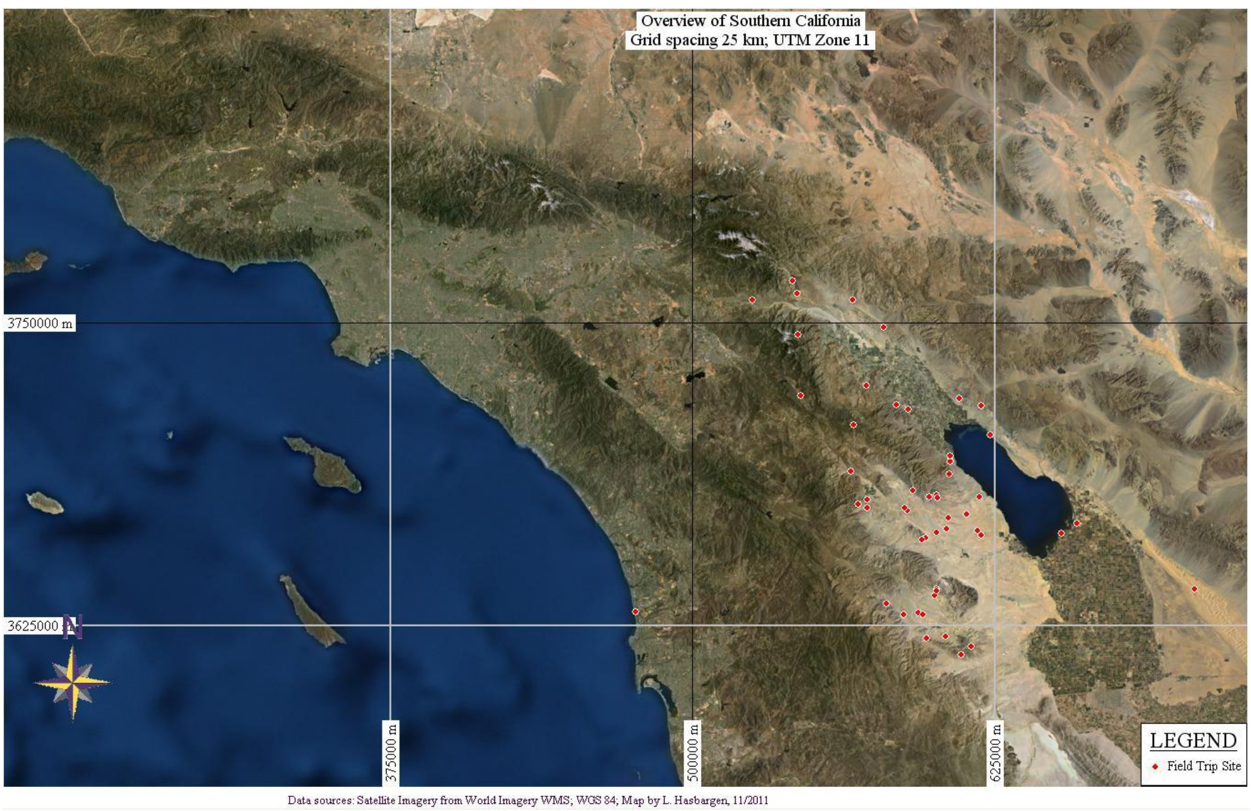
EARTH & ATMOSPHERIC SCIENCES DEPARTMENT AT
SUNY COLLEGE AT ONEONTA PRESENTS

Anza Borrego Geology

Field Trip Guidebook, Spring 2012

Trip Leader: Les Hasbargen
With most capable assistance from:
Drs. Leigh Fall and Martha Growdon and
Lisa Hoffman and Jim Vogler

January 9-20, 2012



Being an excursion into the desert to contemplate how rocks form, deform, and generally misbehave.

Contents

Calendar of Field Trip

January 2012						
S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9 Fly to Ontario San Andreas Fault in Whitewater Canyon	10 Palm Springs Tram and Coachella Valley Preserve in 1000 Palms	11 Mecca Hills Box Cyn: Recon and Intro Mapping	12 Mecca Hills Painted Cyn: Field mapping	13 Painted Cyn: Field mapping; hike Ladder Cyn	14 Move Camp Mud Volcs Imperial Dunes Fossil Cyn
15 Arroyo Tapiado mud caves; Canyon Sin Nombre, if time permits	16 Torrey Pines State Beach Borrego Springs Visitor Ctr	17 Split Mtn Field Mapping	18 Split Mtn Recon? or Lute Scarp, Fonts Point	19 Lute Scarp, Fonts Point or Ocotillo Wells ORV	20 Fish traps, Landslide, Partial melts, Pines to Palms Fly Home	21
22	23	24	25 School Starts	26	27	28
29	30	31				

Camp Duties for the Anza-Borrego Geology Trip

Each group of students will be responsible for assisting with cooking and clean up for all meals on the day of their assignment.

After the trip, all students will be expected to assist with cleaning and arranging camping gear. Remember, your participation points for the course are at stake!

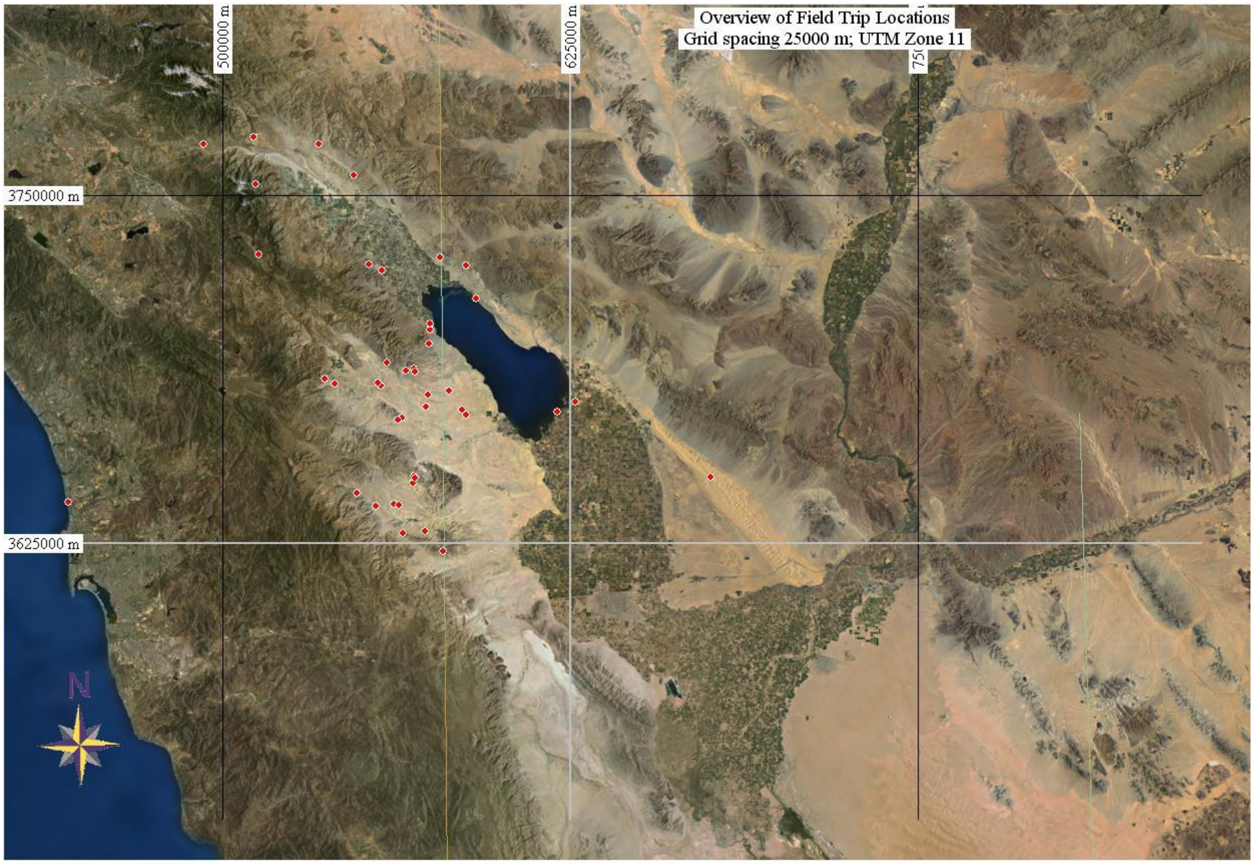
Monday	Day 1	Jan. 9	Alvino, Francis	Aucoin, Christopher	Dolginko, Lauren	Frankel, Mathew
Tuesday	Day 2	Jan. 10	Fuess, Alayna	Keefer, Scott	Krieg, Chelsea	Stahl, Shannon
Wednesday	Day 3	Jan. 11	Maccrea, Duncan	Oakes, William	Pfaffenberger, Kurt	Pipher, Mary Margaret
Thursday	Day 4	Jan. 12	Spaulding, Joseph	Moore, Myles	Titcomb, Amy	Byrd, Kevin
Friday	Day 5	Jan. 13	Downey, Anna	Kopec, Daniel	Powers, Ellyse	Wood, Cailey
Saturday	Day 6	Jan. 14	Alvino, Francis	Aucoin, Christopher	Dolginko, Lauren	Frankel, Mathew
Sunday	Day 7	Jan. 15	Fuess, Alayna	Keefer, Scott	Krieg, Chelsea	Stahl, Shannon
Monday	Day 8	Jan. 16	Maccrea, Duncan	Oakes, William	Pfaffenberger, Kurt	Pipher, Mary Margaret
Tuesday	Day 9	Jan. 17	Spaulding, Joseph	Moore, Myles	Titcomb, Amy	Byrd, Kevin
Wednesday	Day 10	Jan. 18	Downey, Anna	Kopec, Daniel	Powers, Ellyse	Wood, Cailey
Thursday	Day 11	Jan. 19	Alvino, Francis	Aucoin, Christopher	Dolginko, Lauren	Frankel, Mathew
Friday	Day 12	Jan. 20	Fuess, Alayna	Keefer, Scott	Krieg, Chelsea	Stahl, Shannon

Emergency Contact Information

In case of Emergency, try the cell numbers listed below to contact the instructors. However, at times we may be in locations with limited cell coverage.
FOR EMERGENCY USE IF CELL SERVICE IS UNAVAILABLE: Instructor will have a Satellite Phone. Start by dialing 1-480-768-2500 then an automated greeting will prompt you for the satellite number. Enter the 12 digit satellite number: 8816-2242-7558 (This is called 2-stage dialing. The caller will be charged their carrier's long distance rate to Arizona. If the caller makes a call to the satellite phone directly, they will be charged up to $11/minute. Two stage dialing is a much more cost-effective way to get in touch with your satellite phone user). Again, it will take a bit longer to connect to the satellite phone than to a normal cell phone so please don't hang up!

Contact Info for Instructors			
Leslie Hasbargen	607.287.7435 cell		
Lisa Hoffman	607.437.5386 cell		
Martha Growdon	812.679.7389 cell		
Leigh Fall	979.204.1917 cell		
Contact Info for places we will be staying			
Sam's Family Spa, Desert Hot Springs,CA	760.329.6457	1/9/12 (1 night)	Group tent site
Salton Sea State Recreation Area, Mecca Beach, North Shore, CA	760.393.3052 Ranger 760.393.3810 visitor's center	1/10-1/13/12 (4 nights)	No reservations
Agua Caliente County Park, Julian, CA	760.765.1188 park phone number	1/14-1/15/12 (2 nights)	Sites 134, 135, 136, 137, 138
Anza-Borrego Desert State Park, CA	760.767.5311 park phone number	1/16-1/19/12 (4 nights)	Group site G4

Overview



Data sources: Satellite Imagery from World Imagery WMS; WGS 84; Map by L. Hasbargen, 12/2011

Figure. Overview of field trip locations (red dots).

The setting for our geologic trip appears above in a satellite image of southern California (see Figure above). Red dots mark field trip stops. Roads and cities have been stripped from view to provide a clear vision of the landscape. The Salton Sea extends for about 50 km in the north central portion of the map, and rests in a depression southeast of the San Andreas fault. More easily seen lineaments west of the Salton Sea include the San Jacinto and Elsinore fault zones. This region is the northern extent of Baja California, a tectonic microplate headed northwest, recently torn from Mexico in the last 12.5 MY (Umhoeffer, 2011). The motion is largely transtensional, creating the linear strike slip faults and pull apart basins at releasing bends and right-steps in fault strands. In this environment of basins and continental shearing, we still find regions where rocks are being squeezed, resulting in high relief. As if the ripping and sliding aren't interesting enough, it turns out that the Colorado River has been dumping sediment into this area as well, at times clogging the opening outlet to the Gulf of California with sediments, and creating a diverse array of environments over the life of the area, thus far. The agricultural pattern in the southern central portion of the map essentially traces out the delta of the Colorado River. North of the Salton Trough lies the Mojave Desert. West of the trough lies the Peninsular Ranges. Note the northwest trend of the escarpment bounding the western margin of the trough.

The escarpment is more clearly visible at a broader scale on the figure below, an overview of the southwestern US.

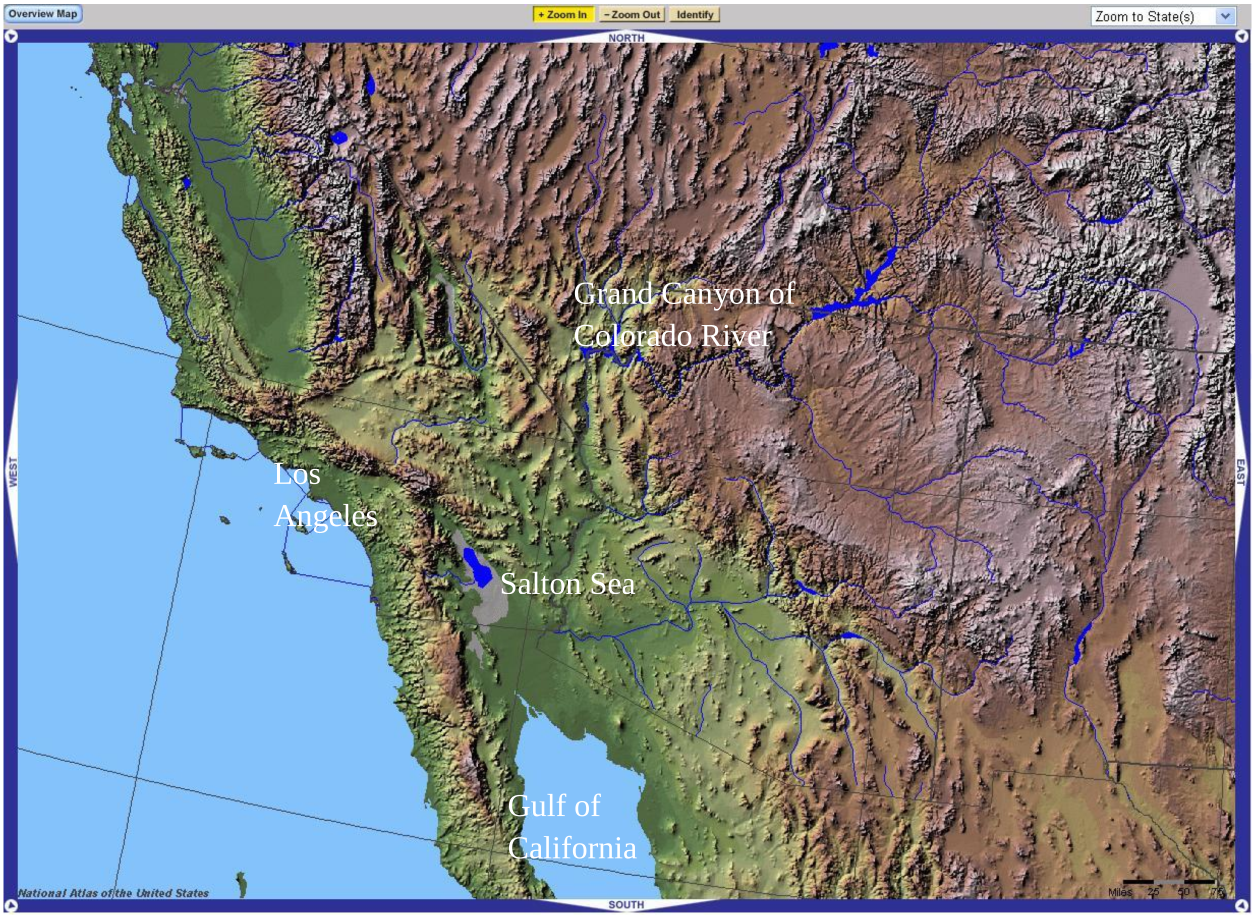


Figure. Shaded relief of southwestern USA. Grand Canyon of the Colorado River is visible in the center of the map, as is the Gulf of California. Note the gray depression north of the Gulf of California, which is the Salton Sea. Image courtesy of The National Atlas (http://www.nationalatlas.gov/mapmaker). Note the diffuse end of the Colorado River, which is largely a result of water withdrawals for agriculture and urban centers. The green region of its disappearance is the delta of the Colorado River, and the location of our investigation.

The field trip begins and ends at Ontario International Airport. We will first head east to the San Andreas fault in the northern end of the Coachella Valley in San Gorgonio Pass. Then we will work our way south toward Anza-Borrego Desert State Park over the next several days. See the figure on the next page for an overview of the trip itinerary.

Use the Table of Contents to locate maps, syllabus, rock description guides, day by day activities, etc. Please note that many figures are not adequately captioned and referenced. This guide is a lot of work!

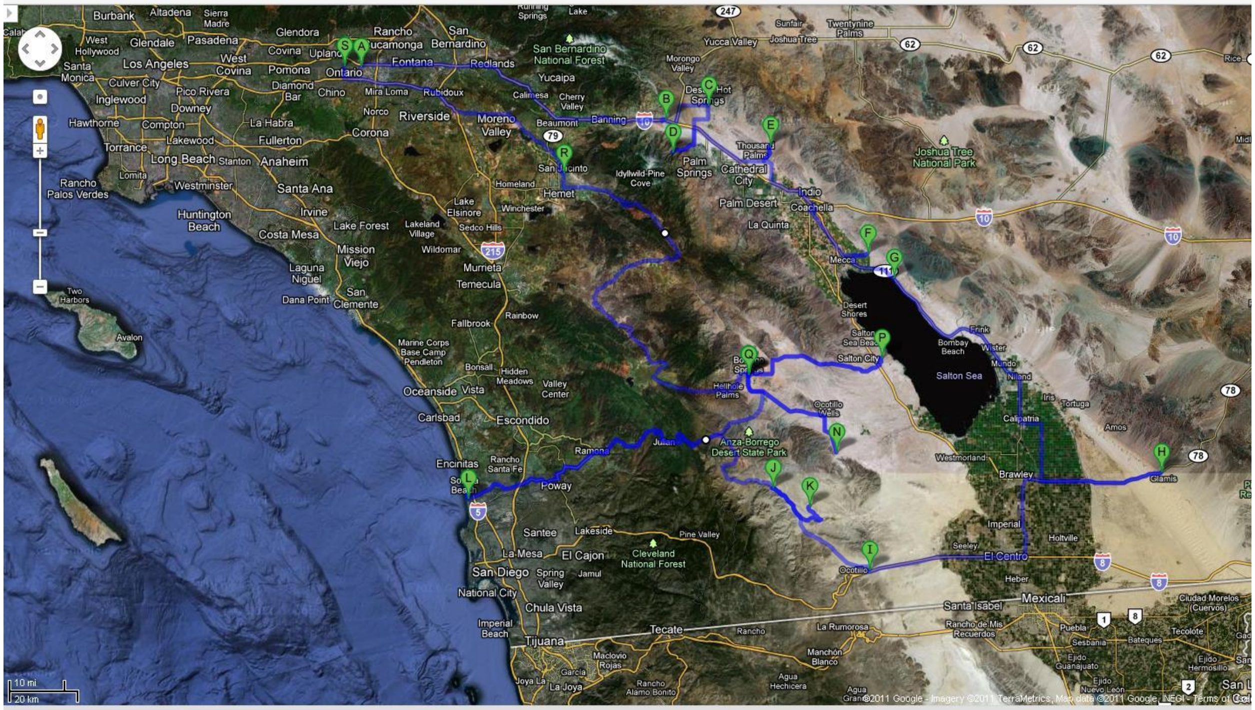


Figure. Tentative road route for Anza Borrego field trip, which starts and ends in Ontario, CA.

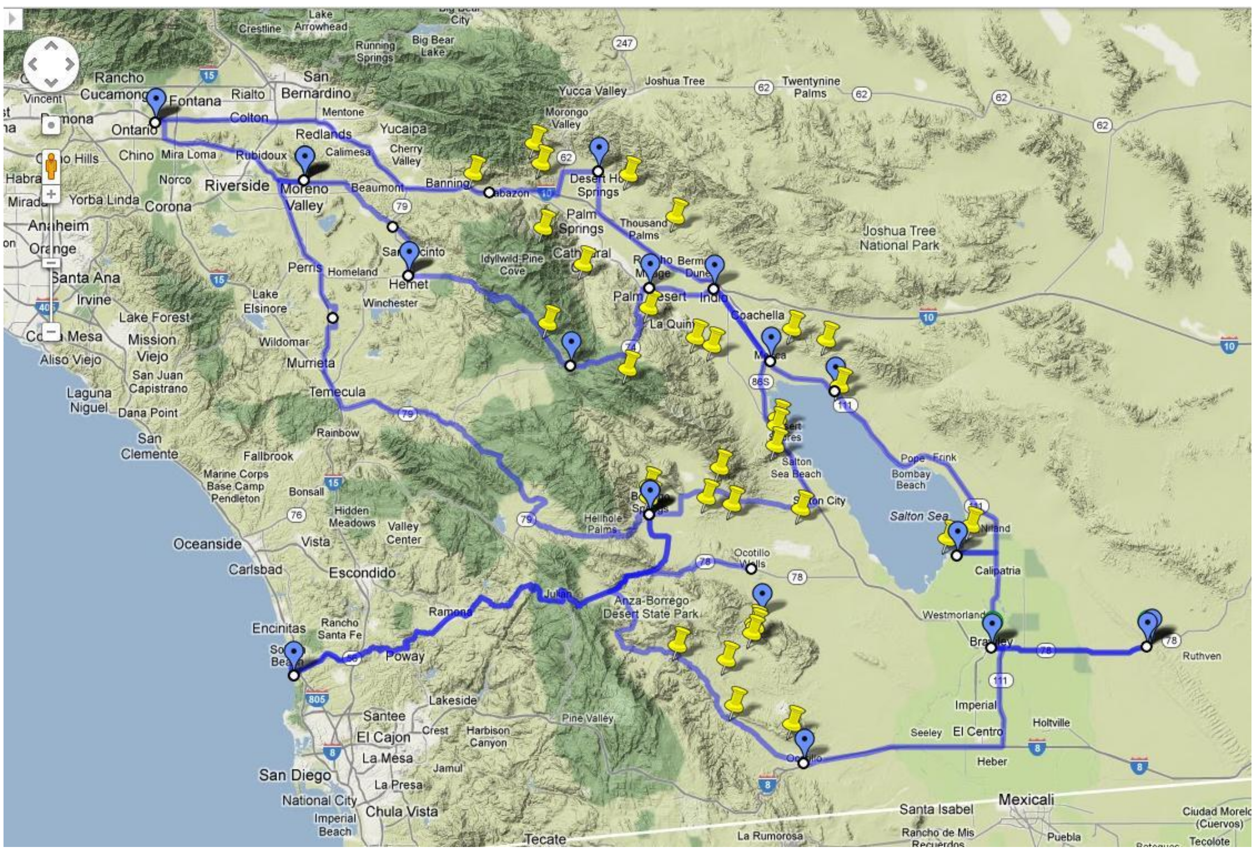


Figure. Google Map of Itinerary (tentative).

Key Themes

Tectonics

- Opening of Gulf of California
- Initiation of Colorado River sedimentation in Salton Trough
- Basin segmentation
- Initiation of strike slip boundary
- San Andreas fault
- Banning segment SAF
- Mission Creek strand SAF
- San Jacinto fault
- Elsinore fault
- Transtension
- Transpression
- Pull-apart basins
- Strike slip faults
- Thrust faults
- Normal faults
- Restraining bends
- Releasing bends
- Fault gouge
- Slickensides
- Tension gashes
- En echelon fractures

Geomorphology

- Mountains
- Lakes
- Streams
- Arroyos
- Washes
- Slot canyons
- Alluvial fans
- Dissected fans
- Drainage divides
- Divide migration
- Perched basins
- Cuestas
- Shorelines
- Travertine
- Hot springs
- Springs
- Oases
- Deltas
- Scarps (erosional and fault)
- Sag ponds
- Beheaded streams
- Shutter ridges
- Offset streams
- Playas
- Pavement
- Ventifacts
- Wind gaps
- Dunes
- Stream evolution
- Badlands
- Pseudokarst
- Spheroidal weathering
- Grus
- Concretions
- Landslides
- Debris flows
- Potrero

Intrusive rocks

- Granite
- Granodiorite
- Pegmatite dikes
- Mafic dikes
- Felsite dikes
- Restite
- Xenoliths
- Tonalite
- Hydrothermal alteration

Sedimentary rocks and environments

- Primary Sedimentary structures
    - Stratification
    - Graded bedding
    - Mud cracks
    - Ripple marks
    - Scour and fill structures
    - Lenticular beds
    - Tabular beds
    - Fossils
- Secondary sedimentary processes
    - Cementation
- Sedimentary basins
- Depositional environments
- Marine
- Lacustrine

Deltaic
Fluvial
Fanglomerate
Evaporite
Near shore
Marsh
Lagoon
Transgressive sequence
Regressive sequence
Walther's law
Fossils: marine and terrestrial;
vertebrates, invertebrates, plants

Extrusive rocks

Lava flows
Tuffs
Domes (obsidian buttes)

Metamorphic rocks

Gneiss
Schist
Marble
Quartzite

Minerals

Orthoclase
Plagioclase
Quartz
Biotite
Chlorite
Epidote
Muscovite
Magnetite
Tourmaline
Hornblende
Pyroxene
Olivine
Pyrite
Gypsum
Anhydrite
Calcite
Halite
Kaolinite
Illite

Cultural

Mines
Artifacts (morteros, geoglyphs, petroglyphs, fish traps)
Trails and roads

Environmental

Salton Sea
Energy resources (geothermal, wind, solar)
Water usage
Agriculture
Climatic changes
Microclimates
Diurnal air movement
Environmental lapse rate
Sky islands
Rain shadows

Mapping Places

Painted Canyon
Box Canyon
Fossil Canyon
Split Mountain

Hiking stops (fun!)

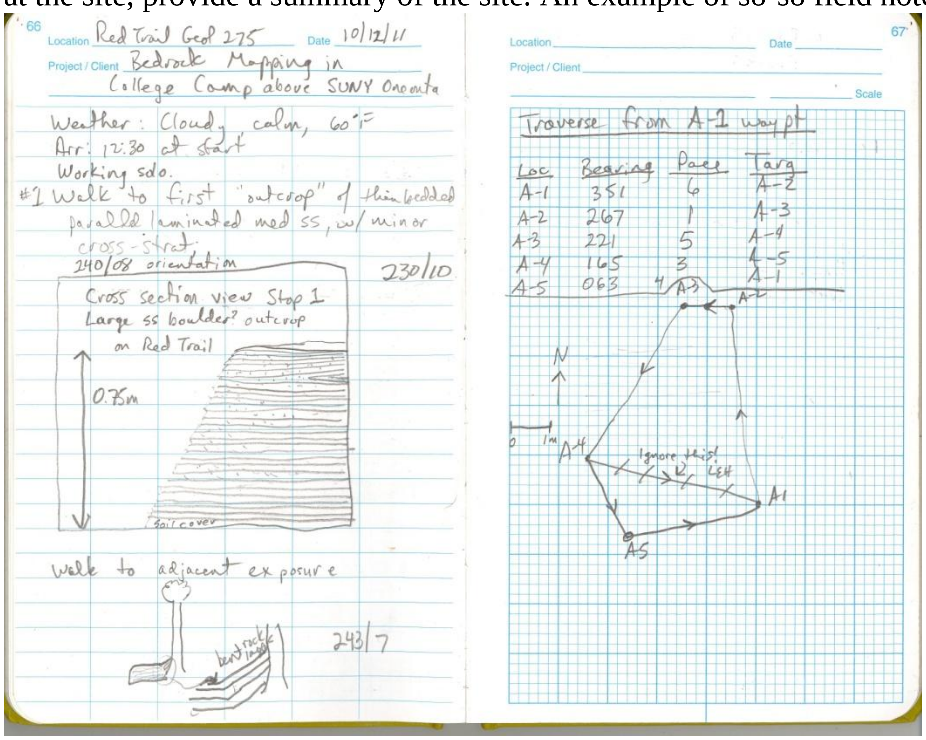
Marcus' place, SAF Whitewater
Palm Springs Tramway
1000 Palms
Ladder Canyon
Carrizo Badlands
Arroyo Tapiado
Canyon Sin Nombre
Anza Borrego Museum
Torrey Pines State Beach
Fonts Point
Borrego Badlands
Lute fault scarp
Arroyo Salado (the mighty mess)
Pines to Palms Highway
Martinez Mountain landslide
Fish Traps
Travertine
Moreno Valley migmatite

Taking Geologic Field Notes

A significant part of this field trip involves observation, and more importantly, the recording of those observations. You will be graded in how well you learn to take field notes. While there is a great diversity of field note styles (especially in the sketching department!), there are nonetheless **necessary items which must always be present in your field notes**. These include for each stop or site of interest:

- Date and Time
- Location: both a verbal description and GPS coordinates
- Weather
- People present
- Brief description of the site
- Purpose or goal of the stop
- Observations at the site
- Summary of the site

When you first arrive, look around to get an overall sense of the site. Try to characterize or verbalize in your mind what you see. Then get "your nose on the outcrop" for a closer inspection of the rocks. Then step back, and try to fit the details into the bigger picture. Talk with your guides and fellow students about what you see. Arguments at the outcrop are common! Then take the time to make a sketch of what you see. Draw a box first to provide a boundary for your drawing. Annotate the sketch. Provide a scale bar. Try to keep the features at the same scale. Estimate the height and width of view. Use profile sketches as much as possible, as these provide clear views into the stratigraphy and they are much easier to sketch than perspective views. You should also consider making small maps (views from above) to show spatial relations. Provide a title or caption for the figure which summarizes what is contained in the sketch. Place numbers on the sketch for features you describe in greater detail in your notes. Finally, when you are done at the site, provide a summary of the site. An example of so-so field notes is given below.



Day 1 Whitewater Canyon

Whitewater Canyon drains the high peaks of the San Bernardino Mountains to the north and west, and cuts across a couple of the strands of the San Andreas fault (SAF). Take a look at the geologic map a few pages down for an overview of the faults and rock types in the area. We will stop to take a look at the Banning segment of the SAF at Whitewater. At this stop, take field notes and make a sketch showing the type of deposits exposed in the walls of the canyon, and the evidence for a fault in this area. Can you tell if lateral movement or vertical movement is readily detectable at this location?

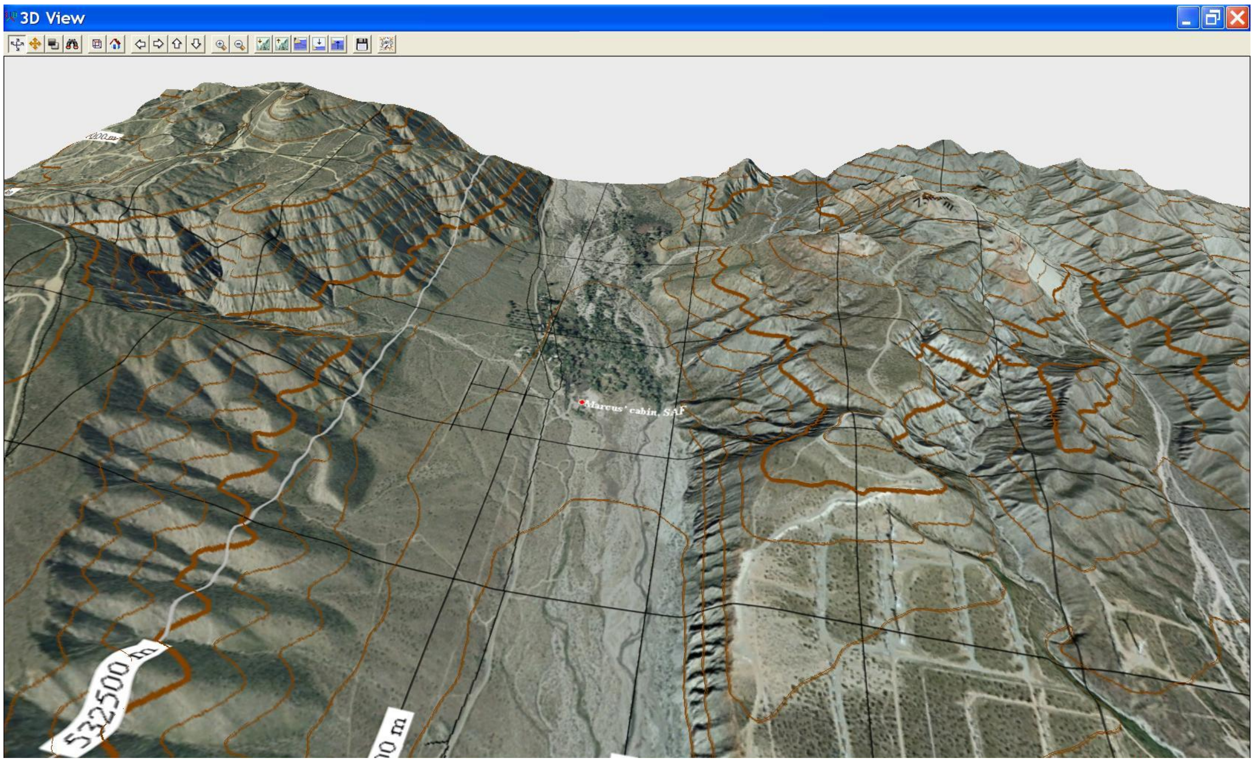


Figure. Perspective view north up Whitewater Canyon. Note the abrupt vegetation change, and hydrothermally altered rocks in the top right corner of the view. Image created by L. Hasbargen, 11/2011, with NED 10 m data from USGS, and World Imagery from Google WMS. UTM Zone 11 grid at 500 m spacing for scale. Contour interval = 30 m.

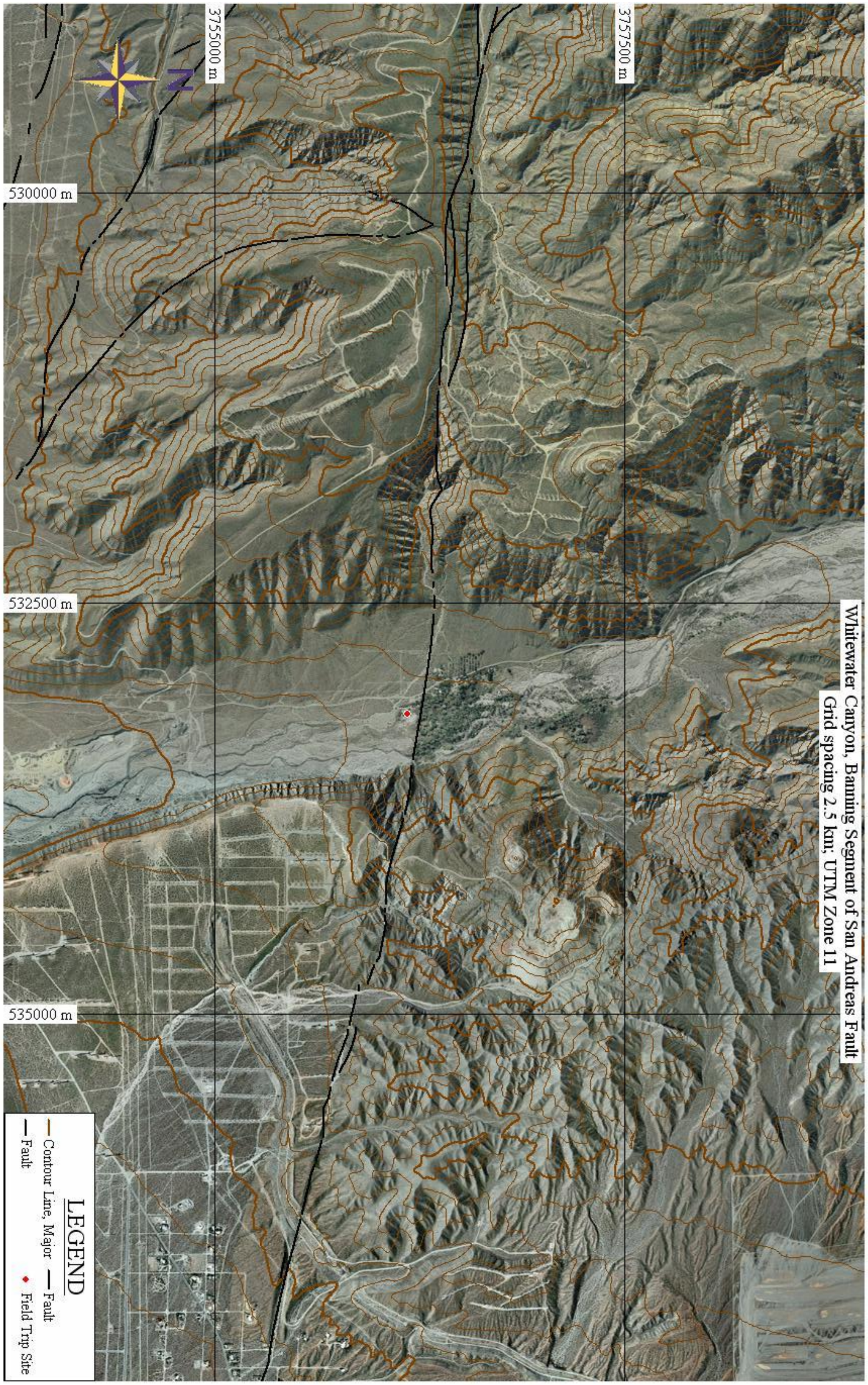


Figure. Whitewater Canyon and the Banning strand of the San Andreas Fault.

Figure. Whitewater Canyon aerial view, with Banning fault.

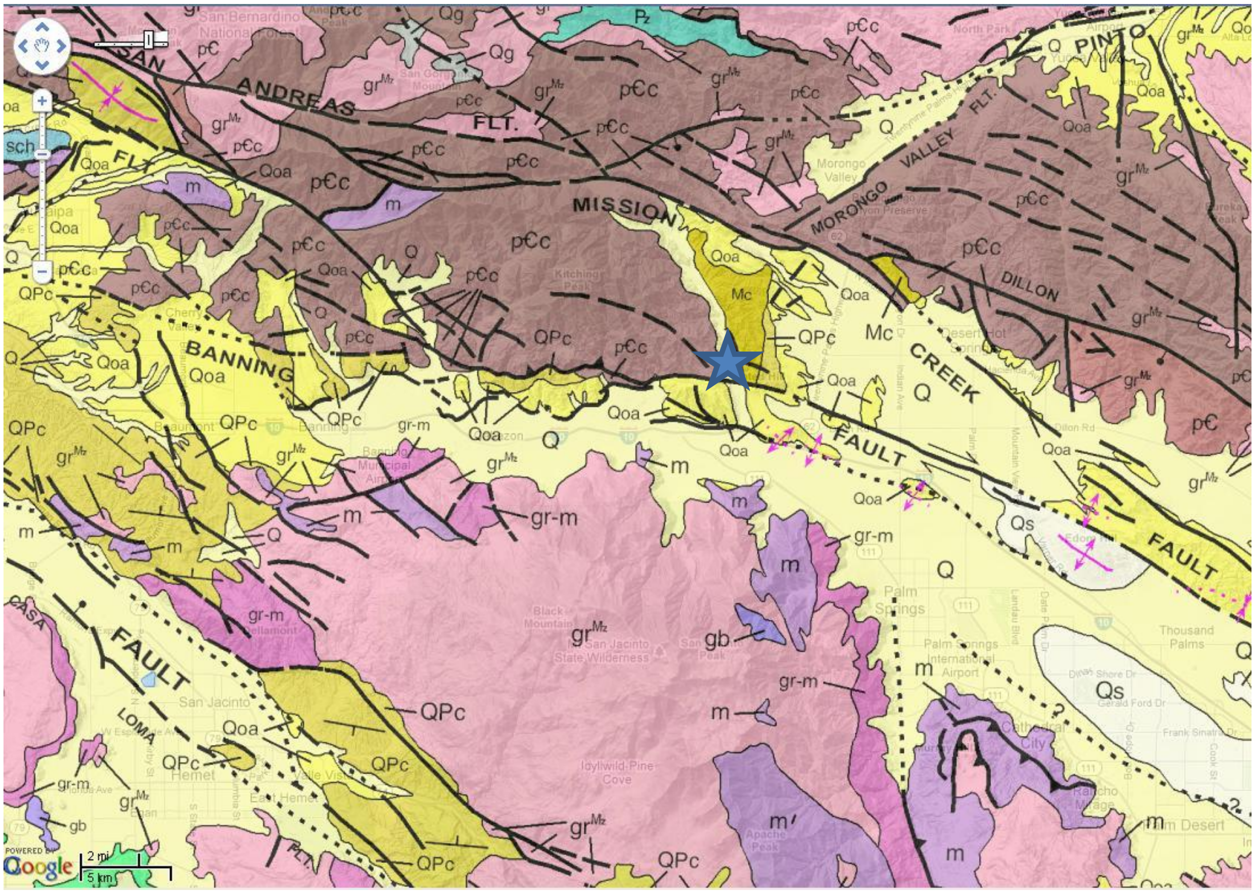
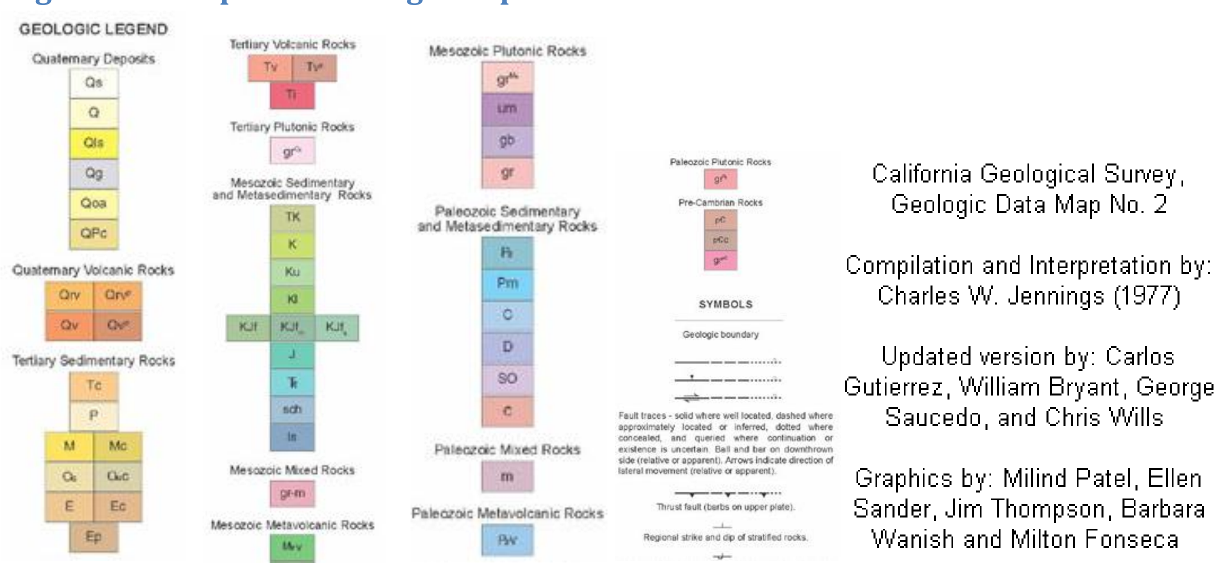


Figure. Geologic Map of Whitewater Canyon area, showing the major faults and rock types in the area. Star marks Whitewater Canyon and Marcus' cabin. Map extracted from California State Geological Map online at **http://www.quake.ca.gov/gmaps/GMC/stategeologicmap.html**.

Legend for Simplified Geologic Map of California



Day 2 Palms Springs Tram

We will take a tram ride up to the high country in the San Jacinto Mountains. En route, take notes on the cross cutting dikes easily visible from the tram—make a sketch in your field notes. For a regional look at the main rock types and faults nearby, see the geologic map below. At the top, we will get a good view of the geomorphology and structure of the great rip in the continent, as Baja California moves northwest. We are on the northeastern margin of Baja. Note the great escarpment that extends south, and the large rift valley.

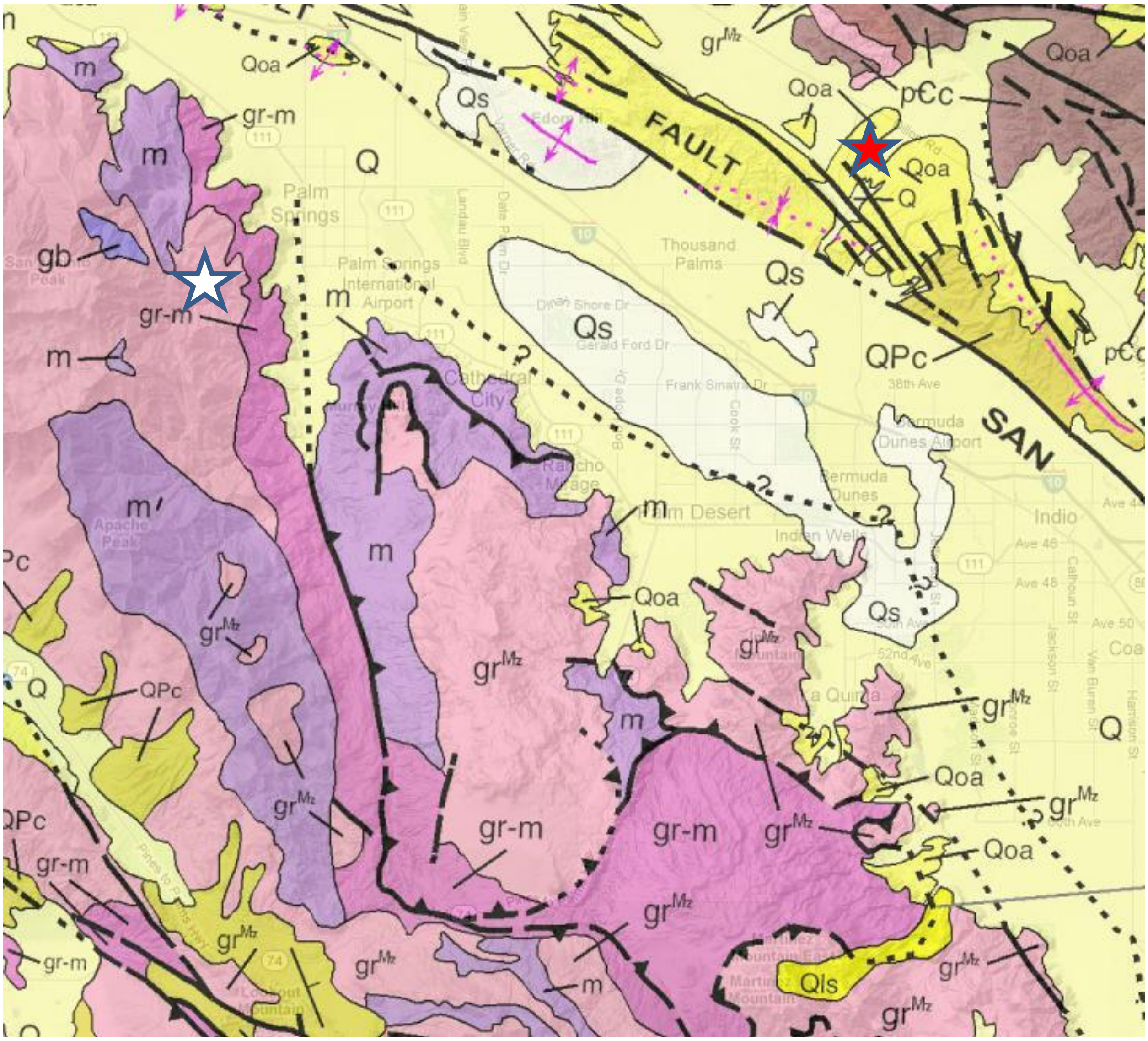
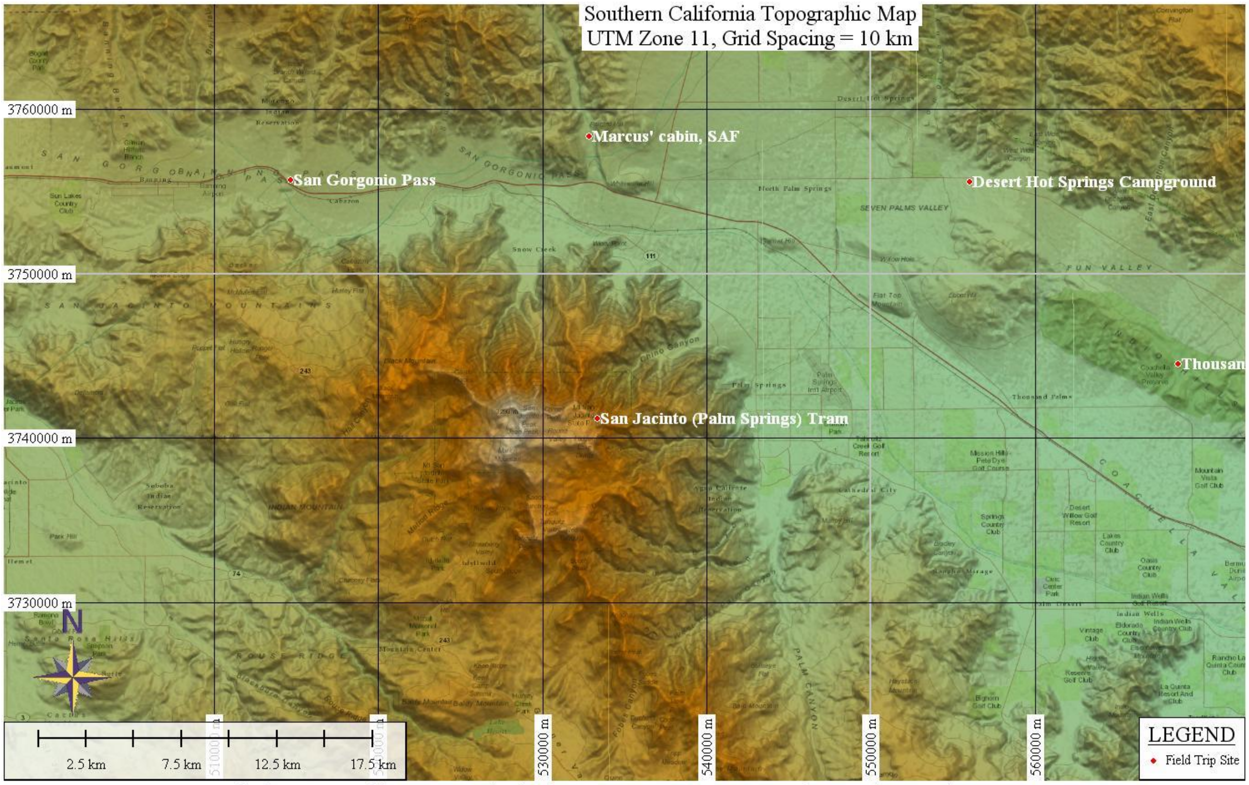
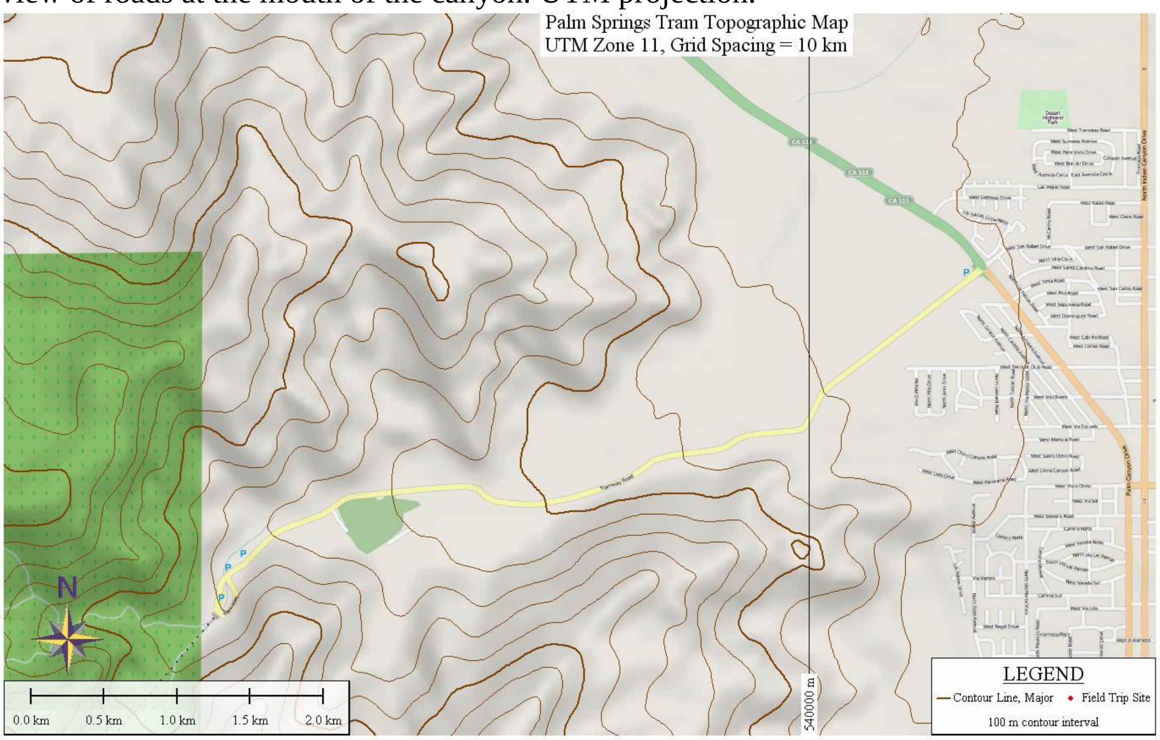


Figure. Geologic map of San Jacinto Mountains and northern Coachella Valley. Red star marks 1000 Palms (Coachella Valley Preserve). White star marks Palm Springs tram. m = mixed Paleozoic sedimentary rocks. gr-m= Mesozoic mixed rocks. gr^{Mz} = Mesozoic granite. Map from California Geological Survey, Geologic Data Map No. 2, Charles W. Jennings (1977), updated by Carlos Gutierrez, William Bryant, George Saucedo, and Chris Wills (2010).



Data sources: Topography from ESRI World Topo WMS; Elevation from ASTER GDEM; WGS 84; Map by L. Hasbargen, 12/2011

Figure. Color relief map of Mt. San Jacinto and tramway. Map below shows expanded view of roads at the mouth of the canyon. UTM projection.



Data sources: Roads from OpenSource WMS; Elevation from ASTER GDEM; WGS 84; Map by L. Hasbargen, 12/2011

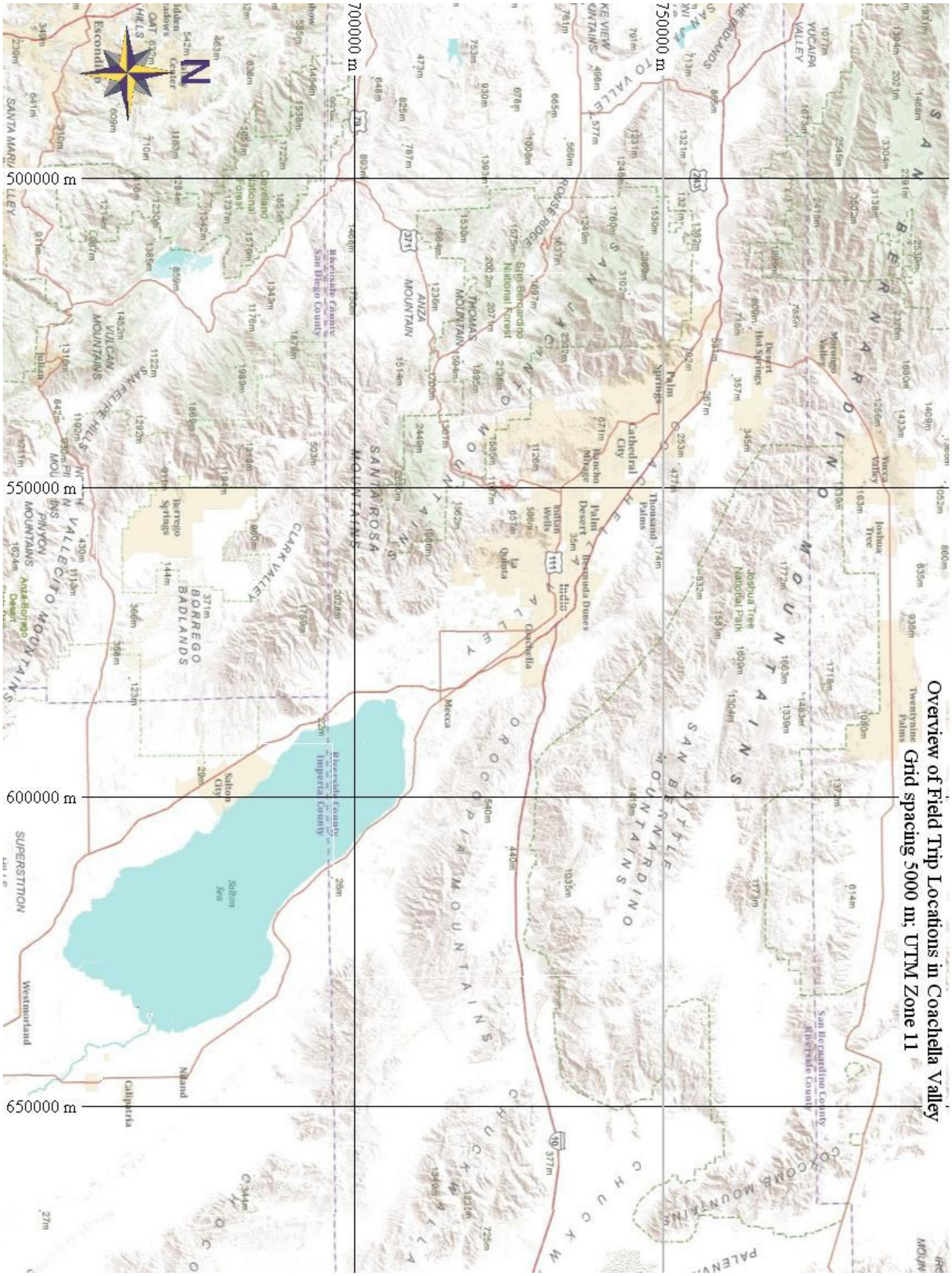


Figure. Topographic map of Coachella Valley and Salton Sea, showing regional mountains and major highways. Star marks Mecca Hills Wilderness. Image courtesy of World Topography WMS. UTM projection. 50 km grid.

Figure. Topographic map of Field Trip Locations in Coachella Valley.

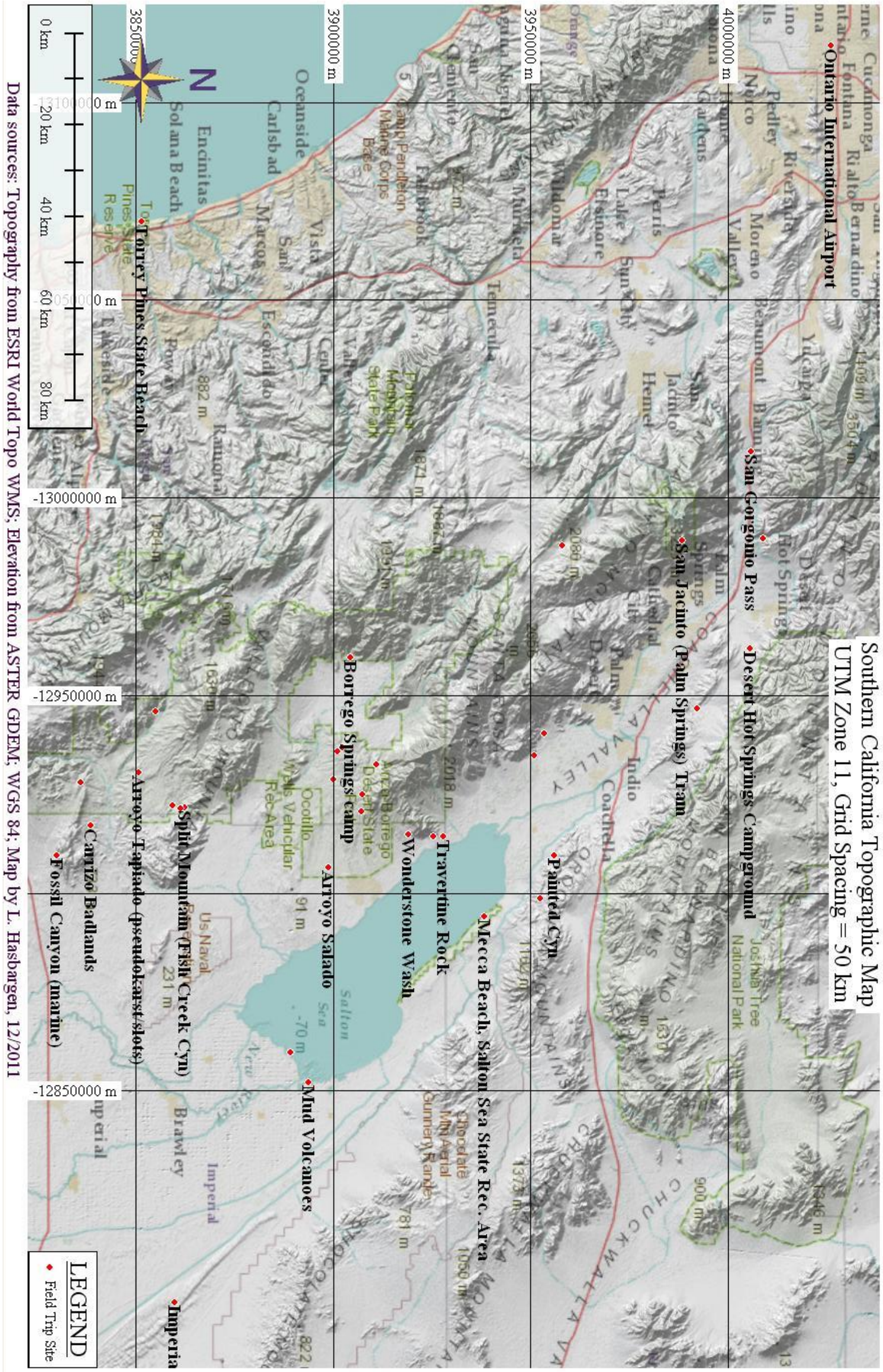


Figure. Relief map of southern California, with field sites.

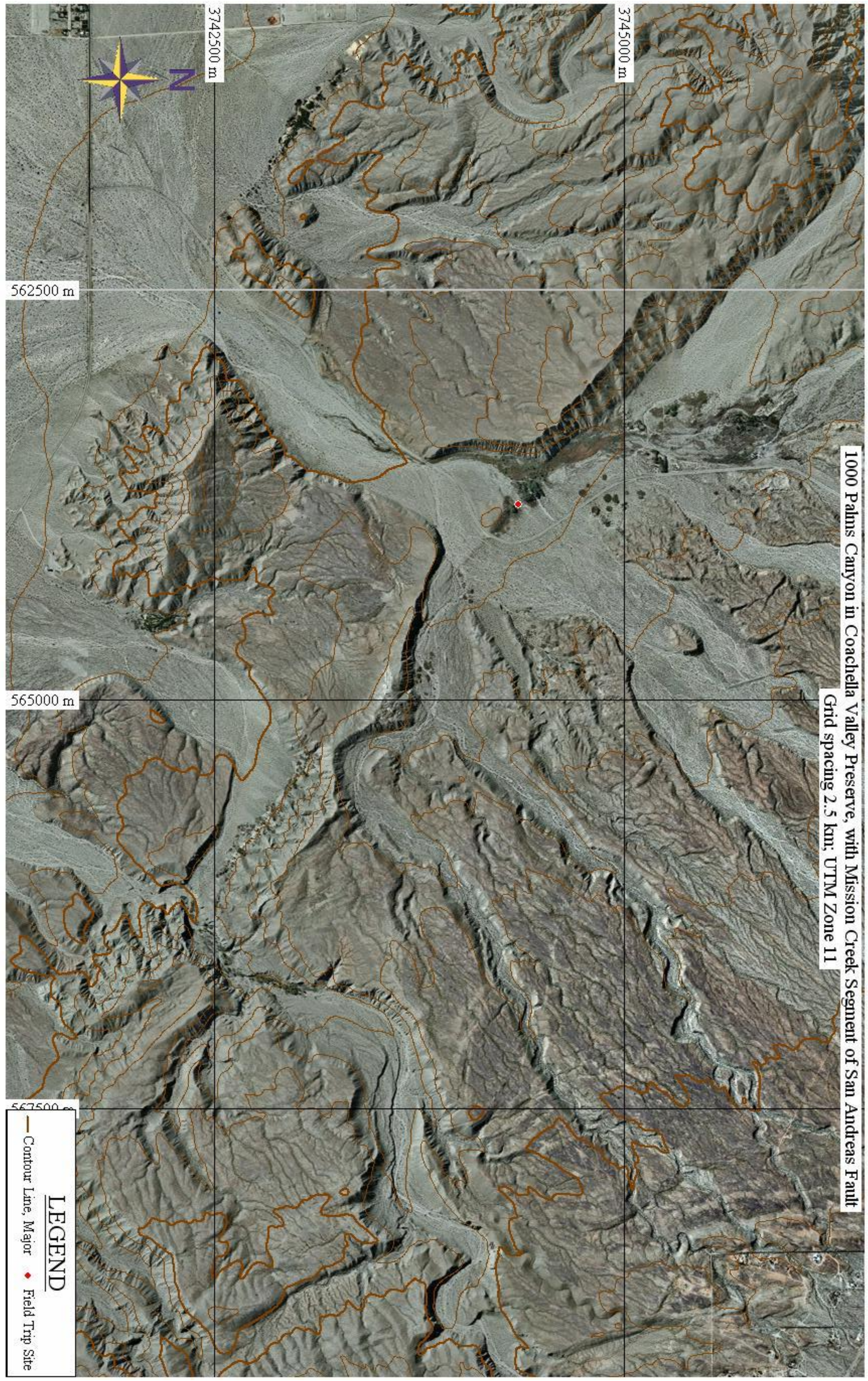


Figure. 1000 Palms Canyon along the Mission Creek strand of the San Andreas fault.

Figure. Aerial view of 1000 Palms Canyon and Coachella Valley Preserve.

Day 2 Coachella Valley Preserve at 1000 Palms Canyon

We will hike along the San Andreas fault (Mission Creek segment) to several palm oases. We should get a very good view of classic arid region geomorphology, including alluvial fans, active washes, desert pavement, ventifacts, and fault scarps. Many springs in southern California mark fault zones, where groundwater encounters a barrier, and is forced to the surface. We will see some of these springs, marked by the California fan palm oases.

Day 3 Box Canyon in Mecca Hills

In the morning, we will drive up Box Canyon to get an overview of the kinds of rocks and structures in the area. Plot the stops on the overview map (p. 10). In the afternoon, we will develop skills in rock description and mapping geologic structures in the western portion of Box Canyon near its mouth. You will need to use the compass, GPS unit, and maps provided. We will identify faults, and follow them across the landscape. We will also map sedimentary layer orientation, make a note of significant changes in groups of layers (mappable units), and try to follow these as well. Make full use of the maps of the area to zoom in and out. Record the GPS locations and layer orientation in your field book, along with the description of the rocks at the site. Plot your strike and dip data as symbols on your field map.

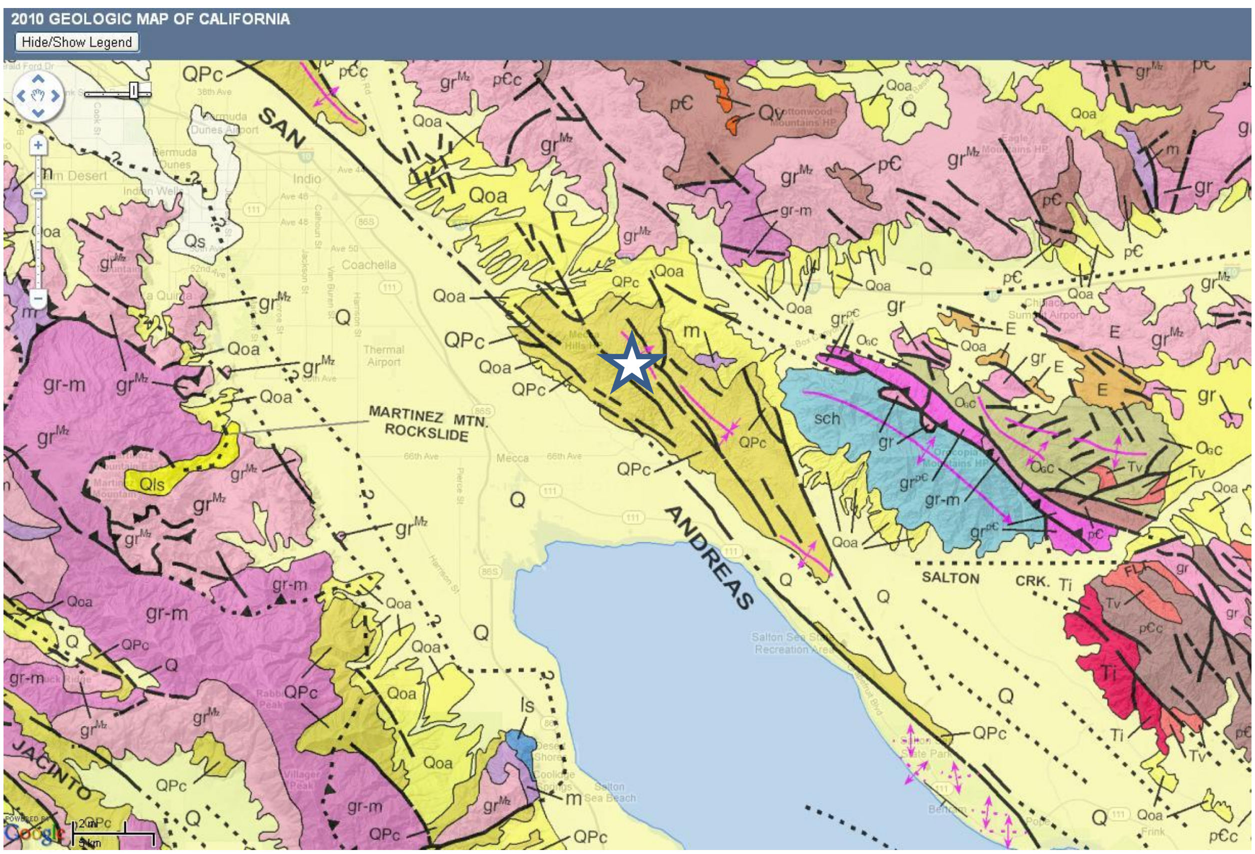


Figure. Generalized geology of southern Coachella Valley and the northern end of Salton Sea. sch= schist. QPc = Quaternary and Pliocene sediments. Qoa = older Quaternary alluvium. Star marks Mecca Hills Wilderness. Map from California Geological Survey, Geologic Data Map No. 2, Charles W. Jennings (1977), updated by Carlos Gutierrez, William Bryant, George Saucedo, and Chris Wills (2010).

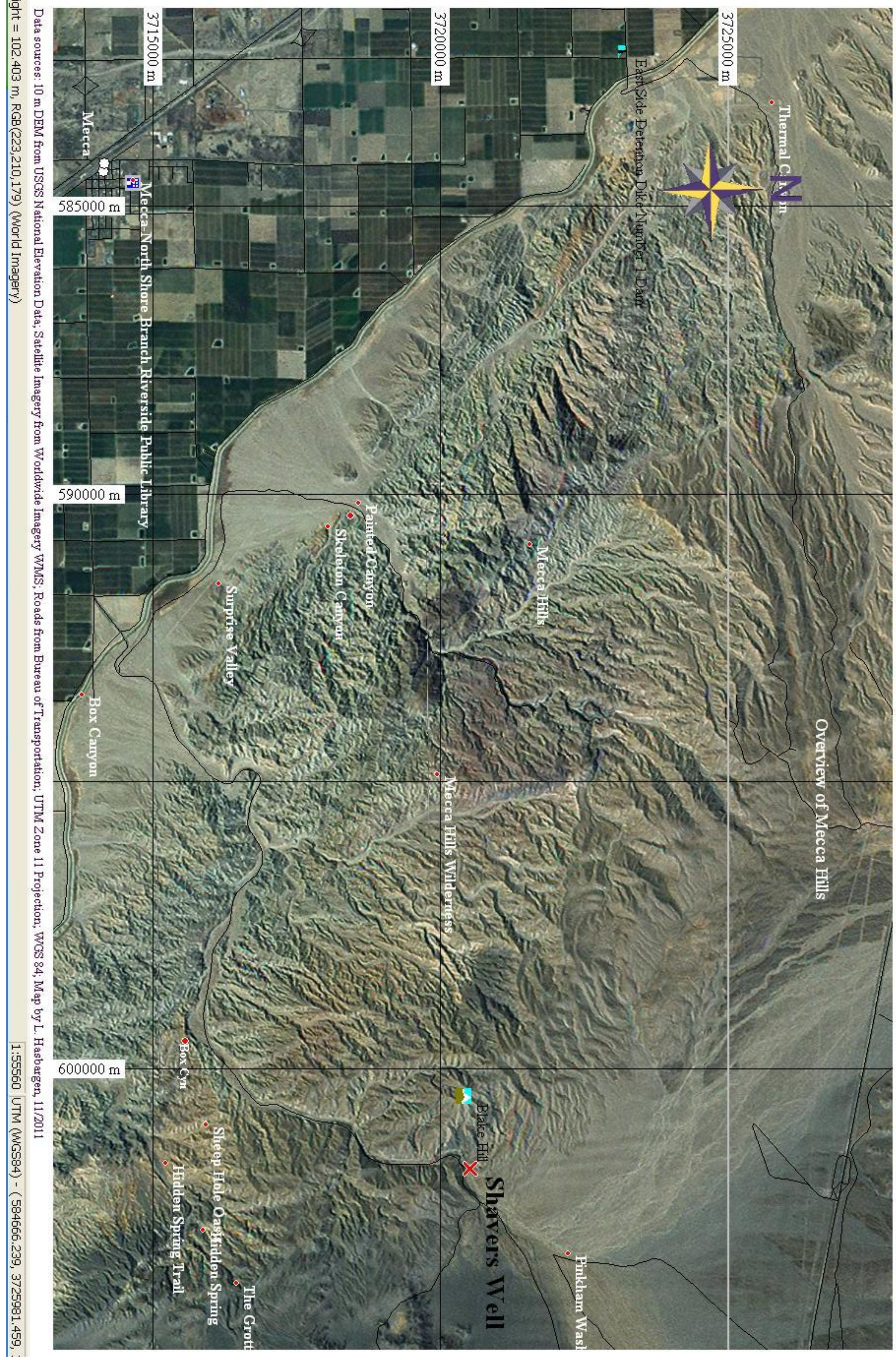
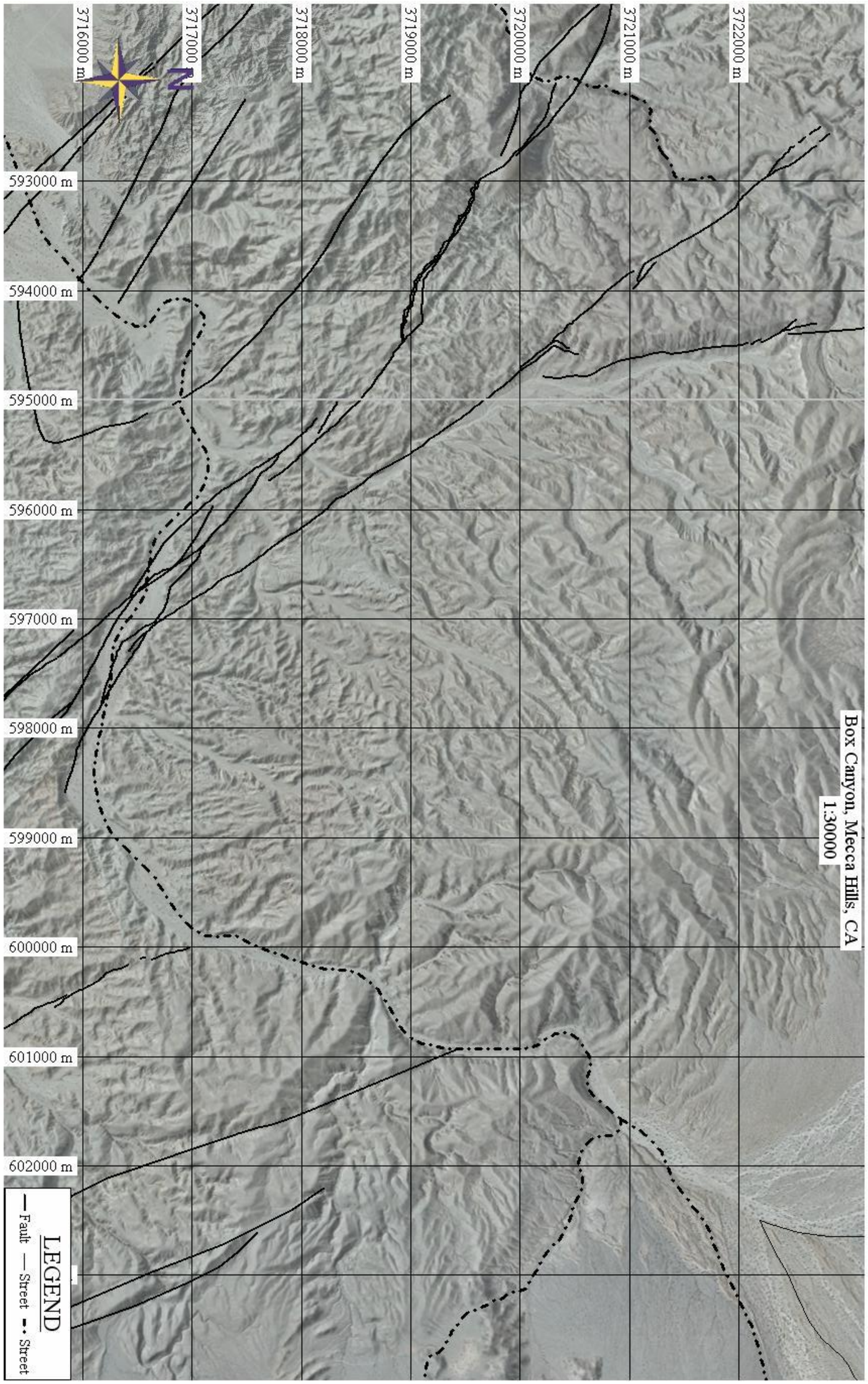


Figure. Overview of Mecca Hills Wilderness, with field mapping areas targeted at Box and Painted Canyons.

Figure. Aerial overview of Mecca Hills region.

Figure. Overview of Box Canyon, with faults as dark lines transecting the area.



Data sources: 10 m NED from USGS; Satellite Imagery from Worldwide Imagery WMS; Roads from Bureau of Transportation; UTM Zone 11 Projection; WGS 84; Map by L. Hasbargen, 11/2011

Figure. Aerial overview of Box Canyon.

Figure. Aerial image of western end of Box Canyon

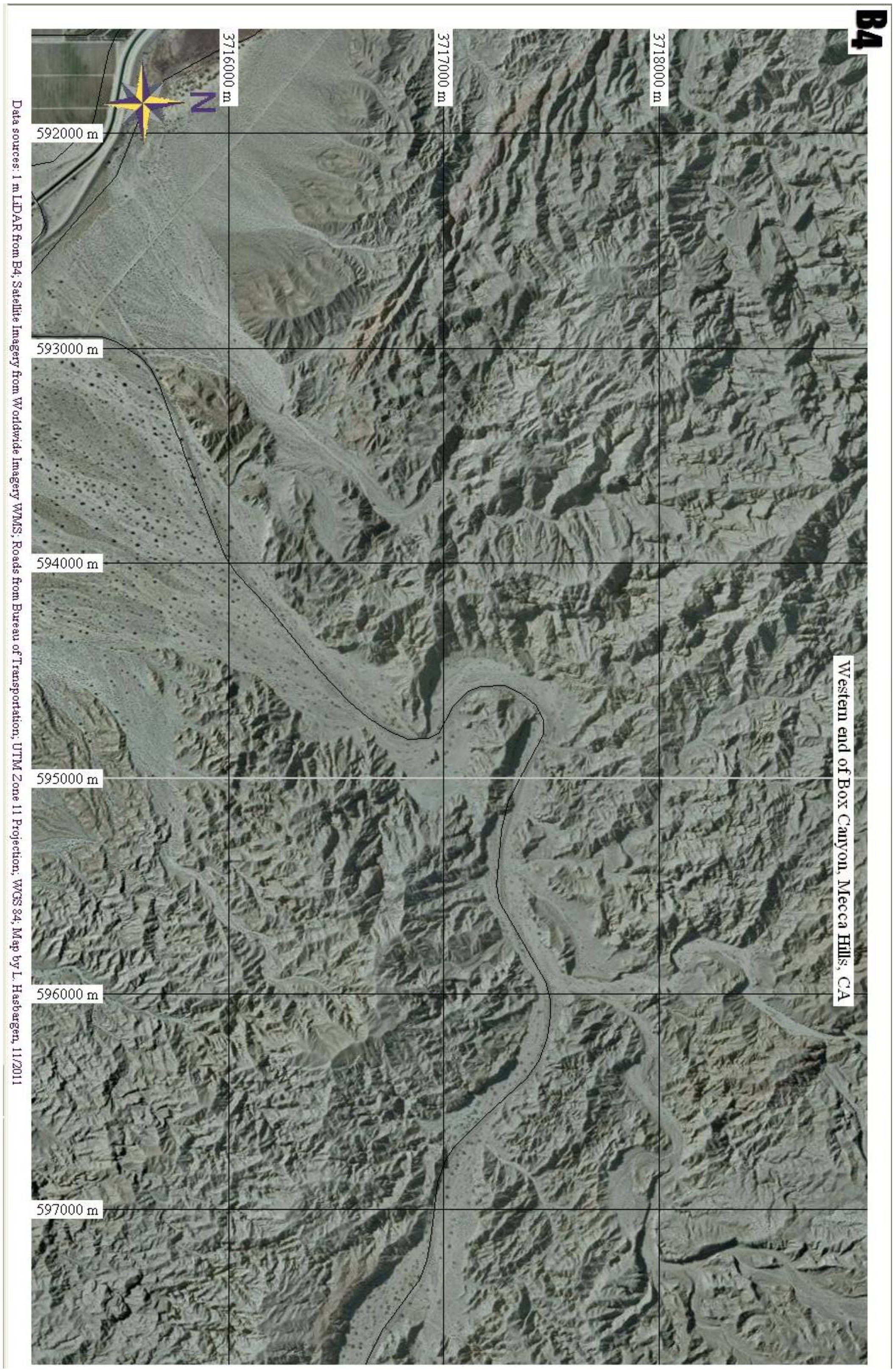


Figure. Satellite view of western end of Box Canyon.

Figure. Aerial image lower Box Canyon mapping area .

Figure. Aerial close up view of mouth of Box Canyon.

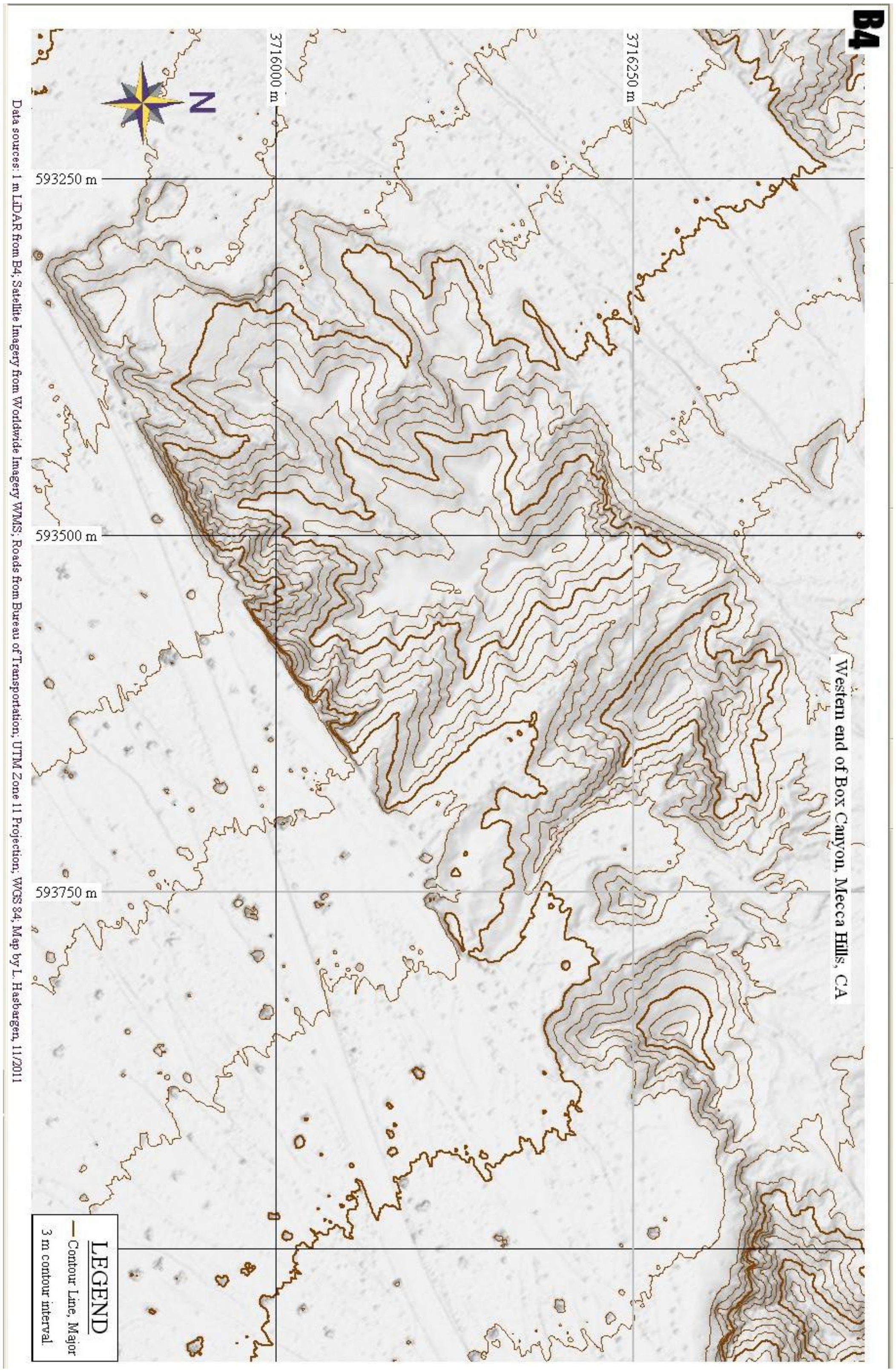


Figure. Topographic image of lower Box Canyon the mapping area .

Figure. Topographic map of the mouth of Box Canyon.

Figure. Topographic image of lower Box Canyon the mapping area, closer view.

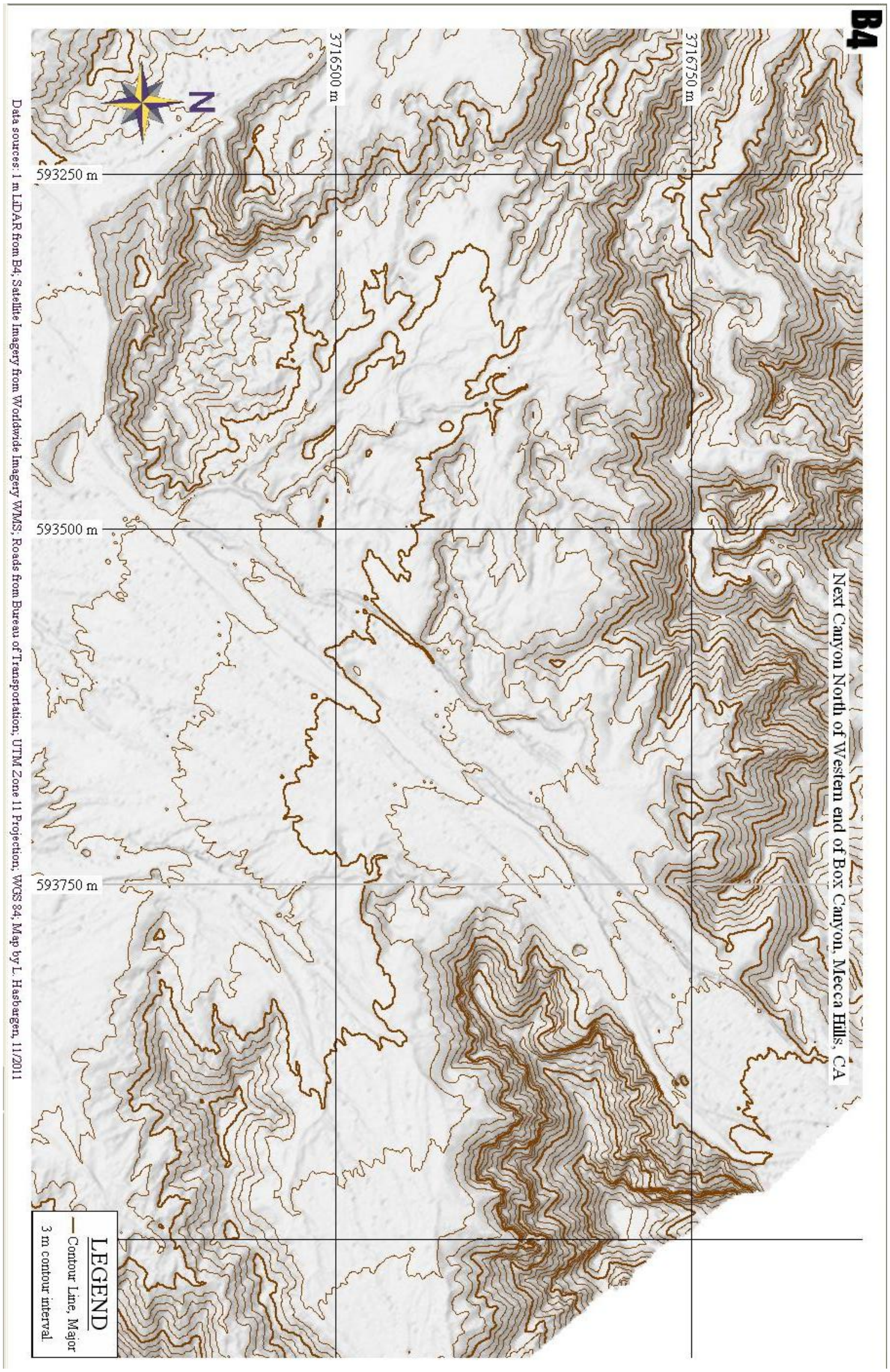


Figure. Topography of southwest portion of Box Canyon, close up view.

Figure. Topographic image of lower Box Canyon the mapping area, closer view.

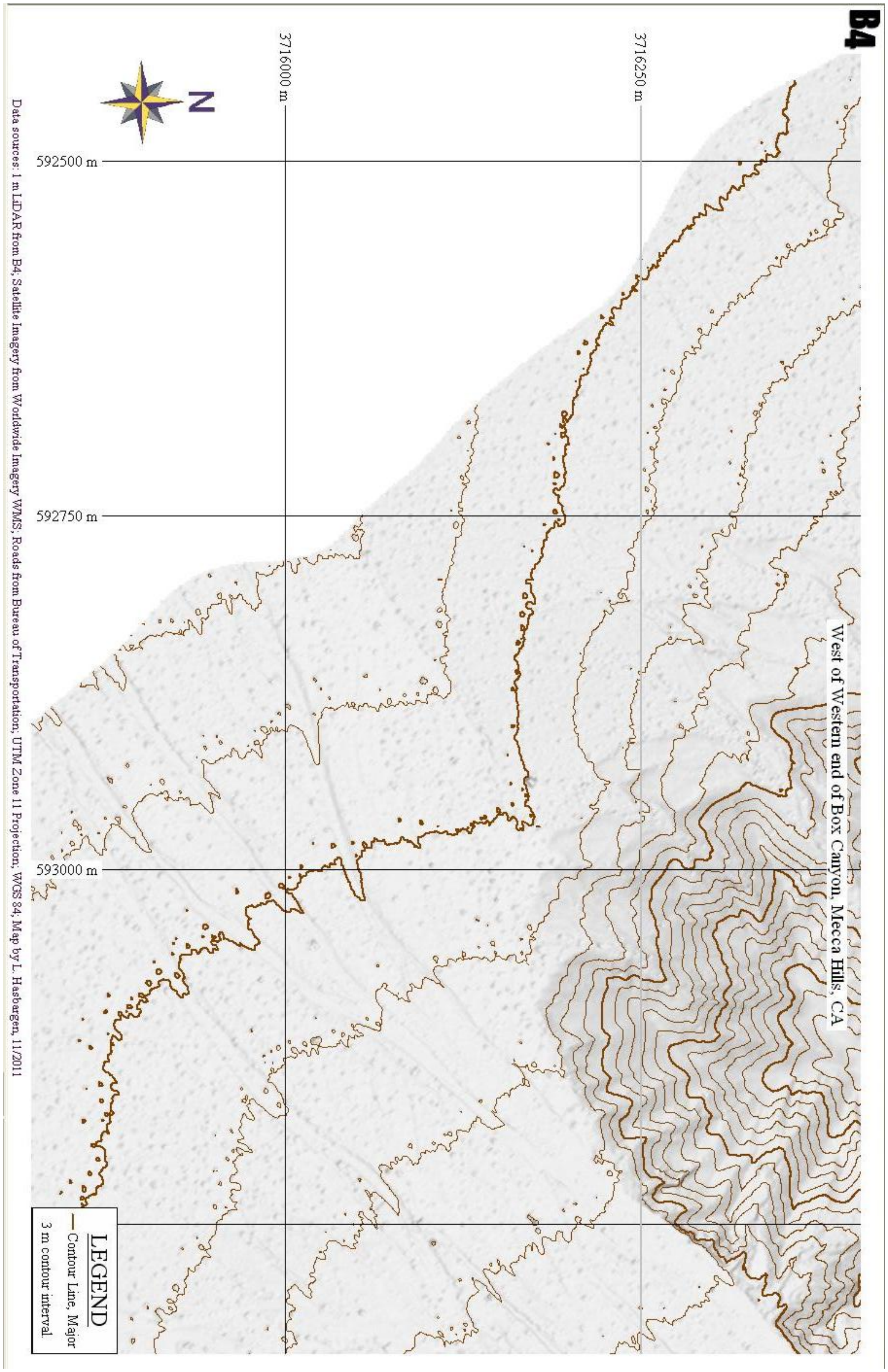


Figure. Topographic map of far west end of Box Canyon, close up view.

Figure. Topographic image of northwest area near Box Canyon..

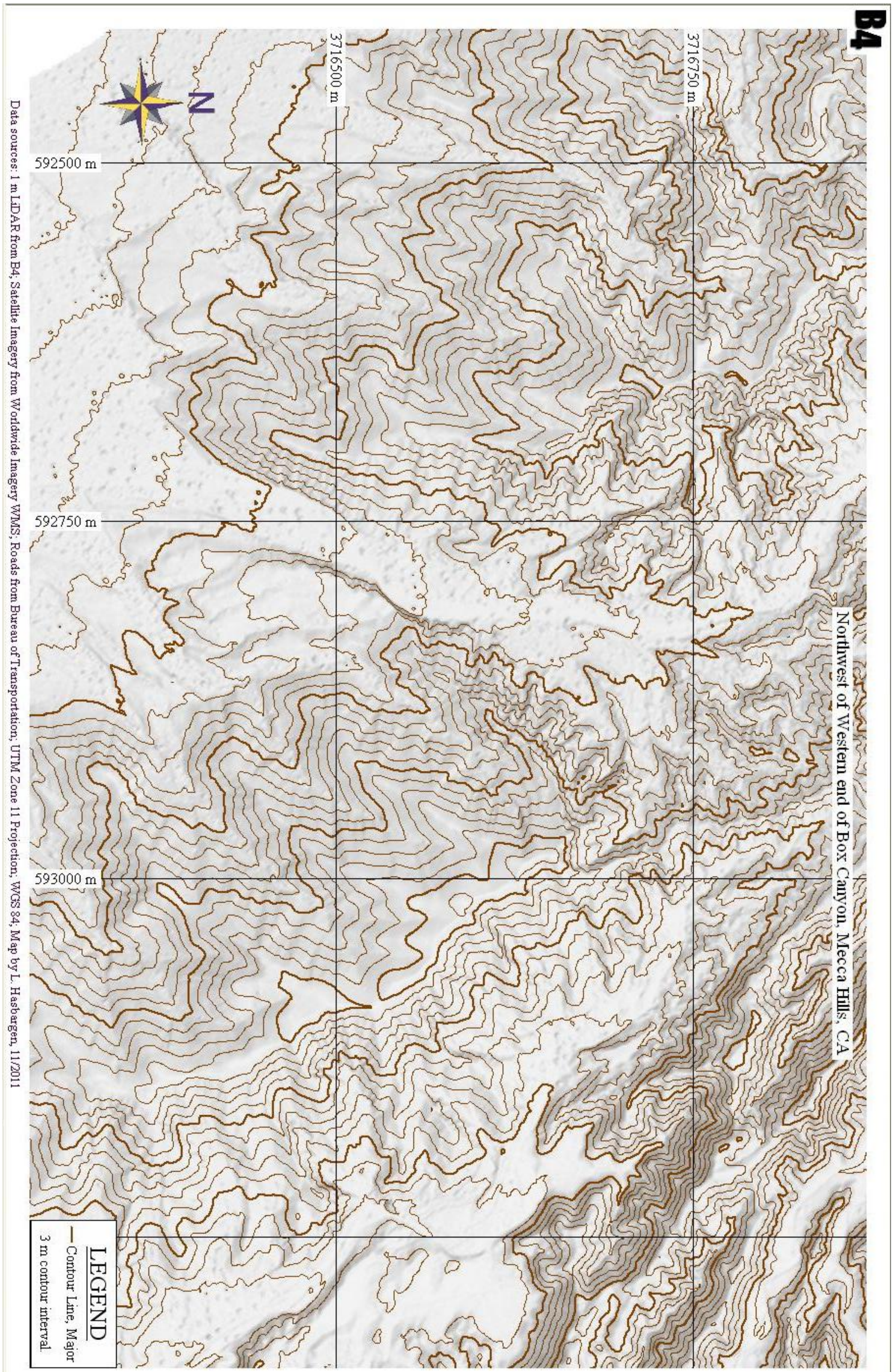


Figure. Topography of northwestern area near Box Canyon, closer view.

Figure. Aerial image of northwest area near Box Canyon..

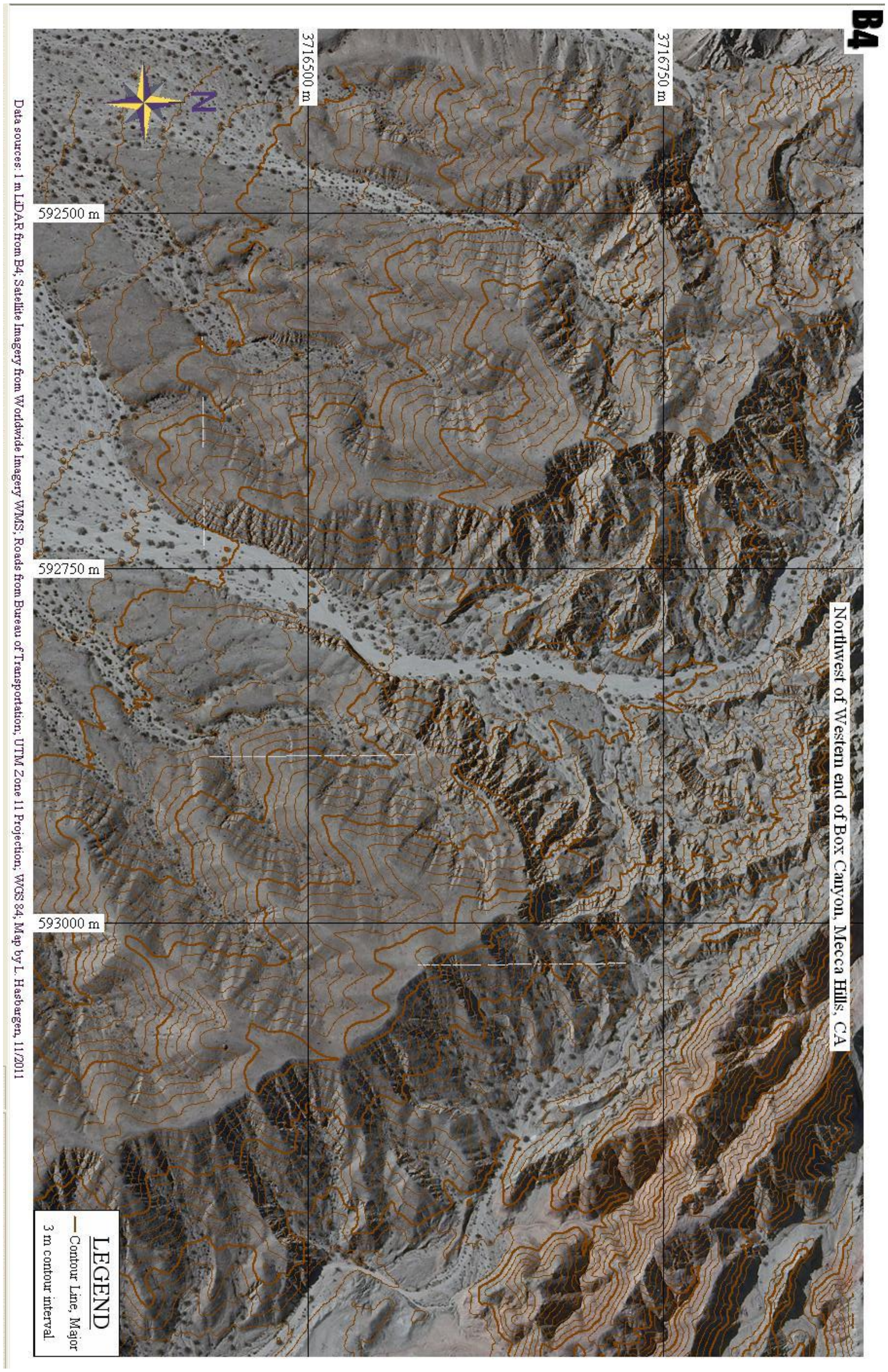
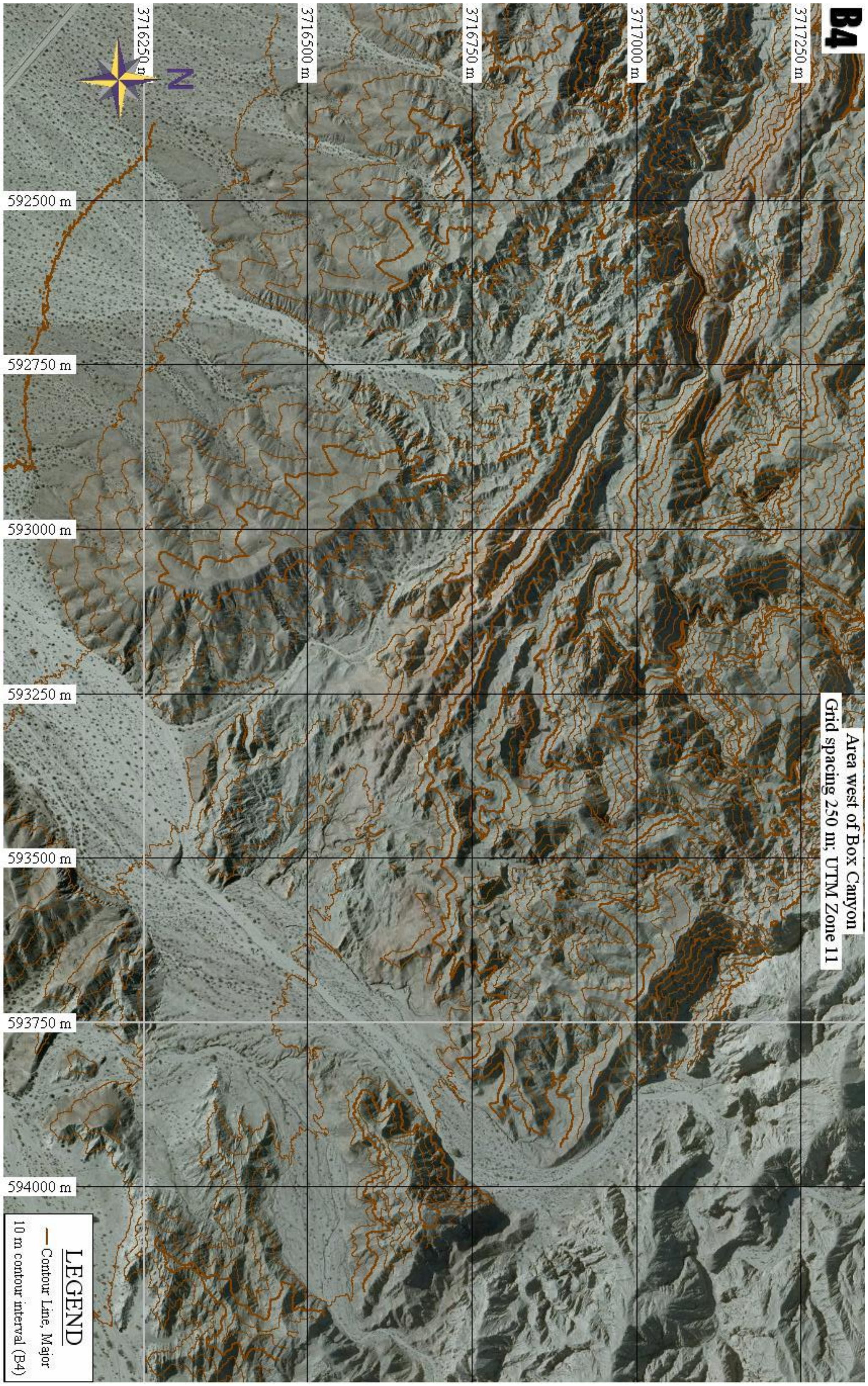


Figure. Aerial image of area northwest of Box Canyon, close up view.

Figure. Aerial image of area northwest of Box Canyon.



Data sources: Satellite Imagery from World Imagery WMS; WGS 84; Map by L. Hasbargen, 12/2011

Figure. Aerial image, fault zones in west end of Box Canyon.

Figure. Topography of area northwest of Box Canyon..

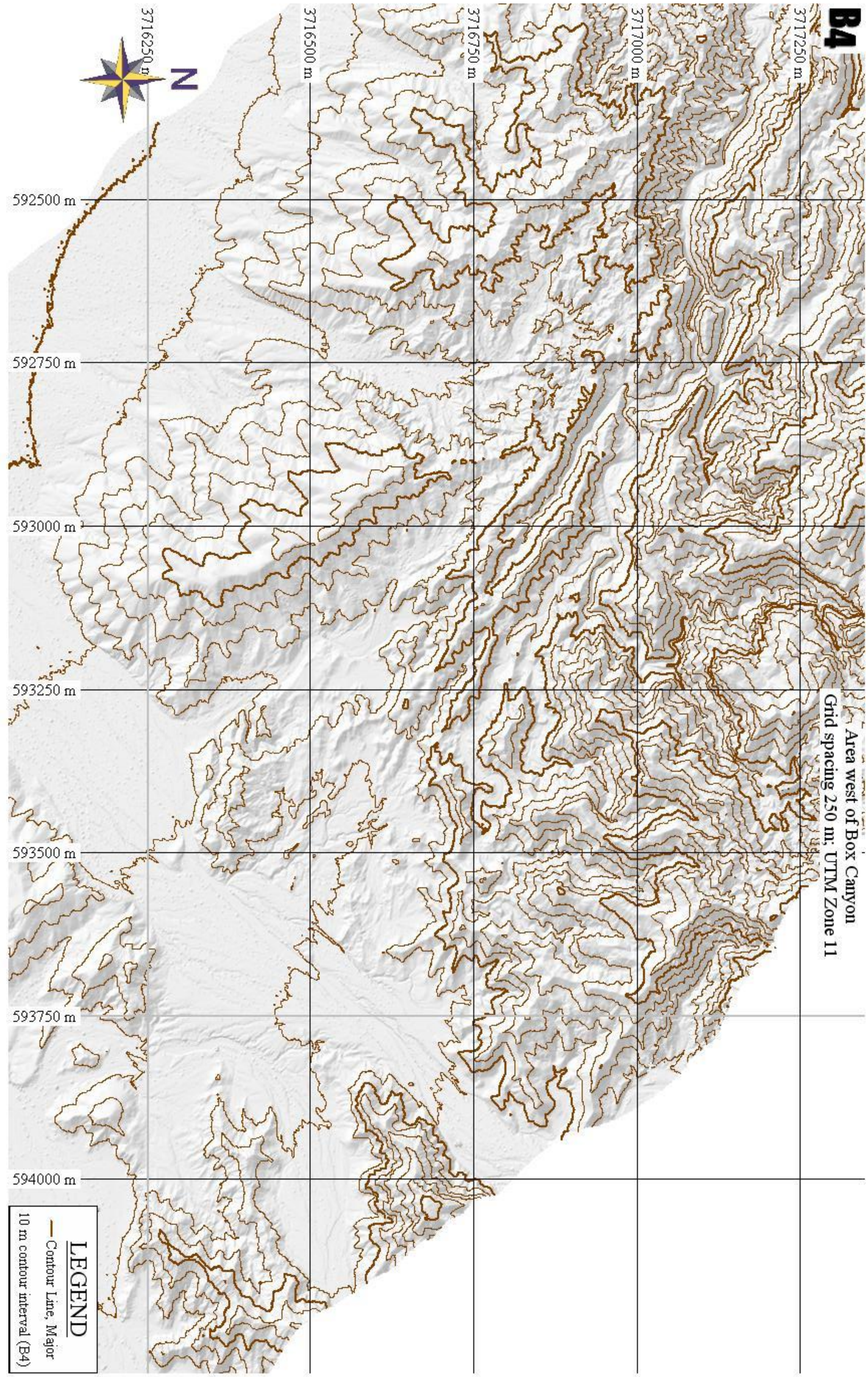


Figure. Topography of fault zones in west end of Box Canyon.

Figure. Topography and faults mapped by USGS (2009) in west end of Box Canyon.

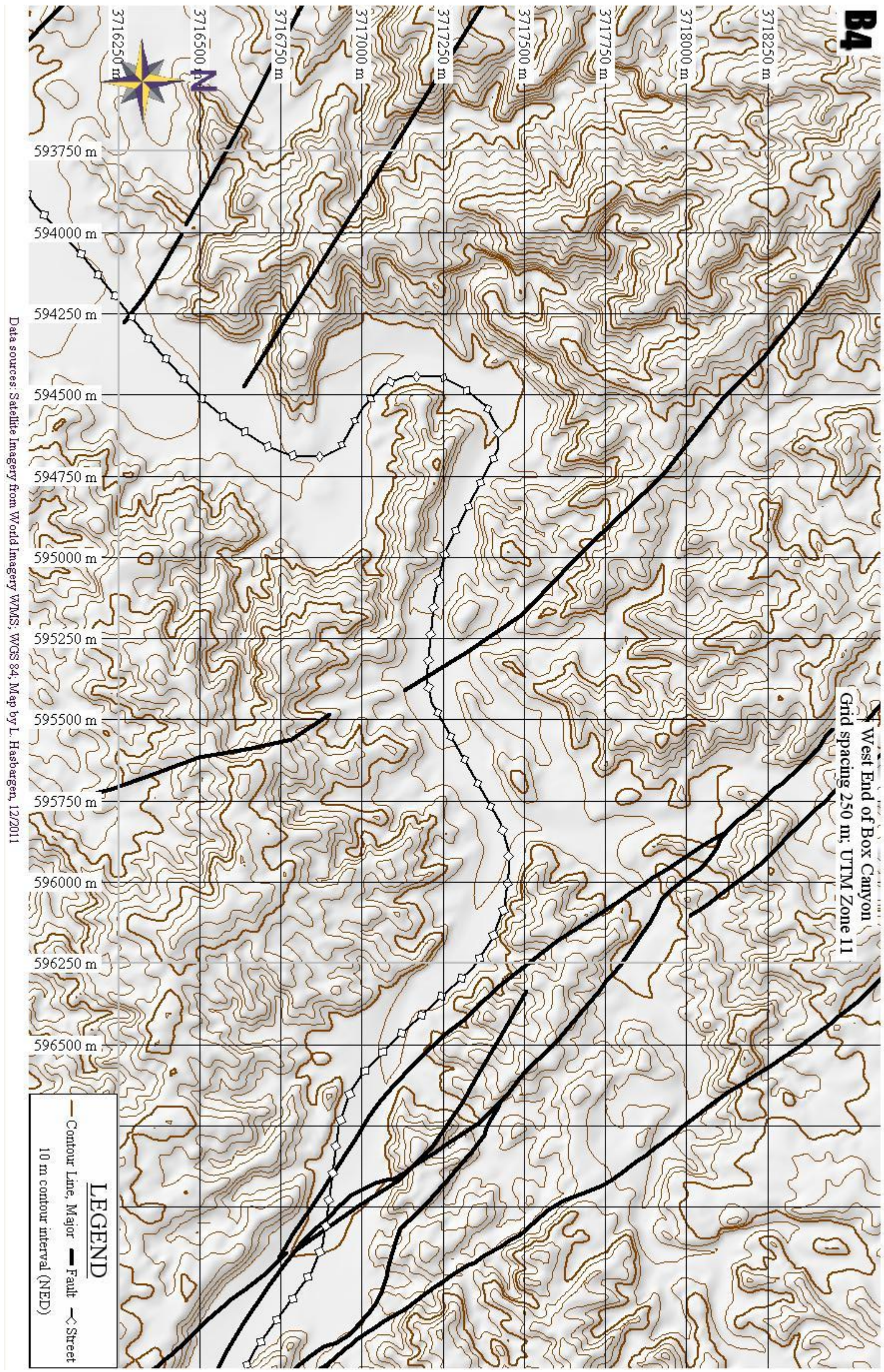


Figure. Topography and faults in west end of Box Canyon, broader view.

Figure. Aerial imagery and faults mapped by USGS (2009) in west end of Box Canyon, zoomed for investigation.

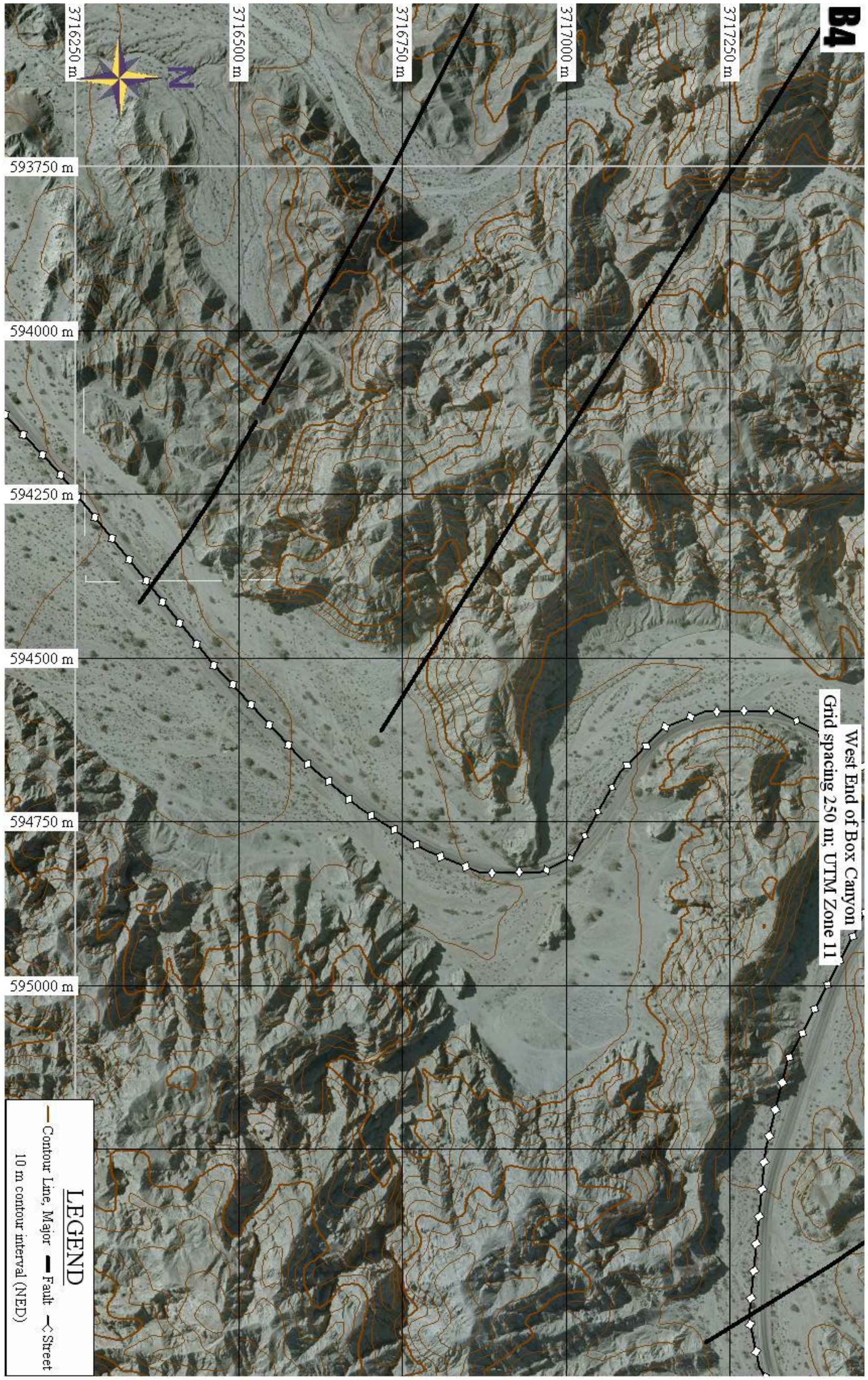


Figure. Aerial imagery and faults in west end of Box Canyon, zoomed for investigation.

Figure. Aerial imagery and faults mapped by USGS (2009) in west end of Box Canyon, zoomed for investigation.

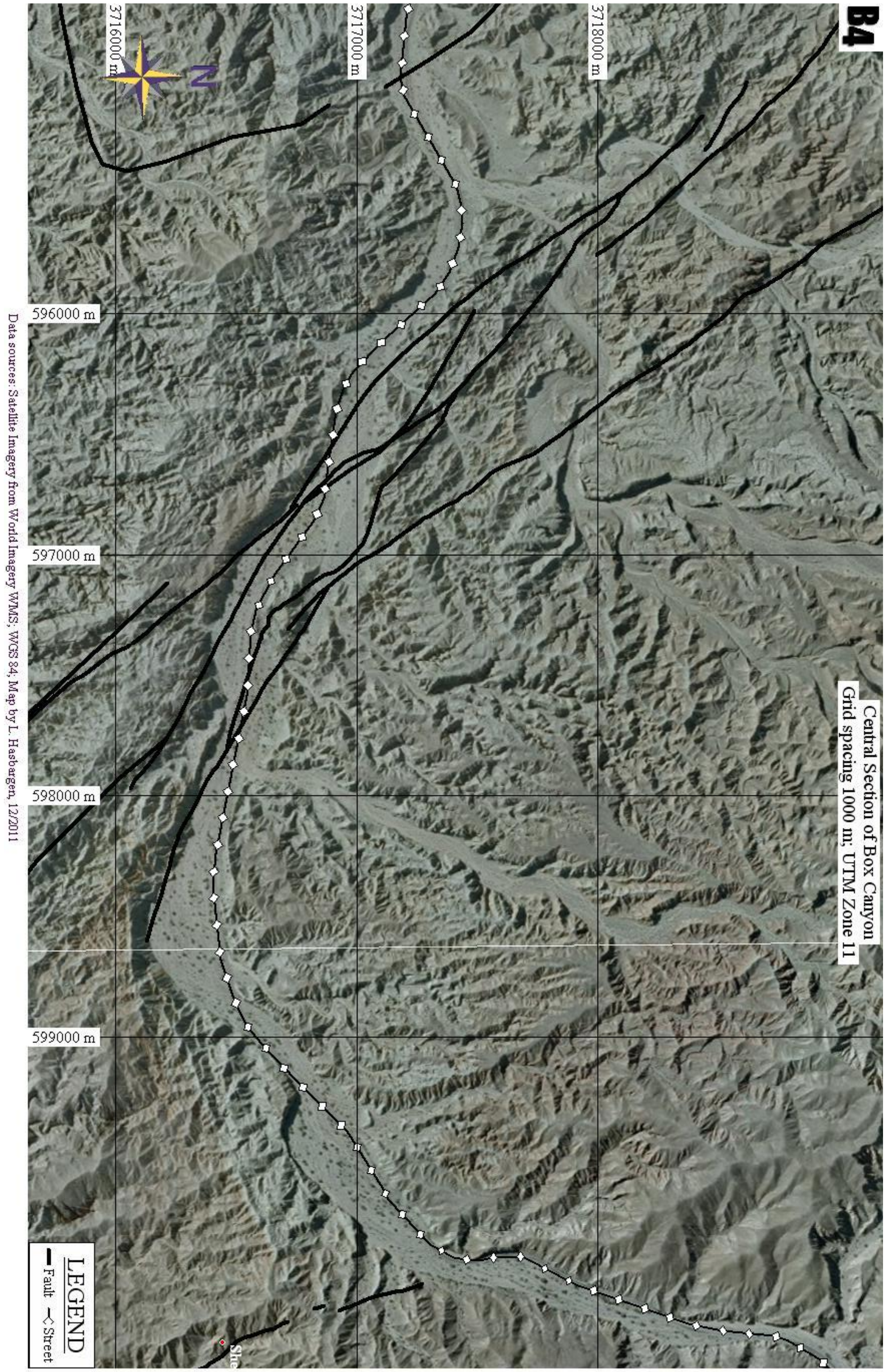


Figure. Close up view aerial imagery and faults in west end of Box Canyon, zoomed for investigation (from faults courtesy of USGS Fault and Fold Database, 2009).

Day 4-5 Mapping Painted Canyon and trek up Ladder Canyon

We will spend the next day and a half mapping faults, folds, and contacts in the Painted Canyon area. You will be using the topographic maps at higher resolution for mapping contacts and rock orientations, but you should also take advantage of the broader view provided by the aerial images. We will begin with a brief reconnaissance up the canyon via vehicle to get a look at the mappable units. Then we will section work in the area north of Painted Canyon near the mouth. Your job is to identify the main structures, and trace them across the landscape. Document the structures with strikes and dips.

The first day of mapping should get the big picture in place, and we will talk about your observations at camp. The second day will involve going to areas where your data is inconclusive. After lunch, we'll drive to the northern entrance to Painted Canyon, and hike up Ladder Canyon.

Figure. Overview of Painted Canyon. Black lines are faults. Dotted line is a road, of sorts.

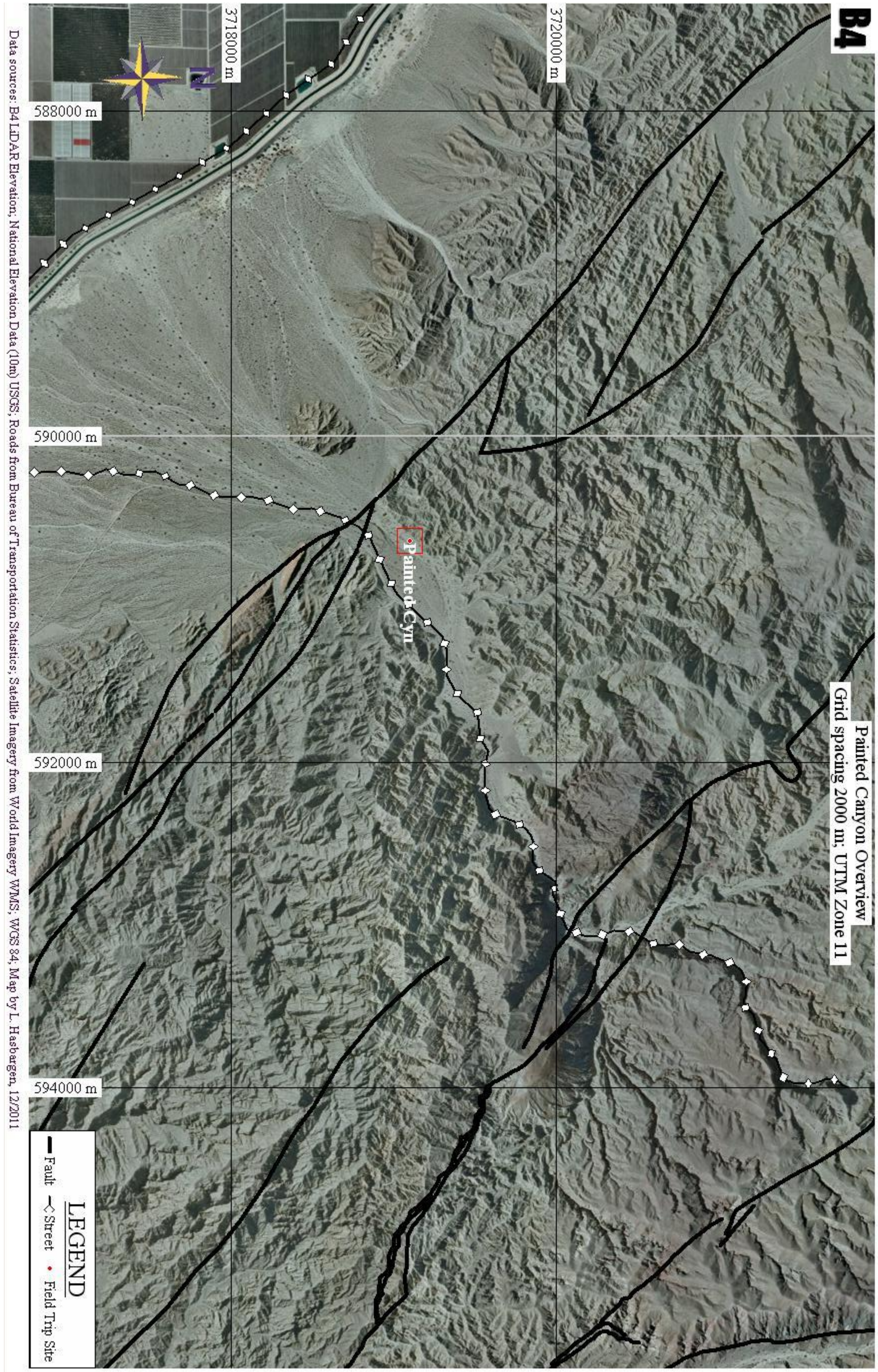


Figure. Aerial overview of Painted Canyon. Black lines are faults. Dotted line is a road, of sorts.

Figure. Closer aerial view of Painted Canyon and the mapping area near the mouth of the canyon.

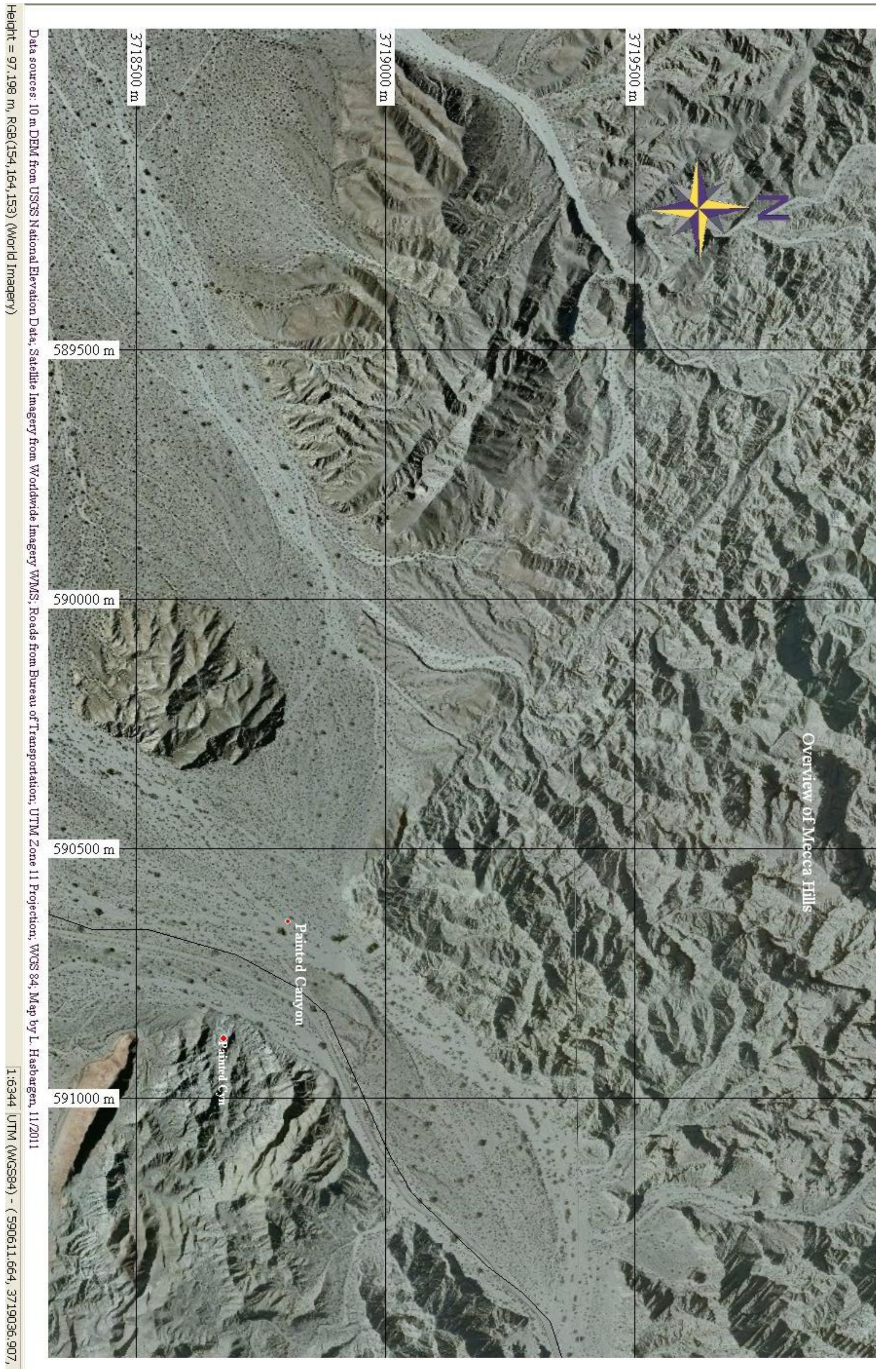


Figure. Closer aerial view of Painted Canyon and the mapping area.

Figure. Shaded relief of Painted Canyon and the mapping area near the mouth of the canyon.

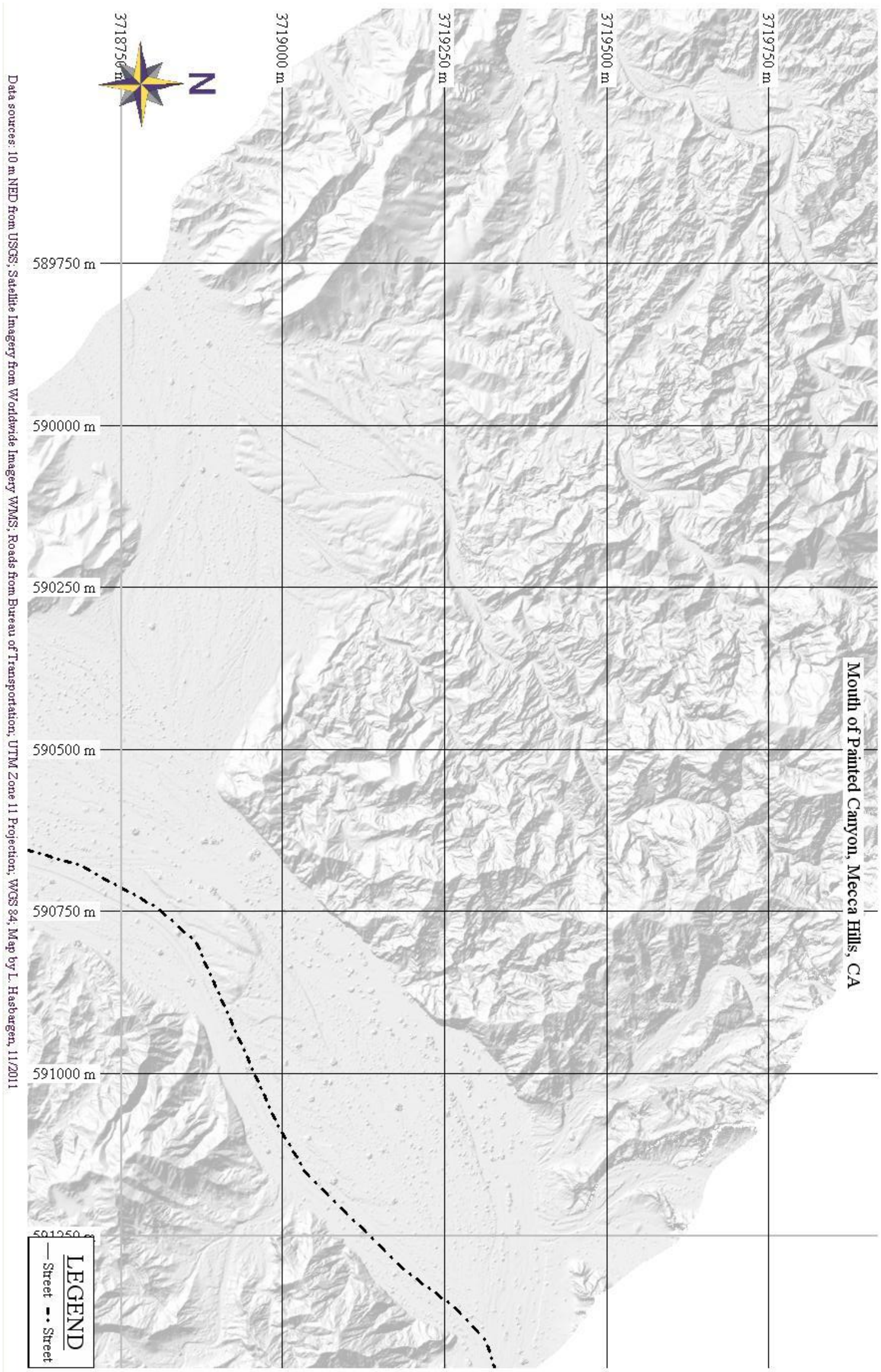


Figure. Shaded relief of Painted Canyon and the mapping area

Figure. Contoured Topography of Painted Canyon and the mapping area near the mouth of the canyon.

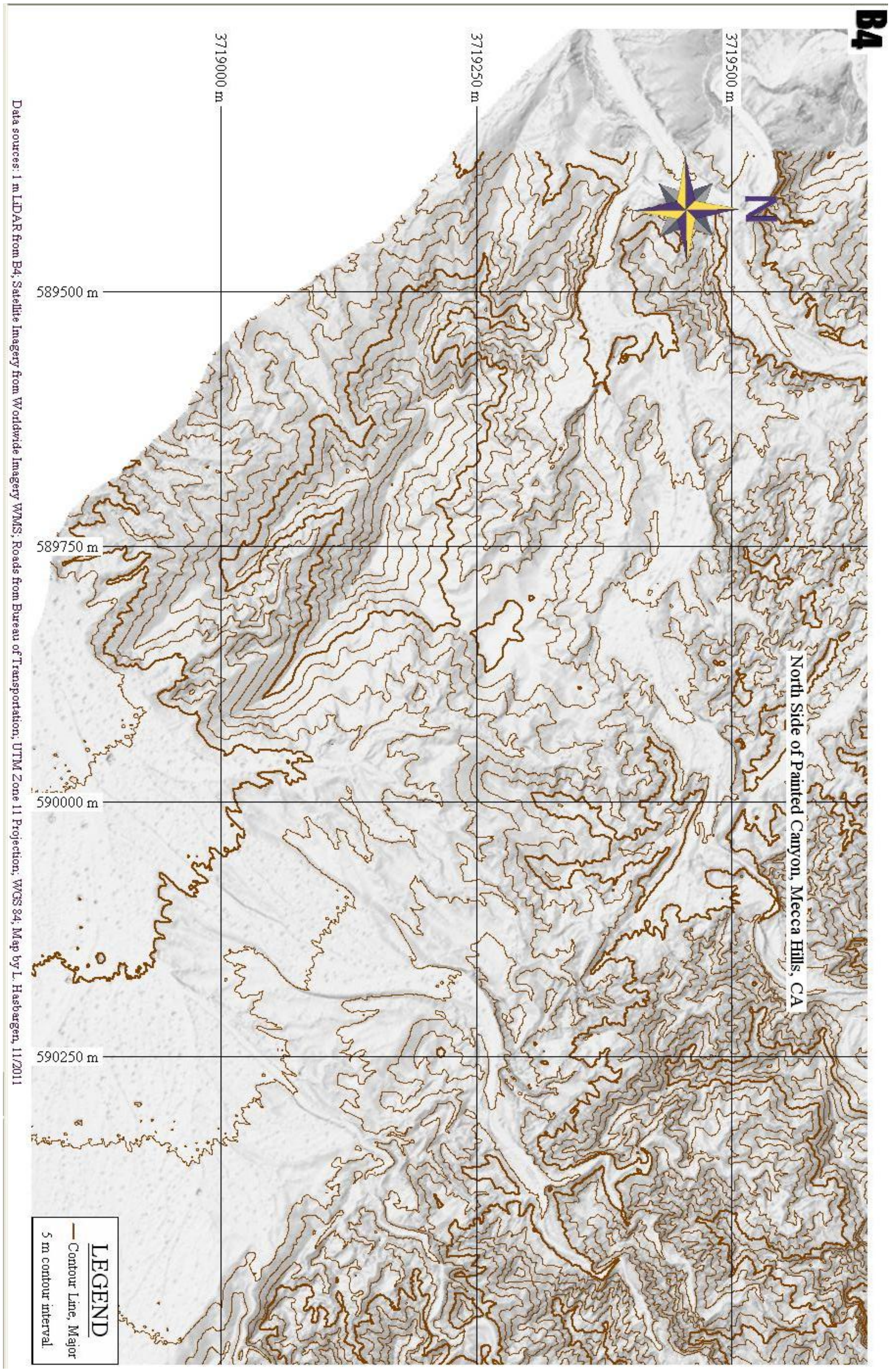


Figure. Topography of Painted Canyon and the mapping area

Figure. Contoured Topography of Painted Canyon and the mapping area on the south side in SkeletonCanyon.

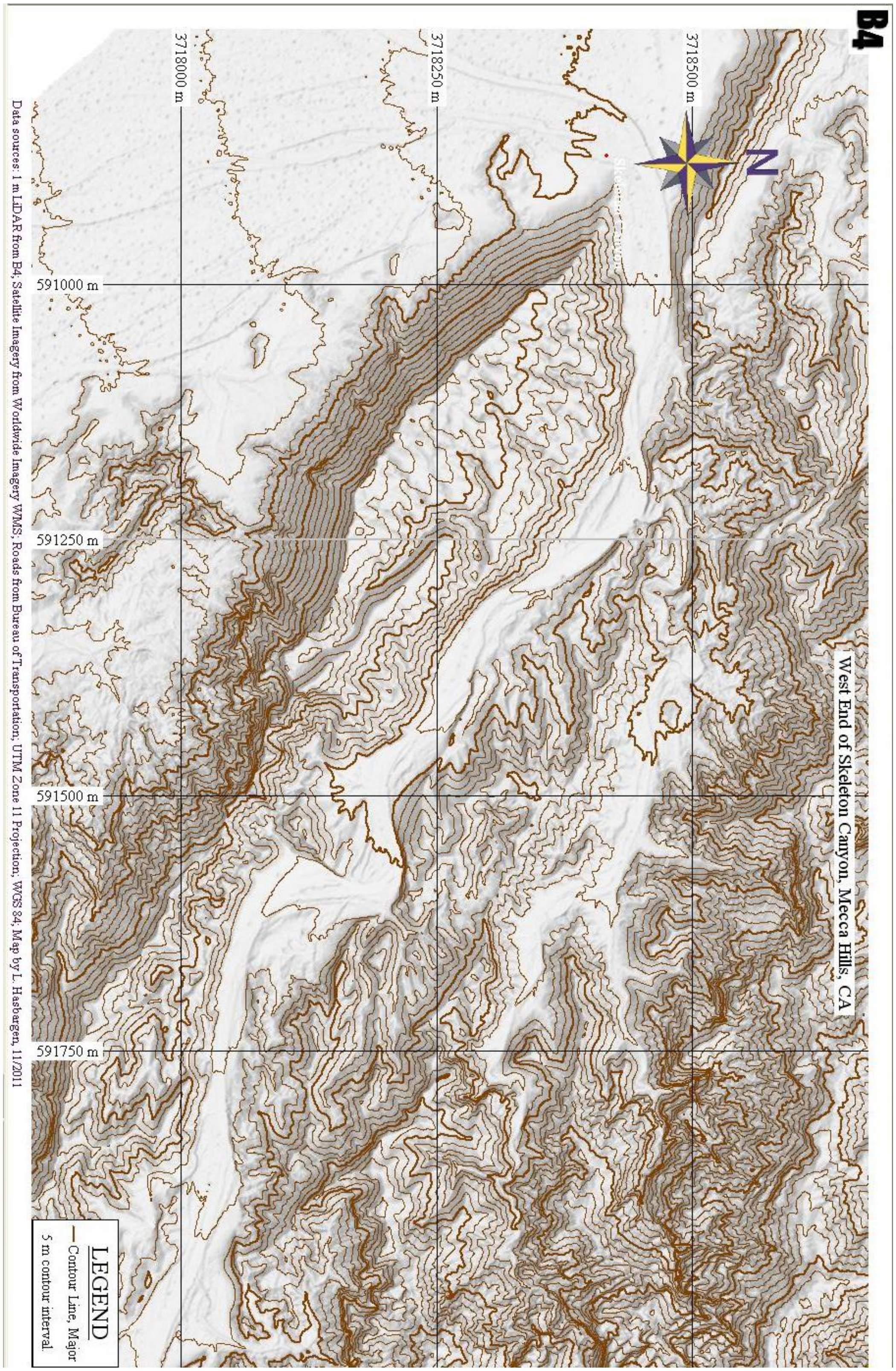


Figure. Topography of west end Skeleton Canyon and the mapping area

Figure. Topography of the mapping area the middle portion of SkeletonCanyon (south of Painted Canyon).

Figure. Topography of the middle portion of Skeleton Canyon, for mapping.

Figure. Topography of southwest side of Painted Canyon and the mapping area .

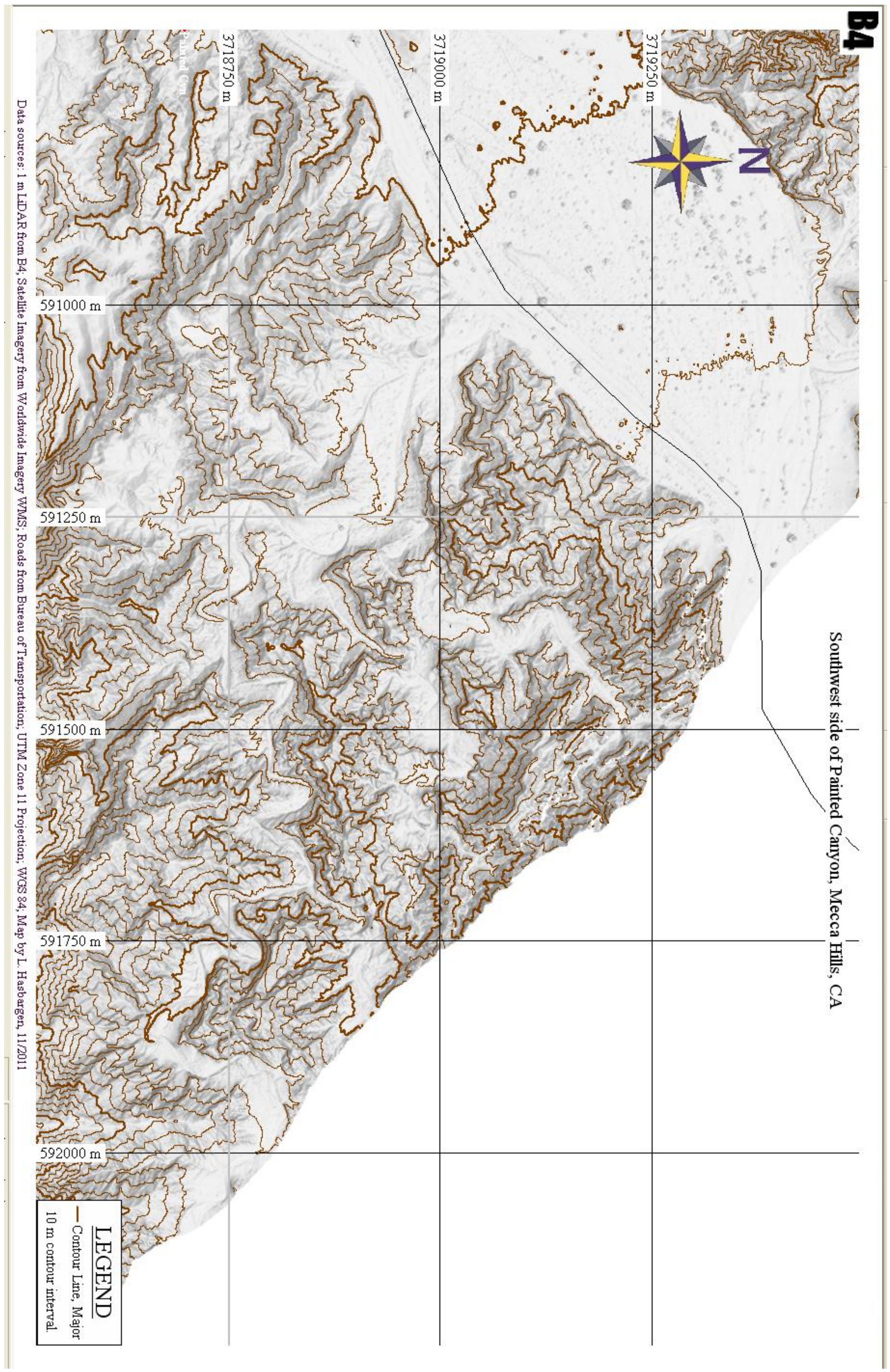


Figure. Topography of southwest side of Painted Canyon and the mapping area

Figure. Aerial imagery and faults mapped by USGS (2009) upper section of Painted Canyon and Ladder Canyon.

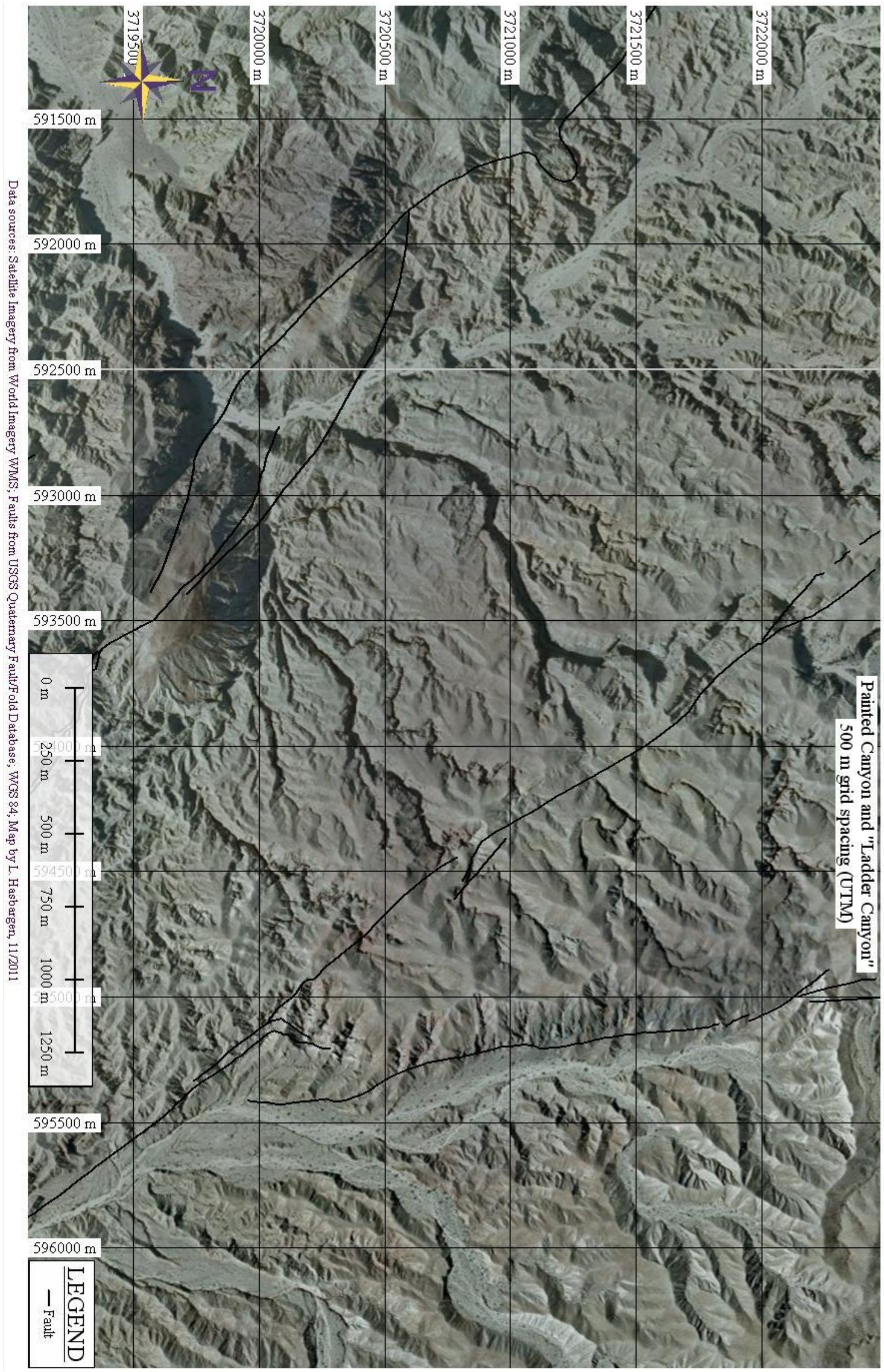


Figure. Aerial imagery and faults upper section of Painted Canyon and Ladder Canyon.

Day 6 Mud Volcano, Imperial Dunes and Fossil Canyon

This day will require some driving time. We will pack up camp, and head south around the Salton Sea through the Imperial Valley, a major agricultural region in the US. Our first stop will be near the geothermal zone along the south end of the Sea, marked by hot springs and volcanic plugs of obsidian, clear signs of young volcanism in this part of the rift. Thick accumulations of young (Plio-Pleistocene) sediment have filled the trough here to a few km depth, and Quaternary intrusions have warmed the sediments sufficiently for greenschist facies metamorphic conditions. As you might imagine, sediment loading below sea level coupled with faulting and high geothermal heat flow could drive fluid circulation. Our first stop takes a look at mud volcanoes, a symptom of the above conditions. Apparently, there is a carbonate layer being dissolved at depth, and it's the source of the gas at the seeps.

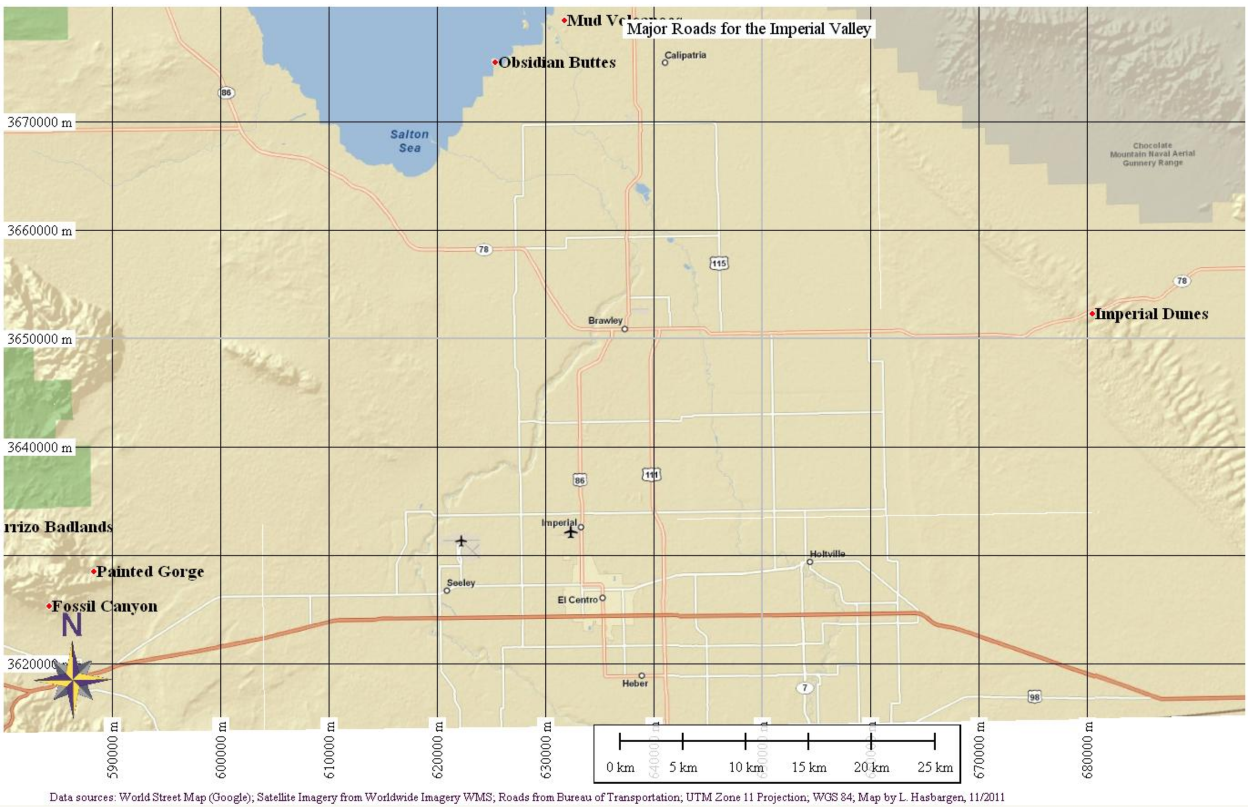


Figure. Road map around southern Salton Sea.

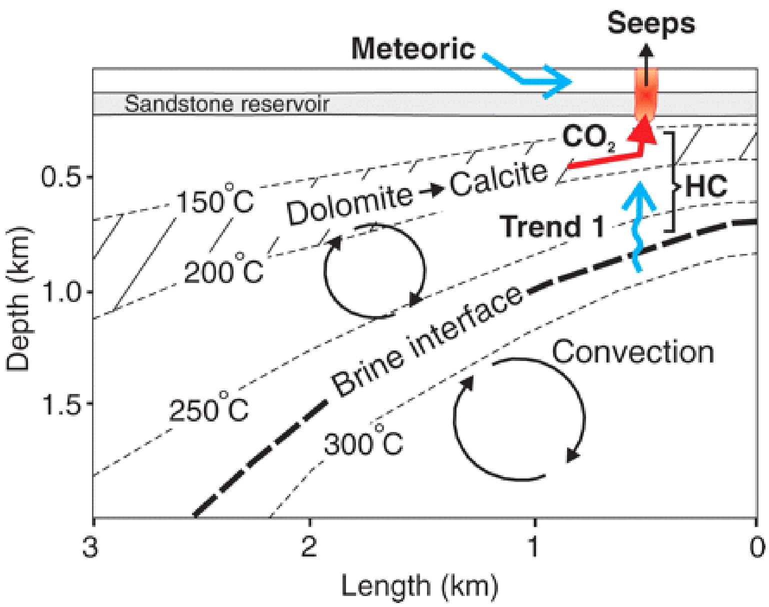


Figure. “**Schematic cross section of Salton Sea geothermal system**, showing location of Davis-Schrimpf seep field in red. Seeps are driven by CO_2 released from decarbonation reactions within 150–200 °C interval. Temperature contours and position of interface between deep highly saline brines and shallow brines are based on Williams (1997). Trend 1 waters have component of deep saline brines mixed with low- to moderate-salinity surface waters. Trend 2 waters have shallow origin.” (from Figure 5, in Svenson et al., 2007).

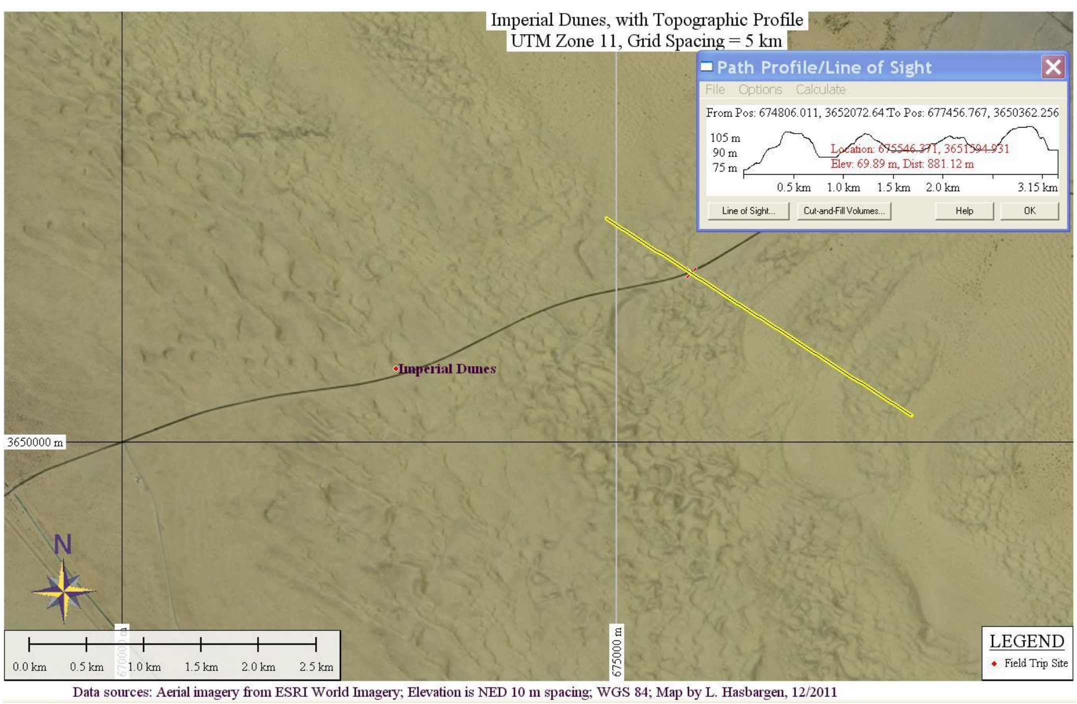


Figure. Imperial Dunes (aka, Algodones Dunes) along Highway 78, with topographic profile.

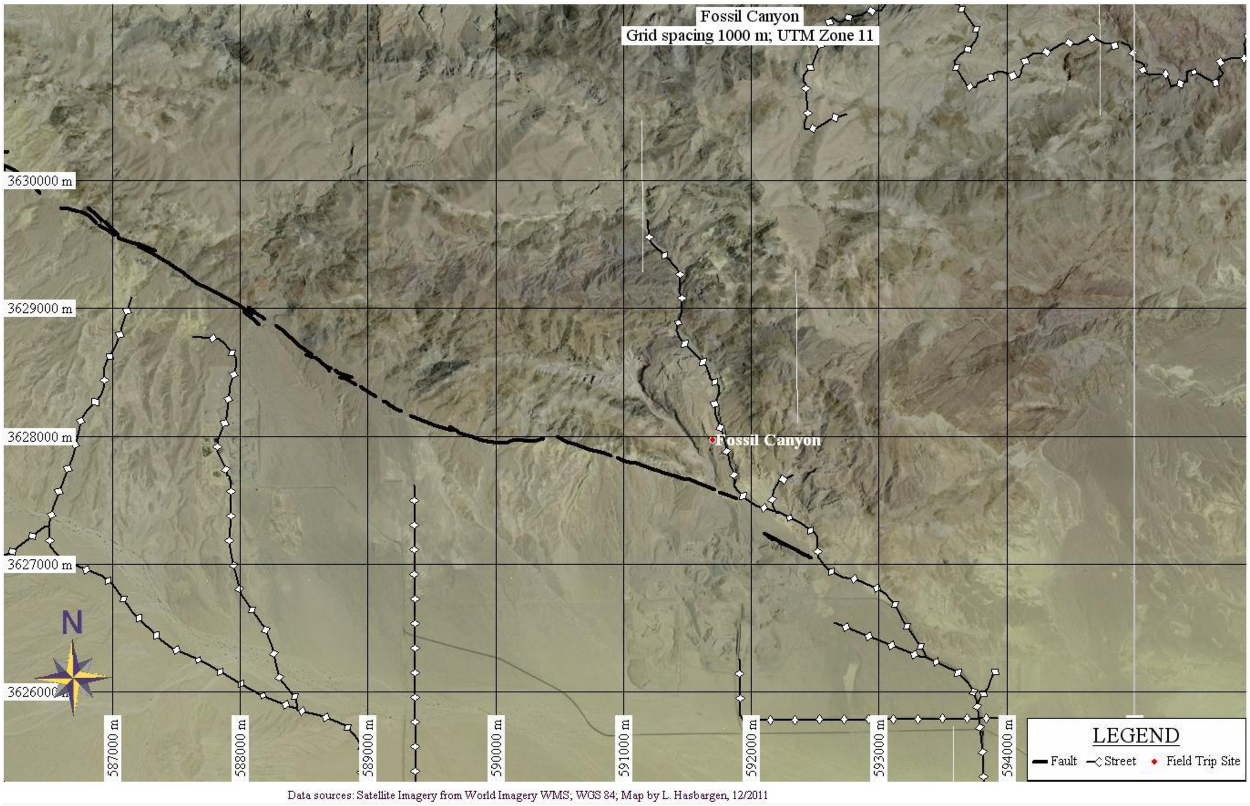


Figure. Aerial view of Fossil Canyon turnoff from Ocotillo Wells. Dark black lines are Quaternary faults.

At Fossil Canyon, we will get a definitive statement about the character of the depositional environment! Fossil Canyon drains the Coyote Mountains, which consist of over 1400 m of metasedimentary rocks including schist and marble, and these are capped by volcanic and sedimentary strata of Miocene age. Exposures of the late Miocene (or early Pliocene?) Imperial Formation are plentiful in Fossil Canyon, and represent the last most northern marine excursion of the ancestral Gulf of California before siliciclastics delivered by the Colorado River caused the shoreline to regress south. Marine invertebrates are common in the Imperial Formation, and include clams, snails, corals, and echinoderms. Other invertebrates such as sponges, bryozoans, brachiopods, foraminifers, and crustaceans are present but they are rare. Most of the fossils are commonly preserved as molds. This means that most of the original shell material has been dissolved and only an internal or external impression of the fossil is available. Many of fossils present in the Imperial Formation are living today along the California coast, Baja California Sur, the Gulf of California, and the Panamic region of the eastern Pacific. Some of these species in the Gulf California are known only from the Caribbean. How is it possible to have Caribbean species living in the Gulf of California?

We will need to leave in time to get to our new campsite at Agua Caliente (yes, that means hot spring!). Along the way, we'll get an overview of the Carrizo Badlands flanking the Coyote Mountains, and we'll see some recent fault scarps on the south side of the highway.

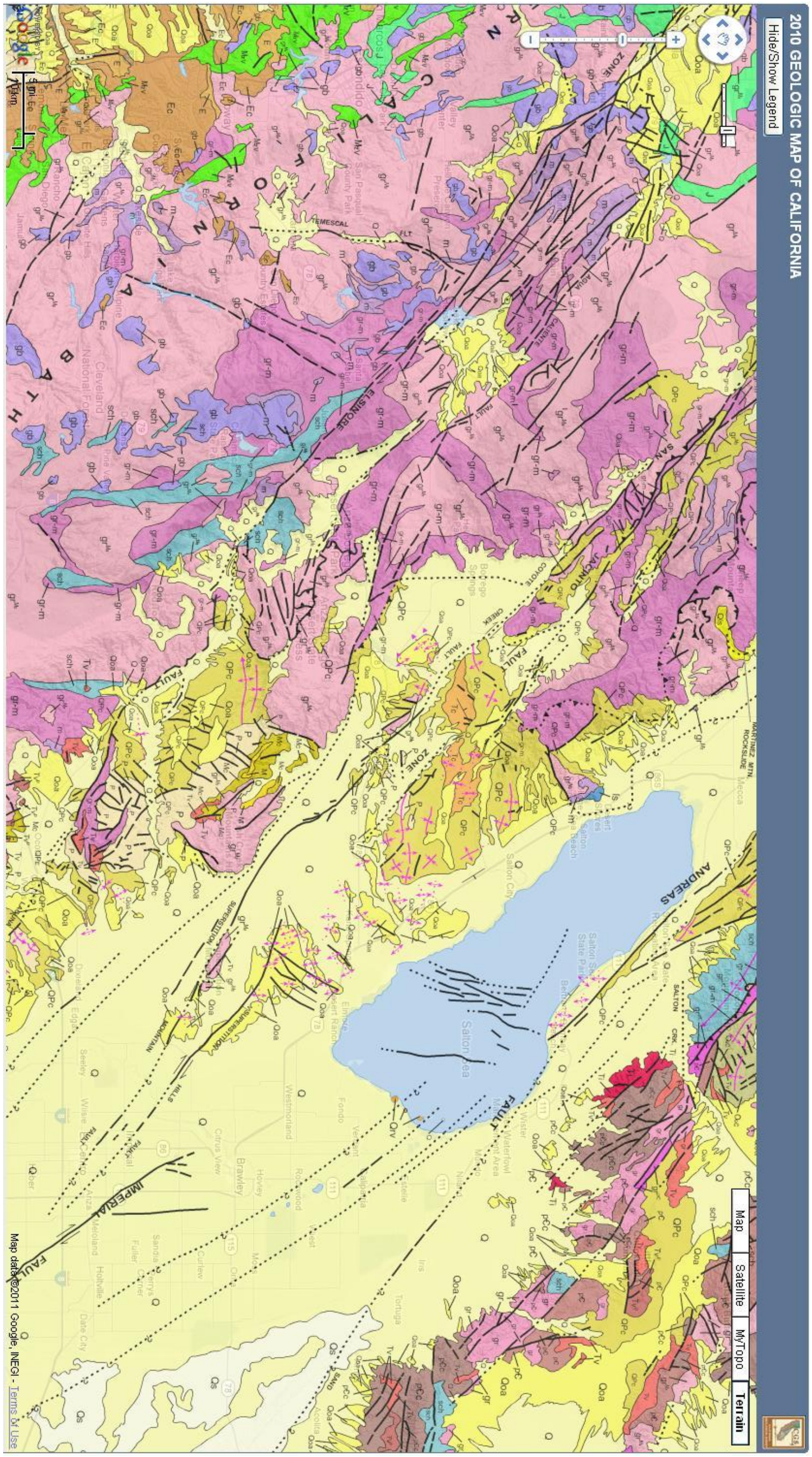


Figure. Geologic map of the southern end of Salton Sea, providing an overview of tectonic and lithologic features. Geology courtesy of California Geological Survery.

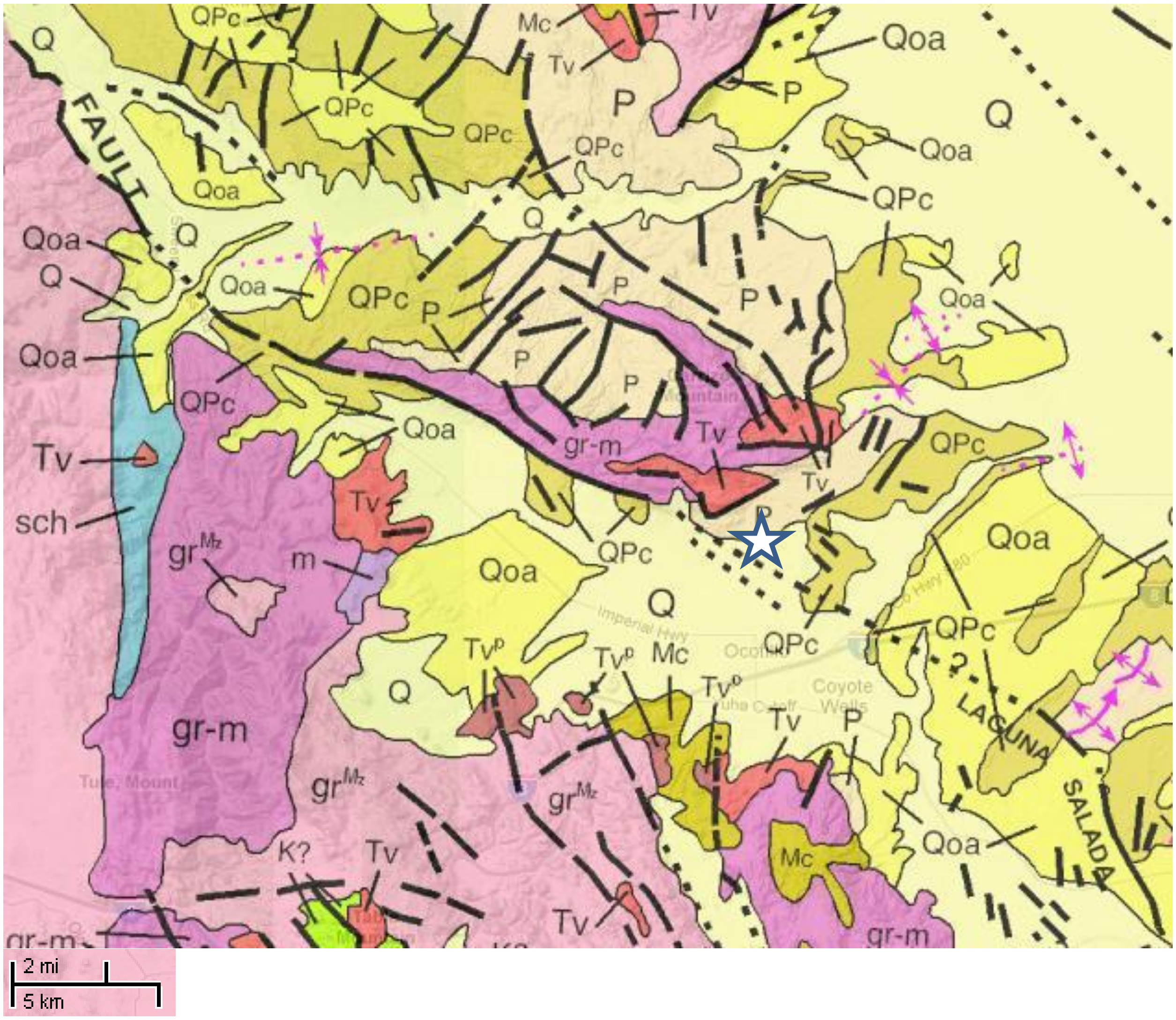


Figure. Generalized geology of southwestern Anza-Borrego area, including Fossil Canyon (star), and Carrizo badlands. Geology courtesy of California Geological Survery.

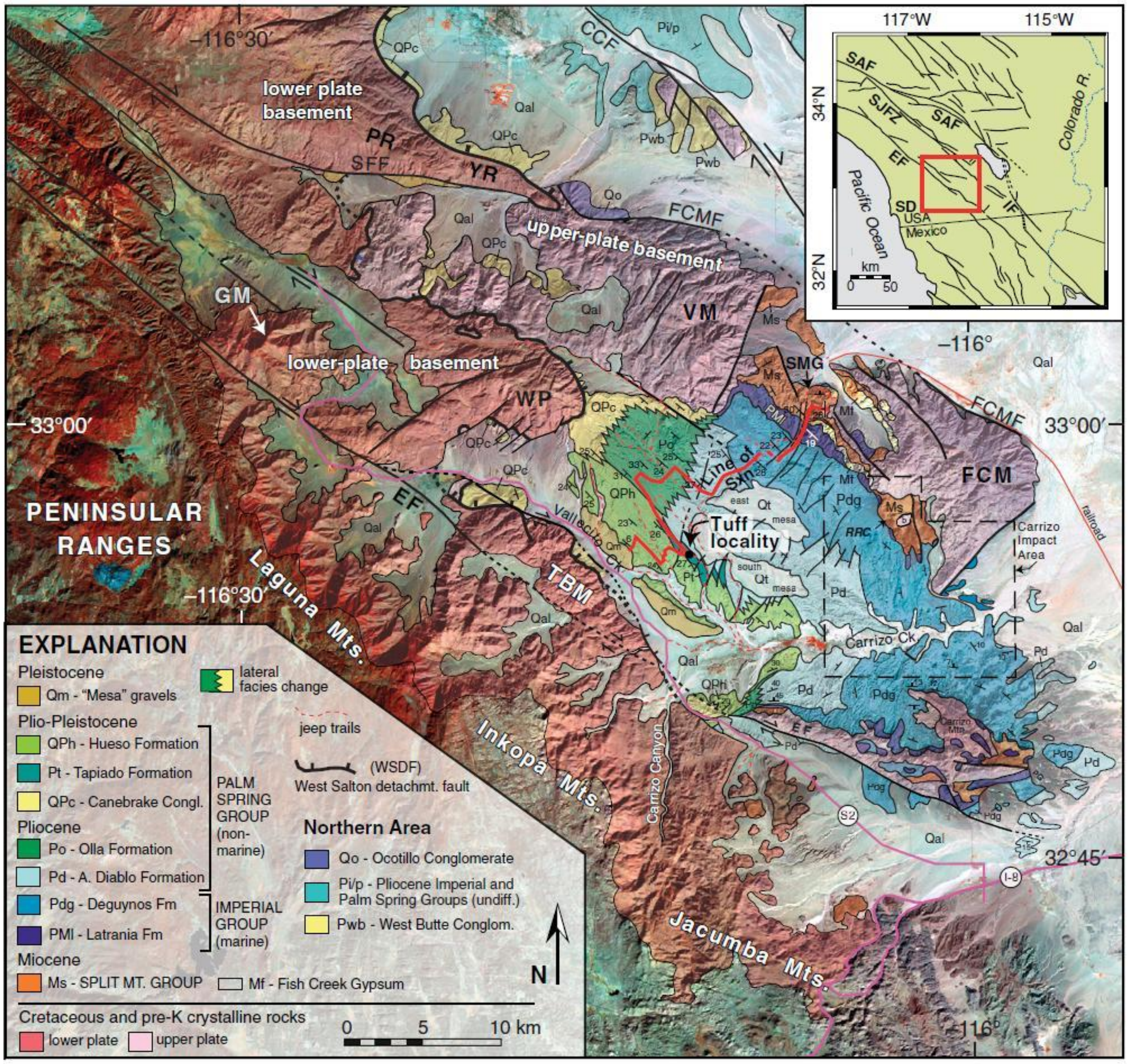


Figure 2. Geologic map of the Fish Creek–Vallecito basin and surrounding area, modified from Winker (1987), Winker and Kidwell (1996), Dibblee (1996), Axen and Fletcher (1998), Kairouz (2005), G. Axen (2008, personal commun.), and Steely (2006). CCF—Coyote Creek fault; FCM—Fish Creek Mountains; FCMF—Fish Creek Mountains fault; GM—Granite Mountain; PR—Pinyon Ridge; RRC—Red Rock Canyon; SFF—San Felipe fault; SMG—Split Mountain Gorge; TBM—Tierra Blanca Mountains; VM—Vallecito Mountains; YR—Yaqui Ridge; WP—Whale Peak.

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Figure. Geologic Map of Fish Creek-Vallecito basin, from Dorsey et al., 2011.

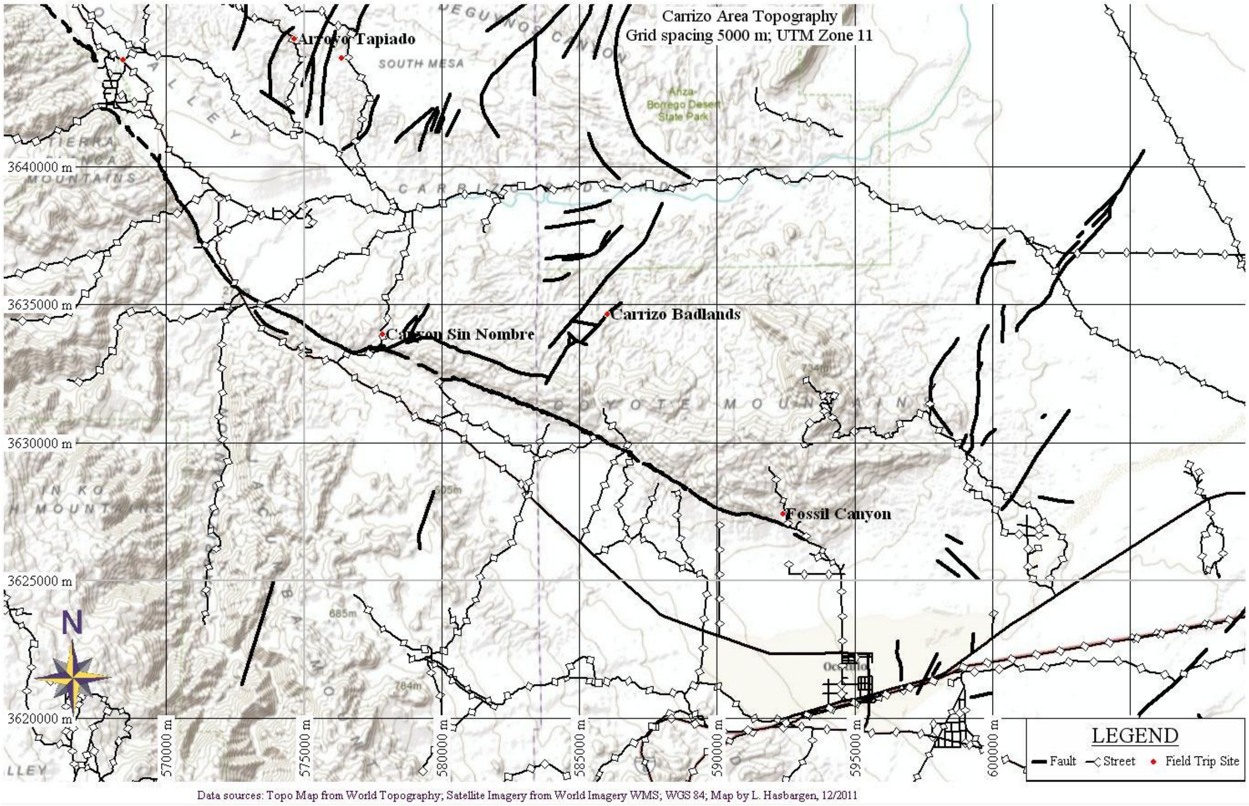


Figure. Topographic overview of Coyote Mountains and southern Anza Borrego Desert State Park. The fault on the south side of the Coyote Mountains is the southern extension of the Elsinore fault, which terminates in the Los Angeles basin.

Day 7 Arroyo Tapiado

This will be a day of exploration. We'll drive along the old Overland stage route to the turnoff for Arroyo Tapiado, where we will spend some time exploring the mud caves. Bring your hard hats and head lamps. We should get a good look at cuestas developed on gently dipping badlands stratigraphy en route.

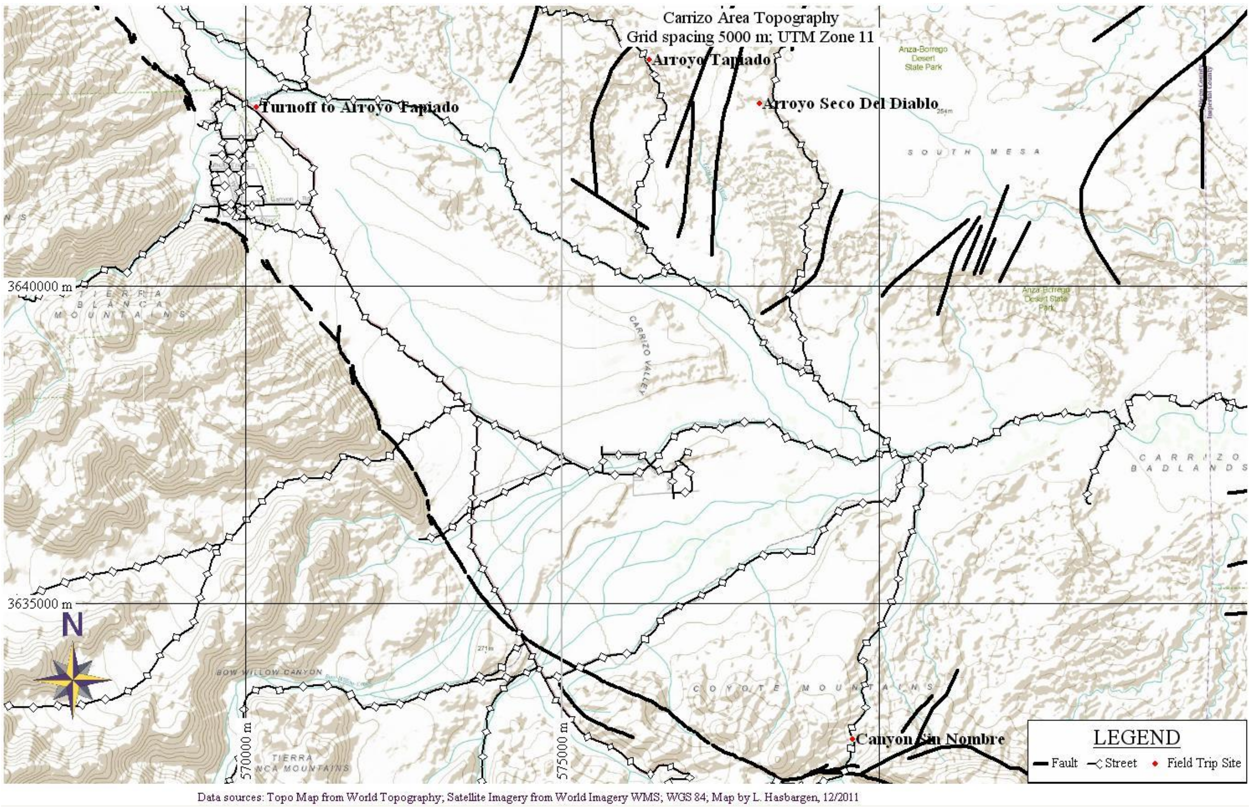


Figure. Route to Arroyo Tapiado Mud Caves. Take S2 to mile marker 43.Take the Palm Springs or Vallecito Wash exit (dirt road heading East). Follow Overland Stage Route to Arroyo Tapiado.

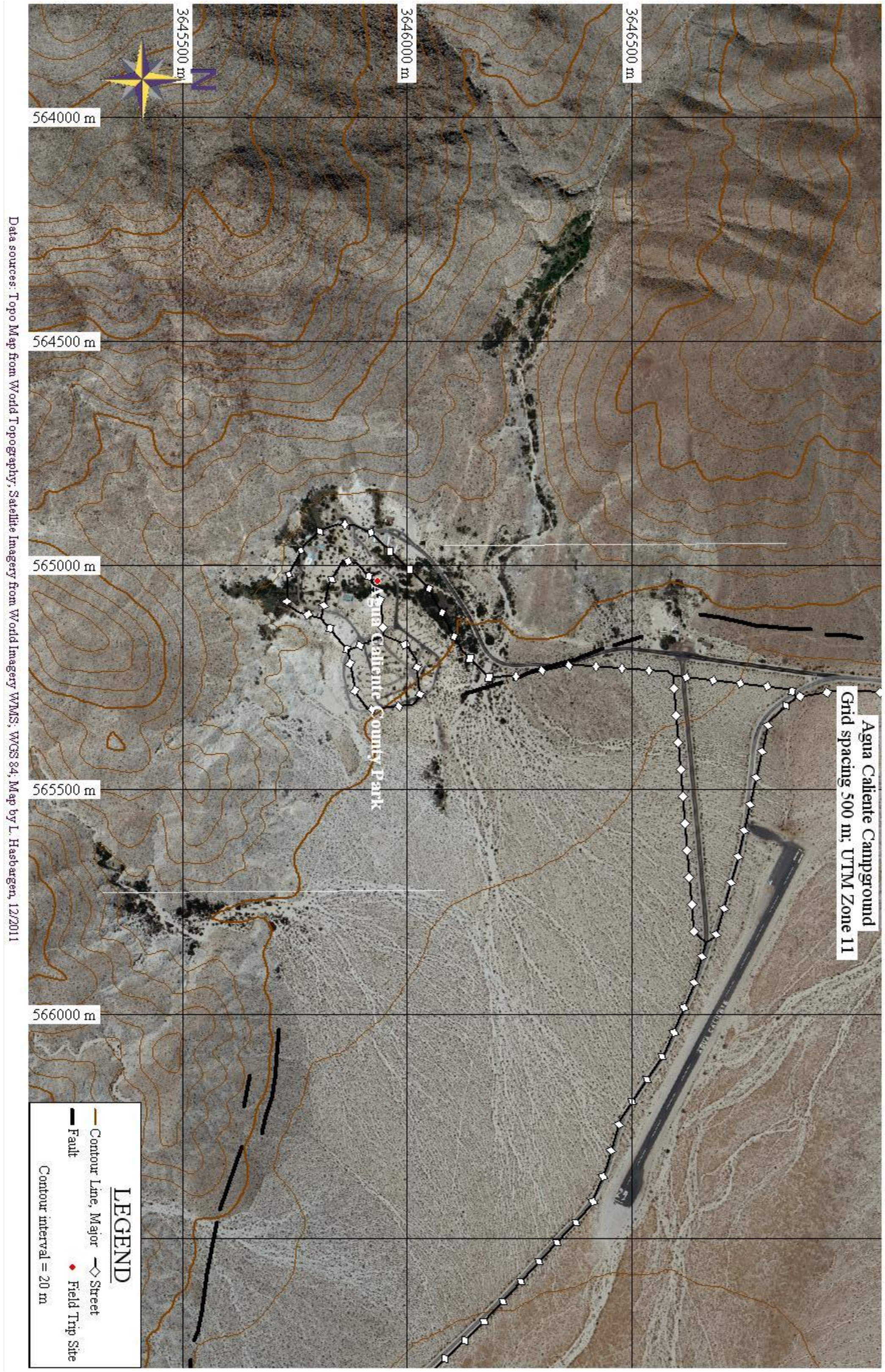
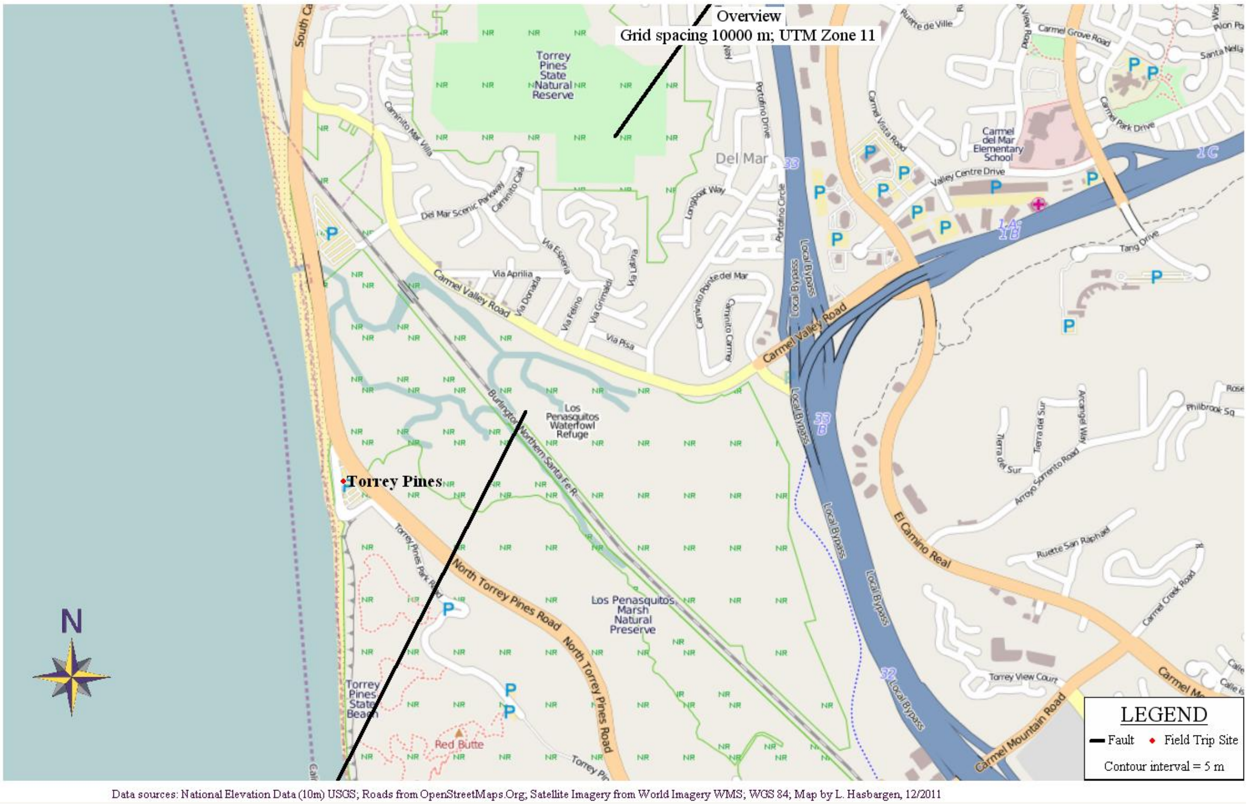


Figure. Aerial image of Agua Caliente campground.



Day 8 Torrey Pines State Beach. Eocene sediments. Faults. Fossils. Waves. Cliffs. Beach.

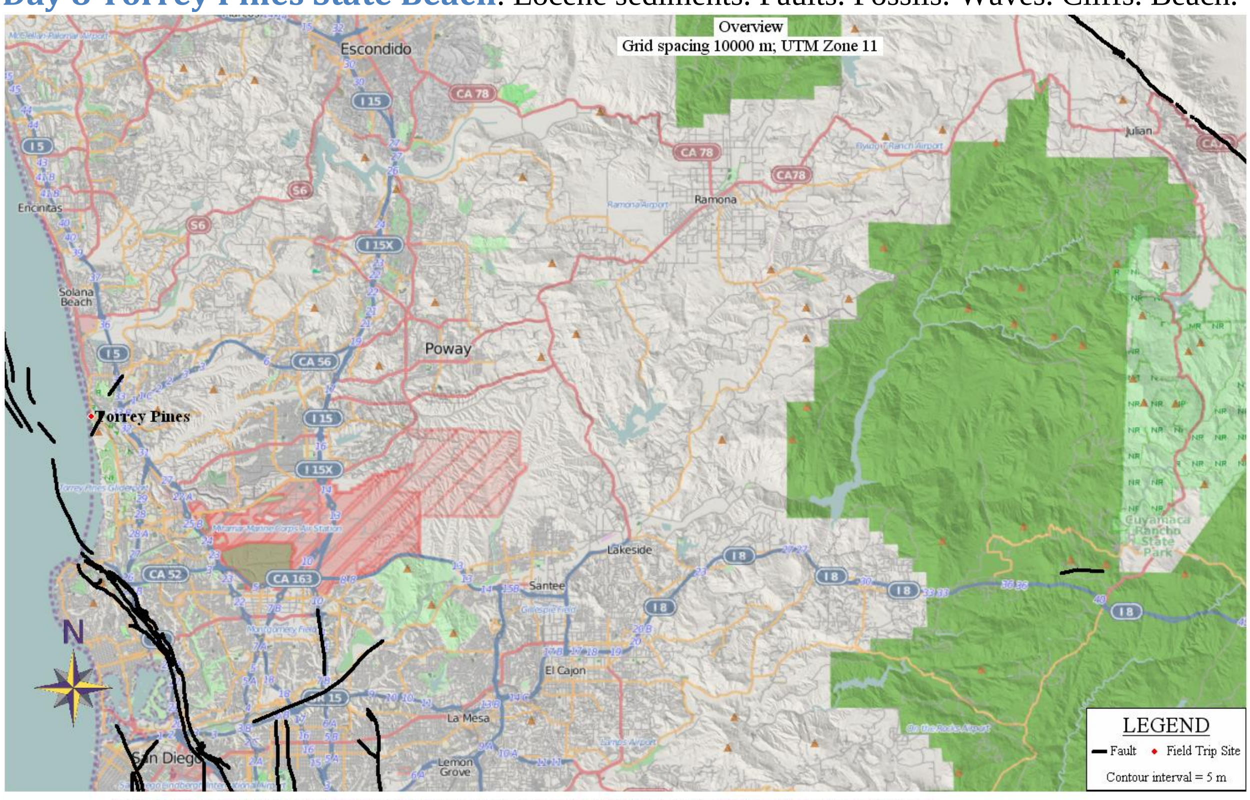


Figure. Directions to Torrey Pines. Take Hwy 78 to Ramona, then CA 56 to Torrey Pines.

From Agua Caliente Campgr CR-S2, 21.5 mi

Bear left onto CA-78, 11.3 mi
Keep straight onto CA-78 / CA-79 / Highway 78 / Main St, 7.0 mi

Keep straight onto CA-78 / Julian Rd, 15.4 mi

Keep straight onto CA-67 / Main St
Pass Mobil in 1.0 mi, 9.1 mi
Turn right onto Poway Rd / CR-S4, 2.7 mi

Turn right onto Espola Rd / CR-S5, 0.8 mi

Turn left onto Twin Peaks Rd 76 on the corner, 2.3 mi

Turn left onto Ted Williams Pkwy, 56, 2.5 mi
Road name changes to CA-56 / Ted Williams Pkwy, 9.2 mi

Take ramp right and follow signs for El Camino Real, 0.2 mi

Keep straight onto Carmel Valley Rd, Pass Shell in 0.2 mi, 1.8 mi

Turn left onto N Torrey Pines Rd, 0.8 mi

Turn right onto Torrey Pines Park Rd, 0.8 mi
Arrive at Torrey Pines State Beach, CA on the right
The last intersection is N Torrey Pines Rd

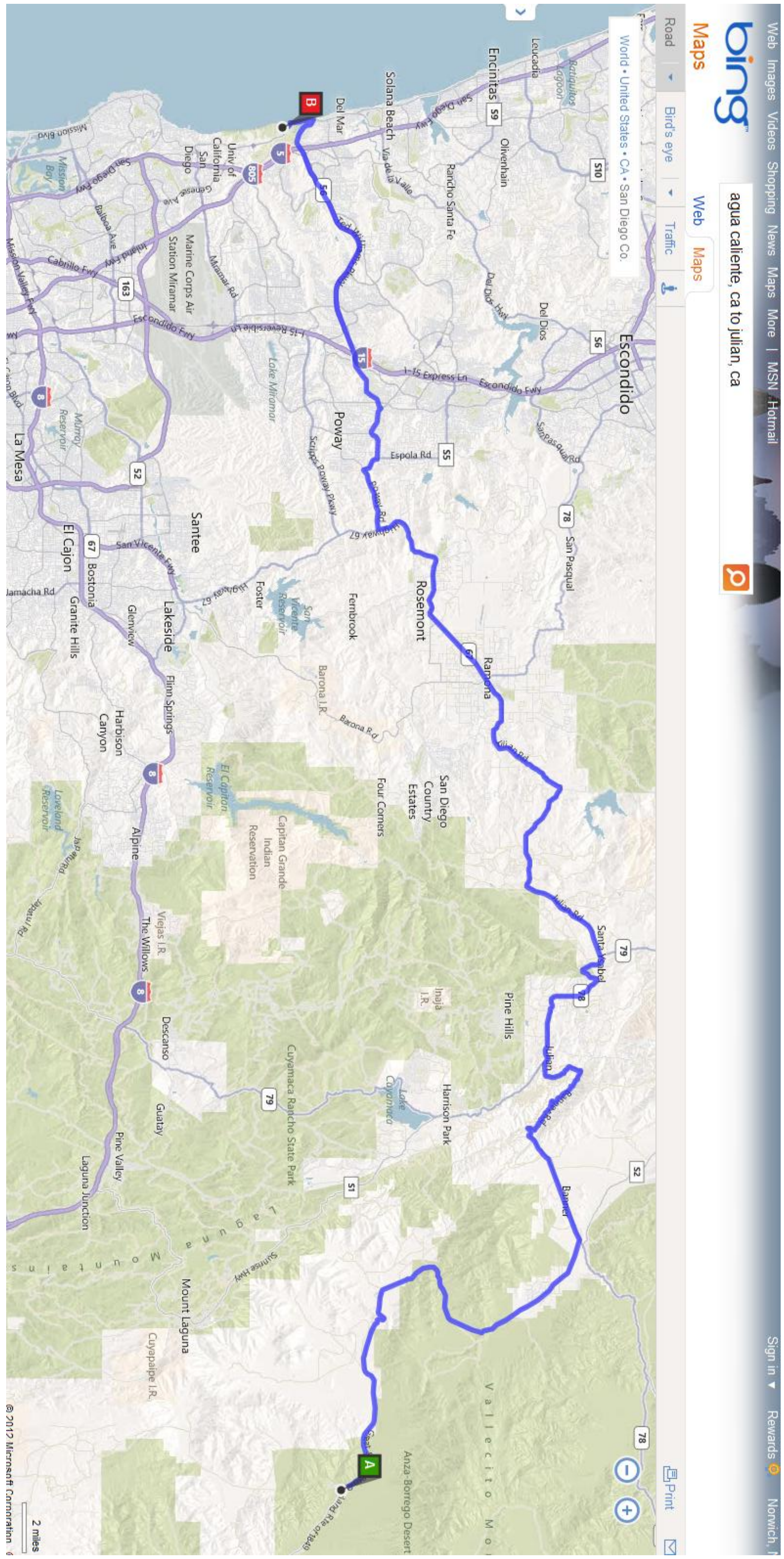


Figure. Road Map from Agua Caliente to Torrey Pines State Beach. Courtesy of Bing Maps. About 90 miles. http://www.torreypine.org/parks/ocean.html

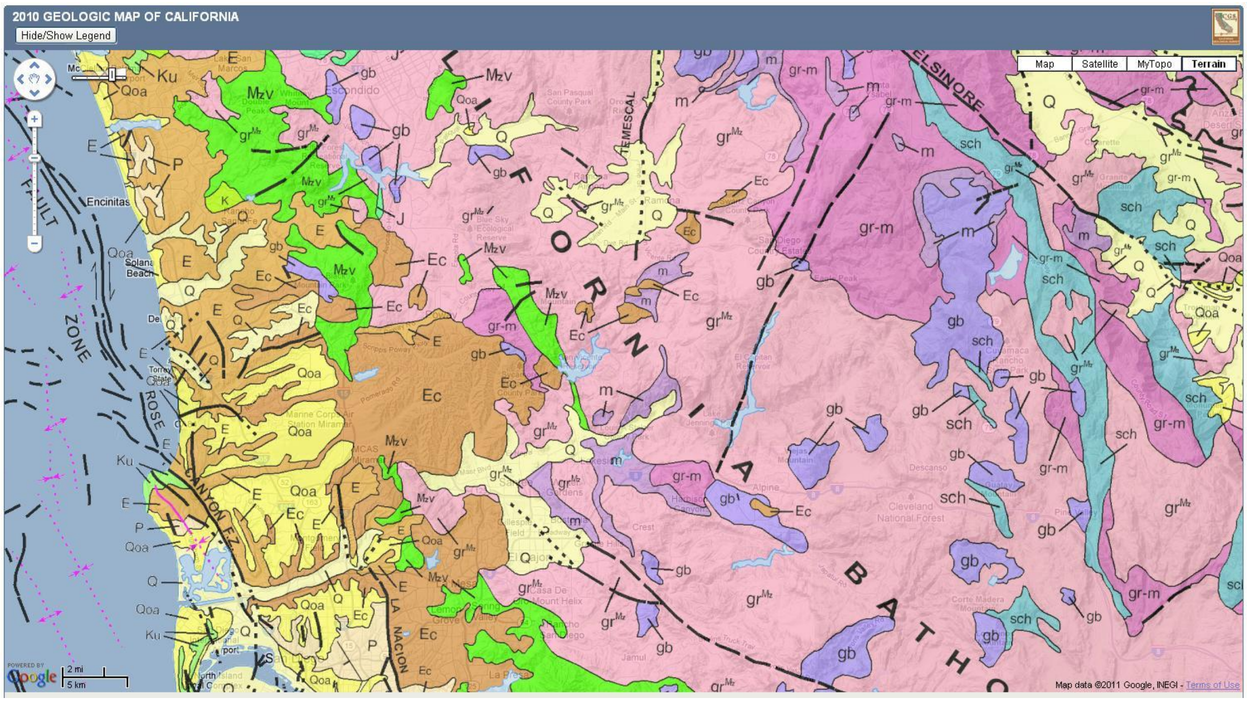


Figure. Geologic map of the San Diego area.

On our drive from Anza-Borrego to San Diego, we cross the Southern California Batholith, intruded during the Mesozoic era. Note the Eocene sedimentary strata pegged onto the western flank of the batholith, which in places overlie Mesozoic volcanic strata (the green units). We also make a drastic change in the ecology. We have been in the rain shadow the entire trip. On the west side, it's more moist, and strongly moderated by the cooling effects of the Pacific Ocean. San Diego may be the most temperate location in the lower 48 states.

Day 9 Borrego Springs area and Split Mountain

Our return from Torrey Pines will be to a new campground at Borrego Springs, in the north central portion of Anza-Borrego Desert State Park. In the morning, we will visit the Anza Borrego State Park center, then head off to Split Mountain. We'll first drive up through the gorge as a reconnaissance, then focus on individual locations. There will be excellent field sketching opportunities here, and we may do some geologic mapping as well.

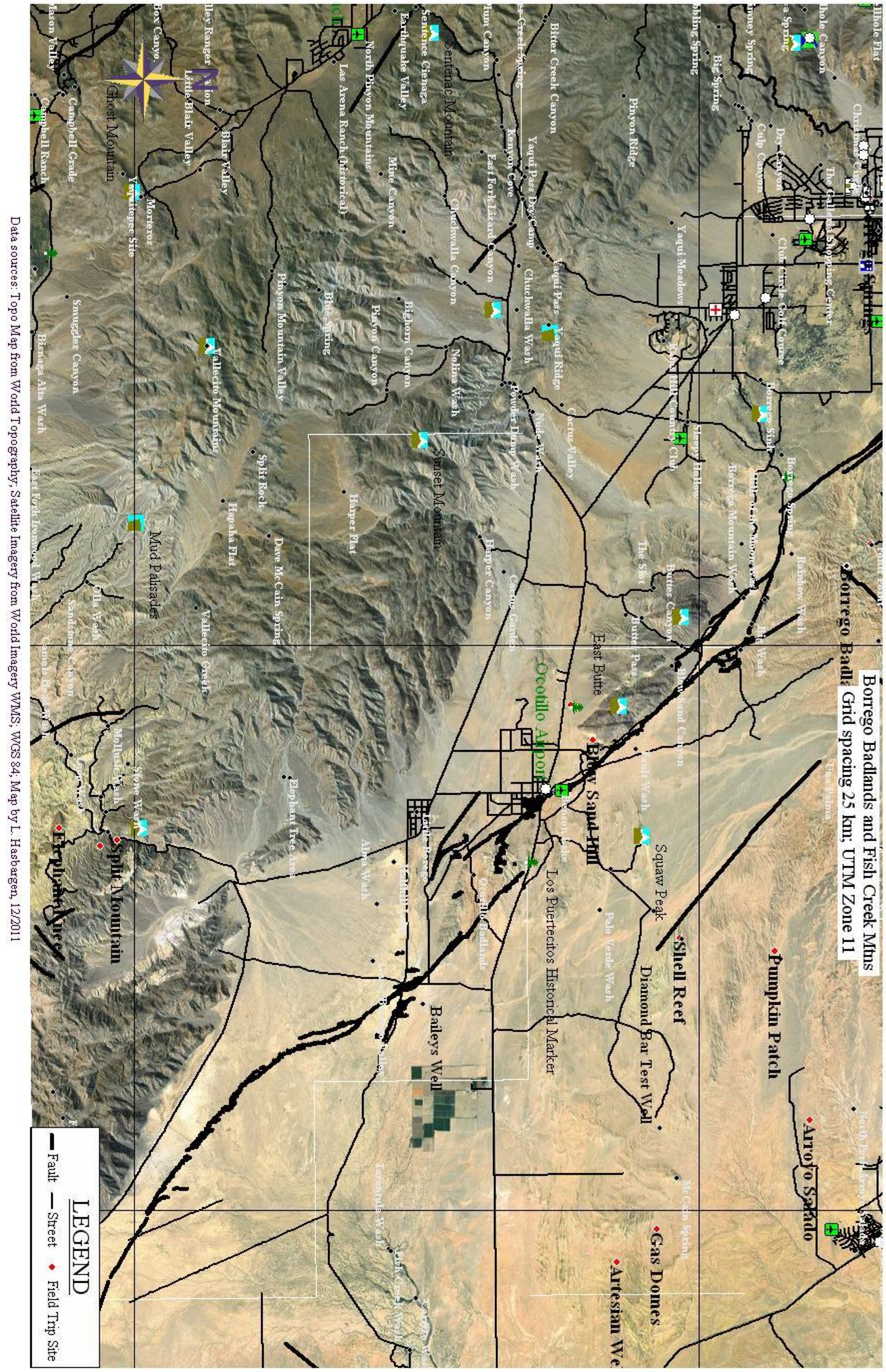


Figure. Aerial image of Borrego Badlands and Fish Creek Mountains (where resides Split Mountain).

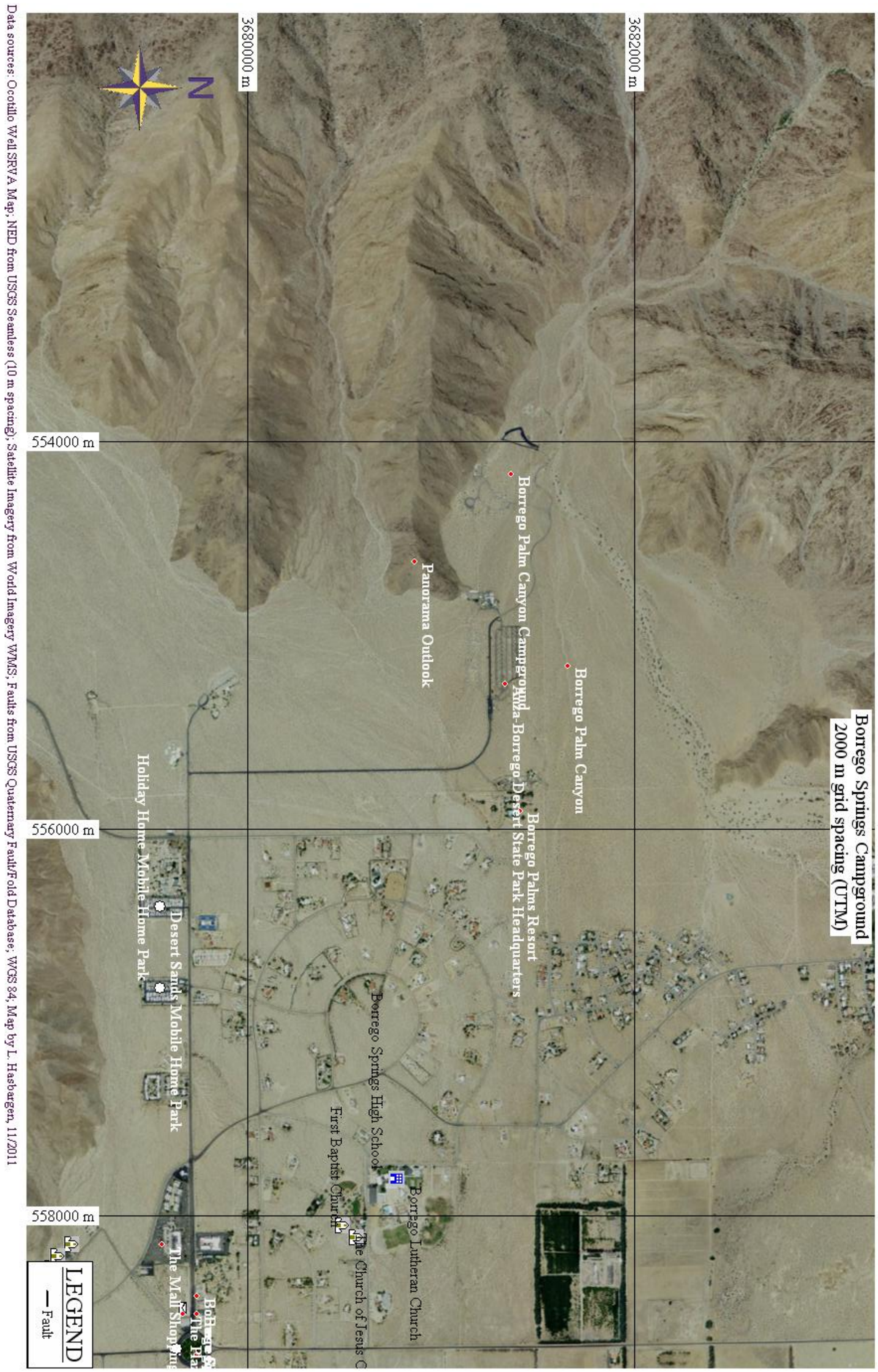
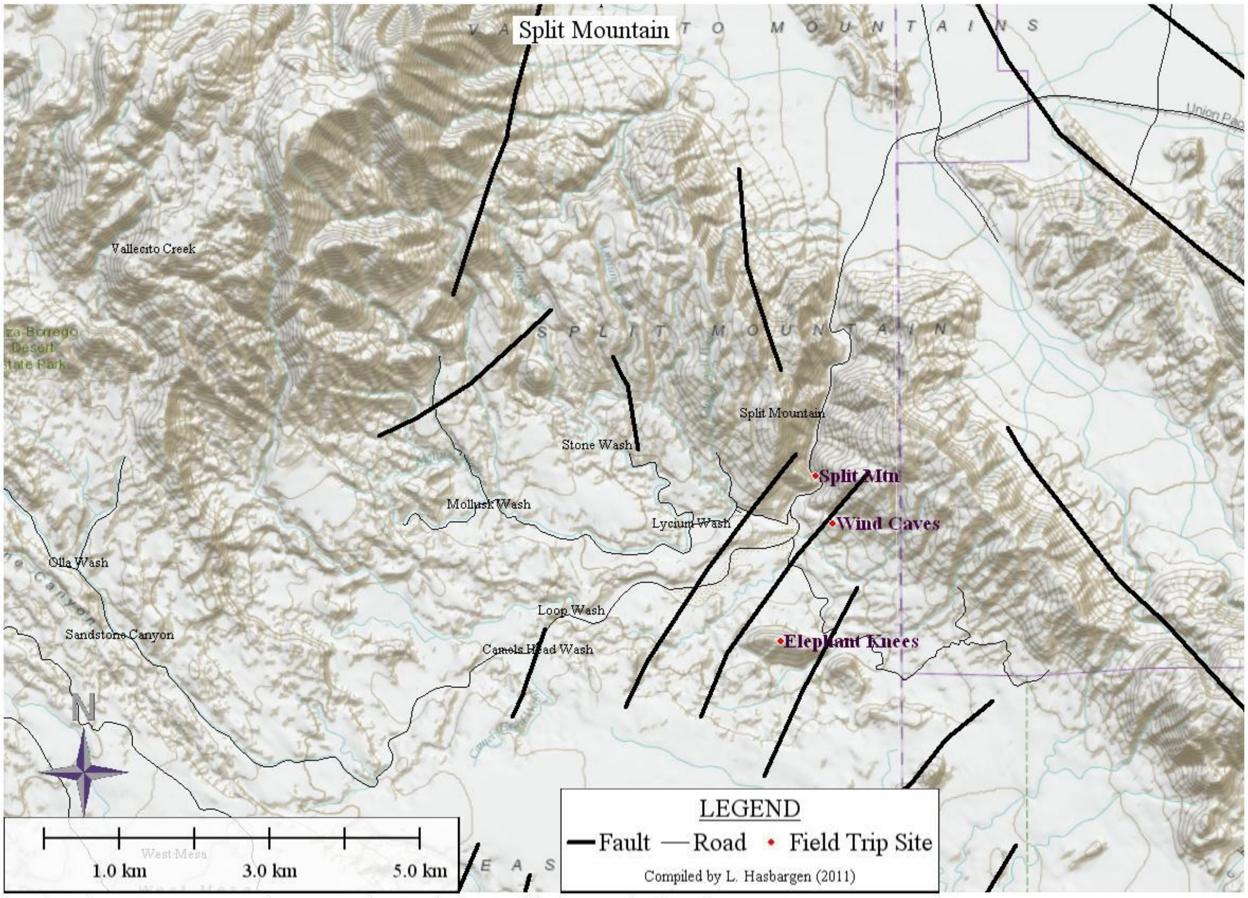


Figure. Aerial map of Borrego Springs and campground.



Elevation: NED 30 m; Faults: CA Faults Database; World Topography (ESRI); UTM Zone 11, WGS 84.

Figure. Topographic map of Split Mountain.

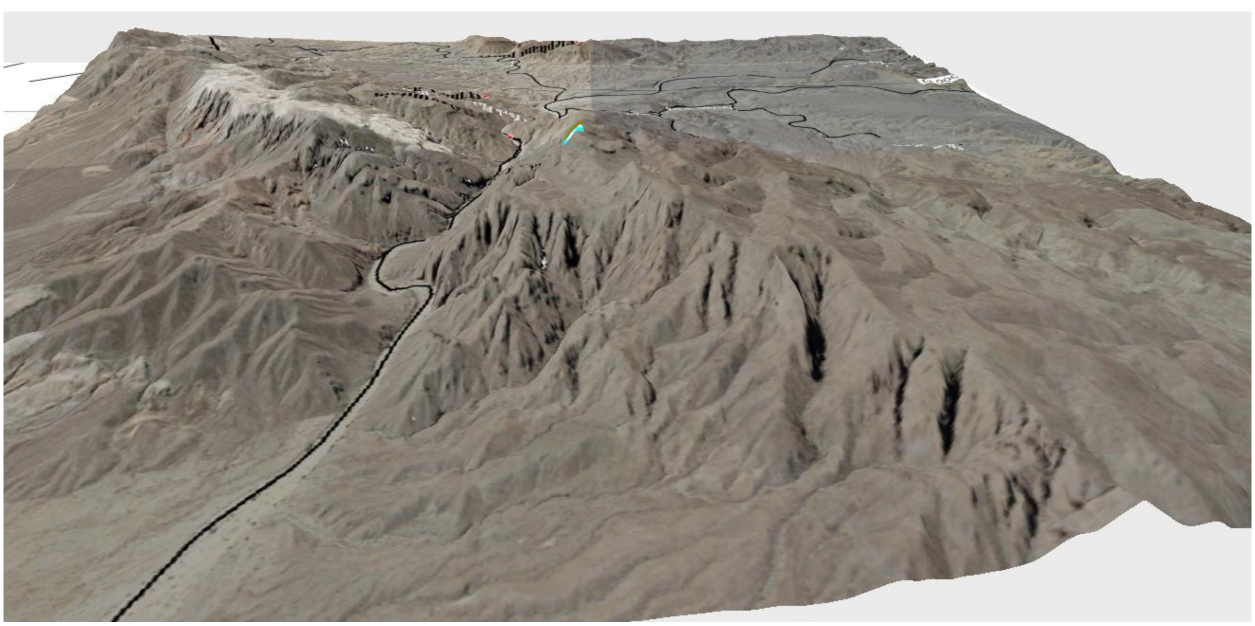


Figure . Perspective view south over Split Mountain in the Fish Creek Mountains.

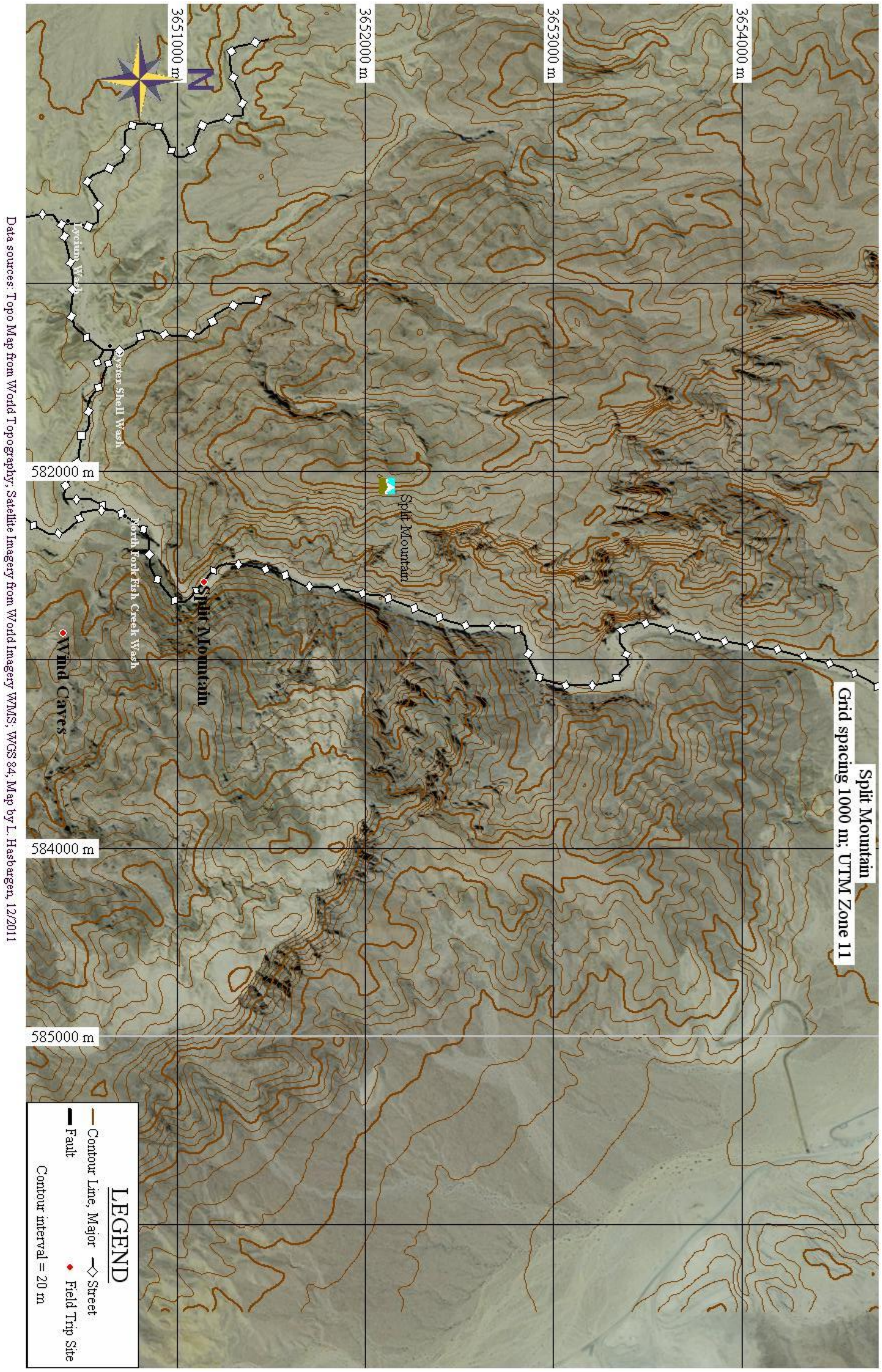


Figure. Aerial image with contours of Split Mountain.

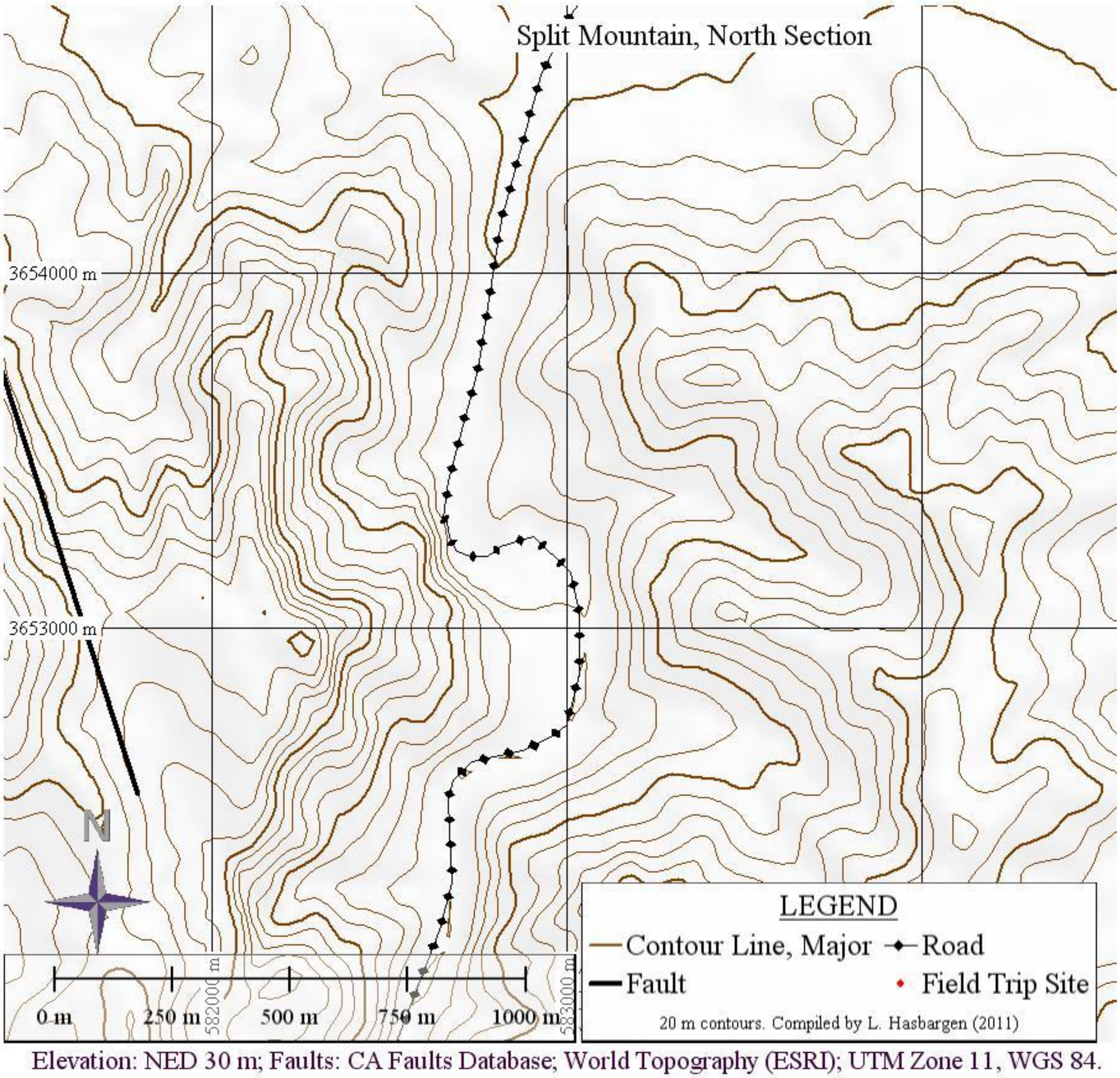
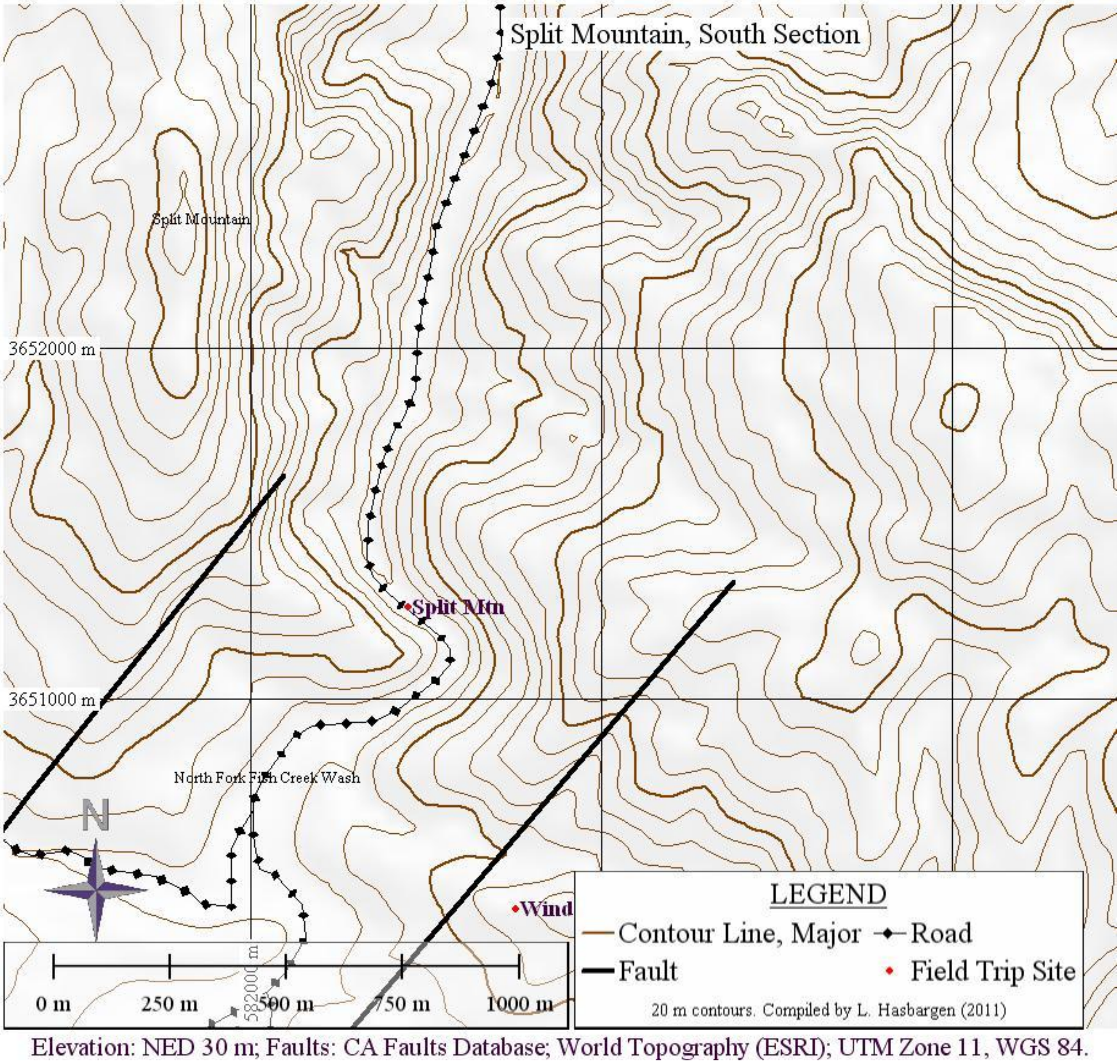


Figure Split Mountain, North. 20 m contour interval. 1000 m grid spacing.

Day 10 Return to Split Mountain Or Ocotillo Wells SRA

Depending on the features we get to see around Split Mountain, we may return for more investigation. If so, the topographic maps below can be used for base maps for geologic mapping.



Split Mountain, south section. 20 m contours.

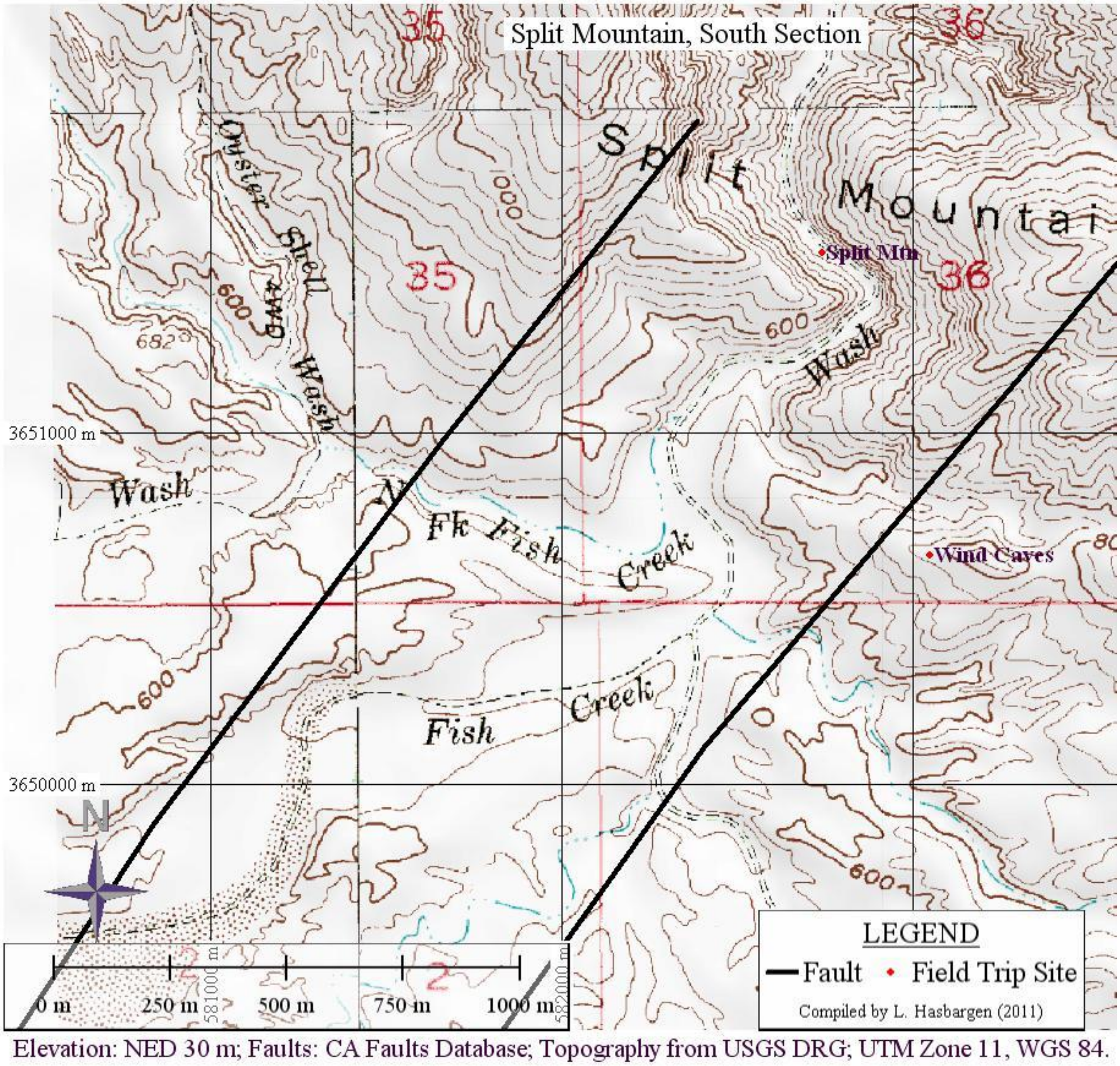


Figure. Split Mountain at the entrance of Fish Creek. 40 ft. contour interval.

Day 10 Alternative: Ocotillo Wells State Recreational Vehicle Area.

This area offers a view into the deeper section of the sediments in the Borrego Badlands region, as well as numerous fault scarps and deformed sedimentary units. Pumpkin Patch with its outlandish concretions is out in this area, as well as a natural gas seep, and oyster reefs.

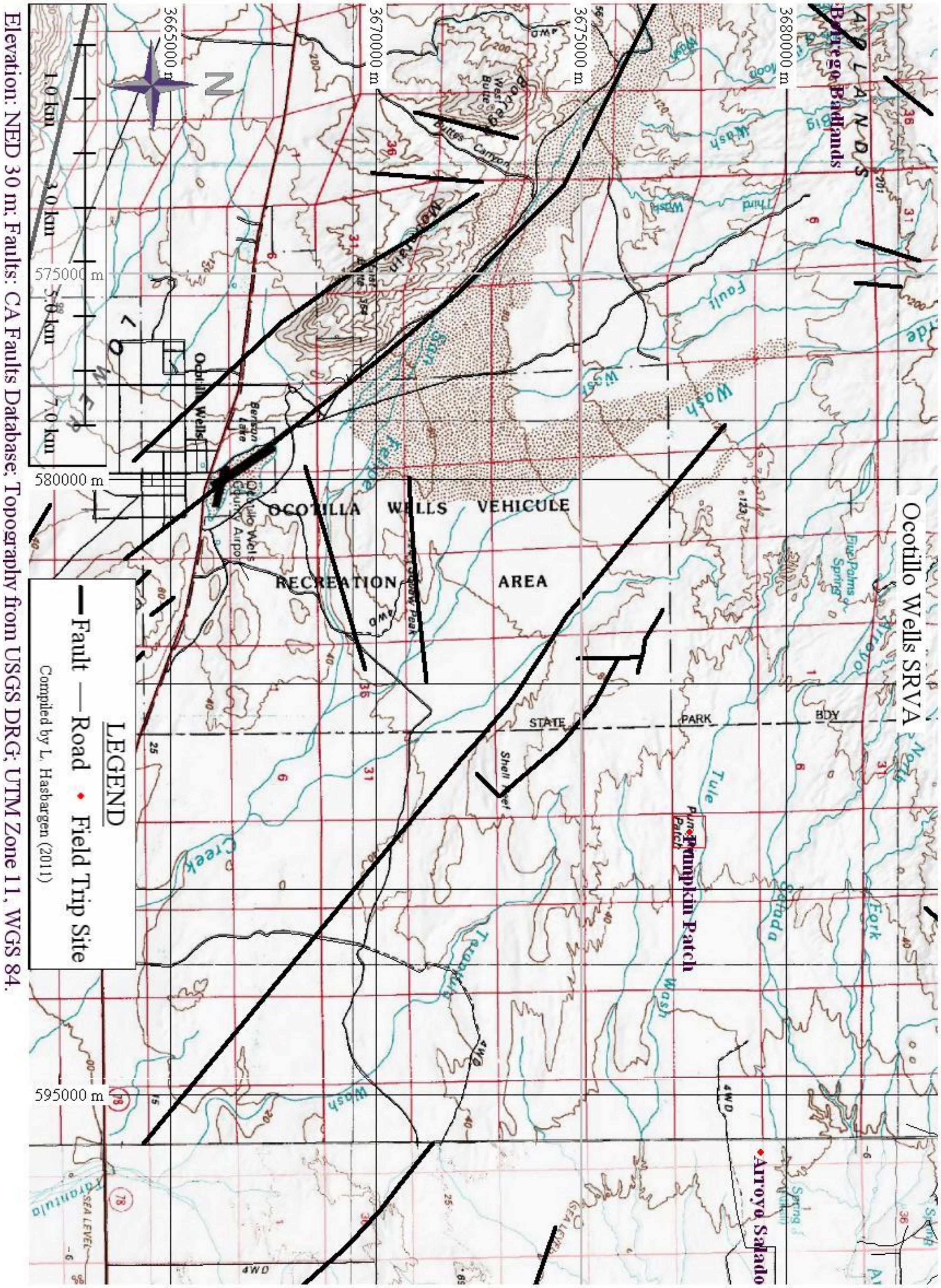


Figure Ocotillo Wells SRVA. Red squares are 1 mi square sections. UTM grid = 5 km.

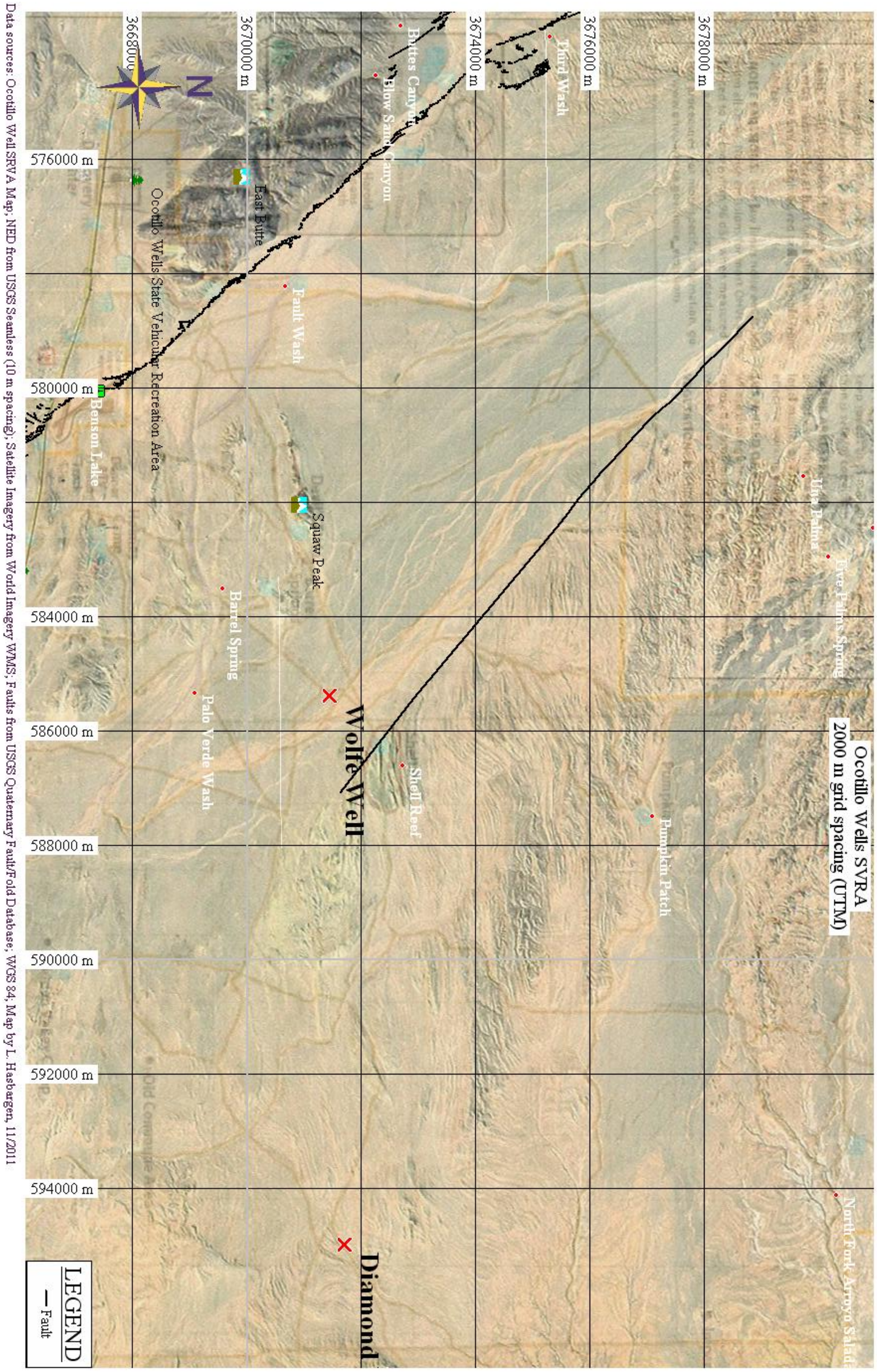


Figure. Overview aerial image of Ocotillo Wells State Vehicular Recreation Area.

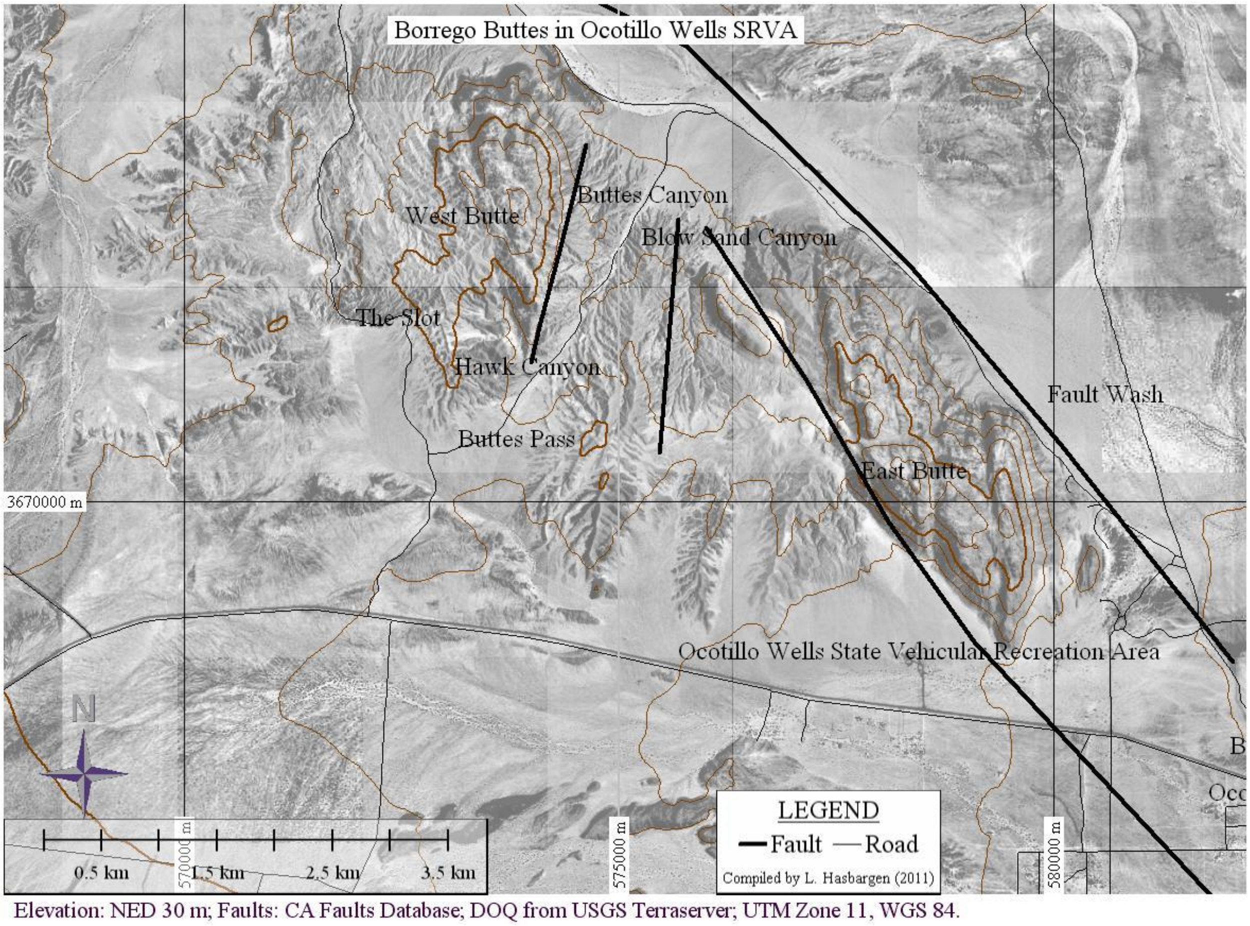
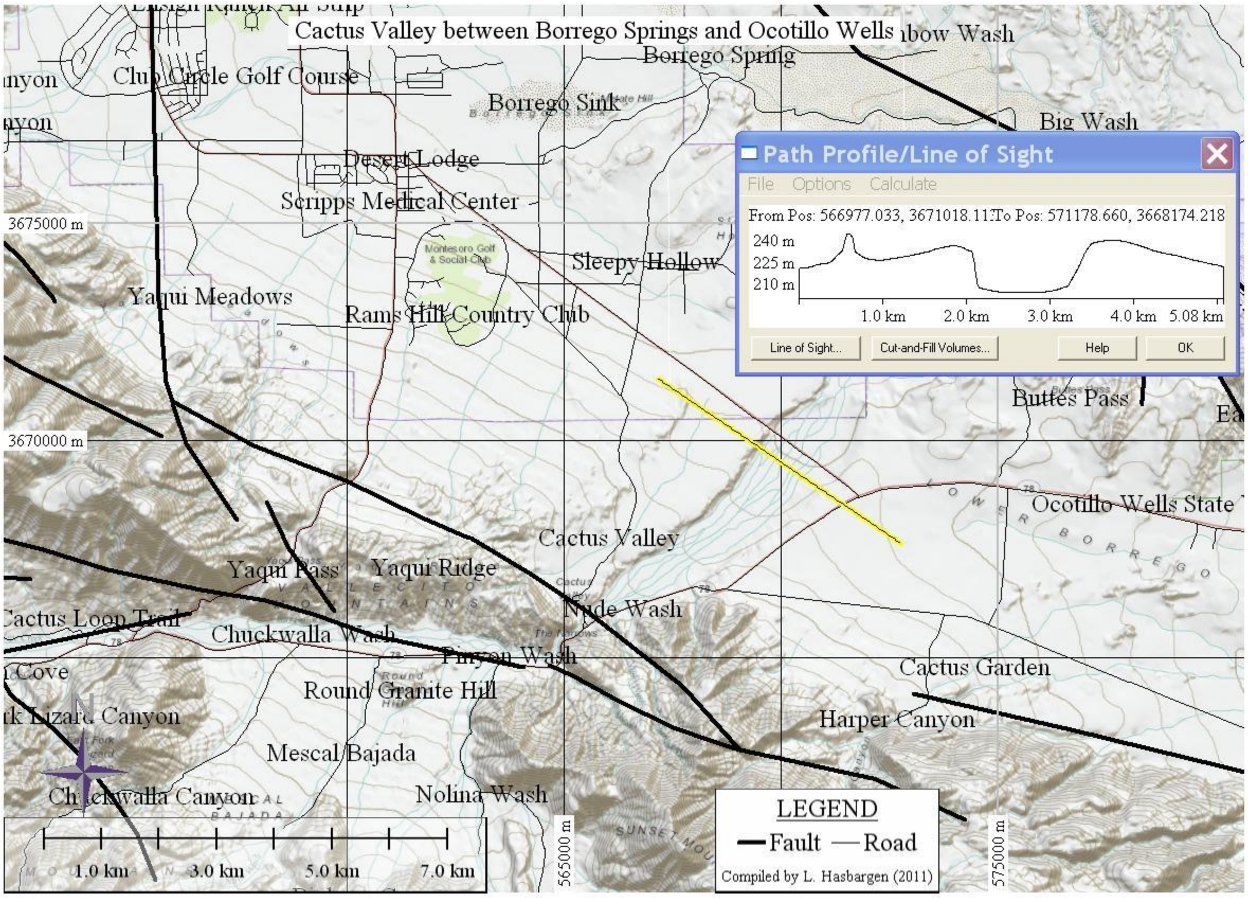
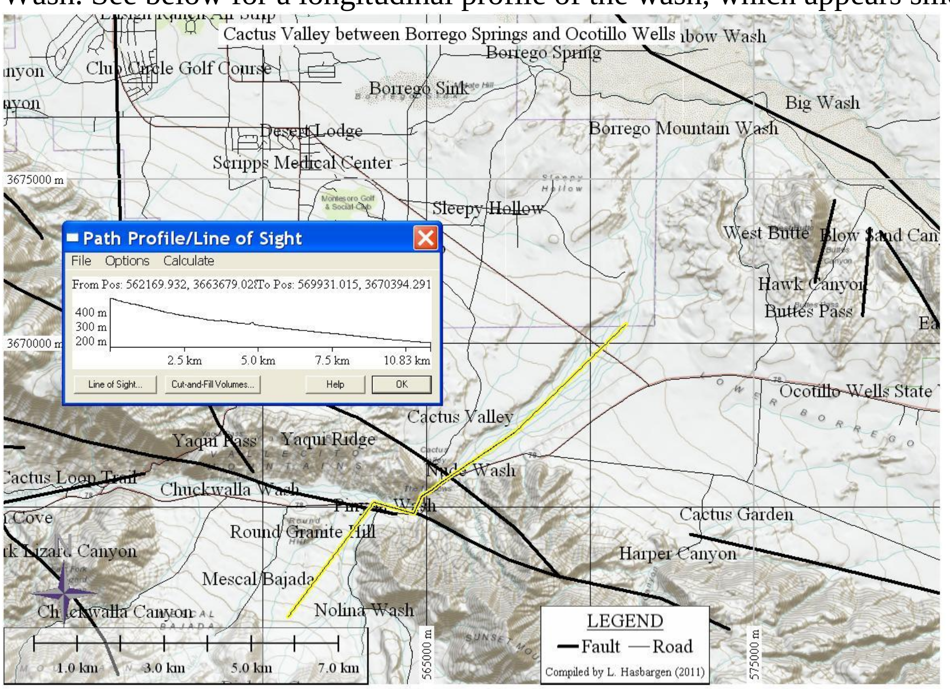


Figure. Borrego Buttes near Ocotillo Wells. 50 m contour interval. UTM 5 km grid spacing.

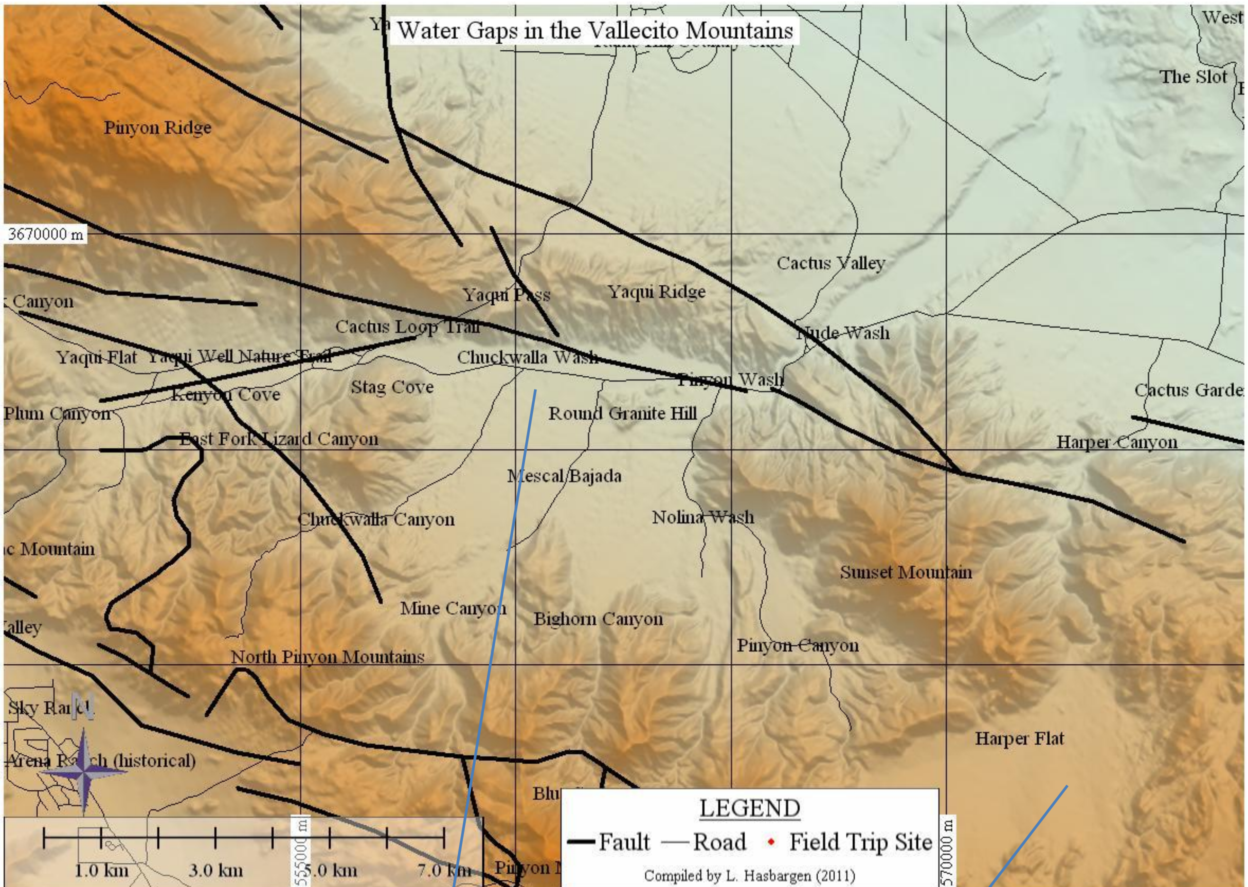


Elevation: NED 30 m; Faults: CA Faults Database; Topo map from World Topo (ESRI); UTM Zone 11, WGS 84.

Figure. Cactus Valley topography, showing the wide incised wash draining from Chuckwalla Wash. See below for a longitudinal profile of the wash, which appears smoothly concave.

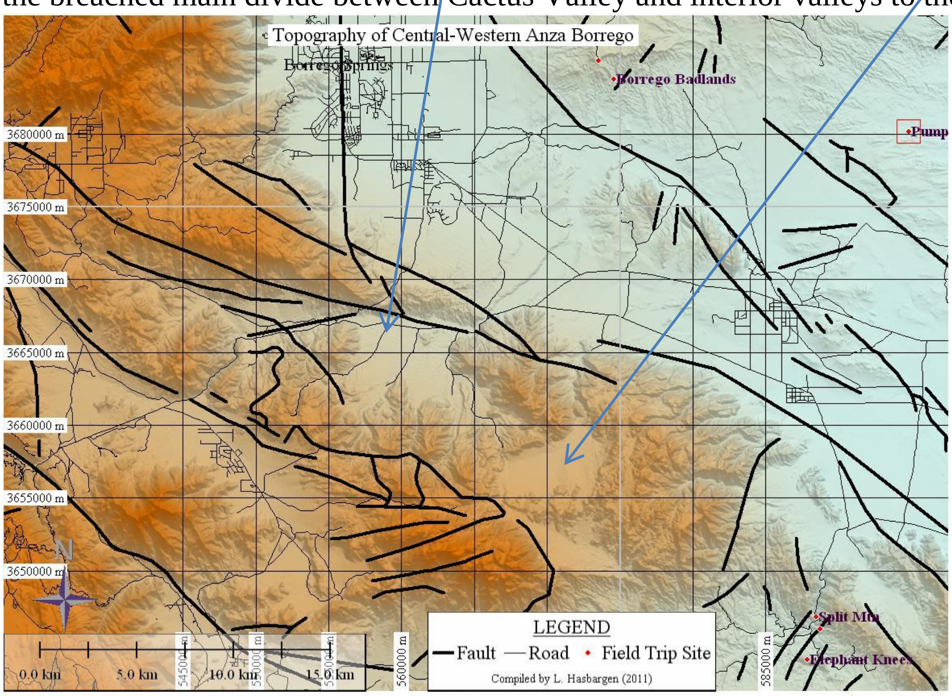


Elevation: NED 30 m; Faults: CA Faults Database; Topo map from World Topo (ESRI); UTM Zone 11, WGS 84.



Elevation: NED 30 m; Faults: CA Faults Database; UTM Zone 11, WGS 84.

Figure. Water gaps in the Vallecito Mountains. Notice the interplay of faults, valleys, and the breached main divide between Cactus Valley and interior valleys to the south.



Elevation: NED 30 m; Faults: CA Faults Database; UTM Zone 11, WGS 84.

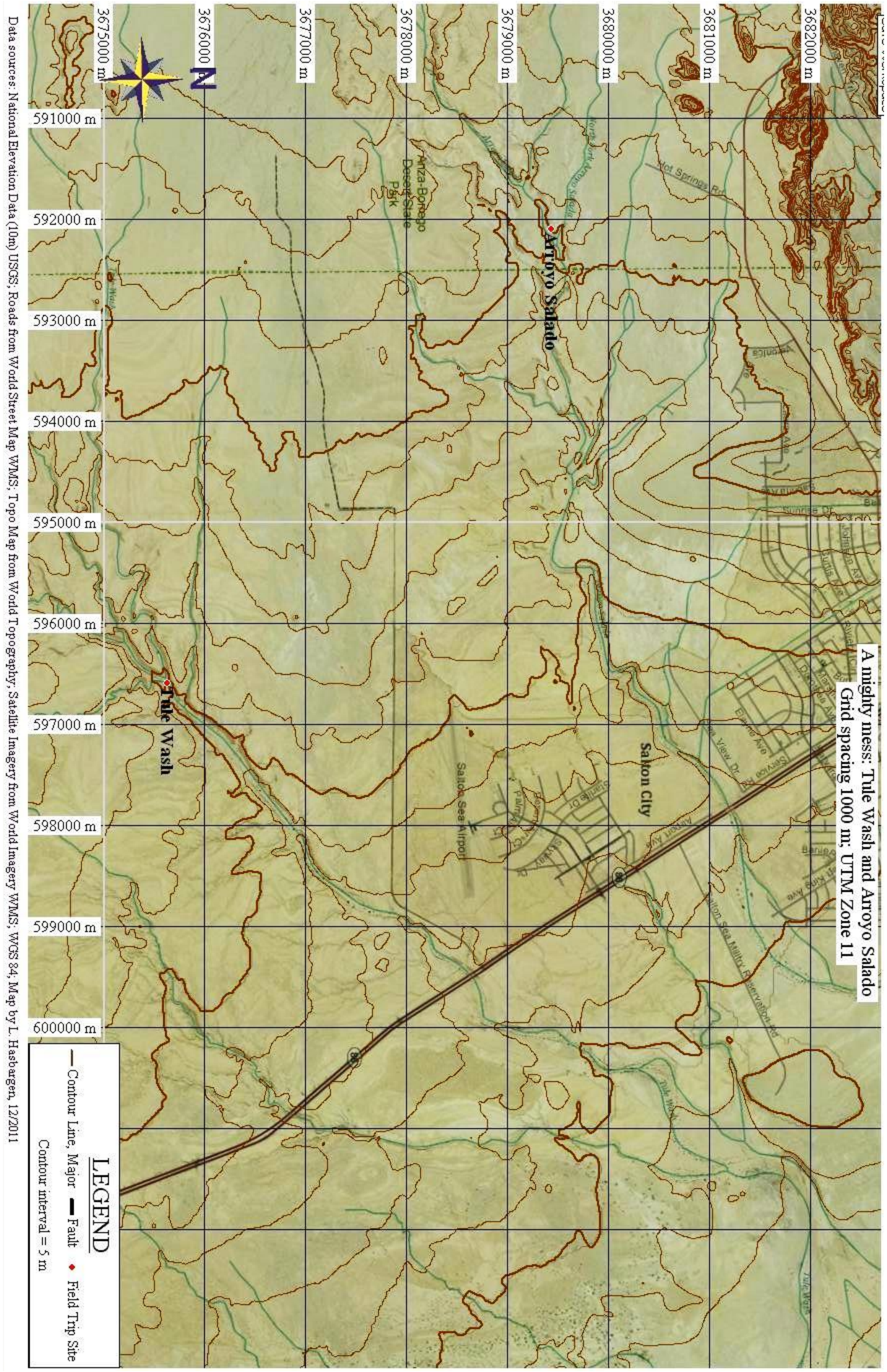
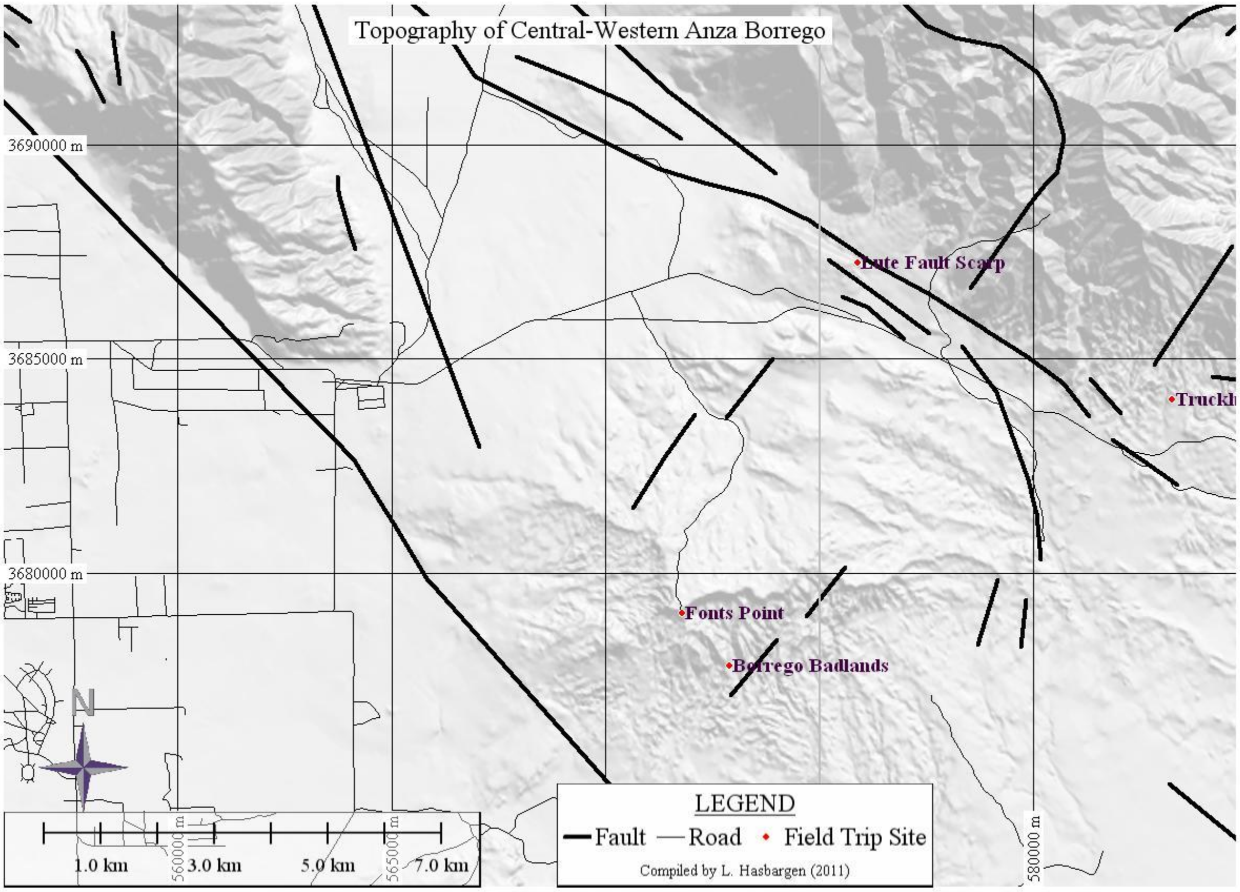


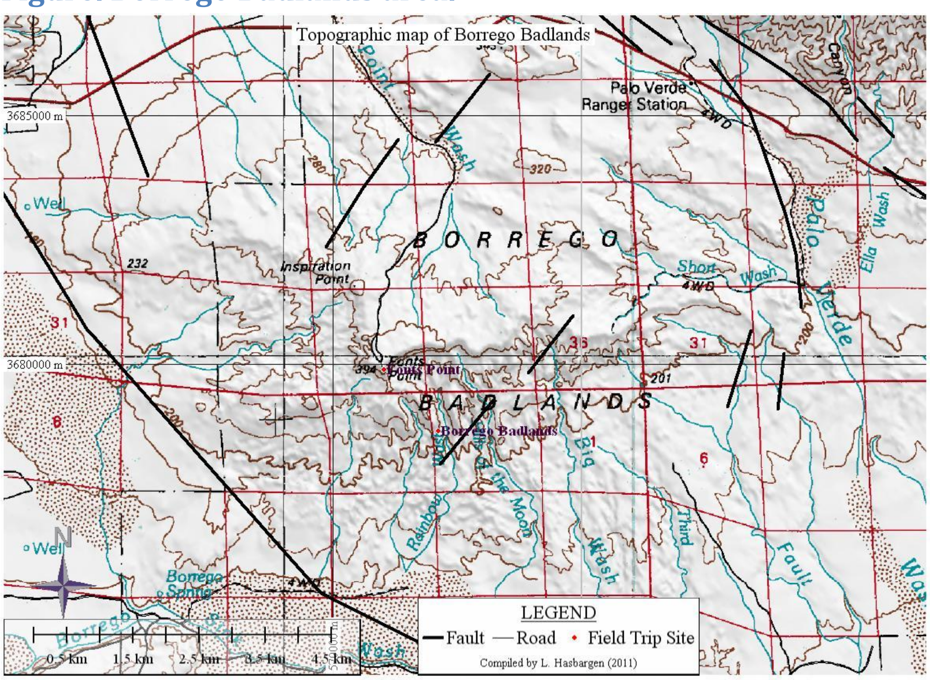
Figure. Aerial image of Tule Wash and Arroyo Salado near Salton City.

Day 11 Lute Fault Scarp, Borrego Badlands, and Fonts Point



Elevation: NED 30 m; Faults: CA Faults Database; UTM Zone 11, WGS 84.

Figure. Borrego Badlands area.



Topo map from USGS DRG server; Elevation: NED 30 m; Faults: CA Faults Database; UTM Zone 11, WGS 84.

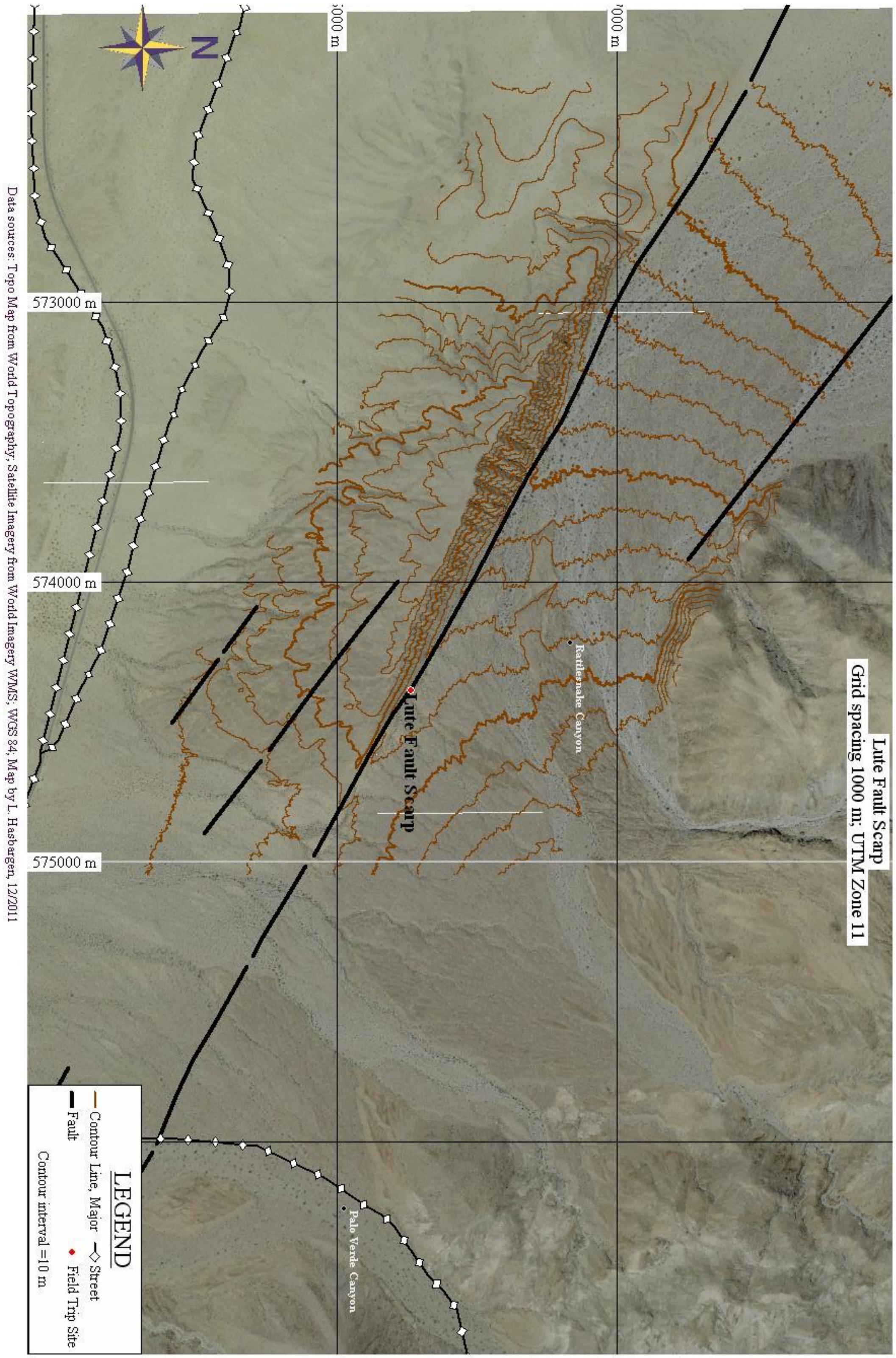


Figure. Aerial image of Lute Fault scarp, with faults and contours.

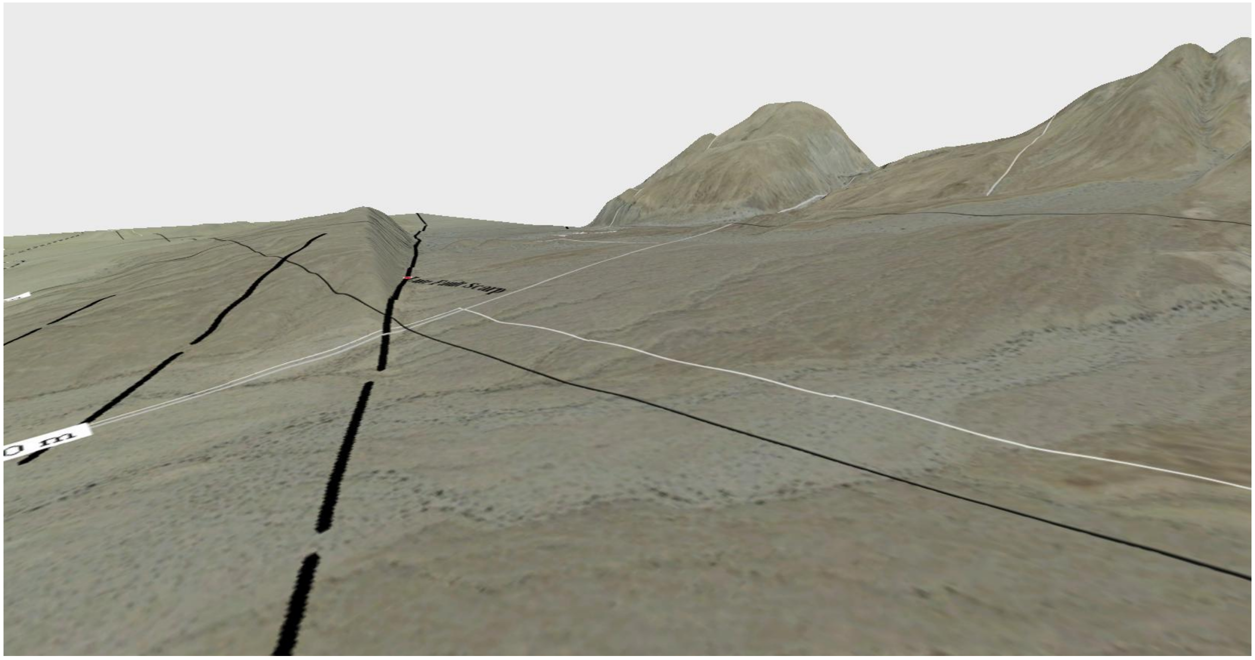


Figure . Lute Fault Scarp, perspective view northeast.

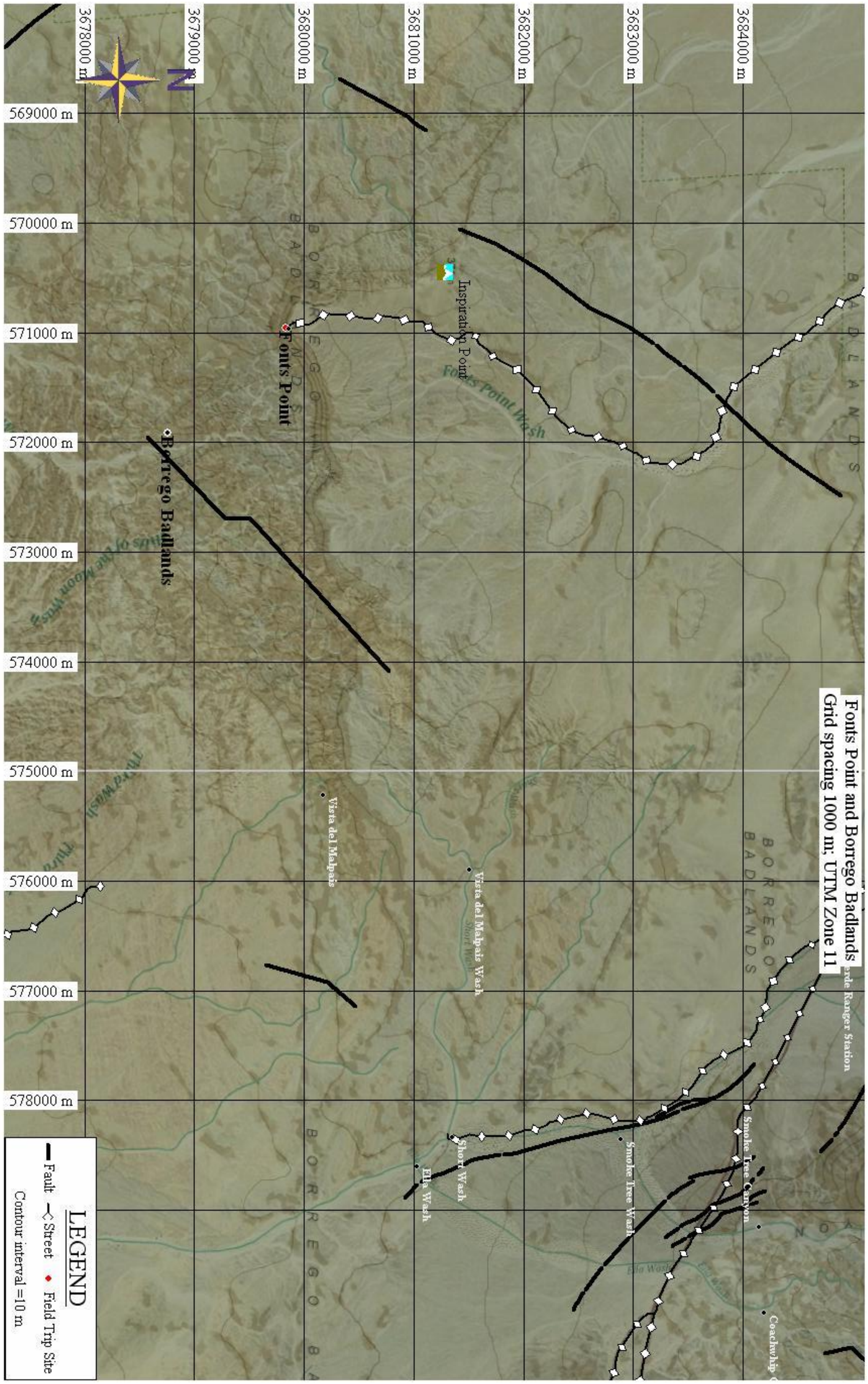


Figure. Aerial image of Fonts Point and Borrego Badlands.

Day 12 Martinez Mountain Landslide, Pines to Palms, Moreno Valley migmatite, and home

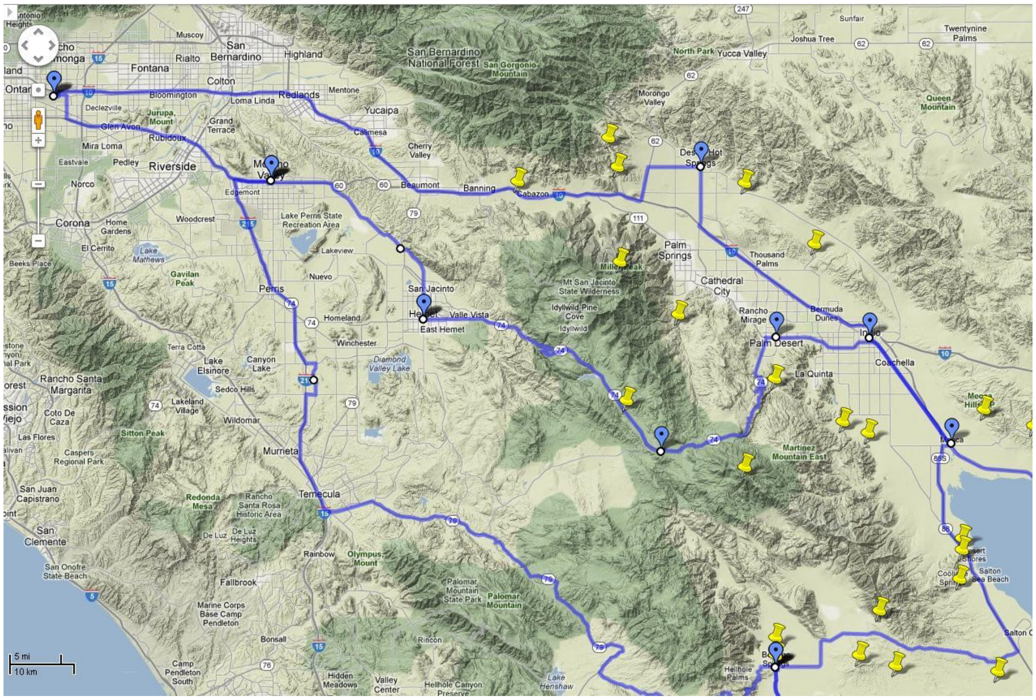
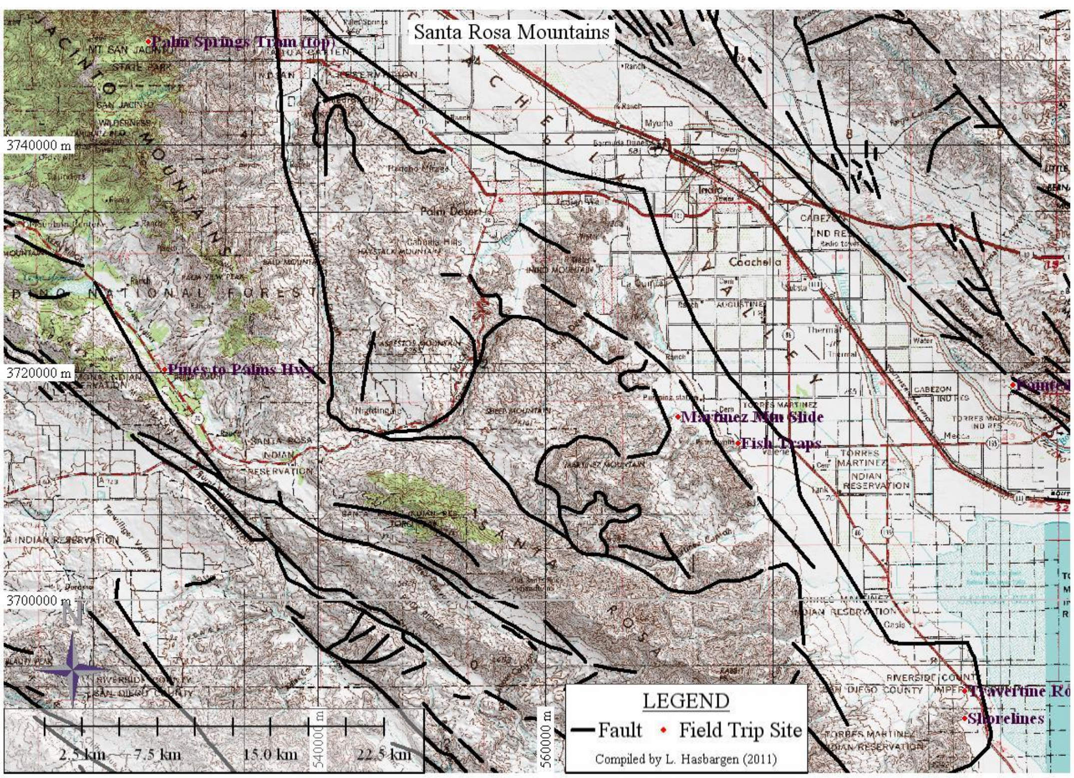


Figure. Route back to Ontario, via Pines to Palms Highway (Hwy 74).



Topo map from USGS DRG server; Elevation: NED 30 m; Faults: CA Faults Database; UTM Zone 11, WGS 84.

Figure. Martinez Mountain slide. Image courtesy Google Maps/Topography.

References

Grine, Don, 2008 Torrey Pines State Natural Reserve Geology Walk, http://www.torreypine.org/activities/Geology-hikes-gps.pdf.

Henrik Svensen, Dag A. Karlsen, Anne Sturz, Kristian Backer-Owe, David A. Banks, and Sverre Planke, 2007, Processes controlling water and hydrocarbon composition in seeps from the Salton Sea geothermal system, California, USA, Geology, January, v. 35, p. 85-88, doi:10.1130/G23101A.1

Remeika, Paul, and Anne Sturz, editors, 1995, *Paleontology and geology of the western Salton Trough detachment, Anza-Borrego Desert State Park, California*, Field Trip Guidebook and Volume for the 1995 San Diego Association of Geologists Field Trip to Anza-Borrego Desert State Park, Volume 1, 1995.

Remeika, Paul, *Geology of Anza-Borrego: Edge of Creation (California Desert Natural History Field Guides, No 1)*, Sunbelt Publications, 1992, ISBN #9780932653178.

Dorsey, Rebecca J., Bernard A. Housen, Susanne U. Janecke, C. Mark Fanning, and Amy L.F. Spears, 2011, Stratigraphic record of basin development within the San Andreas fault system: Late Cenozoic Fish Creek–Vallecito basin, southern California, GSA Bulletin; May/June 2011; v. 123; no. 5/6; p. 771–793; doi: 10.1130/B30168.1.

Sylvester, Arthur G., 1999, Rifting, transpression, and neotectonics in the central Mecca Hills, Salton Trough, in Field Trip Guide Book for SEPM (Society for Sedimentary Geology) Pacific Section, 85.

Spencer, Jon, *4.8 Ma Age for Inception of the Modern Colorado River*, Arizona Geology Magazine, December 22, 2011. http://azgeology.azgs.az.gov/article/feature-article/2011/12/48-ma-age-inception-modern-colorado-river

Data sources for the maps contained in this guide

National Elevation Data (NED) from the United States Geological Survey, via the Seamless Server site.

1:24K and 1:100K Topographic maps (Digital Raster Graphics) from United States Geological Survey, via the Terraserver site.

Topographic map data from ESRI via the World Topography web map service.

Satellite imagery from ESRI via the World Imagery web map service.

National Agricultural Imagery Program data from USGS Terraserver web site.

Digital orthophotoquads (DOQ) from USGS Terraserver web site.

LiDAR elevation data from B4 Open Topography.

Geologic maps from California State Geologic Survey, and from Dorsey et al., 2011.

Road maps, topographic relief maps courtesy of Google Maps and Bing Maps.

Appendix 1 Syllabus

Anza Borrego Geology Trip
Spring 2012

Credits: 3.0
Special Topics Course ***CRN****:* 447
Prerequisite: a 100 level Geology course and a 200 level Geology course
Class meets: January 9-20, 2012 in the field, and MW, 8:00-8:50 am (intermittently throughout course) on campus
Instructor: Les Hasbargen
Office: 219 Science 1 Ph. 607-436-2741
Office hours: MWF, 11:00-11:50 am
Personal web site: **http://employees.oneonta.edu/hasbarle/index.html**

Textbooks

Required: Rite in the Rain Geology Field Note Book, ISBN 978-1-932149-35-7.

Required: Anza Borrego Geology Guide, with maps of the field trip stops, exercises, etc. You will need to print this document, preferably in color, before departing on the trip. It will be available on Angel, and on Les Hasbargen's personal web site.

Optional: Paleontology and geology of the western Salton Trough detachment, Anza-Borrego Desert State Park, California, Field Trip Guidebook and Volume for the 1995 San Diego Association of Geologists Field Trip to Anza-Borrego Desert State Park, Volume 1, edited by Paul Remeika and Anne Sturz, 1995.

Optional: Geology of Anza-Borrego: Edge of Creation (California Desert Natural History Field Guides, No 1), by Paul Remeika, Sunbelt Publications, 1992, ISBN #9780932653178.

Optional: Geology in the Field, by Robert Compton ; John Wiley and Sons, 1985; ISBN: 0-471-82902-1.

Course Description

This field course examines the geology, surface processes, and geomorphology along a complex tectonic plate boundary in southern California. Students will decipher connections between modern depositional processes and environments and the sedimentary structures that are preserved in the rock record. Students will identify and characterize the various ways in which rocks deform. Students will develop geologic field mapping skills and gain experience in the construction of geologic maps and graphical representations of the geology in the area. A minimum of 9 students is needed for the trip to run. Costs should not exceed $825 per student including air fare, food, lodging, transportation, and tuition. Students will stay in campgrounds. The field trip will take place over winter break, with additional classroom teaching during spring semester.

Course Justification

There is a persistent need for trained geoscientists with experience in geologic field investigation. This course will expose students in Geology, Earth Science, Environmental Science, and Water Resources programs to an active plate tectonic boundary in southern California, with most of the trip taking place in Mecca Hills Wilderness and Anza Borrego Desert State Park. These locales provide extraordinary learning opportunities for students, exposing numerous faults and folds, a spectrum of rocks including clastic and chemical sedimentary rocks, intrusive igneous rocks and metamorphic rocks. The landscapes in the area exhibit premier examples of landscape processes and geomorphology, including uplifting mountains, huge landslides, dunes, playas, alluvial fans, and desert pavement.

The focus of Geol 394 is on applied field observation—students integrate much of what they have learned in prior coursework in a real world context. The nearly 100% exposure of rocks and structures in the area offers a view into Earth's processes and the geologic record of past environments. In addition, the close juxtaposition of eroding mountains, and modern depositional settings for clastic and chemical sediments permits field based projects which couple stratigraphy with processes in a very direct way. Field exercises will require students to identify rocks, characterize processes, and develop skills in collecting and analyzing spatial and geologic information. This course will be a profound learning experience.

The course will take place mostly on the field trip, which will run winter break in January 2012, and with lectures during the spring semester. After returning, students will select a field location for greater examination, and present their literary investigation of the area to the class. Students will be evaluated based on participation on the field trip, field notes, field maps, and post-trip presentation.

Specific course objectives. Students learn how to: relate sedimentary features and structures to depositional environments and surface processes; map rock units; identify and map faults and folds; and recognize relationships between tectonic activity and landscape form.

Student Learning Outcomes for the Geology Major addressed by this course:

- Students will demonstrate their ability to describe and identify geologic materials. (GEOL-SLO #1)
- Students will demonstrate their understanding of how rocks, sediments, and soils form. (GEOL-SLO #2)
- Students will demonstrate comprehension of the role of deep time in Earth history. (GEOL-SLO #3)
- Students will demonstrate understanding of processes that occur on and within the Earth and interactions among Earth's systems. (GEOL-SLO #5)
- Students will demonstrate their ability to collect and analyze geologic information in field and laboratory settings. (GEOL-SLO #6)
- Students will demonstrate their ability to apply scientific reasoning and technology to solve geologic problems. (GEOL-SLO #8)
- Students will demonstrate their ability to work collaboratively to solve geologic problems (GEOL-SLO #9)
- Students will utilize scientific methods to design and execute research projects that include collection, analysis and interpretation of data. (GEOL-SLO #10)
- Students will demonstrate their ability to communicate scientific and technical information effectively through appropriate oral, visual and written presentation. (GEOL-SLO #11)

Student Learning Outcomes for the Earth Science Major addressed by this course:

- Students will demonstrate understanding of the governing concepts related to all components of the Earth system (meteorology, geology, oceanography, astronomy) and the relationships that link them. (ES-SLO #1)
- Students will demonstrate understanding of the structure of Earth's interior and the processes that operate within and on the Earth's surface, including a working knowledge of plate tectonics and natural hazards. (ES-SLO #4)
- Students will demonstrate their ability to describe and identify geologic materials and interpret the processes by which these materials form. (ES-SLO #5)
- Students will utilize scientific methods to design and execute research projects or solve problems that include collection, analysis and interpretation of data. (ES-SLO #7)
- Students will demonstrate their ability to communicate scientific and technical information effectively through appropriate oral, visual and written presentation. (ES-SLO #8)

Grades

Students will be evaluated based on **participation** (**5%**) on the field trip, **field notes (50%) and maps (30%)**, and a post-trip **presentation (15%)**.

Participation (5%) on the field trip, which includes asking questions in the field, assisting with tent set-up and tear down, doing dishes at the camp, helping with food preparation, cleaning up the camping area, and assisting with packing up camping gear.

Field notes (50%). These must include a record for each stop, including date, time, location (UTM GPS location), verbal descriptions, sketches, and comments on key themes at the stop.

Geologic maps (30%). Students will create geologic maps for the reconnaissance exercises at select sites including Painted Canyon and Split Mountain. Each map must have a descriptive title, author, date, and lithologic legend. The finished map (the desk copy) should have lithologic contacts, folds, faults, and rock orientation symbols. Lithologic units must be color-coded in the map and on the legend (desk copy only). Students are encouraged to transfer their map data to a GIS format, but paper maps with legible writing and hand-drawn features will not receive less credit.

Post trip presentation (15%). Students will choose a topic on the trip to investigate further in the scientific literature, and present their findings to the group. The presentation must be in the form of a slide show; must have a title, author, and date; must provide new information about the site not contained in this guide book or the textbook, and should give a more detailed picture of what is known about the topic or site.

Rubric for Field Notes (50% of course grade)

Each stop must have the following elements (listed in the criteria) recorded in the field notes.

Weight (%)	Quality Points Awarded	Criteria

10	0-4	Date, time, location (GPS coordinates)
20	0-4	Purpose and Description of stop
40	0-4	Detailed notes of observations
30	0-4	Sketches

Quality Points: 4 = Excellent; 3 = Good; 2 = Fair; 1 = Poor (but passing); 0 = No credit
Grade assignment: A: 100-87.5%, B: 87.5-62.5%, C: 62.5-37.5%, D: 37.5-25%, E: < 25%

Rubric for Geologic Maps (30% of course grade)

Field and finished (office) copies of your geologic maps. Each office copy map will be evaluated based on the criteria below.

Weight (%)	Quality Points Awarded	Criteria
5	0-4	Lithologic contacts
5	0-4	Faults
40	0-4	Rock Orientation symbols, correctly plotted
15	0-4	Legend: Color-coded for lithologic units; all geologic symbols need a symbol (fault, strike-dip, contact, etc)
30	0-4	Verbal description of lithologic units in legend
5	0-4	Title, author, date, references for data sources, north arrow, scale

Quality Points: 4 = Excellent; 3 = Good; 2 = Fair; 1 = Poor (but passing); 0 = No credit
Grade assignment: A: 100-87.5%, B: 87.5-62.5%, C: 62.5-37.5%, D: 37.5-25%, E: < 25%

Rubric for Student Presentations (15% of course grade)

You will present a topic to the class based on a literature search and your field observations of some topic on the field trip. The presentation should be 10-15 minutes long. The presentation will be evaluated based on the ***criteria*** below.

Weight (%)	Quality Points Awarded	Criteria

10	0-4	Title, author, date
25	0-4	Introduction: Provides the setting for the topic
25	0-4	Discovery of information from a literature review
25	0-4	Description of information from field observations
15	0-4	Discussion of what you would like to explore further if you went back…

Quality Points: 4 = Excellent; 3 = Good; 2 = Fair; 1 = Poor (but passing); 0 = No credit
Grade assignment: A: 100-87.5%, B: 87.5-62.5%, C: 62.5-37.5%, D: 37.5-25%, E: < 25%

The rubric score will be re-scaled to the University curve, and final grade assignments will be guided by the standard University curve given below.

Percent	Grade	Percent	Grade	Percent	Grade	Percent	Grade
93-100	A	87-89.9	B+	77-79.9	C+	67-69.9	D+
90-92.9	A-	83-86.9	B	73-76.9	C	63-66.9	D
< 60	F	80-82.9	B-	70-72.9	C-	60-62.9	D-

Tentative Schedule for Field Trip

Date	Day	Weekday	Activity
1/9/2012	Day 1	Monday	Fly to Ontario/Whitewater Canyon
1/9/2012	Day 1	Monday	Desert Hot Springs
1/10/2012	Day 2	Tuesday	Palm Springs Tram
1/10/2012	Day 2	Tuesday	1000 Palms Canyon/Coachella Valley Preserve
1/10/2012	Day 2	Tuesday	Mecca Beach/Salton Sea State Recreation Area
1/11/2012	Day 3	Wednes.	Box Canyon
1/11/2012	Day 3	Wednes.	Mecca Beach Paleoshorelines
1/12/2012	Day 4	Thursday	Painted Canyon
1/13/2012	Day 5	Friday	Painted Canyon; Ladder Canyon
1/14/2012	Day 6	Saturday	Imperial Dunes (Glamis, CA)
1/14/2012	Day 6	Saturday	Mud Volcanoes (Nyland, CA)
1/14/2012	Day 6	Saturday	Obsidian Buttes (Westmoreland, CA)
1/14/2012	Day 6	Saturday	Fossil Canyon
1/14/2012	Day 6	Saturday	Agua Caliente Hot Springs Campground

1/15/2012	Day 7	Sunday	Arroyo Tapiado
1/15/2012	Day 7	Sunday	Canyon Sin Nombre
1/16/2012	Day 8	Monday	Torrey Pines
1/17/2012	Day 9	Tuesday	Anza-Borrego Visitor Center
1/17/2012	Day 9	Tuesday	Split Mountain
1/18/2012	Day 10	Wednes.	Lute Fault Scarp/Fonts Point/Borrego Badlands or
1/18/2012	Day 10	Wednes.	Tule Wash/Pumpkin Patch/Shell Reef
1/19/2012	Day 11	Thursday	Wonderstone/Fish traps/Landslide/Travertine
1/20/2012	Day 12	Friday	Pines to Palms/ Fly to Albany

Class Schedule (this schedule is subject to change as needed).

Date	**Week in sem.**	**Day**	**Location**	**Activity**
Jan 12-20	Pre-Spring	M→F	Anza Borrego, California	Field Trip
Jan-23	Week 1	M	Class does not meet	
Jan-30	**Week 2**	**M**	**Field notes DUE!**	
Feb-6	Week 3	M	Create digital data sets	
Feb-13	Week 4	M	Plot digital geologic data	
Feb-20	Week 5	M	Plot digital geologic data	
Feb-27	Week 6	M	Choose research topics	
Mar-5	Week 7	M	Literature searches	
Mar-12	Week 8	M	Work on maps	
Mar-19	Week 9	M	Class does not meet	Spring Break!
Mar-26	Week 10	M	Work on maps	
Apr-2	Week 11	M	Work on maps	
Apr-9	**Week 12**	**M**	**Work on presentations**	**Maps DUE!!**

Apr-16	Week 13	M	**Student presentations**	
Apr-23	Week 14	M	**Student presentations**	
Apr-30	Week 15	M	**Student presentations**	
May 7	Week 16	M	**Student presentations**	
May 14	Week 17	M	**Finals**	

Spring 2012 Calendar

January 22-24	Sunday-Tuesday	New student arrival & orientation
January 25	Wednesday	Classes begin
March 16	Friday	College closes after last class
March 26	Monday	Classes resume
May 9	Wednesday	Study Day
May 10-16	Thursday-Wednesday	Finals

Emergency Evacuation/Shelter-in-Place Procedures In the event of an emergency evacuation (i.e. fire or other emergency), classes meeting in Science I are directed to reassemble at Chase Gymnasium so that all persons can be accounted for. Complete details of the College's emergency evacuation, shelter-in-place, and other emergency procedures can be found at **http://www.oneonta.edu/security** .

Course Guidelines and Expectations for Students

The following list provides a baseline of what is expected from students in this course (quoted section from the list of *Student Responsibilities* approved by SUNY Oneonta).

"In class responsibilities

Students will:

- Attend all classes and arrive punctually.
- If unavoidably late for a class, enter quietly and unobtrusively, and behave in other required ways to minimize distraction.
- Remain alert and attentive during lectures, discussions, and other class/lab activities.
- Avoid unnecessary conversation during lectures, discussions, and other class/lab activities.
- Contribute to class experiences by asking relevant questions, offering relevant examples or views, adequately answering questions posed by others, engaging in critical and independent thought, and challenging both the instructor and the curriculum materials assigned for the course.
- Demonstrate courtesy and respect in dealing with instructors and classmates.

- Recognize and seek to understand diverse points-of-view."

In the field responsibilities

Students will:

- Assemble all materials they need to conduct field investigations and bring these items with them (this list will be supplied at the start of the semester)
- Participate in group camping activities, such as setting up and taking down tents, preparing food and cleaning up after meals
- Be respectful of fellow students on the trip and of other campers in the campground
- Maintain quiet time from 10 pm to 6 am in the campground (or according to the local campground guidelines)
-

ADA (Americans With Disabilities Act) Statement

All individuals who are diagnosed with a disability are protected under the Americans with Disabilities Act, and Section 504 of the Rehabilitation Act of 1973. As such, you may be entitled to certain accommodations within this class. If you are diagnosed with a disability, please make an appointment to meet with Student Disability Services (SDS), 209 Alumni Hall, ext. 2137. All students with the necessary supporting documentation will be provided appropriate accommodations as determined by the SDS Office. It is your responsibility to contact SDS and provide the teacher with your accommodation plan before a test.

Check list of Useful Items (Think Christmas Wish List!)

_____Hat—preferably wide brim to shade the ears/neck
_____Sunglasses
_____Hiking shoes
_____Sunscreen
_____Warm jacket
_____Gloves
_____Rain jacket
_____Undergarments
_____Long johns
_____Long-sleeved and short-sleeved shirt
_____Several pair of socks
_____A pair of long pants and shorts
_____Toiletries (check with airlines for permissible container sizes)
_____Towel
_____Flipflops or shower sandals
_____Sleeping bag (to 25°F) and small pillow
_____Sleeping mattress
_____Flashlight/headlamp
_____Eating utensils (fork, spoon, knife, plate/bowl, cup)
_____Water bottle (just make sure it's plane transport friendly; or buy water bottles in CA)
_____Camera (optional, but really helpful!)
_____Field book (with water resistant paper, such as Rite in the Rain)
_____*Compass with azimuth and inclinometer
_____Hand lens (see Geo-Tools for geology hardware: **http://www.geo-tools.com/index.htm**)
_____*Rock hammer (protective eye wear/goggles are a good idea)
_____Calculator
_____Whistle (in case you get lost)
_____Clipboard and/or map case (you can make your own with a clear plastic cover)
_____Pencils (mechanical pencils, or wood pencils with sharpener)
_____Pens and Permanent Marker
_____Protractor/6" ruler
_____*GPS unit
_____Charger for cell phone/electronic devices
_____Medium size duffel bag for clothes, sleeping bag, mattress, and personal items (choose a size within airline guidelines)
_____Day pack for lunch/snack items, pockets for water bottles, room for rain jacket, misc. tools
_____*Hard hat for caving

* Indicates item can be checked out from Earth Sciences Dept

Waiver for Use of Photographs

Please initial the statements below and sign and date this form at the bottom, if you agree to the terms.

_____I understand that photographs will be taken of me during the course of this class field trip (Geol 394, Anza Borrego Geology Trip, Spring 2012).

_____I grant permission to Earth Sciences Department and SUNY Oneonta for the photographs to be used for educational and promotional purposes.

____
Name (Please Print)

_________________________________ ____________________
Signature Date

Appendix 2 Describing Sedimentary Rocks in the Field

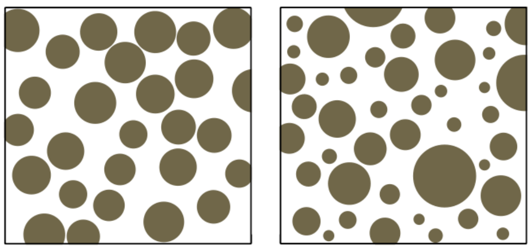
Note, on most field trips to the California desert, we won't be working with many limestone or more generally with carbonate or chemical sedimentary rocks. The description and name below applies to clastic sedimentary rocks.

Color

Record the dominant color: red, brown, tan, buff (yellow-brown), green, gray, black, maroon

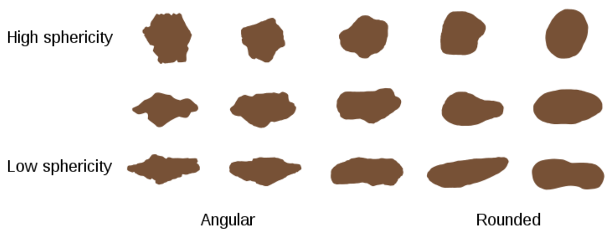
Texture

Note the grain sizes (clay, silt, sand, granule, pebble, cobble, boulder) and degree of sorting (poor-moderate-well), as well as grain roundness (angular-to-round) and shape



Well sorted Poorly sorted

From: **http://en.wikipedia.org/wiki/File:Sorting_in_sediment.svg**



From: **http://en.wikipedia.org/wiki/File:Rounding_%26_sphericity_EN.svg**

Mineralogy

Note especially the relative fractions of quartz, feldspar, accessory minerals (magnetite, mica, amphibole, pyroxene, olivine, etc), and lithic fragments. Identify the kind of lithic: granite, limestone, quartzite, etc.

Fossils

Note the presence of fossils, identify them, and describe their condition (in growth position, fragmented, etc).

Primary sedimentary structures

Bedding thickness: use terms such as laminated (less than 1 cm thick beds), thin-bedded (1-10 cm thick), thick bedded

Character of the contacts: use terms such as sharp, gradational, lenticular, planar, wavy

Stratification: note the presence of layering within individual beds. Use terms such as planar, or cross stratified

Bedforms: note the presence of ripple marks and dunes

Grading: note whether normal (large grains at base to small grains at top) grading or inverse (small grains at bottom to large grains at top) grading is present

Rip up clasts: these are usually fine-grained plate-like pieces of mud incorporated into a sandy bed.

Mud cracks: polygonal patterns on the bedding surface, often filled with a different kind of material than the bed itself.

Induration: this characterizes the degree of cementation. Use terms such as unconsolidated, friable (means crumbly), or indurate (can't break it with your hands, tends to ring when struck with a hammer).

Sedimentary Rock Name

This brings together all of the characteristics you have noted.

Example: buff, thin bedded ripple-marked moderately sorted fine sandstone

Example: reddish brown, indurate lenticular bedded massive poorly sorted sandy conglomerate, dominated by quartzite lithics and less abundant granitic gneiss clasts

For contacts between different kinds of rocks, use terms such as sharp, gradational, unconformity, fault, or intrusive to describe the nature of the contact.

Probable environment of formation

We will encounter sediments deposited in a broad range of environments. Consider the following as possibilities: deep marine, carbonate shelf, near shore, swamp, lacustrine, alluvial, alluvial fan, deltaic, or aeolian.

Worksheet for sedimentary rock identification

Sample ID:	
Sedimentary Features	**Notes**
Descriptive Rock Name (record after noting the features)	
Formation Name (assign after naming the rock)	
Depositional Environment (fluvial, alluvial fan, lacustrine, deltaic, lagoon, beach, near shore, offshore, eolian)	
Color red, brown, tan, buff (yellow-brown), green, gray, black, maroon	
Bed thickness (lamina, thin, med., thick)	
Stratification (massive, cross stratified)	
Character of **contacts**	
Sediment Size (clay, silt, fs, med s, cs, pebble, cobble, boulder)	
Sorting (well, moderate, poor)	
Shape (angular to round; sphericity)	
Mineralogy (qtz, feldspar, accessory minrals, lithics)	
Induration	
Fossils Identify, and describe their condition	
Bedforms (ripples, dunes, lamina)	
Grading (inverse or normal)	
Mud cracks	
Rip-up clasts	
Load casts	
Sole marks	
Additional notes and comments	

Appendix 3 Describing Igneous Rocks in the Field

A significant key to identifying igneous rocks is the texture of the rock. Look at the crystals in the rock. Do they an interlocking fabric? If so, the interlocking character implies crystallization and crystal growth. Can you see larger crystals with clear signs of crystal habit that "float" in the surrounding fine-grained material? If so, the rock is likely an igneous rock.

Color

Color is important for igneous rocks, especially if you cannot see individual crystals very readily.
Light color = white, tan, pink, light gray (felsic minerals)
Dark color = dark gray, black, green (mafic minerals)

Texture

Terms for characterizing crystal size and shape in igneous rocks.

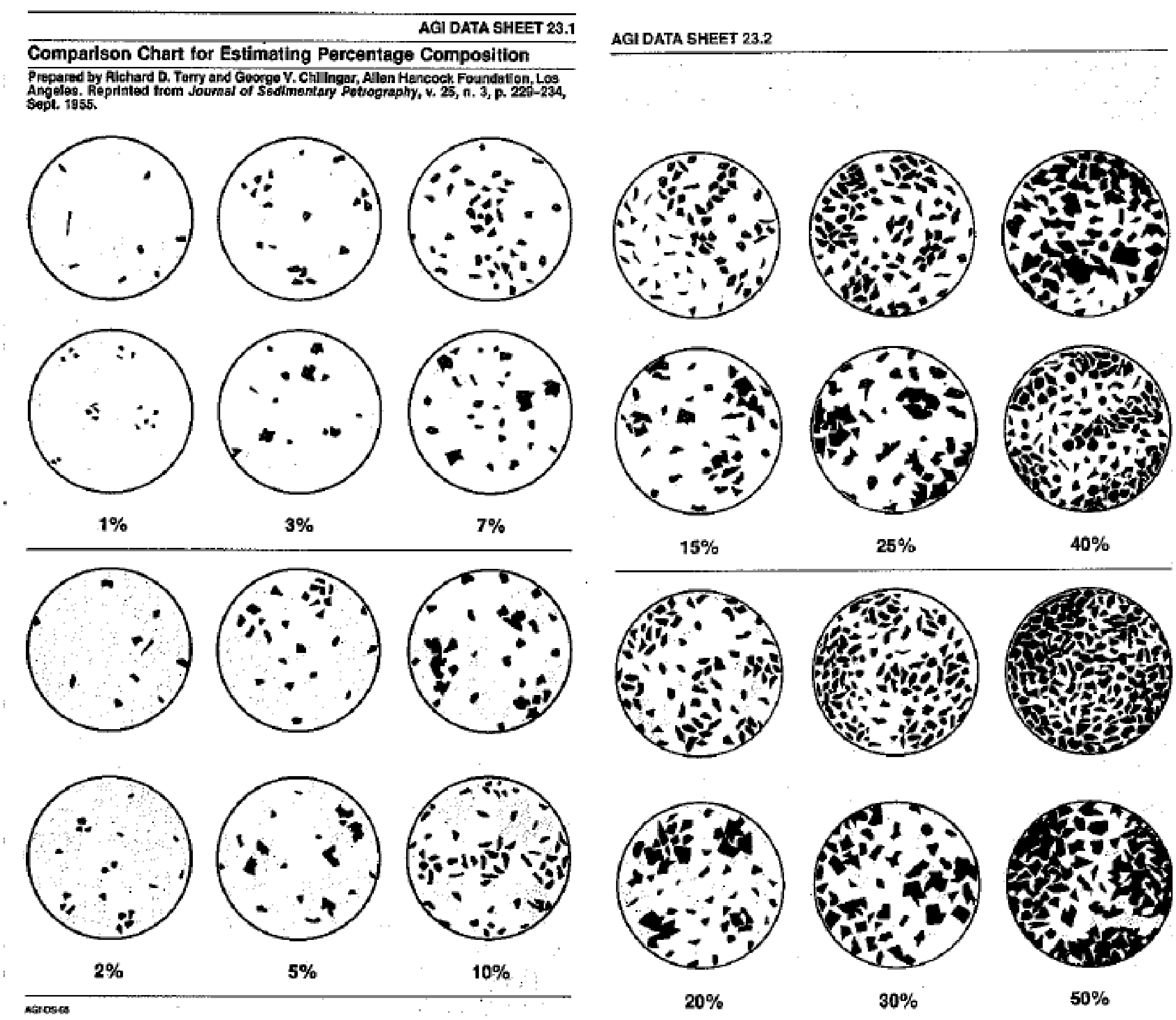
1. **Granularity: Appearance of crystals**
   - Aphanitic — Crystals can barely be identified with a 10X hand lens.
   - Phaneritic — All crystals can be identified with a 10X hand lens.
   - Cryptocrystalline — No crystals can be identified even with a low-powered microscope.
   - Porphyritite — two distinct crystal sizes: one which can be identified with a 10X hand lens, and one which cannot
   - Glassy — no crystals/amorphous. Rock cooled too quickly for crystals to form.
   - Pegmatitic — composed of very coarse-grained minerals (granites and pegmatites)
2. **Grain (crystal) size classification**
   - Fine < 0.062 mm
   - Medium 0.06-2 mm
   - Coarse 2-4 mm
   - Very Coarse > 4 mm
3. **Shape of individual crystals**
   - Euhedral — well developed crystal faces on all sides.
   - Subhedral — crystal faces on some sides.
   - Anhedral — no crystal faces
4. **Ensemble collection of crystals**
   - Granular — most minerals are approximately equidimensional or equant.
   - Porphyritic — two or more populations of crystal sizes.

Use the following terms to describe crystal size in the igneous rocks

fine-grained = aphanitic; crystals are barely visible; most of the rock is homogeneous and indistinct
coarse-grained = phaneritic; crystals are clearly visible and completely fill the rock mass.
porphyritic = igneous rock contains two distinct sizes of crystals
pegmatite = igneous rock that contains minerals > 1 cm

Phenocrysts (Mineralogy)

Identify the minerals present. Use your hand lens to get a clear close up view of the phenocrysts. Look for color, cleavage, and use the tip of a knife or nail to test the hardness. Estimate the fraction of the rock composed of the minerals. Look for quartz (Q), alkali feldspar (orthoclase)(A), and plagioclase feldspar (P). Once you estimate the fraction of each, you can name the rock. First, normalize their percentages to 100% (add the three up, and then divide each by the sum of all three). Also, note the mafic and accessory minerals, such as hornblende, biotite, muscovite, magnetite, pyroxene, and olivine. Most of the rocks we'll see will be dominated by Q-F-P. If the rock is dominated by olivine and pyroxene, a separate ternary diagram is required. We won't be seeing these types of rocks (I don't think!), so it is left out of this lab.

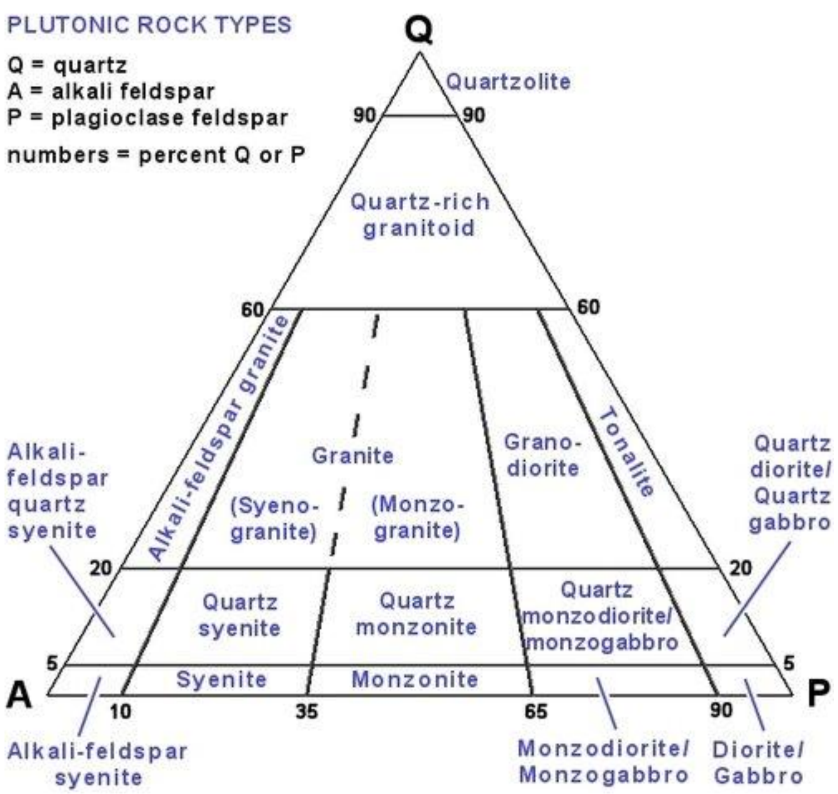


Once you have estimated the quantities of the different minerals, find the name of the igneous rock using the ternary plots of Quartz-Alkali Feldspar-Plagioclase (Q-F-P). Ignore the contribution of the mafic minerals when finding the relative proportions of Q-F-P.
If the rock is fine-grained, then we will name it based on color and any phenocrysts that are visible. Light-colored = **rhyolite**; Intermediate color = **andesite**; dark-color = **basalt**.

Name

Example: You determine the following ratios for Q-F-P for a phaneritic igneous rock: Q = 10%; F = 25%; P = 5%. The sum = 10 + 25 + 5 = 40. Q (%) = 10/40 = 25%. F = 25/40 = 62.5%; P = 5/40 = 12.5%. These values, when plotted on the ternary plot above, fall in the general region of **granite**, and specifically Syeno-granite. If there are two sizes of phenocrysts, modify the name with *porphyritic*, thus **porphyritic granite**.

Example: A fine grained black rock with phenocrysts of olivine is most likely **basalt**. You can modify the name with the mineral, so **olivine basalt.**



http://0.tqn.com/d/geology/1/0/M/N/1/600QAPplutonic.jpg

Probable environment of formation

Texture determines the environment of crystallization. Fine-grained are usually extrusive, and coarse-grained are typically intrusive. Most granites and diorites form in the subsurface below volcanic arcs. Gabbro is more likely formed during sea floor spreading, or during continental rifting.

Appendix 4 Metamorphic Rock Identification in the Field

We will encounter a few of these types of rocks in California. Look for signs of alignment of crystals in the rock. If there are visible layers of light and dark minerals, or a sheen exists in a fine grained rock with a waxy appearance, the rock is foliated. If not, it could be a non-foliated metamorphic rock. As always, note the mineralogy of the rock. If it's harder than a nail or knife, and unfoliated, it's probably a quartzite. If it's softer than a knife, it's likely a marble. Use the acid test to verify. Use the chart below to assist with naming of the metamorphic rock. Note, all of the figures below are modified from Dr. Growdon's notes on igneous and metamorphic rock classification.

CLASSIFICATION OF METAMORPHIC ROCKS IN HAND SAMPLES

Grainsize	Fine (<0.062 mm) silt and finer-size	Medium (0.062 – 2.0 mm) sand size	Coarse (>2.0 mm) > sand size
Unfoliated or Poorly Foliated	**hornfels**#	**granofels**# Special names: marble, quartzite, amphibolite, serpentine	**granofels**# Special names: marble, quartzite, amphibolite, serpentine
(with broken grains — brittle faults)	cataclasite	fault breccia	fault breccia blastocataclasite*
Well Foliated	**slate, phyllite**	**schist**	**gneiss**
Well Foliated and sheared in ductile fault zones	mylonite, phyllonite	mylonitic schist, blastomylonite*	augen** gneiss mylonitic gneiss

Note: All metamorphic rocks take the dominant mineral(s) as prefix names: (dolomite marble; muscovite-garnet schist, etc.).
The term 'fels' refers to rocks lacking strong foliation.
* The prefix 'blasto' refers to any rock with porphyroblasts.
** Augen is the German word for eye, and relates to eye-shaped structures in a rock.

Classification of Metamorphic Rocks in Hand Specimen

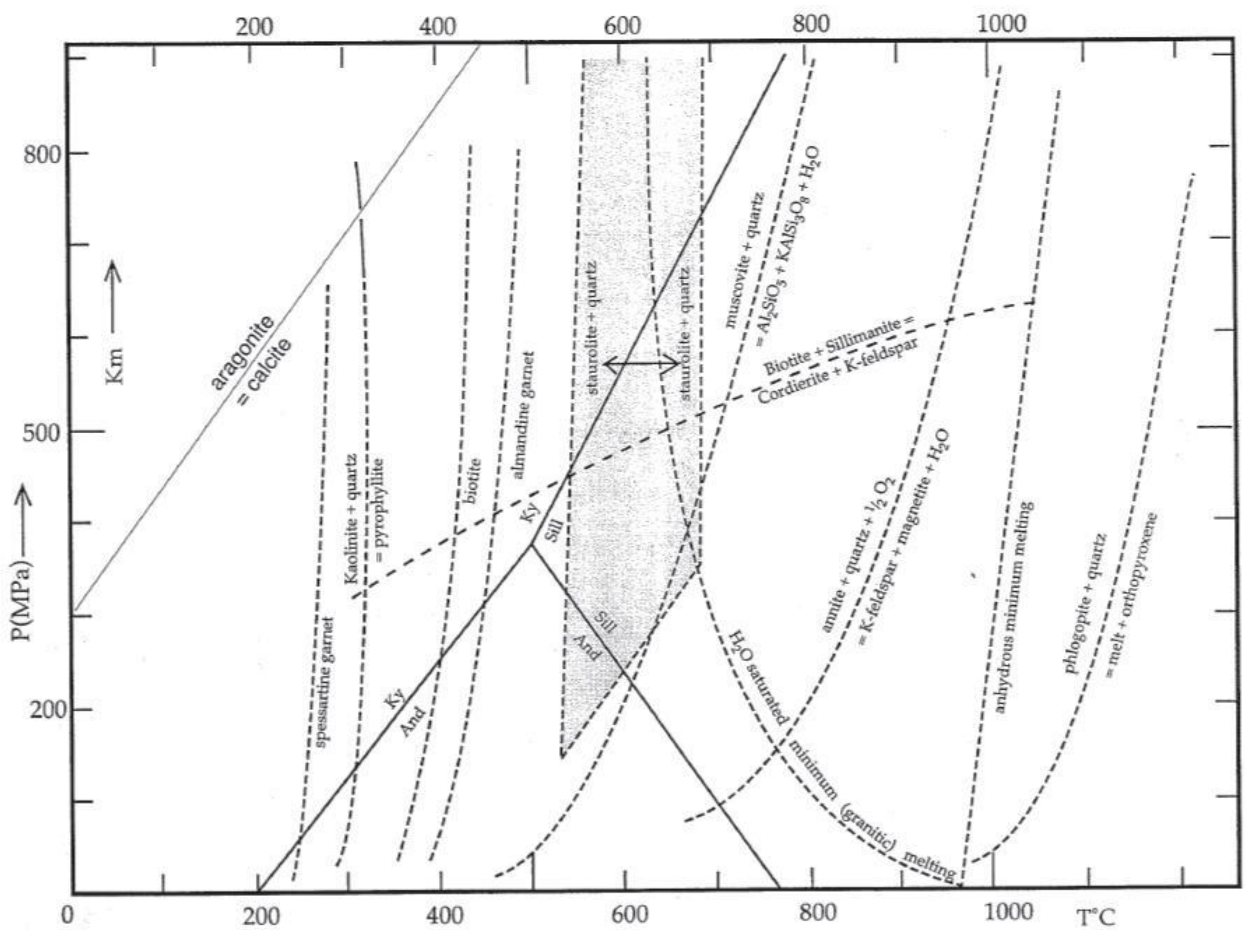
Minerals are temperature and pressure dependent substances. Thus, they can be used to make inferences about the pressure and temperature of formation for a rock. Several key minerals have been identified with distinctive P-T fields, and thus are useful for interpreting metamorphic rocks. On the following page, you will find a list of the minerals.

Mineral Stability Ranges in Metamorphic Rocks

		Dirt	Low Grade		Medium Grade			High Grade	
		Clay	Chte	Bio	Gar	Sta	Kya	Sil	2 Sil
Quartz	SiO_2	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •
Plagioclase	$(Ca,Na)(Al,Si)_4O_8$	• •	Na-rich	• • •	• • •	• • •	• • Ca-rich		• • •
Alkali feldspar	$(K,Na)AlSi_3O_8$	•	• • •	• • •	• • •	• • •	• • •	• • •	• • •
Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$		• • •	• • •	• • •	• • •	• • •	• • •	
Paragonite	$NaAl_2(AlSi_3O_{10})(OH)_2$		• • •	• • •	• • •	• • •	• • •	• • •	
Biotite	$K(Fe,Mg)_3(AlSi_3O_{10})(OH)_2$			• • •	• • •	• • •	• • •	• • •	• • •
Kaolinite	$Al_2Si_2O_5(OH)_4$	• • •	• •						
Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$		• •	• • •	• • •	• •			
Talc	$Mg_3Si_4O_{10}(OH)_2$		•	• • •	• • •	• •			
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	•	Fe-rich	• •	• • •	• •	Mg-rich	•	
Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$			• •	• • •	• • •	• • •	• •	
Actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$		•	• • •	• • •	• • •	• • •	•	
Hornblende	$NaCa_2(Mg,Fe,Al)_5(Si,Al)_8O_{22}(OH)_2$			•	• • •	• • •	• • •	• • •	• •
Epidote	$Ca_2 Fe Al_2 Si_3 O_{12} (OH)$		•	• • •	• • •	• • •	•		
Diopside	$CaMgSi_2O_6$					• •	• • •	• • •	• • •
Augite	$Ca(Mg,Fe)Si_2O_6$							• • •	• • •
Hypersthene	$(Mg,Fe)_2Si_2O_6$								• • •
Wollastonite	$CaSiO_3$								• • •
Chloritoid	$(Fe,Mg)Al_2SiO_5(OH)_2$		• •	• • •	• • •	• • •	• •		
Garnet	$(Fe,Mg)_3Al_2Si_3O_{12}$			•	• • •	• • •	• • •	• • •	• • •
Staurolite	$(Fe,Mg)_2Al_9Si_4O_{22}(O,OH)_2$					• • •	• • •	• •	
Andalusite	Al_2SiO_5			• • •	• • •	• • •			
Kyanite	Al_2SiO_5						• • •		
Sillimanite	Al_2SiO_5							• • •	• • •
Calcite	$CaCO_3$	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •
Dolomite	$CaMg(CO_3)_2$	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •
Ankerite	$CaFe(CO_3)_2$	• • •	• • •	• • •	•				

Mineral Stability Ranges for Metamorphic Grades

The table above provides an approximate grade as a proxy of intensity of the metamorphic conditions. The following diagram provides a more quantitative rendering of the conditions and stability fields of the minerals.



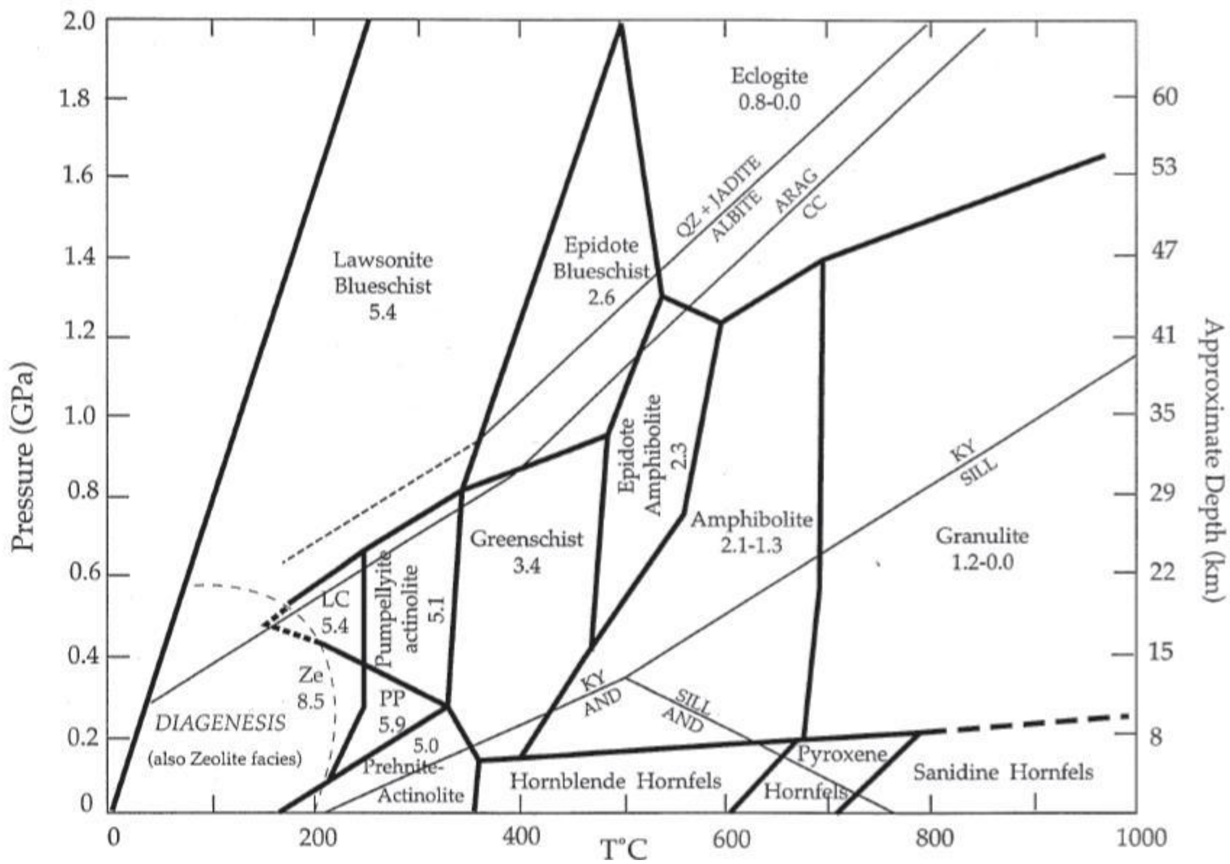
A pressure - temperature diagram showing the relative stabilities of minerals typically found in argillaceous sediments, especially those lacking kaolinite in the protolith. Most of the reactions produce "index" minerals.

P-T Diagram for Minerals Common in Argillaceous Sediments

Probable environment of formation

Metamorphic rocks are commonly found where old mountain building events occurred. They tell us the rocks originally formed under one set of pressure and temperature conditions, and then were moved into a new set of conditions of higher pressure and/or temperature. And of course, they had to undergo a significant amount of exhumation to bring them back to the surface again, cooling and decompressing along the way. We can get an idea of their history (or at least their likely peak P-T conditions) by identifying the minerals, and then finding the stability field for the minerals.

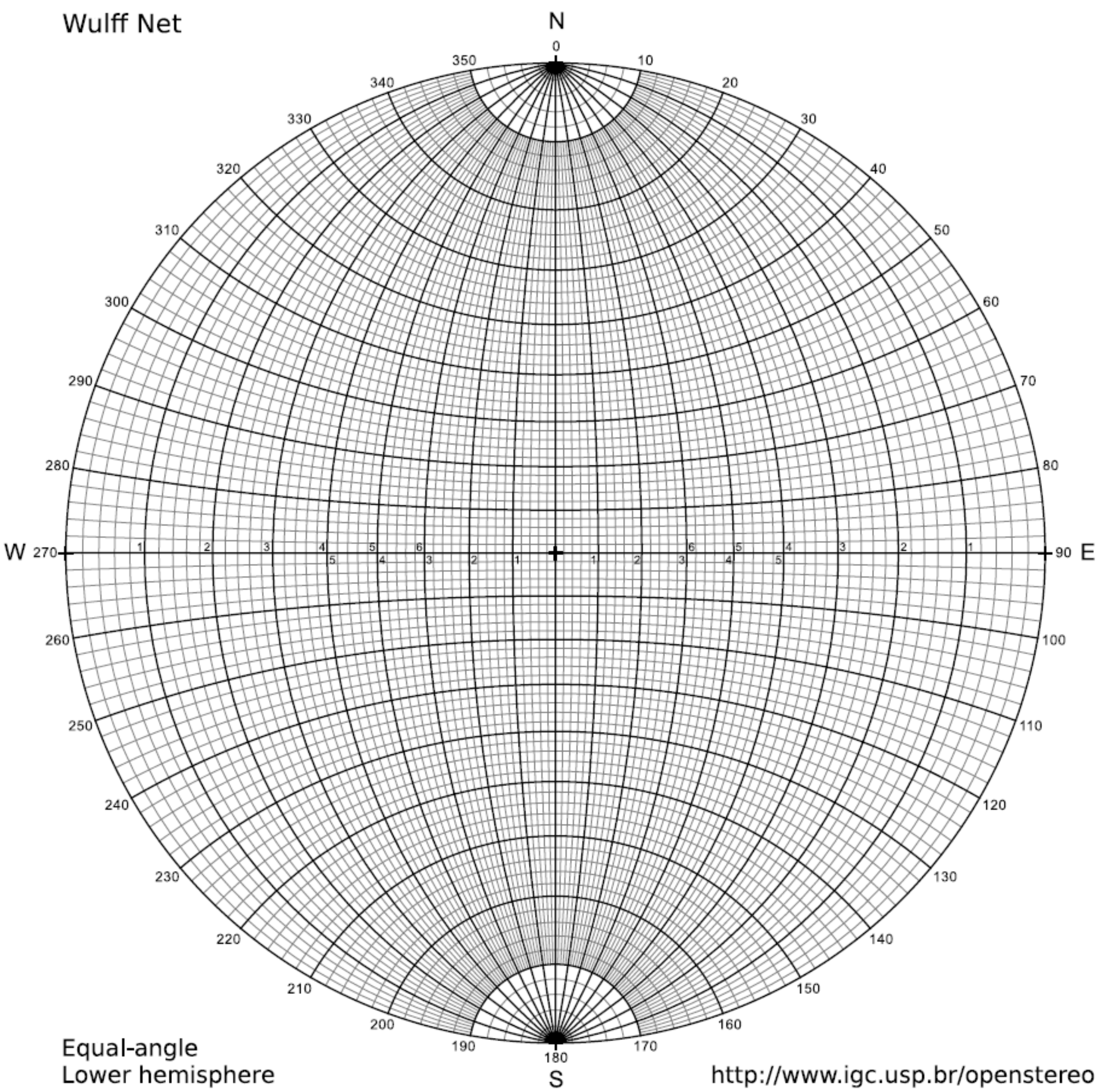
We use the term "facies" for a given set of minerals which coexist at the same P-T. The diagram on the next page shows the metamorphic facies in P-T space.



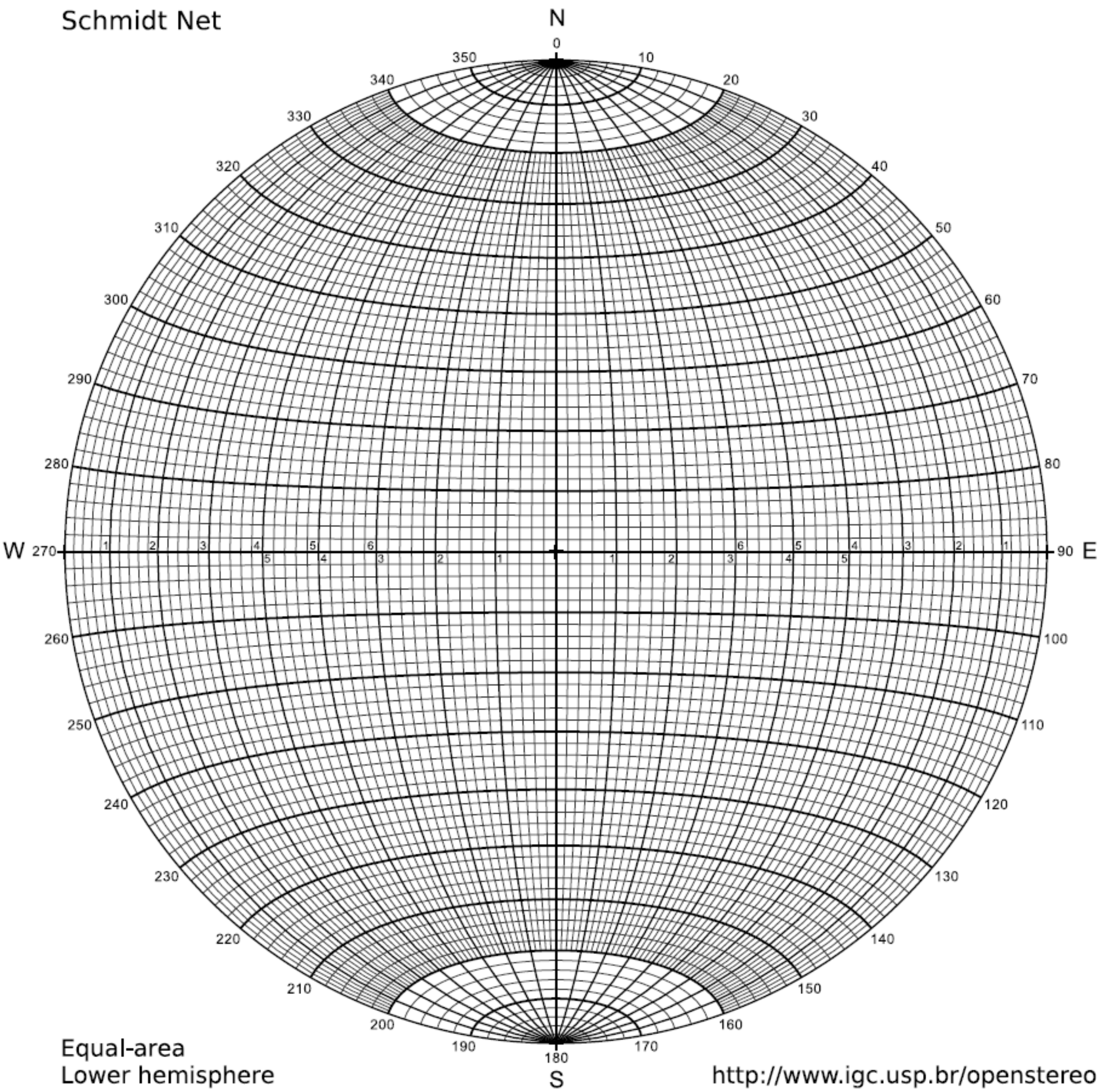
Pressure-temperature diagram with stability fields of selected minerals and metamorphic facies.

Appendix 5 Stereonets

Wulff Stereonet for Plotting Geologic Structure Data



Schmidt Stereonet for plotting geologic structural data



Appendix 6 Places of Interest in Anza-Borrego Desert State Park

The following locations are from a list on Desert USA's site: http://www.desertusa.com/anza_borrego/du-abpmain.html.

Vallecito Stage Station , Earthquake valley
Agua Caliente County Park , hot springs, camping
Imperial Sand Dunes
Mud Caves 22 known caves and 9 slot canyons, http://www.hiddensandiego.com/wiki/index.php?title=Preview_Arroyo_Tapiado
Canyon Sin Nombre
Carrizo Badlands Overlook
Tamarisk Grove is a tree-shaded campground with restrooms and hot showers

Blair Valley is hidden coves near the rocky margins of the valley. Hikers enjoy walks to the **Marshal South Home site (also called Yaquitepec)**, the **Morteros** and the **Pictographs**. Along the southern Emigrant Trail and the Butterfield Overland Stageline Route lies Box Canyon, a narrow defile still scarred by the early wagon roads.

Visitor Center - The Anza-Borrego Desert State Park Visitor's Center is an excellent place to begin your park visit. Maps, books, brochures, exhibits on the desert environment and a superb slide program will give you a general overview of the park and the many points of interest within the park boundaries. The Visitor's Center is located 1.7 miles west of Borrego Springs on Palm Canyon Drive. The Center is open daily 9 AM to 5 PM October through May and Saturdays, Sundays and holidays 9 AM to 5 PM June through September.

Borrego Palm Canyon is located one mile from the Visitors Center. It is the location of the Palm Canyon Campground and the trailhead for an easy three-mile round-trip nature trail that leads to a grove of native California Fan Palms. A free self-guided trail brochure is available to introduce visitors to the canyon and palm grove.

Coyote Canyon is famous for its year-round stream and lush plant life. The canyon is used by hikers, horseback riders and those with sturdy four-wheel-drive vehicles. The roads are rough, but the hiking and riding trails are good. The historic trail of explorer Juan Bautista de Anza passes through Coyote Canyon.

Journey Through Coyote Canyon - Wildllife Viewing Area

Carrizo Gorge Railroad - Follows the old railway route between Campo to El Centro and Imperial Valley. Read about it here.

Ocotillo Flat and Lower Willows
The atractions of Lower Willows are the fresh waters of Coyote Creek running through it and the color, density and variety of the surrounding vegetation.

Ocotillo Flat starts at Coyote Creek and stretches across soft sandy soil to the naked hills and canyons to the east and north. It is bird country, reptile country, and cactus country with wildflowers in season. It includes one of the most impressive stands of ocotillo anywhere

Truckhaven Rocks are orange-colored sandstone slabs that are tilted at a 45 degree angle. They are a favorite spot for desert photographers and can be reached by a 1.5 mile roundtrip walk through a wash. The Truckhaven Rocks can be seen from S-22. Trailhead starts at mile 35.5 on the S-22.

Article - Riding your ATV's over Pegleg's Gold/Ocotillo Wells.
Video - Riding your ATVs over Pegleg's Gold/Ocotillo Wells?
Article - Was Pegleg's Gold Found?
Article - Gold Fever In The Desert.
Article - The Man Who Found Pegleg's Gold.
Pegleg Smith Liars' Contest

17 Palms, 5 Palms and Una Palm are Palm Oases located near the Arroyo Salado Primitive Campground off of S-22. There are many palm oases located within the Park boundaries. These areas are well-known watering holes for the regional wildlife of the Borrego Badlands. The palms at the Oases are often green and brilliant compared to the stark and barren desert that surrounds them. Click here to read more about these oases and directions on how to get to them.

Article about Arroyo Salado, Truckhaven Trail and the Palm Oases.

Pumpkin Patch his unique landscape is the result of wind and water continuously eroding the surface soil and revealing globular sandstone concretions that look much like pumpkins in size and shape. Such concretions are believed to be formed by the natural cementing of sand particles to a small object such as a piece of shell, a grain of sand or even an insect.

Information and photos of the Pumpkin Patch

Font's Point offers a commanding view of the Borrego Valley and **Borrego Badlands**. This prominent viewpoint is reached by a sandy four-mile primitive road, which more often than not is soft and rutted. Four-wheel-drive vehicles are required to reach the view point. Check the road conditions board at the Visitor's Center prior to attempting to visit Font's Point. If you can get to Font's Point the view is well worth the effort. It is one of the most breathtaking viewpoints in the southwest desert regions.

Video - Font's Point - Borrego Badlands

Ocotillo Wells OHV Area includes over 80,000 acres of magnificent desert area open for off-road exploration and recreation. The area includes campgrounds, miles of ATV trails and tracks. Self-guided vehicle tours are available. Check the nearest bulletin board, or visit the Ranger Station to find out about current activities.

Information and maps of the Ocotillo Wells OHV area.
Video about Ocotillo Wells
Video about riding your ATVs over Pegleg's Gold?

Split Mountain, Fish Creek Wash and Elephant Trees Trail

The narrow divide between the Fish Creek Mountains and the Vallecito Mountains is called Split Mountain. Split Mountain is a geological wonder, formed by numerous earthquakes and floods revealing layers of geological and paleontologic history within its walls. You can often drive a passenger car to its entrance for the view from inside a mountain. A walk or drive through the Split will open new worlds for the visitor and the terms "geology," "faults" and "erosion" will take on new meanings.

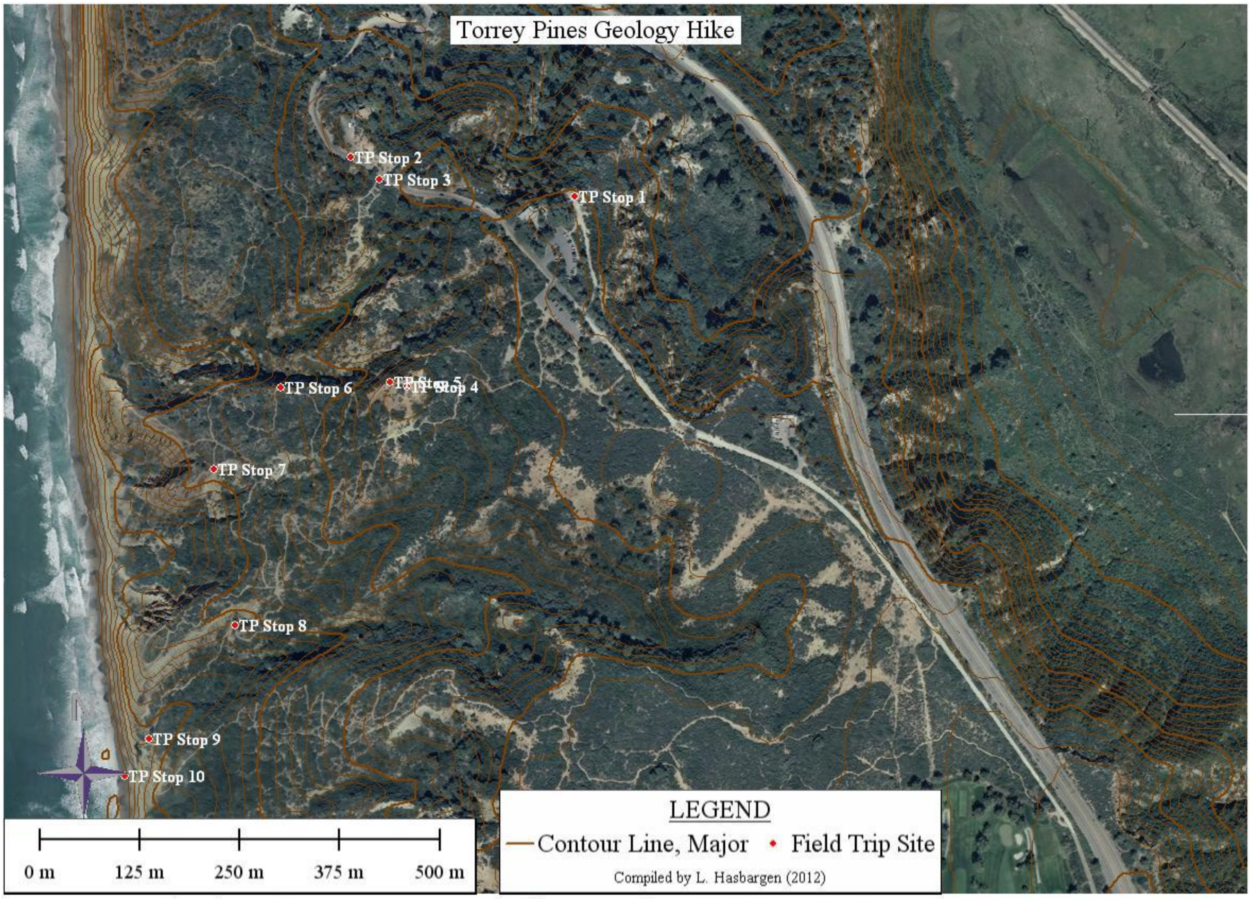
Take Split Mountain Rd. where it intersects from Ocotillo Wells (Hwy 78) heading South. You will continue South on Split Mountain Rd. for approximately 8 miles where you will turn right (West) on Fish Creek Wash towards the Fish Creek Primitive Campgrounds. Fish Creek Wash will take you through Split Mountain.

The Elephant Tree Trail – Only one living Elephant Tree remains, but this hike through a rocky wash is still a delight. This easy walk covers 1.5 miles and takes about one hour. The Elephant Tree Trail turn off is on Split Mountain Rd. approximately 5.9 miles from Ocotillo Wells and Hwy 78.

Article about Elephant Tree Trail

Fish Creek Wash will take you to the **Fish Creek Primitive Campground** and on through Split Mountain. The wash is a jeep trail that you can walk, bike or drive through in a 4WD vehicle. Fish Creek Wash points of interest include: Anticline, Wind Caves, Elephant Knees, Loop Wash, Sandstone Canyon and Olla Wash.
Hike - Fish Creek Walk -
4WD - Fish Creek Jeep Trail
Article about Fossils From Split Mountain, Fish Creek and Surrounding Area
Split Mountain Wind Caves - The sandstone caves and arches are created from erosion caused by wind. You can explore the caves by hiking approximately 1 mile from the Wind Cave Trailhead (2 miles round trip). Trail head is located in Fish Creek Wash just past Split Mountain.
Mud Hills Wash and Elephant Knees - One of the most spectacular sights in the Split Mountain area is a formation known as Elephant Knees. It's a mudhill ridge with thick fluted ridges that look like the knees of elephants.
From the road, you look up at it and view it from a distance. You can also walk Mudhill Wash, to the east of Elephant Knees, to get a closer view. The flat top of Elephant Knees is a layer of marine sediments. You can look at it, but you mustn't climb on it. Click here to read more about Elephant Knees.
Elephant Knees Information and Location
Hike - Mud Hills Wash/Elephant Knees

Appendix 8 Torrey Pines Geology Walk by Don Grine, 2008



Elevation: NED 10 m, 5 m contours; Satellite Imagery from ESRI WMS; UTM Zone 11, WGS 84.

Figure Torrey Pines Geology Tour Map

Stop 1 East Overlook Beside The Lodge, N32° 55.274' W117° 15.155'
The ocean wasn't always 300 feet below this spot. About 140 million years ago, the mountains to the east were a chain of volcanic islands. There was a shallow sea to their east and open ocean to their west, including here. A plate of the Earth's crust from the west was pushing under the islands, melting and sending up the molten rock to the volcanoes, and carrying the whole chain to a collision with North America. The nearer mountains you see now are made of volcanic rocks. One hundred million years ago, blobs of molten rock stopped miles below the surface. They cooled over thousands of years into the granitic rocks that now form most of the mountains to our east. At the same time, large mountains were pushed up so our coast looked like the present Andes.

By 50 million years ago, the mountains had worn down to a plain. Large rivers were carrying sand and gravel from mountains over 100 miles to our east. You would have been standing in the middle of a bay about the size of the present Monterey Bay. The white Torrey Sandstone you see a mile across the valley was being deposited as an offshore sand bar or barrier island. Only a million years ago, the red Lindavista formation on top of the Torrey Sandstone was laid down as the ocean retreated from the nearly flat terrace it had cut. The red rock on top of the white one is seen in the cliffs just in front of you as well as across the valley. At the bottom of the red rock there is a layer of cobbles that the ocean used as tools to cut the terrace on top of the Torrey Sandstone. You will see the cobbles at our next stop. The cobble layer is about 30 feet lower than in the nearest ridge to the north. A fault must lie along the steep canyon just in front of you. A fault is a crack in the rocks with movement of rocks across the crack. Many of the canyons that cross San Diego are cut by running water along faults. Borings show that the mud in the estuary in front of you is about 300 feet deep. The ocean level must have been lower while the valley was being cut for the valley to be so deep. We know that during the great ice ages, the ocean level was indeed several hundred feet lower.

Stop 2 On The Road Below Parry Grove Trail, N32° 55.300' W117° 15.334'
Walk down the steps behind the Lodge and turn right to the road cut. In the road cut, we have a closer look at the layer of cobbles at the bottom of the Lindavista. If you go to the beach later, you will see cobbles much like these. Many of them are not like any rocks in our mountains. The 155 million year old cobbles were washed down from mountains in Sonora, Mexico about 45 million years ago while our area was further south. Our mountains had been worn flat, and there was no Gulf of California. About 25 million years ago, the Pacific Plate ripped us off the North American Plate and has carried us over 100 mile northwest, along with these Mexican cobbles. Rivers and ocean waves erode the old rocks and these hard, tough cobbles begin their cutting action again. At the sharp right curve, lower in the road, we see parallel lines, tilted about 30 degrees, in the white Torrey Sandstone. These are cross bedding, typical of a sandstone laid down by wave action.

Stop 3 Start Of Parry Grove Trail, N32° 55.285'n W117° 15.311'
Go back up the hill and turn off to the right at the sign for Parry Grove. The trail through the Whitaker Garden near the road is edged with cobbles from the base of the Lindavista formation. You can get a close look here without being hit by a car. Past the steps to the Parry Grove, toward the Canyon of the Swifts, you step down about two feet from the Lindavista formation across the layer of cobbles onto the Torrey Sandstone, N32° 55.233' W117° 15.334'. At the end of the trail is a bench that is my favorite place to rest in the Reserve. You get a great view of the canyon, the western Reserve, and the Pacific.

Stop 4 Red Butte, N32° 55.145' W117° 15.289'
Go back to the road and continue south to the West parking lot. Go down the trail to Red Butte and climb the stairs. You are standing on the same red rock you were on behind the lodge. A million years ago, fish would have been swimming in front of your nose. The land here has been rising over the last million years to its present 300+ feet. As the land rose out of the ocean, it became marshy. Heavy vegetation and wet conditions made a laterite soil, full of iron. The red color of the rock is from iron oxide (rust). The rust cements the red Lindavista more strongly than the Torrey Sandstone is cemented, so the Lindavista acts as a cap rock. Look toward the Lodge to see how it protects the softer sandstone from erosion. Leave Red Butte toward the steep canyon you see to the northwest. What makes sand into sandstone? The Torrey Sandstone across the canyon was loose sand on an offshore bar 45 million years ago. As sea level rose, the sands were buried. Water running through them carried minerals that deposited as cement to glue the sand into a weak rock. The cement wasn't very uniform so the rock is weaker in some places.

Stop 5 Canyon Of The Swifts, East Overlook, N32° 55.148' W117° 15.302'
The "wind caves" you see were not mainly caused by wind. These holes are started by running water dissolving the cement from an already weak spot. Then either water or wind may carry the loose grains away. Once a hole gets started, the area inside is shaded so it stays damp, more cement is dissolved and the hole gets deeper. Some of the holes started when spherical concretions (lumps of better cemented sandstone) dropped out of the rock. The "cannonball" concretions in the sandstone are caused by minerals being deposited from water inside the rock. The water dissolves the minerals from the sandstone or from rocks above it, then when the water source is reduced, precipitates them back out. Precipitation starts at some nucleus, perhaps a fossil, then grows on the crystals already there. The concretion of cemented sand then is a sphere if the process started at a point. If the start was along a line like a fossil plant, the concretion is a cylinder. You can see many spheres and a few cylinders in the cliff. The cementing minerals are either calcite from the Torrey Sandstone or iron oxide from the Lindavista.

Stop 6 Canyon Of The Swifts, West Overlook, N32° 55.144' W117° 15.390'
Continue down the trail next to the canyon. The canyon in front of you was eroded by running water, carrying sand. The weak sandstone wears away at the bottom of the canyon and also along the sides where small streams run during storms. The sides cave in when they get too steep and the debris is carried away in the next storm. The canyon probably started along a weaker zone in the rock, perhaps a fault although we do not see rock layers at different levels on the two sides of the canyon. Plants, lichens and animals also help erosion. You can see plant roots prying the rock apart. The lichens produce acids the help dissolve cement. The animals dig holes the allow water into the rock. The nearly horizontal gray rock layers in the canyon wall are old mud layers made into rock. At some time, conditions in the old sand bar changed. Mud was laid down for a while, then sand took over again.

Stop 7 Big Basin, N32° 55.089' W117° 15.443'
Take the trail south, past the entrance to Razor Point. You soon arrive at a level terrace below you toward the Pacific. During the last million years, the land here has risen at an average rate of about five inches per thousand years. The sea has risen and fallen several times. At several times, the level of the sea on the land stayed the same long enough for the sea to cut a beach terrace. A layer of cobbles like those we saw at the base of the Lindavista marks the base of each terrace. These big steps are hard to see because debris has washed down over them. The Nestor Terrace, 120 thousand 2008 Torrey Pines State Natural Reserve Geology Walk3years old, fills the end of the canyon just above the sea cliffs where a new terrace is being cut. You can also see the Guy Fleming and Parry Grove terraces from Big Basin. The "rock" in these terraces is so soft that you can dig it with a spade. It has eroded into gullies to make the "badlands" topography that looks so good in your pictures. When you come to the intersection with the Beach Trail, turn right toward the ocean.

Stop 8 Beach Trail, "Creek Crossing", N32° 54.984' W117° 15.426'
Here are some more of the hard, rounded cobbles so common in the Reserve. Many of them are not from local rock or even from rock in the mountains to our east. Most of the cobbles are volcanic. They came up as lava and solidified near the surface. They cooled too fast for large crystals to grow. The white crystals in many of them are feldspar that solidified at a high temperature and grew while the molten rock was still deep. Then they came up like plums in a

pudding and the rest of the minerals solidified quickly into much smaller crystals. These cobbles are part of the gravel that came into San Diego from the east about 45 million years ago. Geologists looking for their source had to remember that we are on the Pacific Plate of the Earth. This area has moved northwest along the North American Plate by about 200 miles since the cobbles arrived. The cobbles came from mountains in Sonora, Mexico. We are still moving northwest an average of about two inches per year. Our velocity is not constant. We may not move for a hundred years, then make it up in an earthquake lasting only a few seconds.

Stop 9 Lower Beach Trail, N32° 54.907' W117º 15.494

Near the bottom of the beach trail, see the foot-thick layer of fresh looking shells in the soil on your right. These shells are only about 120 thousand years old so most of them are from species still living. The clear layer shows that these are fossils. If these shells wash out (as they have just beside the path) they are hard to tell from the modern shells from the Kumeyaay middens common in the Reserve. Keep going down to the stairs to the beach.

Stop 10 On The Beach, N32° 54.882' W117° 15.514'

The gray-green rock at the bottom of the cliff is the Delmar formation. It was laid down in a lagoon about 45 million years ago during the Eocene. The formation contains shale, siltstone, and sandstone that were deposited during different weather conditions. The harder rock ledges right at the bottom have so many fossil oyster shells in them that they are almost limestone. Shells, tracks, and burrows of other marine animals can be seen in other layers. Only about 3% of the shells are from species still living. Flat Rock (or Bathtub Rock) is just to your south. It is part of the Delmar formation that was hard enough to become a point, then get cut off by the surf. You can see the "bathtub" in the rock from the cliff path that leads past it to the south. Just beside the cliff path, tilted layers of rock are cut off by a horizontal layer. The feature is called a "angular unconformity". The tilted layers were deposited along to edge of an old river channel, then cut off as the layer above washed in. The hard volcanic pebbles on the beach are thrown against the soft cliff by storm waves to erode the bottom of the cliff. The upper layers then fall to the beach. Don't linger too long near these unstable cliffs. You can get back to the lodge by returning up the beach trail or by walking north to the entrance road, then walking up the road. Along the beach, you can see many more of the features we have described. The tide level may decide your route.

Figure Torrey Pines Trails, North Portion, from http://www.torreypine.org/activities/hiking-trails.html.

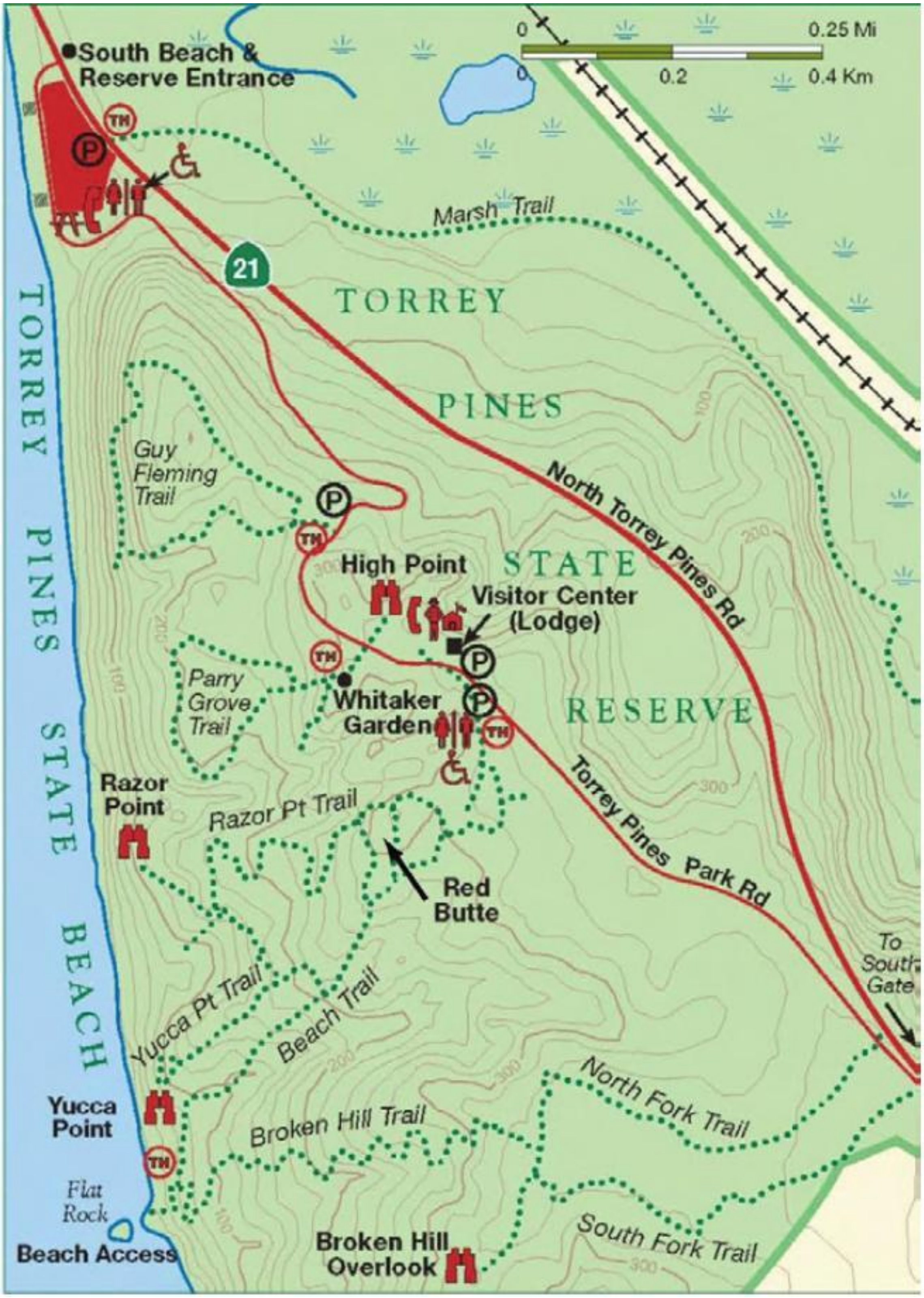


Figure Torrey Pines Trails, South Portion.
From **http://www.torreypine.org/activities/hiking-trails.html**.

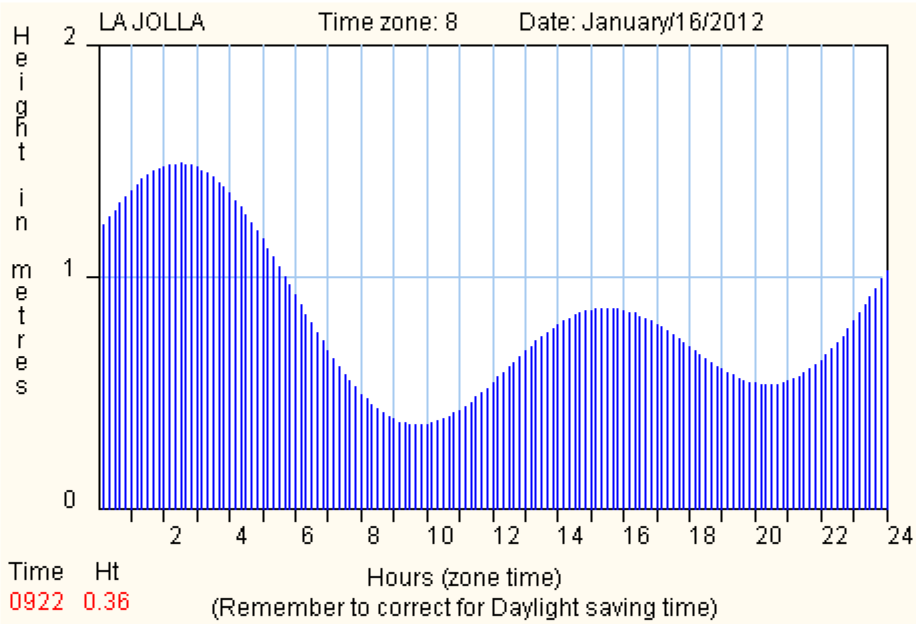
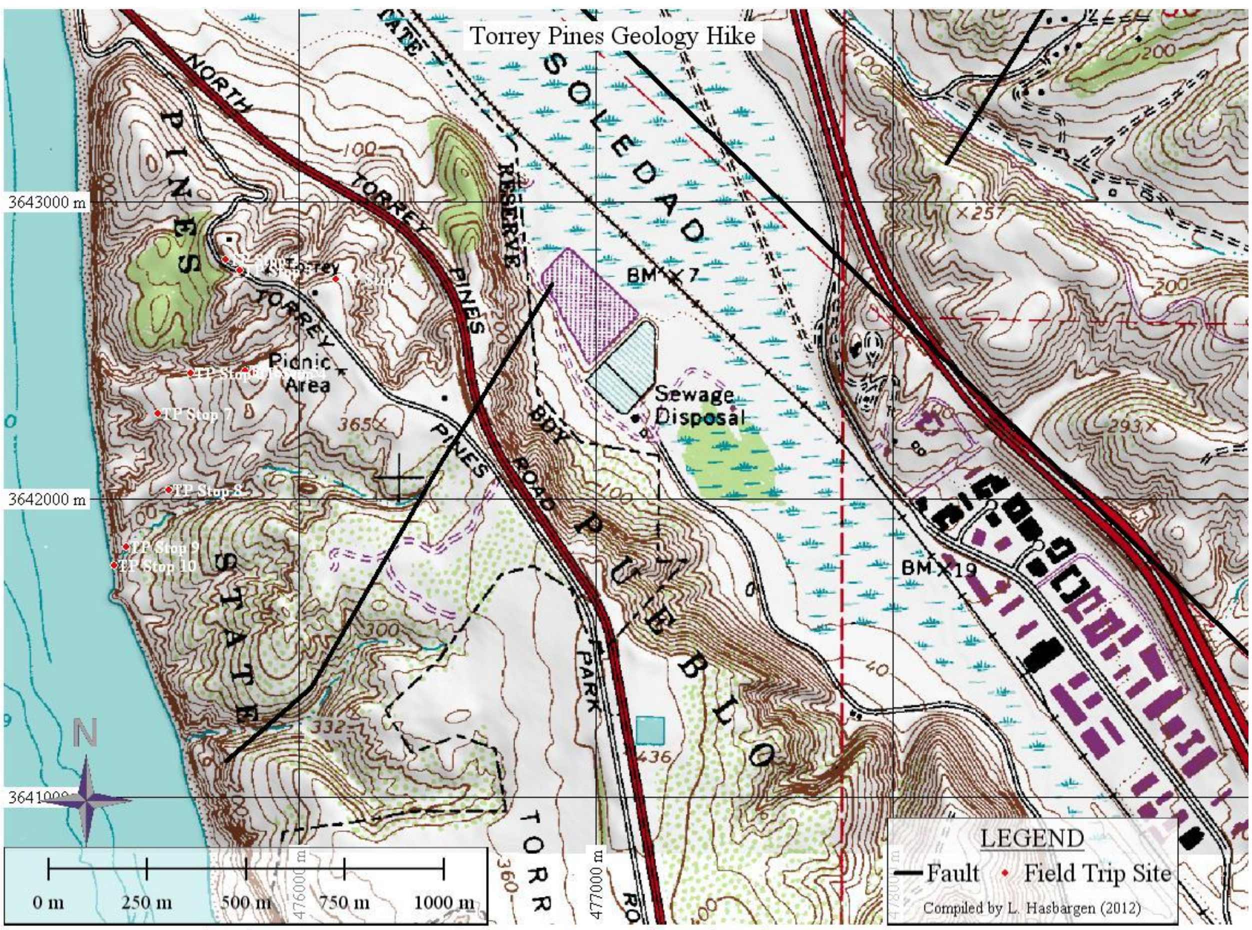


Figure La Jolla Tide for Monday January 16, 2012, from Scripps Institute (http://ocean.peterbrueggeman.com/piertide.html by Peter Brueggeman). The tide should be lowest about 9:30 am Standard Time.



Elevation: NED 10 m; Topo from USGS DRG; Grid spacing 1 km; UTM Zone 11, WGS 84.

Figure Torrey Pines Topography and Faults.