GSN-Southern Chapter
Fall 2005 Fieldtrip
Geology of the Mojave National Preserve
Fieldtrip Guidebook

Image created using NASA WorldWind software

Prepared by:

Joseph Kula

UNLV
Department of Geoscience
Las Vegas, NV
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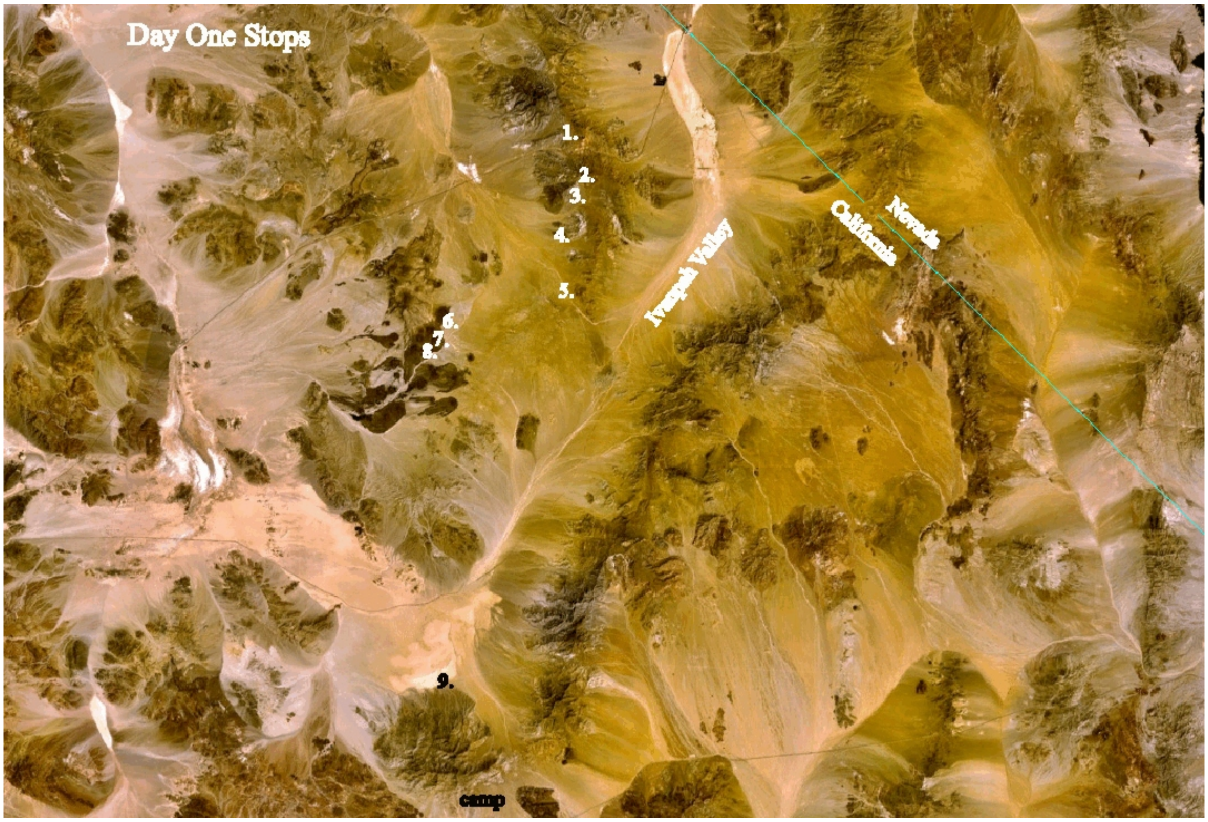
Introduction

This is a fieldtrip guidebook for a Geological Society of Nevada - Southern Chapter two-day field excursion through the Mojave National Preserve, in the eastern Mojave Desert region of southeastern California. The geology exposed in the Preserve is rather diverse, as this region sits in a region of the continent that records a protracted and complex history. Hopefully, this trip will showcase the amazing record of geologic history recorded in the rocks of the preserve, as well as demonstrate the natural beauty of both geological and bio-ecological elements contained within. Have fun!



DAY ONE

Mileage for this trip begins at the Chevron station at Primm off of Interstate-15 south. So, yes we are starting from UNLV campus in Las Vegas, but the first step is to drive south to the Chevron at Primm (or you can use the gas station at Whiskey Pete's if you prefer, I suppose) and gas-up before we continue because we will not be near any other gas stations during the trip, until we come back up past Primm. OK, here it goes:

0.0 miles - Exit Chevron at Primm (Buffalo Bill's side) and head back to I-15 south. We will drive past the playas on the left and right sides of the freeway. The dominant high peak in front of you and a bit to the right is Clark Mountain.

5.2 miles - you should be driving PAST the Yates exit ramp off of I-15.

10.0 miles - PASS the Nipton Road exit ramp. Keep driving on I-15 for another 4 miles or so...

14.7 miles - TAKE the Bailey Road exit to the right of the freeway. At the stop sign, make a right turn.

15.0 miles - Take your first left turn.

15.9 miles - Pavement ends and a dirt road begins, continue on it.

View heading toward Stop 1 on the eastern fringe of Mohawk Hill.

16.4 miles - the road bends to the right

16.5 miles- make a left turn

16.8 miles - turn left again

17.0 miles - make a left turn, and watch for the rut in the road. Continue driving through exposures of some craggy looking Precambrian gneisses.

17.3 miles - Follow a hard left on a switchback and continue uphill,

17.5 miles - stop at flat on top of the hill and park. We are now at

STOP 1. Mohawk Hill

We'll need to do a very short hike up the hill a bit, where we will see Cambrian limestone in fault contact with Precambrian gneiss. This is the Keaney/Mollusk Mine thrust fault. We'll talk a bit about this structure and then look at what happens to it to the south in the Mescal Range.

View to the south of the Mecal Range.

After discussion, we'll backtrack along the dirt road and at about 19.0 miles we'll be back on a paved road.

Mohawk Hill – Keaney/Mollusk Mine thrust fault.

The Keaney/Mollusk Mine thrust places the lower section of the Cambrian Bonanaza King formation over Precambrian crystalline basement rocks (Burchfiel and Davis, 1988). At this location, fracturing of the footwall (Precambrian rocks) should be apparent indicating a brittle deformational style. Burchfiel and Davis (1988) proposed that this thrust moved at or very near the land surface –an interpretation consistent with thrust fault correlatives such as the Muddy Mountains thrust to the north where synorogenic fluvial sediments containing clasts of Cambrian Bonanza King limestone (hanging wall) was shed off the advancing thrust sheet into the foreland (Brock and Engelder, 1977; Bohannon, 1983). Conglomerate containing limestone clasts can also be found below the Wilson Cliffs thrust in the Spring Mountains, indicating the frontal thrust was a surface riding structure.

We'll discuss more about the nature and timing of the frontal thrusts related to Sevier orogenesis at the next stop. Heading back to the vehicles, and retracing our path back towards I-15, we will cross over the interstate and turn left (~southeast) onto a graded dirt road and follow this trail up through and then down out of the topography of the eastern most Mescal Range. When we reach the Piute valley we will park for a broad perspective view to the north of the fold-thrust-belt as preserved in the Mescal Range.

19.9 miles - we should be back at the stop sign at Bailey Road, make a right and drive over the freeway (I-15) and past the on-ramp for I-15 north.

20.1 miles - make a left turn onto a road with a sign that says "unmaintained road" or "road not maintained" or something of this nature.

20.4 miles - Should be passing a Kokoweef sign, continue on this main road even after the pavement ends and it becomes graded dirt.

21.2 miles - follow the sign to Kokoweef

22.8 miles - stay straight on the road with Kokoweef Peak off to the left, and a high standing package of volcanic rocks off to the right.

23.0 miles - follow the Kokoweef sign

23.75 miles - Make a right turn and then take the left fork up the hill. Both lead to the same place, but the road to the left is in a little bit better condition than that on the right.

24.0 miles - find parking near an old abandoned car frame. There is additional open space to park approximately 10 m further up the road. (That 'm' is *meters* <u>NOT</u> *miles*).

We are now at <u>**STOP 2**</u>.

We'll do a very short hike up the road a bit, and then bear to the right onto a road that goes slightly downhill with a drop-off to the right. We'll stop at an outcrop of crossbeds in the Jurassic Aztec sandstone. The Aztec sandstone is the only dinosaur fossil bearing unit in California (Reynolds, 2005). At this location, the Aztec sandstone exhibits smaller scale crossbeds than to the northeast in the Spring Mountains, and Muddy Mountains. Addtionally, the section is much thinner here than at these other locales, these two observations seem to be the fundamentals of (at least) two interpretations - Aztec in the Mescal Range represents a more coastal depositional environment and is thus thinner with smaller crossbeds, and the Aztec here in the Mescal Range is thinner due to differential uplift between this location and exposures to the northeast. Alternatively, comparison between SE California Aztec and other locales of 'Navajo' sandstone may not even be fair due to ages determined for Cowhole Volcanic rocks that intrude into the Aztec further west indicating the Aztec is ~170 Ma and thus younger than the ~190 Ma Navajo sandstone (Ferriz, 2002; Reynolds, 2005).

Aztec sandstone in the Mescal Range.

Walk back to the vehicles, and double back to the main dirt road that we had come into the valley on.

24.3 miles - bear to the left

25.5 miles - pull off to the side of the road and stop. We'll get out of the vehicles and have this as **STOP 3**, which is a perspective view both to the north and the south to discuss continuity (and lack there of) of units and structures across Piute Valley.

View to the south

View to the north.

Mescal Range – Delfonte Volcanics & the frontal thrust

In the eastern Mescal Range, a sequence of basaltic to rhyolitic lavas and ash-flow tuffs erupted in the latest Early Cretaceous, sits disconformably upon Jurassic Aztec sandstone (Fleck et al., 1994). This volcanic sequence, called the *Delfonte volcanics* (Fleck et al., 1994) represents some of the youngest stratigraphic units deformed by the southern Sevier fold-and-thrust belt (Burchfiel and Davis, 1971; Fleck et al., 1994). These deposits sit in the footwall of the Keaney/Mollusk Mine thrust fault, therefore, their age offers a maximum constraint on the timing of the latest stage of Sevier deformation in the southern region of the fold-thrust belt (Burchfiel and Davis, 1971; Fleck et al., 1994). The Delfonte volcanic rocks are exposed as a northwest plunging overturned syncline bounded to the west by the Keaney/Mollusk Mine thrust and to the east and north by the South fault/Kokoweef fault system (Burchfiel and Davis, 1988). A thrust fault repeats the volcanic sequence, and this structure is also folded with the syncline indicating at least two stages of shortening followed eruption and deposition of the Delfonte sequence.

As mentioned (and as we've seen at the previous top), the Delfonte volcanics rest disconformably upon Jurassic Aztec sandstone. In the Mescal Range, the Aztec sandstone is considerably thin when compared with that exposed to the north in the Spring Mountains (Wilson cliffs region). This observation hints that a significant amount of Aztec sandstone was removed from the section prior to deposition of Delfonte rocks. Erosion of Aztec sandstone is even more pronounced at Goodsprings, NV where the Lavinia Wash sequence sits unconformably on Triassic rocks (Carr, 1980; Fleck and Carr, 1990). The Lavinia Wash sequence consists of nonmarine clastic sediments containing volcanic boulders similar to those in the Delfonte volcanics. Lavinia Wash sediments, like the Delfonte rocks, sit below the easternmost thrust faults in the central Spring Mountains (Carr, 1980). ^{40}Ar/^{39}Ar ages of 99 and 98 Ma for an ashflow tuff and large volcanic boulder, respectively in the Lavinia Wash sequence support correlation with the ca. 100 Ma Delfonte volcanics (Fleck et al., 1994). Rb-

Sr analyses from boulders further corroborates the relationship between Lavinia Wash and Delfonte volcanics, indicating the boulders found in the Goodsprings region were likely derived from the Delfonte (Fleck et al., 1994).

Correlations may be made based on latest Early Cretaceous volcanic rocks and their relation to thrust faults, as well as constraints on the timing of faulting. Volcanic rocks with an age of 100 Ma have been recognized in the North Muddy Mountains (Fleck, 1970), the Spring Mountains at Lavinia Wash (Fleck and Carr, 1990), the eastern Mescal Range in the Delfonte sequence (Fleck et al., 1994), and further south across Ivanpah Valley, in the New York Mountains below the Sagamore Canyon thrust (Smith et al., 2003). In the Mescal Range, timing of thrusting along the Keaney/Mollusk Mine thrust is constrained as between deposition of the Delfonte rocks (100 Ma) and intrusion of the Teutonia batholith (71-97 Ma), which is inferred to cut the thrust although this relationship is not exposed (Adams et al., 1967; Fleck et al., 1994; Walker et al., 1995). In the New York Mountains, constraints on the timing of motion along the Sagamore Canyon thrust are more robust. Metasedimentary and metavolcanic rocks sitting below the thrust yield a U/Pb ion microprobe age of 100.6   1 Ma (Smith et al., 2003). The thrust fault is then cut by the Mid Hills monzogranite which yielded a zircon age of 90   1.3 Ma (Smith et al., 2003). Therefore, in the New York Mountains, the timing of motion along the frontal thrust of the Sevier belt is constrained between 101-89 Ma based on observable crosscutting relationships and ion microprobe zircon geochronology (Smith et al., 2003).

When we're finished, we'll get back in the cars and continue along the road.
At **25.6 miles** - turn left

26.4 miles - make a right at the fork in the road

27.2 miles - bear to the left

28.2 miles - bear to the right

28.7 miles - go right

29.6 miles - take the left fork in the road and drive across a wash

30.4 miles - Stop at the top clearing of a small hill along the west side of the Striped Mountain.

STOP 4. We are in the western Striped Mountain standing in ductiley deformed rocks related to the Sterling Thrust. This structure is correlated north with the oldest episode of thrusting within the Clark Mountains thrust complex.

Initial thrusting in the Clark Mountains thrust complex.

Thrust faults in the Clark Mountains thrust complex are oldest to the west and get progressively younger to the east. Western thrusts are ductile, and grade into brittle deformation styles (Burchfiel and Davis, 1971, 1988). The oldest structure with timing constraints is the Pachalka Springs thrust in the western Clark Mountains, where Jurassic granitic rocks are placed over Neoproterozoic-Cambrian quartzite (Walker et al., 1995). Based on U/Pb zircon geochronology of the crystalline hanging wall and a range interior pluton, and cross cutting relationships with associated structures, the Pachalka Springs thrust is interpreted to be a Latest Jurassic-to-Earliest Cretaceous structure, likely active at ~144 Ma (Walker et al., 1995). This thrust fault may be correlated north with the Winters Pass thrust fault, and to the south with the Sterling Thrust in the western Striped Mountain (Burchfiel and Davis, 1988; Walker et al., 1995).

Where we are standing on the Striped Mountain, mylonitic rocks making up the hill to our left (west) are overturned below a structurally higher thrust fault in the valley, and are in turn in thrust contact with the rocks making up the hill to our right (east). These western thrusts, the Pachalka Springs/Winters Pass structures, are considered to represent intersection of the fold-thrust-belt with the Mesozoic magmatic arc that was developing along the western coast of North America due to Kula/Farallon subduction. The age constraints on the Pachalka Springs thrust permits correlation with the East Sierran thrust system, which is characterized by high-angle, short-transport, ductile thrusts placing arc-rocks over the continental margin sedimentary rocks (Dunne and Walker, 2004). Walker et al. (1995) interpret the Pachalka Springs thrust to be late with respect to the East Sierran thrust system, and early with respect to the Sevier fold-thrust-belt (Clark Mountains thrust complex).

View to the north.

If you turn around and face to the south, you will have a view of Cima Dome and Teutonia Peak. This is where we are headed next. So, when we finish discussion here, we'll get back in the vehicles and doubleback on the road.

View to the south.

31.3 miles - make a right turn

31.8 miles - bear left around section of road that is washed out, then get back on the road.

31.9 miles - Make a right turn on road heading west out toward Cima Road.

34.5 miles - Make a left turn onto Cima Road by a corral. This will be a nice big paved road.

37.4 miles - should be passing a road to Valley View Ranch on your right

38.6 miles - Stop at a pulloff on the right side of the road with a trailhead to Teutonia Peak.

STOP 5. There will be an information sign about hiking to Teutonia Peak and perhaps a bit about the Cima Dome and the batholith (?). (*I actually don't know, I didn't read it*). We can have a look around at the sign and then congregate across the street on an open outcrop of granite, where we'll discuss intrusions of the Teutonia Batholith.

The Teutonia Batholith and Cima Dome

The Teutonia Batholith represents one of the larger arc-related intrusions in the Mojave Desert region. Plutons of the batholith were described by Beckerman et al.(1982), and range in age from about 90-97 Ma. Rock chemistries indicate the plutons were derived from partial melting of lower crustal quartzofeldspathic sources (Beckerman et al., 1982). Intrusive relationships and chemical signatures also indicate the batholith was emplaced into the shallow crust (upper ~10 km's).

The Cima Dome is a rather dominant geomorphological feature of the eastern Mojve

Desert Region. It may represent the erosional remnant of a once topographically significant plutonic complex (namely Teutonia grantiods). It has also been interpreted as a degraded or retreating fault block scarp (Reynolds et al., 1996). This interpretation is based upon comparison with smaller domes located in the Halloran Hills region. It was noted that all of the granitic domes present at this locale are bordered to the west by listric normal faults, along with east dipping sediments and volcanic rocks east of their apex (Reynolds, 2005). If the Kingston Range detachment does in fact extend as far south as the Cima Dome, it may represent the listric normal fault which is separated from the dome apex by a deposit of Peach Springs tuff, indicating a comparable geologic components to the domes of the Halloran Hills.

Ok, we'll get back in the vehicles, and turn around, and double back on Cima Road.

39.8 miles - Turn left onto the road heading to Valley View Ranch.

41.4 miles - Pass a barn on your right and continue straight through the intersection past the white house.

45.9 miles - Pass a corral with a tank (*tank like container not like war machine*)

47.6 miles - should be at a corral with telephone poles. Drive straight through.

49.6 miles - should be passing a cinder cone on your right

50.1 miles - <u>**STOP 6**</u>.

The view to the right (northwest) should be of a breached cinder cone with what appear to be lava flow terraces. We are in the Cima volcanic field.

Cima Volcanic Field Part 1.

The Late Miocene to Quaternary Cima volcanic field consists of over 70 cinder cones and vents having extruded ~150 km^2 of lava flows. Lavas are typically alkali basalt that were erupted during two stages; 7.6 to 3.0 Ma, and 1.0 Ma to present (Wilshire et al., 1991; Farmer et al., 1995). Isotopic studies of these rocks indicate an asthenospheric source similar to MORB- which may be the result of upwelling of material through a slab gap during development of the transfrom boundary that replaced the convergent boundary along the southwestern U.S.

Cima Volcanic Field Part 2. Mesozoic insight from xenoliths

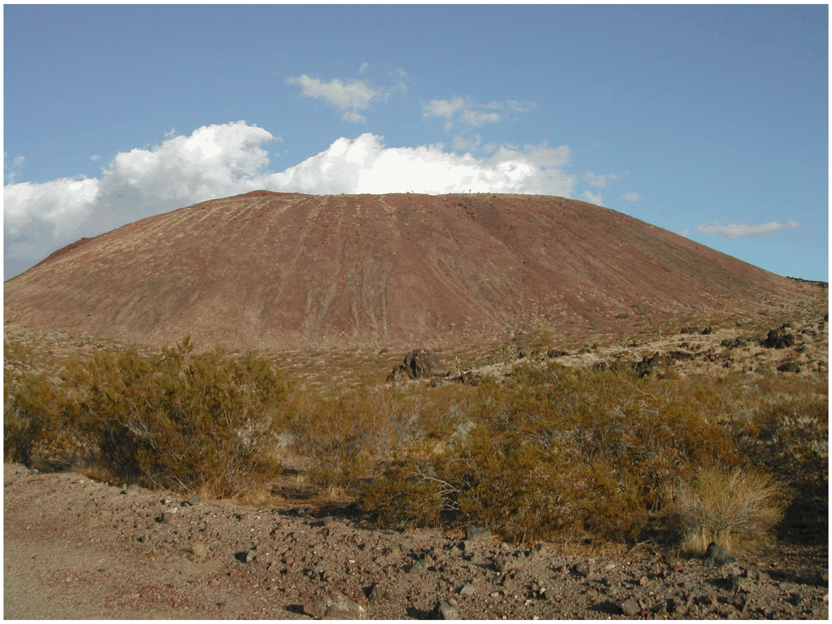
Within some of the lavas of the Cima Volcanic field, mantle derived xenoliths have been recovered, which offer insight into the earlier lower lithospheric structure and development. Mafic and ultramafic xenoliths yield low Sr and high Nd ratios that are consistent with a MORB asthenospheric source (Levanthal et al., 1995). Whole-rock and mineral isochron ages for these xenoliths indicate intrusion/crystallization at 65-101 Ma. Isotopic data from Neogene Cima lavas indicates elevated Sr ratios, further demonstrating the xenoliths are not related to the younger lavas (Levanthal et al., 1995). The timing of upwelling of a MORB like asthenosphere is consistent with melting of a quartzofeldspathic lower crust to create the magmas of the Teutonia batholith, which would have required a significant heat source. Ascent of asthenosphere may be the result of several scenarios - convective erosion of a thickened crustal column following Sevier thickening (England and Houseman, 1989), - injection during slab steepening in the wake of the Farallon flat-slab segment (Saleeby, 2003), - delamination of mantle lithosphere at the onset of flat-slab subduction (Wells et al., 2004; 2005).

Continuing on the same road...........

51.95 miles - **STOP 7**. Pulloff along the right side of the road up a slight hill. There are layers visible in a terrace cut of basalt, that may represent proto-soil formation (?) in the basalt. Or it may not really be anything.

Continue along the road and when you reach the Aiken Mine turn off to the right to find the gate leading to where the road picks up.

53.4 miles - **STOP 8**. We are now in the back of the mine and have a nice photo opportunity of the sizeable cinder cone that was being mined.



Just continue on this road for several miles and enjoy the ride through the volcanic landscape.

59.9 miles - Make a left turn onto Kelbaker Road. This is kind of a long drive to our next stop. Something you can do on the way is contemplate the abundance of Joshua Trees you are driving past, and then (if you've been there) compare them to Joshua Tree National Park, and wonder whether or not you feel it was named correctly.

74.2 miles - You should be passing the Kelso Depot on your left and preparing to drive over several railroad tracks.

81.9 miles - make a right onto Kelso Dunes road

84.7 miles - **STOP 9**. The Kelso dunes trailhead and restroom area. We'll walk out just a bit onto the sand of the dunes and talk a little bit about why they formed there, and then we'll talk about the geology of the surrounding mountain ranges.

Kelso Sand Dunes

Along the western side of Kelbaker Road, about midway between I-15 south and I-40 west, the Kelso Dunes sit just north of the Granite Mountains in the southern region of the Preserve. The dunes are constructed upon a broad north-dipping alluvial apron extending off of the northern Granite Mountains. Projecting the surface of this apron beneath the highest dunes indicates a sand thickness of 700 feet or more (Sharp and Glazner, 1993).

The sand making up the dunes is derived from Afton Canyon in the northern Cady Mountains, about 60 km to the west-northwest. There is abundant magnetite in the sand at the dunes, which is seen as thin beds of "black sand" or as dark streaks in the light sand. The magnetite also points to Afton Canyon as a source because mines in the region have produced magnetite in commercial volumes. In the Afton Canyon region, the Mojave River flows east from the canyon and builds a broad alluvial plain. With each flood, loose sediment is spread over the surface of the plain, and subsequently blown eastward with the prevailing westerly winds. As to why the Kelso dunes formed where they have, a typical explanation for dune formation is an initial small-scale topographic feature that traps sand behind it, with the trapped pile of sand growing into a dune with time. The Kelso dunes however, warrant a different (more likely) explanation. Dune formation north of the Granite Mountains and west of the Providence Mountains is likely due to some marked anomaly (for lack of a better word) in the wind currents. Referring to topography of the Preserve and the regions immediately surrounding it, the mountain ranges northwest of the Granite Mountains all strike generally northwest. However, the ranges to the northeast, strike to the northeast. The Granite Mountains mark the apex of a south-pointing arrow defined by the opposing strikes of the valleys and ranges to the east and west. As such, the Granite and adjacent Providence Mountains obstruct the westerly winds decreasing their velocity and thus causing the winds to lose competency and drop the sand.

The Kelso Dunes probably began accumulating sand during the last glacial period ~14,000 years ago. This age (14 ka) reflects the time when Lake Manix began to overflow through Afton Canyon, and by inference, construction of the Mojave River fan delta out from the canyon. *Most of this information comes from Sharp and Glazner's "Geology Underfoot in southern California".*

We'll return to the vehicles and trace back to Kelbaker Road.

87.5 miles - Turn right onto Kelbaker Road heading south.

93.9 miles - Drive past radio towers on a small hill in Granite Pass, which marks the boundary between Late Cretaceous granites of the Granite Mountains to the right and Jurassic granitoides of the Providence Mountains to the left.

97.6 miles - Make a right onto a dirt road marked by a radio tower. Drive past the tower and continue on this road heading towards the mountains.

98.9 miles - CAMP. Road should end or turn around at a fenced off location. There should be plenty of space to put some vehicles and so we can just find flat spots to set up tents and a kitchen. The fence marks the boundary of a biological research center stationed in the southeastern Granite Mountains.

END DAY ONE

DAY TWO

We'll start by retracing the dirt road that led us to our campsite back out to Kelbaker Road.

0.0 miles - Make a left onto Kelbaker Road, and we'll pull off to the side wherever the shoulder is not too soft that we sink.

STOP 1. Looking west is the southeastern Granite Mountains, to the southeast is Van Winkle Mountain. Van Winkle Mountain is made up dominantly of Miocene volcanic rocks that sit upon Late Cretaceous granite, indicating surface exposure of the granite by that time. The southern portion of the Granite Mountains displays a very rugged morphology and the valley off of the topography to the south is one of several pre-Miocene pediments in this region (Miller, 1995).

Van Winkle Mountain

Southeastern Granite Mountains.

Continue north on Kelbaker Road. We will be driving past the dunes on our left and see Kelso Depot up ahead of us.

17.5 miles - turn right onto Kelso/Cima road.

17.6 miles - **STOP 2**. Make a right turn into the Kelso Depot parking lot. The Kelso Depot has been renovated to become the new headquarters of the Mojave National Preserve. Inside are geologic, biologic, and historic exhibits depicting the natural development and use through time of the Preserve. We'll spend some time here visiting.

Continue on Kelso/Cima road for approximately **19 miles** until we reach the intersection with Cima Road, Morning Star Mine Road, and the Union Pacific Railroad. Here, we'll find a place to pull off to the side and park.

~36 miles - **STOP 3**. To the east stand the New York Mountains. We'll discuss some of the geology that is visible from this location, as well as consider correlation of structures across the Ivanpah Valley.

Returning to the vehicles, we'll drive onto Morning Star Mine Road heading north for about **9 miles**.

~45.5 miles - make a left turn onto wide dirt road heading toward large mining operation at the base of the Ivanpah Mountains.

47.9 miles - **STOP 4**. Park on the side of the dirt road. In front of us in the New Trail Canyon region of the Ivanpah Mountains. We should be able to clearly see the contact of the Ivanpah Pluton with complexly faulted and folded platform carbonate rocks.

Ivanpah Pluton & New Trail Canyon region

One of the more enigmatic rock units in the Mojave National Preserve is the Ivanpah Pluton –named for the Ivanpah Mountains of which it makes up a large portion (Robinson and Anderson, 1979). The Ivanpah pluton is a Late Jurassic (147 7 Ma, Walker et al. (1995)), texturally heterogeneous felsic intrusion dominated by alkali feldspar. It differs from other plutons in the region of similar age in that chemical signatures indicate the magma crystallized from a melt derived from drier conditions or a smaller degree of partial melting of a more calcic source (Beckerman et al., 1982). In the New Trail Canyon region of the Ivanpah Mountains, there are several additional small intrusions that make up the Oro Wash granodiorite. These intrusions are only exposed to the east of the Ivanpah pluton, and in outcrops of lower elevation. The Oro Wash granodiorite is a more mafic intrusion than the Ivanpah pluton – containing abundant biotite and hornblende indicating it is likely a genetically distinct magma from that of the Ivanpah granite. U/Pb zircon ion microprobe geochronology and hornblende-plagioclase thermobarometry indicate the Oro Wash granodiorite was emplaced in the shallow crust at 150 Ma (Kula, unpublished data). Shallow emplacement is consistent with ^{40}Ar/^{39}Ar data, with biotite yielding an age of 150.8 0.5 Ma, and K-feldspar recording similar ages in the later gas release steps, indicating rapid cooling through <300 C upon emplacement (Kula, unpublished data). At New Trail Canyon, the cratonal platform rocks are estimated to have been as thin as 2-3 km in thickness. The Oro Wash granodiorite intrudes into these units, which are thrust-imbricated and overturned but not metamorphosed, however, there is no evidence for deformation in the intrusions. So, if structural orientations observed in the Mescal Range to the north are continued to the south into the Ivanpah Mountains (and across Ivanpah Valley into the New York Mountains for that matter), inference may be made on the timing of thrust faulting within the carbonate section as coeval with that to the north which resulted in folding of the Delfonte volanics into a syncline (101-89 Ma). With a lack of evidence for strain in the Oro Wash granodiorite, coupled with thermobarometry and thermochronometry data, these plutons were emplaced in the upper crust at 150 Ma, where they resided for approximately 50 Ma before they were involved in a brittle, localized thrust faulting/ folding event.

Where the Ivanpah Pluton fits into this tectonomagmatic scenario is a bit more difficult. Perhaps a place to start is to consider what is known about this intrusion. Walker et al. (1995) report a U/Pb crystallization age of 147 7 Ma for the pluton. Chemically, the intrusion is felsic and derived from an anomalous source when compared to other Late Jurassic plutons in the region (Beckerman et al., 1982). Contact-metamorphosed west-dipping upper Paleozoic carbonate rocks mark the western boundary of the Ivanpah pluton, and are interpreted as sitting above the intrusion (Walker et al., 1995). To the east, overturned Cambrian carbonates (also contact metamorphosed) interpreted as below the pluton mark the eastern boundary of the Ivanpah granite (Walker et al., 1995). In their interpretation, Walker et al. (1995) view the Ivanpah pluton as sitting in the core of an eastward-overturned anticline, which is paired with the Kokoweef syncline to the east (this is basically the same fold that is cored by Delfonte volcanics in the Mescal Range to the north). Therefore, the Ivanpah Pluton intruded into the continental margin ~50 Ma before it was folded(?) during thrust faulting (Fleck et al., 1994; Walker et al., 1995).

In the southern Mescal Range, there is a small exposure of Ivanpah granite which is overlain by an arkosic sandstone and channel conglomerate. The arkose is interpreted to be derived from the Ivanpah granite. These units are within the western limb of the Delfonte syncline, and therefore it seems the Ivanpah granite was emplaced at ~147 Ma, and was exposed to a topographical expression, by 100 Ma.

48.1 miles - make a left turn onto a smaller dirt road. We will follow this road to the Kewanee Hills.

49 miles - **<u>STOP 5</u>**. Pull off to the right at the base of the Kewanee Hills. Here we see ridges of Cambrian-Devonian carbonate above Ivanpah granite. Also exposed here is the Morning Star Mine thrust fault, which we will discuss.

Ivanpah Pluton – Morning Star Mine thrust

The Ivanpah pluton is interpreted to sit in the core of a north-plunging eastwardly overturned anticline-syncline pair (Walker et al., 1995). Along the western margin of the pluton, upright west dipping Paleozoic carbonate rocks mark the Contained within the pluton are the Morning Star Mine and Sunnyside thrust faults. Both are north-northeast striking east-vergent ductile thrusts mildly overprinted by brittle deformation (brecciation and cataclasis) (Walker et al., 1995; Sheets, 1996). Timing of deformation along these shear zones is not well constrained, but must have occurred between emplacement of the Ivanpah granite at ~147 Ma and the end of thrust faulting in this region, as marked by the Teutonia batholith ca. 90 Ma. An apparent conundrum exists in that spatially, the Ivanpah pluton appears to intrude into an anticline-syncline pair. If these folds do in fact make a pair, the age of formation of the folds is 100 Ma, the age of the Delfonte volcanics which core the syncline. However, the Ivanpah granite is nearly 50 Ma older, so the scenario is not that clear. It is perhaps possible that the Morning Star Mine thrust system is the southern deeper crustal segment of the Keaney-Mollusk Mine thrust fault, and therefore is late Early Cretaceous in age. The Keaney-Mollusk Mine thrust has previously been correlated across Piute Valley into the Striped Mountain to the west (Burchfiel and Davis, 1988; Walker et al., 1995). This correlation requires a westward inflection of the structure, and also places the Ivanpah granite and internal thrusts along with the New Trail Canyon into the foreland of the thrust belt. This scenario is complex because the Kokoweef syncline correlates very nicely to the north with the Delfonte syncline, and therefore folds in the Ivanpah Mountains are more open than the tighter structures seen in the Mescal Range.

Returning to the vehicles, we'll retrace our path on the small dirt road.

49.9 miles - make a right onto the wide dirt road heading south towards Morning Star Mine Road.

52.5 miles - make a left onto Morning Star Mine road.

58 miles - turn left onto Ivanpah Road. Follow this road until you run into Nipton road.

61.1 miles - turn left onto Nipton Road. This road will take you to I-15, where you make a right and head back towards Las Vegas.

<u>END DAY TWO</u>

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