstones, protoliths of the quartzite and hornfels, respectively, may represent western terrigenous deposition within the lower Poleta carbonate sequence from sand source to the south. This conclusion is supported by the presence of shale interlayers in many of the westernmost lower Poleta outcrops farther to the north and the abundant sandstone in the lower Poleta Formation to the south, in the White-Inyo Mountains (Moore, 1976). *Skolithos* has not been reported previously from the terrigenous units of the lower Poleta Formation. However, vertical burrows are common in the carbonate units of the lower Poleta Formation, and *Skolithos* is present in the middle member of the

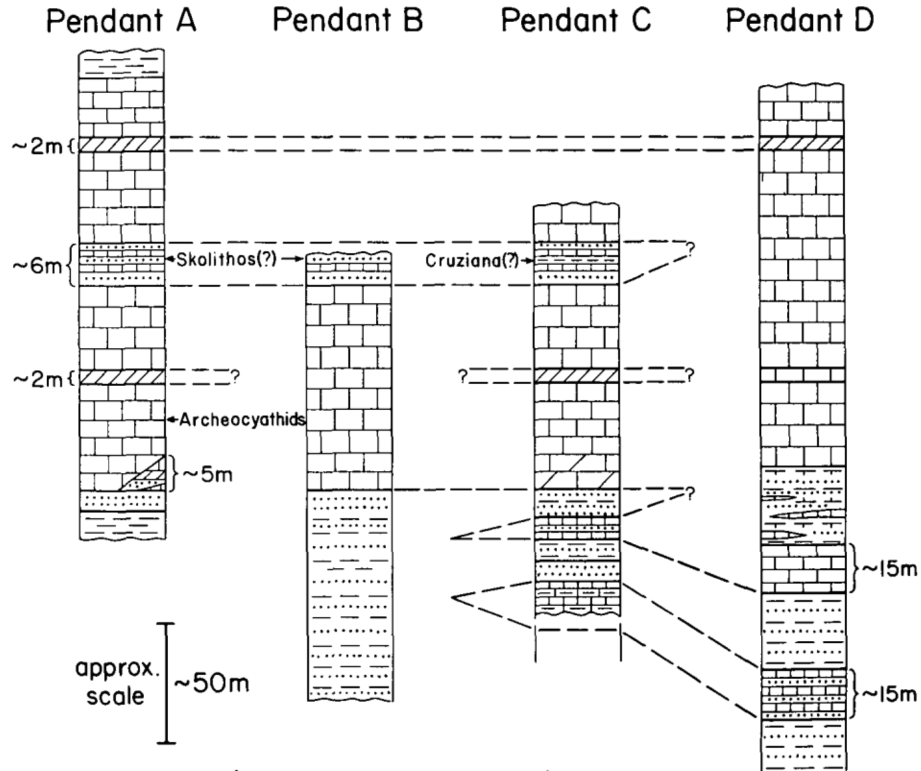
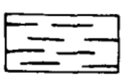
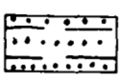


Figure 3. Generalized stratigraphic columns for Big Pine Creek pendants A through D.

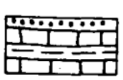
EXPLANATION OF LITHOLOGIC SYMBOLS
FOR FIGURES 3 AND 4



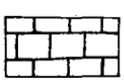
HORNFELS: dark brown to dark gray, locally platy, quartz-rich beds; skarn abundant in irregular masses.



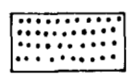
QUARTZITE AND HORNFELS: dark brown to black and olive gray. Quartzite: very fine grained and commonly in medium beds. Hornfels: platy, locally contains cross laminae(?), trace fossils(?), and irregular layers and lenses of limestone.



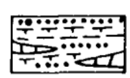
QUARTZITE, HORNFELS AND MARBLE: even, thin interlayers, local irregular and anastomosing layers; marble dominant, light gray; quartzite, very fine grained and gradational to hornfels and calc-silicate hornfels, greenish gray to reddish brown.



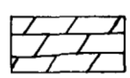
CALCITE MARBLE: white and light to medium gray and brownish gray; locally mottled by brownish-gray dolomitic marble; structureless to thinly layered and laminated; laminae as elongate lenses and irregular layers about 1 cm thick; white marble commonly medium to coarsely crystalline; locally contains ooids(?) and archeocyathids; minor brownish-gray dolomitic layers.



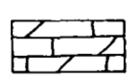
QUARTZITE: light to dark gray; structureless to indistinctly laminated and cross laminated(?); medium to thick beds; very fine grained.



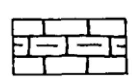
CALC-SILICATE HORNFELS, QUARTZITE AND MARBLE: thinly interlayered. Marble: gray to brownish gray, as irregular layers and elongate lenses, locally contains silty laminae. Calc-silicate hornfels: gradational to very fine-grained calcareous quartzite, light to greenish gray; thin to medium bedded.



DOLOMITE MARBLE: brown to brownish gray; medium crystalline to indistinctly mottled; locally contains archaeocyathids.



MARBLE, undifferentiated brownish gray; as distinct units; medium to coarsely crystalline calcite and dolomite; structureless to indistinctly laminated.



MARBLE AND CALC-HORNFELS: irregular and thinly interlayered. Marble: light to medium gray, structureless. Hornfels: light green to grayisn brown, structureless; locally as very irregular layers and blebs, rarely grades to quartzite.

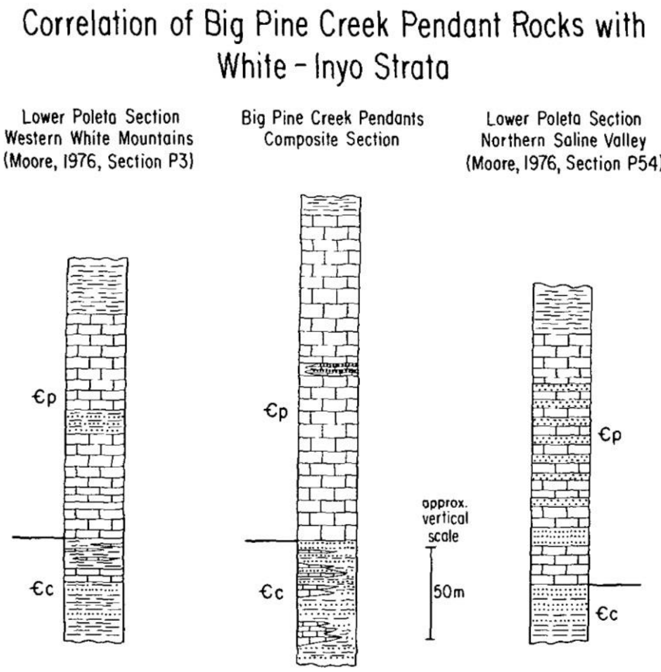
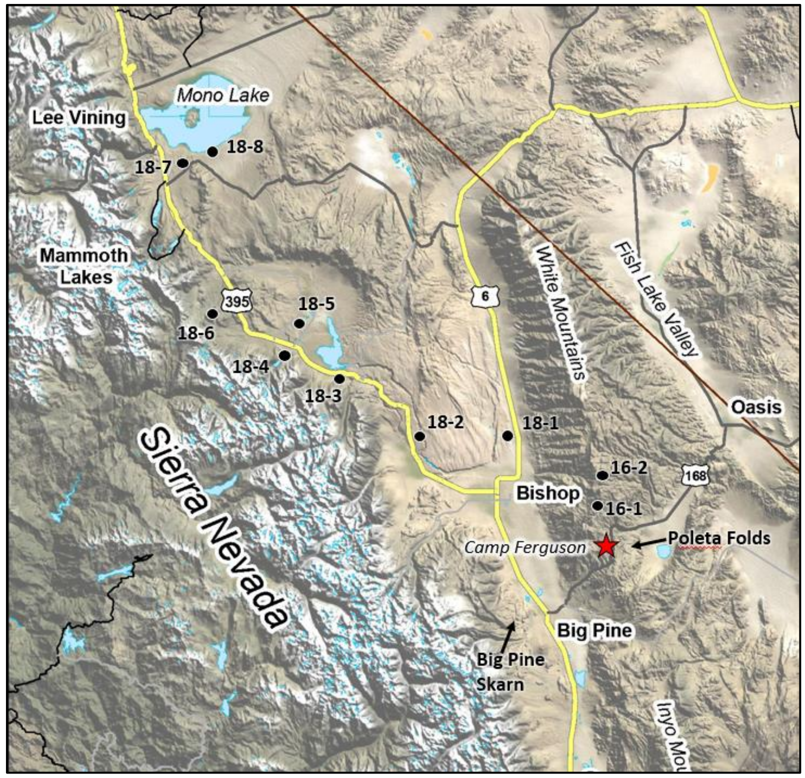


Figure 4. Correlation of Big Pine Creek rocks with Lower Cambrian strata of the western Great Basin. Quartzite, hornfels, and marble at base are Campito Formation; thick marble and overlying hornfels are Poleta Formation. Explanation of lithologic symbols same as for Figure 3. See p. 39.

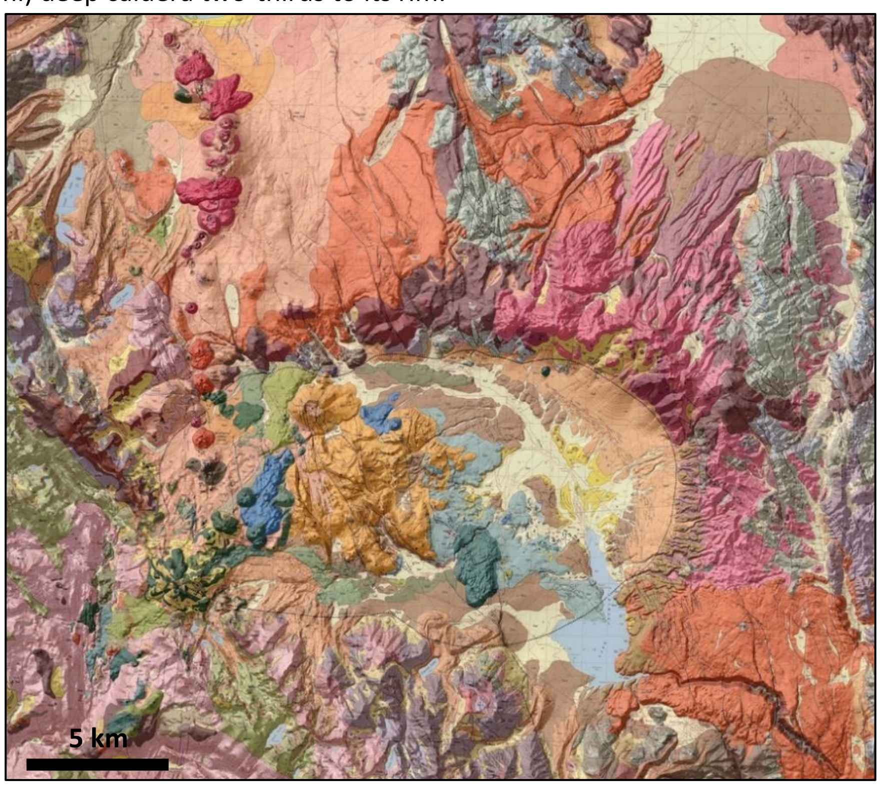
Poleta and also in stratigraphic units both below and above the Poleta Formation in the Inyo Mountains (Alpert, 1975; Moore, 1976); thus, the occurrence of *Skollithos*-like trace fossils is not a limiting factor in the detailed correlation.

Day 18 (May 13) - Long Valley Caldera Field Trip



The caldera is a giant bowl-shaped depression, approximately 20 mi (32 km) long (east-west) and 11 mi (18 km) wide (north-south), and up to 3,000 ft (910 m) deep. It is surrounded by mountains, but open to the southeast.

The known volcanic history of the Long Valley Caldera area started several million years ago when magma began to collect several miles below the surface. Volcanic activity became concentrated in the vicinity of the present site of Long Valley Caldera 3.1 to 2.5 Ma with eruptions of rhyodacite followed by high-silica rhyolite from 2.1 to 0.8 Ma. All but one of these volcanoes, Glass Mountain, were destroyed by the major (VEI 7) eruption of the area 760,000 years ago, which released 600 km^3 (140 cu mi) of material from vents just inside the margin of the caldera (the 1980 Mount St. Helens eruption was a VEI 5 eruption releasing 1.2 km^3 or 0.29 cu mi). About half of this material was ejected in a series of pyroclastic flows of a very hot, 1,500 °F (820 °C), mixture of noxious gas, pumice, and ash that covered the surrounding area hundreds of feet (meters) deep. One lobe of this material moved south into Owens Valley, past where Big Pine, California now lies. Another lobe moved west over the crest of the Sierra Nevada and into the drainage of the San Joaquin River. The rest of the pyroclastic material along with 300 km^3 (72 cu mi) of other matter, was blown as far as 25 mi (40 km) into the air where winds distributed it as far away as eastern Nebraska and Kansas. However, much of the material ejected straight into the air fell back to earth to fill the 2–3 km (1.2–1.9 mi) deep caldera two-thirds to its rim.



Near the center of the bowl, there is a resurgent dome formed by magmatic uplift. The southeastern slope from the caldera down towards Bishop, California is filled with the Bishop Tuff, solidified ash that was ejected during the stupendous eruption that created the caldera. The Bishop tuff is thousands of feet thick and is cut by the Owens River Gorge, formed during the Pleistocene when the caldera filled with water and overtopped its rim. Mammoth Mountain is a lava dome complex in the southwestern corner of the caldera, consisting of about 12 rhyodacite and dacite overlapping domes. These domes formed in a long series of eruptions from 110 to 57 ka, building a volcano that reaches 11,059 feet (3,371 m) in elevation. The Mono–Inyo Craters are a 25 mi (40 km)-long volcanic chain situated along a narrow, north–south-trending fissure system extending along the western rim of the caldera from Mammoth Mountain to the south shore of Mono Lake. The Mono-Inyo Craters erupted from 40 to 0.6 ka.

Stop 18-1: Pumice Quarry (Chalfont); north of Bishop (modified from Jessey, 2007)

Drive north through Bishop and bear right on US 6 at the intersection with Hwy 395. After 7 miles, turn left on Rudolph Road. Two main units of the Bishop Tuff deposit are visible here: The lower 15 feet of the section consists of the poorly-sorted airfall tuff that was de-posited downwind from the eruption of the Long Val-ley caldera. The upper 15-20 feet of the section consists of the basal portion of the pyroclastic flow that comprises much of the Volcanic Tableland. At this location, it is remarkably well-sorted for a pyroclastic flow. The dark layers just below the contact between the two units are manganese oxide stains resulting from groundwater circulation. The table below summarizes the average major element content of 32 samples taken from the two units exposed in the Chalfont Quarry and the Upper and Lower Bishop Tuff of the Owens River gorge (next stop). Statistically, the four sample locations/units are indistinguishable. This supports the theory that the Bishop Tuff was emplaced in a single event over a limited span of time.

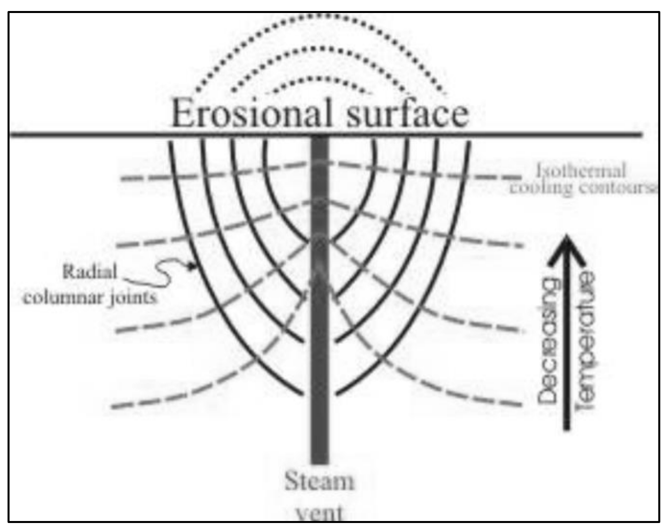
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
Chalfont Ash Flow Tuff	77.88	0.08	11.80	0.93	0.05	0.07	0.45	3.52	5.21	0.018
Chalfont Air Fall Tuff	78.07	0.08	11.80	0.99	0.04	0.08	0.56	3.36	5.03	0.016
Owens River Upper BT	78.22	0.07	11.60	0.86	0.03	0.05	0.44	3.65	5.08	0.013
Owens River Lower BT	78.24	0.07	11.83	0.92	0.03	0.05	0.50	3.42	4.95	0.015

Stop 18-2: Owens Valley Gorge (modified from Sharp and Glazner, 1997 and Jessey, 2007)

This a very popular area for rock climbers and parking on weekends can be problematic. Best viewed in the afternoon. The Owens River has eroded downward 500 feet entirely through Bishop Tuff at this locality. The Tuff is comprised of two lithologies. The upper unit (UBt) is poorly indurated and has striking radial columnar jointing. Column diameters typically range between 3 and 5 feet (Gilbert, 1938). Most columns are oriented in a radial pattern. The lower Bishop Tuff (LBt) is a strongly-welded, massive tuff with irregularly developed vertical jointing.

The Upper Bishop Tuff consists of pale pink, poorly welded, vitric pumice ash. It readily darkens to gray on weathered surfaces. The UBt contains abundant pumice shards as well as phenocrysts of sanidine, quartz and plagioclase. The Lower Bishop Tuff is more strongly-welded with flattened and elongated pumice fragments common (See if you can locate the contact as you walk down the DWP access road). Unweathered LBt is pale red to gray and noticeably denser than the overlying UBt. In all respects the lower unit resembles a "textbook" ash flow welded tuff. Note from the table presented at the last stop the two units are chemically very similar.

A Stanford graduate student, Mike Sheridan, undertook a computer simulation of gas flow in geothermal systems. He suggested (Sheridan, 1970) that each joint set represents the locus of fumarolic activity. The radial jointing is similar to the heat flow pattern developed during cooling around a gas vent (see figure at right). The joints form normal to isothermal surfaces. If you look to the east, across the gorge you will see a hummocky terrain with numerous surface bumps. Each "bump" would be the location of an inactive fumarole.



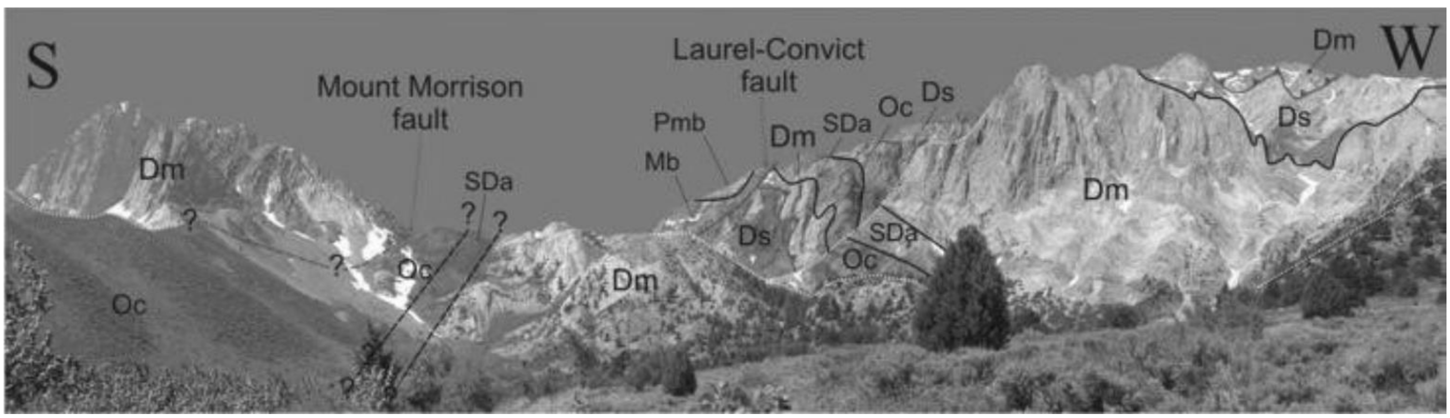
Stop 18-3: Lake Crowley viewpoint

A short stop in a pullout on Hwy 395 next to Lake Crowley. Here, we have descended into the caldera at the southeastern margin. The eastern and northeastern rim beyond Lake Crowley is clear as are the low-relief rolling hills to the north marking a few of the many resurgent domes.

To the west, the McGee Creek moraine emerges from the prominent valley. Near the range front, the moraine is cut by the Hilton Creek fault and a series of scarps transverse to the moraine are evident. On June 8th and July 14, 1998 two earthquakes of M=5.3 ruptured the Hilton Creek fault. The June 8th quake had right lateral strike-slip motion and the July 14th epicenter had normal movement.

Stop 18-4: Convict Lake Parking Lot (from Jessey, 2007)
One of the most asked questions is always, "How did Convict Lake get its name?" Despite books on the subject there remains some inconsistencies in the details. What is known is that a large group of inmates escaped from the federal prison in Carson City, Nevada in 1871. A group of escapees subsequently robbed and murdered a pony express rider. Posses were organized and three of the escaped felons were discovered (apparently from the smoke of their campfire) in Monte Diablo Canyon. A fierce firefight ensued and one or two of the posse were killed (details are sketchy). The convicts escaped unhurt, but were later captured north of Bishop. Vigilantes hung two in Bishop while the fate of the third is uncertain. Monte Diablo Canyon is now known simply as Convict Lake in honor (?) of the events that occurred here. Mt. Morrison is actually named after the leader of the posse who was killed in the firefight.

The geologic relationships within the Mt. Morrison roof pendant are typical of those found in roof pendants throughout the eastern Sierra. What is atypical is the exposure, completeness of the section and detailed geologic mapping. A bird's-eye view of the geology can be seen by walking down to the east shore of Convict Lake where an interpretive plaque discusses the geology. However, the best way to "see" the geology is by making the 1.5 mile walk around the lake. The hike follows a relatively level path and can be made in as little as 20 minutes, although an hour is necessary to do justice to the geology. Below is an annotated photograph showing the geology of the area taken from Greens and Stevens (2002) Geologic Map of Paleozoic Rocks in the Mount Morrison Pendant.



We will begin by walking around the north shore of the lake, since the ridge on the northwest side of the lake provides a good exposure of the lower Paleozoic section. As we walk to the west, the steeply east-dipping rocks comprise the overturned limb of a syncline, so the units will become progressively younger. The first rock unit we encounter is the Cambrian Mount Agee Formation. Outcrops are sparse on this side of the lake, but float is abundant. The Mount Aggie is a dark gray siliceous argillite. Continuing to the west, the next unit to crop out is the Ordovician Convict Lake Formation. It is somewhat lighter in color, and while it is often difficult to distinguish in weathered float the contact can be readily seen in the ridge face. To the west of the Convict Lake Formation lies, the Silurian/Devonian Aspen Meadows Formation. Aspen Meadows float is sparse and the distinctive green-banded hornfels is best seen by making the hike up to the ridge crest. The remainder of the ridge is comprised of the well-indurated quartzite of the Devonian Mt. Morrison Formation. This highly resistant rock forms many of the near vertical slopes of Sevehah Cliff.

At the west end of Convict Lake, the view of Sevehah Cliff is truly impressive. The calcareous quartzite of the Mount Morrison Formation is the most prominent unit. Bedding dips steeply to the northeast, more or less parallel to the slope of the cliff creating apparent structural complexity that is actually a function of the steep dip and subsequent erosion. The more gently sloping base of the cliff is caused by metasomatic alteration of the Mt. Morrison by underlying intrusives. Quartz + calcite --> wollastonite, a softer, more easily eroded mineral. On the southern base of the cliff, Aspen Meadows and Convict Lake crop out. Above the Mt. Morrison Fm, on the north end of the cliff, the rusty brown chert and argillite of the Squares Tunnel Formation is a striking marker horizon. At the very top of the cliff, Mt. Morrison Fm lies in fault contact with the underlying Squares Tunnel. At the base of the cliff, the Convict Thrust fault (not visible) repeats the section in the low hills to the southwest. In the far distance, Mississippian Bright Dot and Pennsylvanian Mount Baldwin Marble are visible across the main strand of the Laurel Convict fault. On the south side of the lake, Convict Lake and Mount Aggie Formations outcrop. Small scale folds in these units mimic the large scale structural complexity seen in Sevehah Cliff. Further to the south, Mount Morrison is the prominent peak on the horizon. It lies to the southeast of the Mount Morrison fault. In the panorama, only Devonian Mount Morrison Formation is clearly visible, but from the parking area, a fault (a splay of the Laurel-Convict fault?) can be seen to cut the face of the mountain juxtaposing Aspen Meadow and Con-vict Lake Formations. Most of the units are siliciclastics indicative of deeper water shelf/slope transitional environments. Similar, unmetamorphosed, strata outcrop to the east in the White Mountains. The Mount Morrison Paleozoic section, however, is unlike the shallow water carbonate-dominated Paleozoic sections of the Inyo Mountains and Mojave to the south. For a more thorough discussion of the geology see Stevens and Greene (2000).

Stop 18-5: Hot Creek (modified from Jessey, 2007 and Sharp & Glazner, 1997)
Exit right off US 395 onto Airport Road (Mammoth Airport) and follow Hot Creek road to the parking area for the Hot Creek Geological Site of Interest. From the interpretive overlook note the steam rising from fumaroles and hot springs along the creek. There are also hot springs discharging directly into Hot Creek near the remains of the bridge that formerly spanned the creek. The mingling of hot spring water with snow-melt fed stream water produces extreme temperature gradients in the creek. The wide range of temperatures has made this area popular for swimming year-round so the Forest Service constructed change rooms for visitors. Unfortunately, an increase in geothermal activity in 2006 led the Forest Service to fence off the creek to prohibit swimming and bathing.

Note the altered rhyolite in the gorge. Hydrothermal activity has kaolinized and opalized the rock producing the white, bleached appearance. The rhyolite has been dated at 300 ka. The northeast trend of Hot Creek is consistent with that of the Hilton Creek fault, so many geologists have theorized the main fault, or a branch, is the conduit for hydrothermal waters. This hypothesis became more difficult to defend when recent strong earthquakes on the Hilton Creek fault (1998) had little impact on the thermal regime of Hot Creek. As you walk down the path to the creek also note the hummocky terrain on the northeast side of Hot Creek, reminiscent of the Owens River gorge.

Many of the current hot springs appeared suddenly on the evening of August 25, 1973. At least five hot springs formed, with the two largest starting as geysers that spouted water 10 feet into the air. Within a few weeks, geyser activity had ceased, but the hot springs remain today. The origin of the new hot springs remains unclear, but it has been noted that they appeared within hours of a relatively small (M=3.5) earthquake 25 miles southeast of Hot Creek. Presumably, seismic activity altered the subsurface plumbing system giving rise to the springs. Prior to the small earthquake, heated water was trapped below an impermeable horizon. The seismic event breached the impermeable strata and superheated water and steam rose rapidly initiating geysers at the surface. After the initial pulse of superheated water reached the surface, the heat flux decreased, and the geysers became hot springs.

Stop 18-6: Obsidian Dome (modified from Jessey, 2007 and Sharp & Glazner, 1997)
Obsidian Dome is one of several domes in the Inyo-Mono Craters chain. It is comprised of flow-banded obsidian and weakly porphyritic rhyolite extruded as extremely viscous lavas creating domes that locally exceed 300 feet in height. The non-vesiculated rhyolite is black and glassy whereas the vesiculated blocks are gray. Contorted flow banding and tension cracks can be seen in many blocks. Ropy textures with iron-staining may also be seen. The obsidian lacks the brilliant glassy texture, rather it is resinous to dull. Samples were analyzed with XRF and compared to other local outcrops of obsidian. In general, Obsidian Dome was lower in silica (75%) and contained about 1% more iron than other local obsidians. Some publications have suggested that obsidian from this stop was used by Native Americans to make tools, but there is no evidence of any activity and the poor quality of the obsidian argues otherwise.

The age of this "dome" is uncertain, but tree ring and tephra dating indicate that it is less than 1500 years old. Miller (1985) suggested the dome may be as little as 500 years old. Drilling was undertaken in 1984 to explore the feeder system for Obsidian Dome (Eichelberger, et. al, 1985). Three drill holes intersected a 125-foot-thick rhyolite dike that is thought to have been the feeder structure. The Obsidian Dome lavas were extruded as highly viscous flows along the feeder dike much like toothpaste might to squeezed from the tube. The viscosity caused the flows to mound up rather than spread laterally. As the exterior cooled and cracked large blocks of autobreccia rolled down the steep side of the flow generating the blocky talus apron.

Stop 18-7: Panum Crater (modified from Jessey, 2007)

Panum Crater is an example of a phreatic explosion pit in which the subsequent lava plug was not large enough to completely engulf the initial tephra ring. The tephra ring, with a diameter of 3500 feet is comprised of pumice ash and lapilli, obsidian fragments and granite pebble ejecta. The central rhyolite dome consists of light gray, pumaceous rhyolite and rhyolite breccia containing angular, pebble and cobble-sized fragments. Most of the rhyolite is flow banded, the bands dipping steeply away from the dome summit.

The formation of Panum Crater required a sequence of events. The first event occurred as magma rising from depth contacted water just below the surface. The water expanded into steam and a violent eruption followed. The blast opened a huge crater. After the initial explosion, a fountain of ash and cinders shot into the air, falling back to earth and forming a pumice ring, around the original crater. When the violent eruptions ceased, the remainder of the thick magma rose slowly to the surface to form a series of domes. Each dome began with an extrusion of viscous, rhyolitic lava that hardened and formed a cap over the vent. As magma continued to push up, the cap shattered and fell away from the newly formed dome. This created a mountain of broken rock, a crumble breccia. As the final dome hardened, a period of spire building began. Thick lava squeezed up through cracks in the dome and formed needle-like spires. Imagine toothpaste squeezing through the opening of a tube and forming a small tower before it topples over under gravity. Most of the spires at Panum collapsed and broke. The debris you see at the top of the dome is the remains of crumbled spires.

Stop 18-8: Tufa Towers at Mono Lake (from Jessey, 2007)

This is the final stop! Most of the pinnacles of calcareous tufa deposits lie along the south side of the Mono Lake, but a few isolated knobs and towers lie north of Lee Vining, near the Visitor's Center. The knobby calcium carbonate columns of tufa form as fresh water springs discharge subaqueously into Mono Lake. The tufa masses that surround the saline lake record former high stands of the present Mono Lake and its predecessor, Lake Russell. Some of the tufa columns have delicate fluting, adding to their unusual appearance and the fairyland nature of the tufa outcrops.

Tufa forms by chemical precipitation of calcium carbonate in the alkaline lake waters (pH=9.7). Remember, the solubility of calcium carbonate decreases dramatically in alkaline solutions. CO3 saturated fresh water (pH=7) would immediately precipitate calcium carbonate when encountering alkaline waters like those of Mono Lake. A recent study suggests that algae play a role in the tufa formation. The algae extract carbon dioxide during photosynthesis reducing calcium carbonate solubility and causing precipitation of tufa.


Colorado Plateau
Basin and Range
Sierra Nevada
0
50
100
150
Kilometers
UT
NV
AZ
NV
NV
CA
St. George
Beaverdam Mountains
Virgin Mountains
Mesquite
Mormon Mountains
Overton
Gold Butte
Glendale
Valley of Fire
Lake Mead
Hoover Dam
Boulder City
Nelson
Searchlight
Las Vegas
Spring Mountains
Pahrump
Mercury
Amargosa Valley
Shoshone
Baker
Yucca Mtn
Beatty
Funeral Mountains
Black Mtns
Death Valley
Panamint Mountains
Ballarat
Panamint Valley
Panamint Springs
Barstow
Tonopah
Goldfield
Lida
Ridgecrest
Oasis
Fish Lake Valley
White Mountains
Bishop
Big Pine
Inyo Mountains
Owens Valley
Lone Pine
Owens Lake
Bakersfield
Mono Lake
Lee Vining
Mammoth Lakes