

Field Report

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12.110 Sedimentary Geology
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Stop #1: Sunrise Mountain West

Sunrise Mountain is located east of the northern end of Las Vegas. From this stop, the Spring Mountains are visible to the west of Las Vegas. The Spring Mountains were not affected by the extension and faulting of the basin-and-range area and are in the autochthon. The Las Vegas Basin and Sunrise Mountain were affected by faulting. In the same generation of faulting, the Sunrise Mountains were lifted and the Las Vegas basin went down.

On the outcrop on Sunrise Mountain, the lowest layer mapped was Precambrian metamorphosed red granite. Basal Cambrian units lie on top of this unit, so an unconformity is present. On top of the metamorphosed granite, a paleosol horizon was seen (Figure 1). Paleosols form when rock is exposed subaerially, and erosion occurs, creating a layer of soil, which then is later lithified. This paleosol layer has been re-weathered now, and therefore is a recessive layer in the section.

The Tapeats Sandstone rests on the paleosol. This is an erosional contact, i.e., an unconformity. The Tapeats Sandstone is a coarse, stratified quartz arenite. Planar stratification and both small-scale and large-scale cross stratification are seen. Bedding planes are visible and vary in thickness from 8 cm to 0.5 meters.

The Tapeats Sandstone unit comprises several facies. Directly on top of the paleosol is a reddish-yellow-weathered quartz arenite interbedded with some layers of arenaceous conglomerates. Studies of a hand sample of the quartz arenite showed an upper fine grain size with larger coarse grains. Petrological studies on this sample showed that it is poorly sorted with subangular grains, mostly of quartz with a little feldspar. The rock is entirely sutured, with no matrix and low porosity.

Above this reddish-yellow facies is a white-weathering quartz arenite. Study of a hand sample indicated upper very fine to upper very coarse grain size. Petrological studies of this sample showed that it is mainly quartz with a few rock fragments. It is poorly sorted, with rounded to subangular clasts. There is some carbonate cement in this rock as well.

The next subfacies is a layer that is weathered yellow with black spots. On a fresh surface there are large round black and orange spots 1-2 mm in diameter in a white sand matrix of lower middle grain size (Figure 2).

The Tapeats Sandstone was probably deposited by a middling-speed current with dunes to form the large-scale cross stratification. All the large-scale stratification is in one direction, so the transporting agent was probably a unidirectional flow in a river or shallow ocean. Small-scale cross stratification has apparent dips on the outcrop surfaces that are locally in different directions, but that could be because the current was perpendicular to the rock face.

After we walked upsection over a covered interval, the next unit seen was the Bright Angel Shale, with red shale succeeded upward by green shale. (This covered interval could have been mainly or partially shale as well, inasmuch as shale is easily weathered away.) The green shale has a high concentration of mica along bedding planes. In addition, thin, subcentimeter beds of fine green sandstone are interbedded with the green shale. These beds had sharp bases, some with burrows and tool marks on them (Figure 3). The sandstone is planar laminated, and in some places ripples can be seen.

The depositional environment for this unit was slow settling, i.e., fallout without traction. Micaceous particles would fall more slowly owing to their shape, thus aggregating on bedding surfaces as seen in the outcrop. It was most likely in a marine environment because of the presence of the shale. A chemical change in the environment caused the shift in color from red to green. The green shale represents a reducing environment where iron in the grains and/or rock becomes ferrous iron oxide whereas the red shale was deposited in an oxidizing environment. The green sandstone beds were event beds which are turbidites or tempestites. The shale represents the background sedimentation, and the green sandstone layers formed only during storm events.

As we progressed upsection, there was an increasing percentage of the green sandstone beds, with a thickening of beds (up to 1 meter) and a coarsening of grains. This suggests a shallowing-upward and coarsening-upward succession.

Suddenly we found units of shale again as we continued walking upsection. This suggests a sudden rise in sea level, so we only get shale. Therefore there was an asymmetric regression, because the siliciclastic supply was cut off. There appears to be a cycle in the rocks seen. It was probably a transgression overall, but with transgressive-regressive cycles.

We then walked laterally upsection to look at a section of Precambrian carbonate rocks. This section is mainly a weathered gray and tan ribbon rock that was very deeply weathered. There are solution rills on the gray part, which indicate it is limestone because solution rills do not form in dolostone. The tan part is dolostone. Four subfacies were seen in this unit: ribbon rock with ooids that were preferentially dolomitized (Figure 4), ribbon rock with “nubbly” tan parts that we looked at in lab, a thinly laminated, fine-grained dolostone with some small-ripple cross stratification (Figure 5), and a mainly dolostone ribbon rock.

Some layers are dolomitized, but others are not. Also, white ribbons of material cut through the carbonates, in general perpendicular to stratification. The “nubbly” nature of the ribbon rock is an indication of diagenesis. Petrological studies of the sample of ribbon rock in lab showed varying grain size from lamina to lamina. Some limestone layers were upper very fine grains with large calcite crystals and poorly sorted angular clasts. There were also layers of well sorted, slightly coarser grains.

Interpretation of this area with various carbonate facies is that there was sea-level fluctuation, but this is in reference to the larger facies, not the microfacies. It was a marine environment judging by the carbonate deposits, with a changing depositional environment. The layers with ooids indicate that at those times the area was in shallow water. It could have been a carbonate tidal flat. The delicacy of the stratification seen, especially in the dolostone, suggests mechanical stratification, not microbial. It is probable that dolomitization occurred after deposition, because of the preferential dolomitization seen and the mixture of dolostone and limestone.

Stop #2: Sunrise Mountain East

In this outcrop, we looked at the Permian redbeds. These are orange sandstone that is well sorted, with grain size from upper middle to lower fine depending on the laminae. Planar lamination in this outcrop is mainly due to difference in grain size from lamina to lamina. Petrological studies of a sample showed abundant quartz with subangular to rounded clasts. There is some fine-grained carbonate cement embaying the quartz grains (carbonate replacement). Overall the sandstone is not strongly lithified, given that it crumbled when rubbed.

Abundant cavy weathering and erosion was seen in the outcrop. Jointing, with joint planes spaced meters apart, was noted; the joints are nearly perpendicular to the stratification (Figure 6). (Joints are fractures at an angle to the bedding plane that are created as the rock moves toward the surface.) There is noticeable packaging, with layers of very thin lamination interbedded with packages of less distinct coarser laminae (Figure 7). Significant cross stratification is present on both a small and a large scale, with sets 3-5 m thick. A bed with rib and furrow was seen, which allows one to see the direction the wind or current (Figure 8).

These beds were probably deposited in a subaerial environment. This is because the packaging noted above can be explained by alternating grain-flow and grain-fall deposition. (Figure 7) Subaqueous environments would not show this difference in lamination. Dunes, which have since been weathered away, probably caused the low and long lamination seen in the outcrop. Eolian environments can also cause the cross stratification that was seen in the bed.

Stop #3: North Shore Lake Meade

We looked at an unconformity between an upper gray unit and a lower orange unit (Figure 9). The gray unit is a coarse conglomerate that is tightly packed and well lithified. It is poorly sorted with subrounded pebbles as clasts, up to 2 cm in length. Some carbonate clasts were noted, and there could be some carbonate in the matrix as well. (It was unclear because we were unable to find a fresh surface.) This conglomerate has some planar lamination (Figure 10).

The orange unit is semiconsolidated sandstone that could be crumbled by hand. It is fine-grained sand with some silt-size particles. A fresh surface bubbled slightly with hydrochloric acid, suggesting carbonate cement, but this could have been from carbonate that precipitated into the rock. Abundant large-scale structure is present in the orange unit, as well.

We were not able to gather much information about the depositional environment from our study. Strong currents would have been needed during the deposition of the gray conglomerate to carry the coarse clasts, which were up to 2 cm. It is interesting that the gray coarser unit is on top of the reddish unit. Normally, one would think that a current strong enough to carry that coarse a load would have eroded away the orange sand and silt that was underneath it. The fact that this erosion does not seem to have happened indicates that the current was so saturated with the load that it could not erode any of the material underneath it.

<u>Stop #4: North Shore Lake Meade, Bowl of Fire</u>

We then traveled to the Moenkopi Formation which is Jurassic in age. We walked downsection on this formation to look at the stratigraphic sequence. Therefore the following facies are in the order we walked, i.e., moving from younger to older rocks.

The first facies we noted was a grayish-orange sandstone with very noticeable planar lamination. Some of these beds have black speckles in them. The sandstone also has large-scale cross stratification, in addition to the planar lamination. The next facies is a planar-stratified conglomerate with clasts up to 2 cm in size.

After a covered interval, a unit of red shale interbedded with green sandstone was seen. The green sandstone layers have oscillation ripples in them, indicating tempestites. Thus the green sandstone are probably event beds within the background deposition of the red mud. Combined-flow ripples are also seen in the green sandstone (Figure 11). As one continues walking downsection, gypsum begins to be interbedded with the red shale and green sandstone (Figure 12). In many places, the gypsum layers are conformable to the beds of shale and sandstone, but in a few places they cut through the laminae. This suggests that this gypsum was deposited as veins. As we continued, we saw evidence of diagenesis because of the presence of gypsum nodules and folding in some places. In addition, we saw ribs of gypsum standing in high relief due to the differential weathering of the surrounding shale and the gypsum. Farther downsection in this same unit, the red shale becomes coarser and is now red sandstone. At this point, most of the gypsum is not conformable with the red and green sandstone and instead cuts through these layers.

The depositional environment could not have been subaerial because of the presence of the gypsum. The environment could have been a large evaporite basin or lake or a marine environment. The area was probably shallow because oscillation ripples were seen. The water was also probably supersaturated in salt, which led to the deposition of gypsum. As mentioned above, the green sandstone layers are event beds, probably formed by storm events. The change from red shale to red sandstone is simply because of a slight change in source material. Our hypothesis explaining the conformable and nonconformable gypsum layers is that gypsum was mixed in with the red mud and sand during deposition. Then, through later diagenesis, the gypsum was recrystallized to form the layers seen.

As we walked along the outcrop, we saw some large blocks of float from the red shale and sandstone that were interesting and that were discussed in detail. A good example of low-angle climbing ripples, with rib and furrow on the bottom of the block, was seen (Figure 13). These climbing ripples were oscillation ripples, because they are uniform and can be followed for a large distance. Thus these ripples were probably formed by oscillatory currents moving along the bottom.

The next unique bed we saw in the outcrop was a bed of red sandstone that had soft-sediment deformation (Figure 14). This means that deformation occurred before lithification. There is a great deal of deformation in the rock, suggesting mass liquefaction. Following this bed laterally, we saw two deformed beds with an undeformed layer in between them (Figure 15). Also there is a layer with small-scale troughy ripples that has some deformation (Figure 16). This indicates that the deformation was probably only local deformation.

Stop #5: Red Rock Park

This outcrop was a canyon composed of the red-colored Aztec Sandstone. Two hand samples taken from this outcrop were studied in the lab. They are both quartz arenites with planar lamination and parting along bedding planes. These samples are between upper and lower medium grain size. One of the rocks is a crumbly clay red rock that is not well lithified, whereas the other is speckled with white dots. Petrological analysis of these two quartz arenites showed that they are composed mainly of quartz grains with a few rock fragments. The clasts are rounded to subrounded and relatively well sorted, although the speckled rock is better sorted. In the speckled rock, it was observed that some of the rock fragments are "squeezed" between the surrounding quartz grains.

At the outcrop, we saw significant large-scale cross stratification (Figure 17). There are also many examples of swoopy cross stratification (Figure 18a). Laminae and beds vary in thickness from 2 cm to meters thick. In addition, not all beds are dipping in the same direction; there is much variation with some dipping down into the ridge whereas others are dipping out of the ridge. The swoopy cross stratification and the variation in dip direction are typical indicators of an eolian environment. The swoopy large-scale cross stratification is probably from eolian dunes. One theory explaining the "swoopy" look is that the troughs are filled by the plastering of new trough laminae, not just on the upcurrent side but also on the lateral and downcurrent sides as well (Figure 18b). The great variation in dip directions is typical of eolian depositional environments because wind direction changes more frequently than current direction in water.

The variation of dip angles seen on the outcrop suggests that we are looking at faces that are at a large angle to the wind direction.

There is also a variation in the color of beds. Some are very rich in hematite, i.e., red in color, and other layers are just spotted red. At the bottom of the canyon, there is an alternation of red and whitish layers; farther upsection, the rock is entirely red. At the top, there is a jagged change from all red to all white rock, which we did not have time to investigate. The alternation of red and white layers is probably because circulating deep pore solutions chemically reduced the hematite in some layers, resulting in a red color. Other layers that were less porous did not undergo this reduction, thus causing the alternation in color.

Stop #7: Eagle Mountain

The units we studied at this stop were all Cambrian in age (Figure 19). The oldest formation is the Zabriskie Quartzite (although it actually is quartz arenite, not quartzite). Above is the Carrara Formation, which is a mixed bag of siliciclastic and carbonate rocks. Above the Carrara, the blacker, dark section with stratification is the Bonanza King Formation, which is composed entirely of carbonates.

The first outcrop we looked at was in the Zabriskie. It was a quartz arenite hill that is relatively high in elevation because of a greater resistance to weathering than the surrounding facies. The quartz arenite is pinkish in color with medium to coarse grains. Planar lamination was seen, but it is very noticeable only on the weathered surfaces because desert varnish forms along the laminae (Figure 20). Parting exists in the outcrop parallel to the bedding planes, which are dipping 50° to the east. There also is a 5 degree difference in dip as one looks along strike.

As we continued to walk upsection, the grains in the arenite become less well sorted and coarser. Also there is darker weathering of the quartz arenite.

The unit of quartz arenite was probably not formed on a beach, inasmuch as we would see truncation surfaces because the beach is prograding. Therefore it was probably deposited by a tidal current or a river flow. The planar lamination and stratification could develop from a high-speed flow or fallout without traction. In this case, it probably was a high-speed flow, judging by the coarse to medium grains seen in the rock. (Fallout without traction normally deposits fine particles.) This high-velocity flow would have had to be sustained to deposit enough sand for the formation of the quartz arenite. Meters of sand would be required to form this unit. It is unusual that a flow would be sustained long enough, at a fast enough velocity for this to occur.

As we continued walking upsection, we found layers of dark reddish quartz arenite interbedded with the quartz arenite seen before. This rock is cemented by hematite, with rounded quartz grains that range from very coarse to pebble size (Figure 21). It is a grain-supported rock. This rock is probably still in the same facies as above with the same depositional environment; it is just a noticeable subfacies.

After a four-meter covered interval, there is a layer of fine siliciclastics. Interbedded with these fine siliciclastics are coarse-grained layers, with some 4 mm pebble clasts. Due to the topographic saddle between these sections in the covered interval, it seems probable that there is a sudden change between these two facies, which has been weathered away. This sudden fining of siliciclastics could be caused by a sea-level rise or a river avulsion where the old channel later filled up with mud. The sea-level rise would be allocyclic (imposed by exterior) whereas the river-channel movement would be autocyclic (imposed on self.) In order to tell which this system is, one needs to look at more than just this outcrop. Allocyclic changes affect wide areas, and therefore facies should not change if followed laterally. Autocyclicity is local shifting of the environment and therefore changes are patchy and do not continue laterally. This area is probably a mixture of the two: partly river-channel shifting and partly sea-level rise.

As we continued to walk upsection, there was a gradual upward coarsening from the fine-grained siliciclastics until we entered another coarse-grained area in the same general quartz arenite facies as the first outcrop. The parting along bedding planes is much thinner here, i.e. thinner beds, and there is more mica on the parting surfaces as well. It is mainly planar laminated, but some low-angle cross stratification was seen.

Fining of grains abruptly occurs in a 0.5-m-thick section of quartz arenite. In this manner, the quartz arenite grades into a bed of very fine siliciclastics with thin cleavage planes, i.e., red shale. It then changes to green shale, indicative of a reducing environment. A little farther upsection, coarse red sandstone event beds are interbedded with the green shale. These event beds become more frequent, thicker, and coarser as we move upsection. In addition, these sandstone event beds are planar laminated. This suggests an increasing closeness to the silica source because of the coarsening and thickening of the sandstone beds. The depositional environment is a shallow-water environment that is probably shallowing upward with thicker turbidites and/or tempestites.

Upsection, we saw an abrupt change from shales to carbonates, although because of significant fracturing and weathering, it was hard to tell if the carbonate facies was dolomitic or calcitic. Farther upsection, there is an interbedding of a carbonate conglomerate with background red shale. A hand sample from this conglomerate that was studied in lab contained pebbles with 1 mm diameter and a lower very coarse to lower fine-grained, yellow matrix. Some preferred alignment of the pebbles is seen. An acid test showed that this rock is dolomitic. Petrological studies showed many long thin carbonate clasts (which were probably fossil fragments), some fine-grained quartz, ooids, and a carbonate cement. This dolomitic conglomerate is probably an event bed.

This section of the outcrop contains many different event beds, some of which are carbonate and some of which are siliciclastic. These layers are up to 20 cm thick. We saw event beds of the dolomitic conglomerate, a dolomitic limestone, and the very weathered dolostone or limestone from farther downsection.

The outcrop became poor upsection, so we moved laterally to a better exposed outcrop, specifically to take a closer look at the carbonates. We entered a wash walled by very fine sandstone or siltstone, i.e., background sedimentation from normal quiet-water deposition. In some places, it does not have the prominent cleavage characteristic of shale, but it appears to be the same facies that we called shale earlier. Oscillation ripples are seen, in addition to small-scale hummocky surfaces on thicker event beds (Figure 22). The chunky event beds are lower fine to upper very fine quartz arenite, which thin-section studies showed had well sorted, subrounded clasts. Some calcareous cement is seen embaying the quartz grains as well. The oscillation ripples must have been formed in the sediment between storm wave base (storms affect sediment to this depth) and fair-weather wave base (everyday waves reach this depth) because both oscillation ripples and storm event beds were seen. As we moved upsection, the deposits thickened and coarsened. We noted hummocky cross stratification, which is indicative of stronger oscillations and upward shallowing (Figure 23). This suggests that a marine regression was occurring.

We then skipped upsection to look at carbonates. There is a grading from mainly sandstone and siliciclastics to carbonates. We could see a visible “line” i.e., an unconformity between the quartz arenite and the carbonates, which indicates minor faulting. The carbonate face that we looked at was a gray and tan ribbon rock. Rills are seen in the gray area, indicating it is limestone. Ooids are abundant in the limestone layers. The tan layers are dolomitic. There is abundant planar lamination as well as large-scale planar stratification between beds seen in the rock. The limestone is cross stratified. In the hand sample taken from this outcrop, the grains are well sorted within layers but varied from upper fine to lower coarse from lamina to lamina. Petrological studies showed that the ribbon rock is mainly carbonate mud, with some rounded clasts and a few quartz grains in some layers. In the outcrop, some layers of well-laminated orange dolomitic sandstone are interbedded with the ribbon rock. Above the ribbon-rock facies, there is a layer of carbonate rock (not ribbon rock) interbedded with 4 cm of shale, then more carbonate, then 6 cm of shale, then ribbon rock again.

The interpretation of this area is that it was a shallow-water marine environment, because there are ooids but no oscillation ripples. There appears to be autocyclicity in these carbonates. Even though the section has asymmetric lithologies, the change in sea level could still be symmetric. The rock facies suggest that there was a regression because the environment was a shallow tidal area.

Overall the rocks facies seen at the stop have an overall signal of upward shallowing. But there was a cycling of shallowing upward, deepening abruptly, etc., in the depositional environments. We do know that a transgression was occurring throughout the entire Cambrian, not a regression.

We also proposed some ideas to explain the overall change from siliciclastics to carbonates. The hinterland, high-relief areas behind the shoreline, which was supplying the siliciclastics, could have been weathered away over time. Or an overall progradation could have taken the ocean far away from these siliciclastics, shutting off the source. The change could also have been a result of a climate change. Warm shallow water without fine siliciclastics is needed for carbonate deposition, because the siliciclastics shut off the carbonate factory. A carbonate platform could have formed.

Stop #8: Eagle Mountain, South

This outcrop is Miocene (Cenozoic) siliciclastics that are much younger than the rest of Eagle Mountain. It rests unconformably on the bedrock of Eagle Mountain, and it has been tilted. The first unit we looked at was an orthoconglomerate with many carbonate clasts. The clasts include quartz arenite, limestone, ribbon rock, and limestone with white ribbons, all of which are seen in the rest of Eagle Mountain, i.e., older rocks. The clasts are poorly sorted and range in size from under 1 cm to over 10 cm. The conglomerate has a limestone matrix or cement. No stratification was seen in the conglomerate. This unit is approximately 5-6 m thick.

This unit is probably an event bed, because there is no stratification. The fact that the clasts are well rounded suggests that they were transported for a long distance and/or time. The clasts could be rounded alluvium carried and transported in a river. This unit was not formed by tractional stream deposition because there would be stratification and more variation in grain size. The unit could be a landslide or a debris flow. A debris flow requires that the sediment have at least 5% mud, which could be present in this orthoconglomerate. Also, debris flows are characteristically unstratified. The event forming the orthoconglomerate had to be rather large, because the unit is very thick. The unit also extends laterally for a great distance, which is uncommon for such an event bed. (This could be explained if we were looking at the outcrop face parallel to the transport direction, but we were unable to determine the transport direction.)

The contact between the orthoconglomerate and the sandstone above it was clearly visible. The contact is conformable with the planar lamination in the sandstone (Figure 24). On the contact, the sandstone was a lower coarse-grained quartz arenite with dolomitic cement. The uppermost 0.5-1 m of the conglomerate contains the same interstitial sand material as is in the dolomitic quartz arenite above it. This could have been a result of sand filling in the empty interstitial sites, infiltrating the gravel before it was lithified. Alternatively, the uppermost part of the conglomerate, which contains the interstitial material, could have undergone dissolution, creating empty sites that were later filled when the sand was deposited. One can see the sand going around the upper most pebbles in the conglomerates (Figure 25). Also in some places the lamination in the sandstone follows the contours of the conglomerate clasts. This is obviously a depositional contact.

Upsection of the dolomitic quartz arenite, there is a fine-grained, yellowish-brown sandstone that is more broken up and weathered. It does show planar lamination, though. This is succeeded upward by a 1-2 m bed of red shale with abundant slaty cleavage. The red shale is interbedded with reddish sandstone with a lower medium to upper fine grain size. Some ripples are preserved in the sandstone. Farther upsection, there is a planar-laminated, yellow sandstone with medium grain size that differs from lamina to lamina. Right above this facies is a bed of bright yellow limestone with visible solution rills (Figure 26). Some planar stratification could be seen in the limestone as well.

We skipped upsection a little, but a cursory glance of the area showed it is mainly fine-grained, yellowish-brown sandstone. The next bed we looked at in detail (Figure 27) was a yellow, medium- to fine-grained sandstone with some planar bedding and soft-sediment deformation. Above it is a layer of tan fine-grained sandstone. A hand sample from this bed, which we studied in lab, was a planar-laminated calcareous quartz arenite with subangular clasts. There is fairly good sorting within laminae, and most of the clasts are just barely touching each other, i.e., there is considerable carbonate cement. In the bed that we studied in detail, the sandstone becomes very fine-grained and then abruptly there is a layer of medium-grained sandstone with oscillation ripples. The oscillation ripples are finer grained than the rest of the rock, and they are interbedded with bright yellow dolomitic sandstone or dolostone. Bright yellow stringers of similar material were seen throughout the section we were studying. Some layers farther upsection are composed almost entirely of the yellow dolostone. Some cross stratification is seen in the layers of the medium-grained sandstone which are interbedded with the bright yellow dolostone.

Farther upsection, a facies of reddish intraformational conglomerates was seen. It contains clasts of the yellow sandstone, yellow dolomitic sandstone or dolostone, and many of the other rocks below it in the stratigraphic sequence. Laterally upsection of this unit, there are good examples of huge quantities of soft-sediment deformation in a yellow and red sandstone (Figure 28).

The siliciclastics that we observed at this stop must be nonmarine, because they are only millions of years old, and the oceans had receded past Eagle Mountain by that time. Therefore, the depositional environment was probably a local basin or river. The yellow sandstone showed cross stratification, so there definitely was a strong current present. Large-scale cross stratification in sets 1-2 m thick indicates that the basin or river had a significant depth. The intraformational conglomerate seen at the top of the section suggests that the depositional environment was fluvial, perhaps a braided river. In braided rivers, the channels shift frequently, and the load material changes frequently. This would also explain the oscillation ripples interbedded with cross stratification. These oscillation ripples could have formed in puddles left when the river shifted, and wind blowing over these puddles created small ripples. The bright yellow stringers layers of dolomitic sandstone or dolostone could be carbonate silt event beds in either the basin or fluvial setting.

Stop 9: Tecopa Lake Beds

The Tecopa Lake beds are lake deposits from Tecopa Lake, which was formed around 200 million years ago when tectonic movements created a dam to the south. Then the main interior drainage of the continent occurred, but the lake water was held back by the dam. Lake levels fluctuated after that time. The dam was breached 186,000 years ago, and the lake began draining. Over 100 meters of sediment were deposited over 2 million years. The Lake Tecopa deposits are therefore of Pleistocene age. Today, in the lowest point of the valley, there are still the remnants of Tecopa Lake.

The Tecopa Lake deposits have sometimes been quarried for evaporites, specifically borax. But the beds are not entirely evaporites. The Tecopa Lake Beds contain a mixture of siliciclastics and evaporites, with some volcanic ash deposits (Figure 29). The area was not exposed to the air though, and therefore the ash was deposited after falling into the lake from the sky and settling to the bottom. This alloformation has a thin layer of alluvium on top, as well. The lake deposits have been deeply dissected by flowing water, as evidenced by a number of valleys and hills, etc. Close study of the formation shows abundant planar stratification. We also saw some soft-sediment deformation in one layer, (Figure 30) and some cross stratification in another layer (Figure 31). The cross stratification indicates that there was a strong enough current in the lake at some time to create ripples.

Stop 10: China Ranch Beds

The China Ranch beds are much older than Tecopa Lake. They are from the Miocene. Formed from evaporites, they contain gypsum. Gypsum was mined in the China Ranch Canyon from 1910 to 1918. The date grove was first planted in the 1920s, and it has expanded today, after going through many different hands, to become the China Ranch Date Farm. The beds have a unique weathering to them, which was seen to a lesser extent in the evaporite deposits in the Tecopa Lake Beds (Figure 32). We also observed planar lamination in some of the beds and a normally graded bed (Figure 33). An angular unconformity between the China Ranch evaporite deposits and younger alluvium was also seen (Figure 34).

Stop #11: South Nopah Range

Looking at the South Nopah Range (Figure 35), we can see the Noonday Dolomite, a pure white unit that rests unconformably on Precambrian metamorphics. The Noonday is a Neoproterozoic formation that formed after the last Neoproterozoic glaciation, when there was a huge precipitation of carbonate. Above the Noonday is the Johnnie Formation, which contains a mixture of carbonates and siliciclastics and has clearly visible stratification. On top of the Johnnie is the Sterling Quartzite, composed of red and white sandstones. The Wood Canyon Formation is a deeper-water deposit with turbidite or tempestite event beds. It contains the boundary between the Neoproterozoic and the Cambrian. Capping the mountain is the Zabriskie Quartzite, the Cambrian formation we saw at Eagle Mountain. The Nopah Range contains one of the best stratigraphic sequences and the most complete and well-preserved sequence in the area for this age.

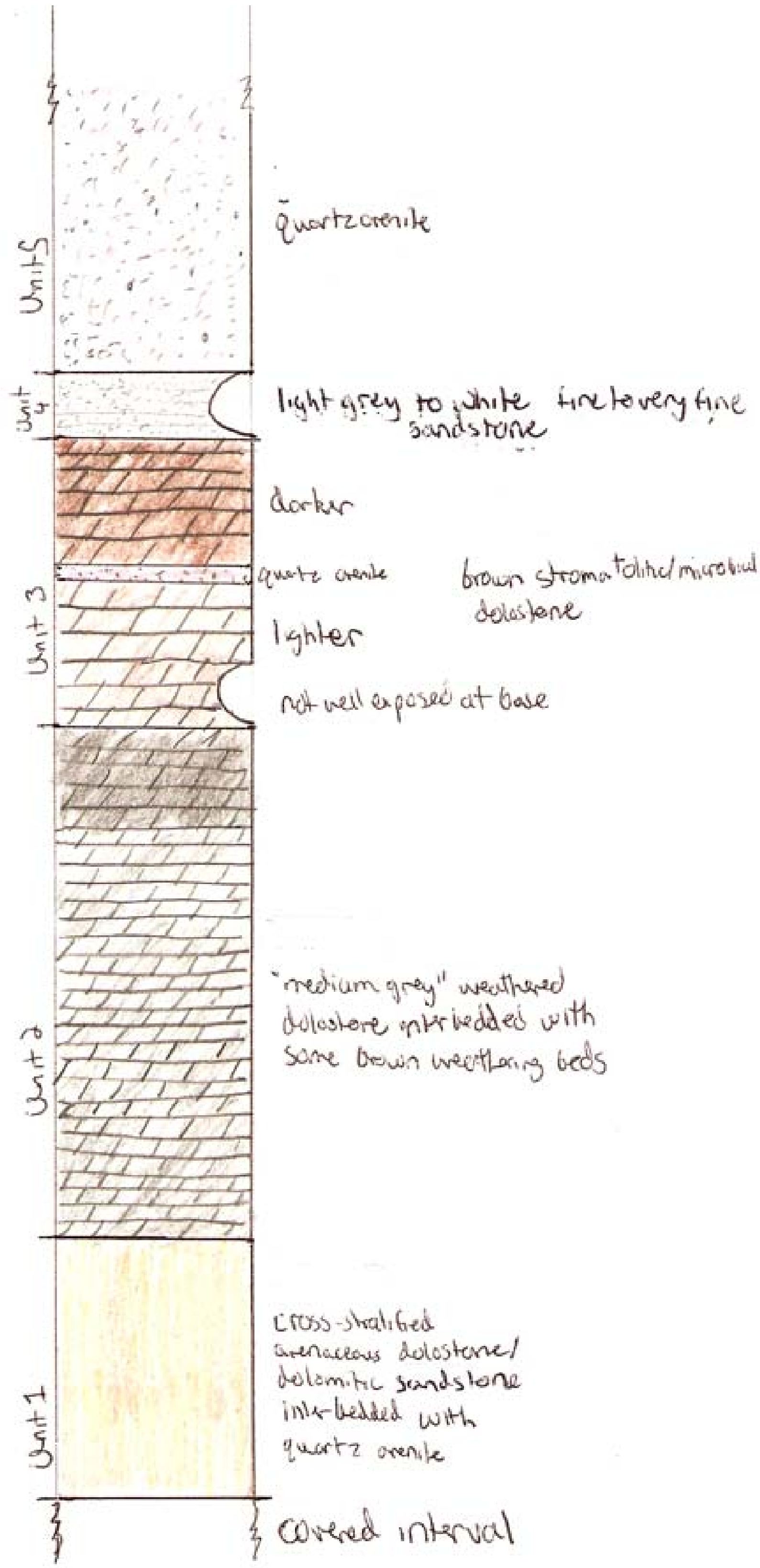
On the western flank, there is a west-dipping normal fault which creates the range. This normal fault moves younger rocks on top of older rocks. At the southern end, the range is a classic block-faulted range, so all the beds are dipping to the east (Figure 37).

At this stop we worked to create the stratigraphic column shown on the next page. The section of the Johnnie that we mapped was 55% exposed and had a dip of 60° east. The eroded slope we walked up was close to perpendicular to the dip.

Unit 1 is cross-stratified arenaceous dolostone or dolomitic sandstone that is interbedded with quartz arenite (Figure 37). The dolomitic sandstone has rounded upper coarse grains with some pebbles up to 2-4 mm in size. The dolomitic sandstone layers are slightly recessive compared to the quartz arenite. The quartz arenite has rounded to subrounded very coarse grains, and is coated with desert varnish. Some diagenesis occurred in this unit, in that many layers have slightly distorted bases.

Unit 2 is a medium-gray-weathering dolostone, with some brown-weathering dolostone interbedded. This unit has differing lamination from bed to bed, both microbial lamination (Figure 38) and mechanical lamination (planer and cross stratification). There is an interbedding of different dolostone subfacies; some are fine-grained, some are arenaceous, etc. In addition, there are layers of coarse to granular quartz arenite interbedded with the dolostone (Figure 39). This quartz is the same rock that was seen before in Unit 1. At the top of this unit, the weathered face of the dolostone is a darker gray, but there are still some brown layers interbedded.

Stratigraphic Column



Unit 3 is a brown stromatolitic and microbial dolostone (Figure 40). These beds have indistinct bedding, and some beds have small intraclasts. In this unit, there are two subfacies; the lower is weathered light brown, and the upper is weathered a darker brown (Figure 41). The subfacies are separated by 1 meter of quartz arenite.

Unit 4 is a relatively thin unit of fine to very fine light-gray to white sandstone (Figure 42). It is not as well exposed as the brown dolostone below it. Planar lamination is visible in this unit, though. Unit 5 is a coarse-grained quartz arenite with some granular grains at the bases of beds. It is pinkish red with black spots, and planar lamination is seen in the beds. There are also some normally graded beds seen in this unit (Figure 43).

This area does not show the cyclicity seen in other successions we have studied. The quartz arenite keeps appearing, but that is the only repeating unit. We know that these units were at least partially deposited in a marine environment, because of the presence of the carbonates. Unit 1 had to be deposited in water that was several meters deep with a strong current to form the cross stratification. Some of the larger cross stratification was formed from dunes 0.5 meters high. In Unit 2, there was a shift in environment from this strong current to water that was quiet enough for microbes to grow. There is a mixture in this unit of mechanical and microbial lamination, so the environment may have still been shifting in this period to allow both stromatolites and cross stratification to develop. Also, shallow depths are necessary for stromatolites to form and microbes to grow. Unit 3 was probably deposited in shallow water, judging by the presence of stromatolites and microbes. The whole region could have been a coastal area with a gentle gradient and low relief. In the hinterlands, sheet floods could have mobilized quartz grains, which would explain the beds of quartz arenite that are interbedded with the carbonate beds. Sea-level fluctuation could also have caused the interbedding of siliciclastics and carbonates, though.

Stop 11B: South Nopah Range, Johnnie Fm.

We looked at some areas upsection in the Johnnie Formation in more detail. We walked through brown-weathering sandstone that was planar laminated. Cross stratification was also seen due to the planar lamination of different beds. There is swoopy, curvy stratification between layers and internally as well. The layers also show pinch and swell, i.e., thickening and thinning along strike. A layer was also seen with hummocky cross stratification on top of the bed and planar lamination in the lower part (Figure 44). We also saw a gutter cast, which is a furrow created by erosive near-bottom flow, usually during a highly turbulent storm event. These sandstones are all storm event beds, and they are interbedded with fine sandstones or siltstones. Therefore this area had to be tens of meters deep during deposition to allow the preservation of these storm events. This is common in the upper Johnnie, which has a deeper depositional environment than lower in the unit, but the depositional area is still on the upper oceanic shelf. Next, we entered an area of shallow-water carbonates again, indicating a shallowing of the depositional environment.

After skipping upsection, we looked at a large unit of paraconglomerate, perhaps with some intraclasts from lower in the Johnnie Formation (Figure 45). It has huge clasts up to boulder size which are floating in a fine-grained matrix. The matrix is dolomite cemented. The clasts are subrounded to subangular and contain coarse quartz arenite and carbonate rock. Many of the carbonate clasts are dolostone. One carbonate clast has amazingly large centimeter-size ooids. The lower contact of this paraconglomerate is with quartz arenite. There is an intermingling of these two units at the contact, with some larger clasts at the top of the sandstone and a bed of finer conglomerate. We also studied a huge 4 meter hunk of gray and tan weathered dolostone below the quartz arenite with some quartz veins in it. We decided that it was an isolated mass, a giant block or clast from another source.

As we followed the conglomerate laterally, we noted it showed the rule of V's because the dip of the conglomerate was at a greater angle than the dip of the wash. The layer of conglomerates thus appeared on the surface in these "V" forms (Figure 46).

The paraconglomerate pinches out on either side to both the north and the south and is 50 meters at its thickest point. It pinches out asymmetrically, though. To the south of the thickest part, the thinning occurs over a few hundred meters, whereas to the north, the thinning is relatively abrupt (Figure 47). This conglomerate is an incised-valley fill. This is caused by a base-level change. The area rose up and/or the sea level dropped, and a valley was eroded by a channel cutting into the previous bedrock, which was the Johnnie here. The water level rose again and the valley was filled, in this case, with a conglomerate. This conglomerate fill could have been from a landslide or a debris flow. It is unclear if the fill is marine or nonmarine, though. After this event, more normal deposition occurred, and the next layer in the Johnnie is seen.

<u>Stop 13: Amargosa River near Dumont Dunes</u>

At this stop we looked at the Kingston Peak Formation, consisting of siliciclastics. The Kingston Peak is older than the Noonday Dolostone seen at the Nopah range, but still Neoproterozoic. There are some 1-3 m thick layers, probably huge event beds. Some layers are normally graded, and rather large flute marks are seen on the underside of one of these beds

(Figure 48). Some of these flutes are irregularly shaped, but some are very regular. A normally graded siliciclastic paraconglomerate event bed was also seen with subangular clasts at the base and rounded clasts at the top.

These normally graded beds are part of the Bouma sequence, Division A, because they are coarse and non-laminated. These event beds are probably from turbidity currents or river flood events or storm events, because we saw flute marks and normal grading. This means that there was a strong current, which waned after making the flute marks.

The “background” sedimentation i.e., sandstone, was reddish in color and tightly cemented. It has a fine to very fine grain size, although some beds are coarser than others. As we continued laterally along section, we saw some thinner gray event beds with cross stratification and planar stratification with the background red layers.

Two lonestones were seen in two different layers; one is 30 cm in diameter (Figure 49) and the other is 4 cm. Both are much larger than any of the surrounding clasts or grains seen. Each lonestone deforms the layers underneath it, and the laminae on top of this stone also follow the contours of the lonestone (Figure 50). This suggests that they were dropped onto these layers and then more sediment settled on top of them, forming laminae. The lonestone could have been carried along by a tree root, by pack ice, or by icebergs floating on the surface. It seems unlikely that it would be pack ice, because there is not much sediment in pack ice. It seems most likely that these stones, specifically the larger 30 cm one, were carried in icebergs, which as they melted dropped and deposited all sediment, pebbles, and/or rocks they were carrying on their bottom. Therefore these lonestones can also be called dropstones. This hypothesis therefore means the area had to be a marine depositional environment.

Therefore for this formation or set of beds, the depositional environment contains both turbidity currents in a slope or a basin and floating icebergs. This makes sense, in that much of the world was covered in glaciers at the time of deposition. Also, glacial marine deposits are commonly well stratified but poorly sorted, which fits with the beds seen at this formation.

Stop 14: Small Dunes near CA 127, west of Dumont Dunes

We stopped and looked at some small dunes. As we walked toward the dunes, we were able to see some interesting eolian sand ripples. Here smaller ripples which are in the current prevailing wind direction overlie and fill in larger ripples from a past prevailing wind direction (Figure 51). Once at the dunes, we were able to see that the last major sand-moving wind was from the north, judging by the ripples going vertically up the northern face of the sand dunes. The dunes were nearly at the angle of repose, but natural grain flow was not occurring. We could see sand being transported over the lee side, and we even saw a saltation cloud (Figure 52). We formed grain flows with our feet, though, on the side of the dune. They look tongue-shaped, and narrow waves or ripples can be seen at the tip going up the slope. It is also interesting to note that grain flows become immobilized from the bottom up.

Stop 15: Afton Canyon

The Mojave River was dammed up to form Afton Lake. There was considerable deposition of fine siliciclastics and evaporites in the lake. (Much later, these deposits are being mined.) Then a river cut through the natural dam, so the lake was drained and disappeared. There was a deep incision because the water level dropped so greatly. Alluvial-fan deposits formed on top of the lake deposits. These rivers and/or the source rock originated from high elevations to the south. Much of the source area is now gone. Faulting has revealed mafic and felsic volcanic and volcaniclastic rocks to the south. Under the lake deposits from Afton Lake, there are ancient alluvial fans, so the lake deposits are bounded by alluvial-fan deposits.

We studied the shore of the river and saw excellent examples of climbing ripples and rib and furrow on the top (Figure 53). We were able to figure out current direction from these, without using the fact that the river was flowing nearby. Below this layer, the sand is planar laminated. Part of the shoreline also had oscillation ripples visible in the sand, which had a natural vertical cut through them. Looking at this cut, we could see that they are climbing ripples as well (Figure 54).

We could see three levels of incision of the river, in the form of terraces in the alluvium before we entered the main part of the canyon (Figure 55). Looking at the terraces, there was a lot of variability in particle size of the alluvium. There is a layer of a conglomerate with 6 cm clasts, and there are layers with clasts all under 1 cm. There are also poorly sorted layers with a wide range of particle sizes. The terraces are very planar stratified. We also noted some pebble imbrication, in which the clasts align in the direction of the current. They lodge in that orientation (Figure 56). As we continued walking upsection, we saw some very thin low-angle cross stratification.

The lack of cross stratification could be due to the fact that for planar lamination, there must be a high-speed flow that is relatively shallow. The flow and/or sediment could cut off before there is time to form dunes, i.e., large-scale cross stratification. As we continued upsection we saw some very small-scale, low-angle cross stratification. So perhaps, for some layers, there were low-angle dunes moving very fast along the lake or river bottom.

An alternative explanation for the lack of cross stratification is that the flow was a hyperconcentrated flood flow. This means the flow was highly concentrated with large amounts of sand, gravel, etc. because sediment was freely picked up during floods. This flow would have low turbulence. Therefore there would be a restriction on dune building, so no cross stratification would be formed.

As we continued walking upsection, we noticed a few outsized clasts, which were even of cobble size in a few cases. These clasts probably were rolled along the bed of the river along with the finer sediment. This is because if an outsized clast lodged in the bed all by itself, it would be so much larger than the surrounding mud that it would stick out. The current would keep hitting it, creating force on the clast to move and roll along the bottom.

We then studied the banks on either side of the incision and/or valley we were walking up. To our left was planar-stratified gray sediment. It also was seen in a layer on the right, but there also was less well stratified, coarser tan material. We hypothesized, from the remaining topography, that this is a case of valley fill again (Figure 57). The ancient tan alluvium was in place, and then there was later aggradation and fill of the gray stuff. After the gray material was lithified, an incision formed and removed the gray alluvium, exposing the old tan alluvium valley walls. This also accounts for the chunks and layers of gray rock still seen between layers of tan. These are simply places where all of the gray alluvium has not been eroded to show the tan alluvium. Therefore, the gray material is a partial fill, which has been reincised.

It is unclear what the source of the gray fill is. It could be an external source, or it could be a reworking of the earlier tan alluvium. For example, a current flow, weathering, etc. could winnow out certain materials in the tan alluvium, which were carried away, and then the remaining material was reworked. Therefore, the gray fill is a fraction of the tan alluvium.

As we walked farther up the wash, we noted a buttress unconformity, which fits with our hypothesis of the gray partial fill (Figure 58). The tan alluvium is at an angle to the newer gray fill. Here the top contact between the gray and tan is just from where the re-incision was on the valley walls; only the lower contact is the buttress unconformity formed from deposition.

We studied an old alluvium wall with a rock fall. It has a light-colored cement that is probably an evaporite because it did not fizz with hydrochloric acid. There are also some intervals of light-colored, white material. These are fault surfaces with recrystallization of the white material along them, forming a vein. The one part of the alluvium that we looked had abundant quartz, some potassium feldspar, and many volcaniclastics as clasts.

Overlying the tan conglomerate is a dark gray deposit. It could be an upper valley conglomerate related to the gray fill conglomerate, but that seems very unlikely. It probably was deposited before the valley incision.

We noted that the walls were generally vertical to the wash. This is because the walls are eroded at the base and then collapse down. This prevents the area from having gently sloping canyon or valley sides. Weathering of this kind also helps in the creation of buttes, when rivers flow around and incise hem. We saw an excellent example of a butte (Figure 59). Because they are formed from undercutting, buttes have vertical walls, and an overlying layer helps prevent the collapse of these walls inasmuch as it is more resistant to erosion. Without the capping layer, which in our case was a layer of green lake deposit, the top of a butte would be rounded instead. The vertical rills on the slopes of the butte were formed by erosion from running water as it streamed from the top of the butte down the sides.

We saw a 1-m-thick layer of paleosol (an ancient soil horizon) that grades from the underlying tan conglomerate (Figure 60). The paleosol was finer grained than the conglomerate, with fewer large clasts and a lighter-colored tan. The tan conglomerate was exposed and weathered, developing as regolith. There must have been tectonism during the erosion process because the paleosol is conformable with the overlying conglomerate deposited after the paleosol was formed and not the underlying rock.

We saw a large angular unconformity between the dark gray conglomerate and the tan alluvial deposits (Figure 61). There was just a small difference in dip, though. The tan conglomerate has slightly steeper stratification than the dark gray, although the gray conglomerate is dipping as well.

We noted some interesting erosion in the valley as we continued walking upstream. Each of the minor tributaries flowing into the larger channel has an alluvial fan as well. But because of the wind or the current in the large channel, these alluvial fans are eroded. On the stoss side, material is carried away, whereas on the lee side, the alluvial fan remains exposed and stretch out for a distance.

The valley suddenly opens up with gently sloping walls. Also, the layer of green lake deposits is no longer present. We hypothesized that the slopes are gentle because there is no "capping" layer on the dark gray conglomerate. We saw the lake deposits functioning as a resistant capping layer on the butte, and perhaps it was important in keeping the walls of the channel vertical too. Instead of the green lake deposits, there is a unit of tan rock interbedded with some gray rock above the dark gray conglomerate. (This is not related to the older tan alluvium we saw earlier.) This suggests that we had reached the limits of the lake.

We started to see terraces again, indicating a narrowing up the channel and slope. We then observed a knickpoint in the channel. As one moves up a channel, there is a gently slope to the elevation. If the base of the channel drops, then there will have to be erosion of the basal plate or river bed in the lower part until the stream reaches equilibrium. The headward limit of the erosion (which starts at the mouth) to get to this equilibrium is the knickpoint (Figure 62). There almost always are waterfalls and rapids at the knickpoint in streams.

We then came to a buttress unconformity or fault between a gray stratified conglomerate and some very steeply dipping, light green material. There is significant steeply dipping stratification in this light green rock (Figure 63). Some layers in the section are entirely quartz with very fine white ash, and others are simply the fine-grained ash. This is a felsic ash tuff, but since there are so many quartz grains, it has probably been reworked.

We then found a dark gray, fine-grained basalt. We were certain that it is a volcanic rock because we found amygdules in it. These are vesicles that are later filled in by another mineral (Figure 64). Ahead we could see a large layer of dark rock, probably basalt flows, on top of the reworked ash. There is significant folding and faulting in this area, suggesting the contact between the conglomerates and reworked ash noted earlier is probably a fault.

Stop 16: Route 161 at Jean, Bird Spring Formation

The Bird Spring Formation is uppermost Pennsylvanian into Permian. There were considerable glacioeustatic sea-level fluctuations during that time, and cyclicity is commonly observed in rocks sequences of that age. From a distance, the Bird Spring Formation looks “ledgy,” with prominent carbonate ledges and recessive slope material between them. At this stop, we were looking to perceive cyclicity. So after detailing each unit in the stratigraphic sequence briefly, we then looked to group them into fewer facies. Below is a list of the units as we walked up section, with these brief descriptions (and depositional environments in some cases), plus petrological data from the lab where it is pertinent.

Unit A	-Orangish-brown-weathered limestone, quartz packstone -Burrows that stand in relief to surface -Fewer burrows as move down bed; possibly a hardground *A carbonate facies was deposited, then a stop in sedimentation occurred perhaps with rising sea level, and organisms burrowed into the layer as they lithified. -Bioturbation and planar lamination seen (Figure 65) -Lower-fine to lower-medium, subangular to subrounded grains -Many siliciclastics indicating a shallow environment, so perhaps not a hardground; alternatively, sand was deposited when bed was raised, and then burrowing occurred.
Unit B	-Pink-weathering arenaceous limestone, mudstone -Recessive layer due to weathering -Some fossil fragments, rhombohedral crystals seen in thin section, in addition to carbonate mud and scattered quartz grains -Quiet-water deposition
Unit C	-Gray-weathering limestone; cherty arenaceous fossiliferous wackstone -Brachiopod fossil seen; therefore a marine depositional environment, probably shallow -Scattered quartz grains are coarser than previous layers, so the depositional environment was closer to sea level -Presence of fossils also indicates shallow water -Many chert nodules (Figure 66) -Possibly quiet-water deposition as well
Unit D	-Yellowish-orange, well-stratified dolomitic quartz arenite -Large-scale cross stratification seen as well with 1 meter sets -Cross stratified right up to top of the unit; an angular unconformity with next unit -Considerable variation in lamina thickness *This suggests an eolian environment because of the difference between grain flow and grain fall, but it could also be a shallow-water environment inasmuch as it does not have the different packets and shapes classic to eolian deposition.
Unit E	-Interbedded pink and white quartz arenite with limestone cement -Recessive layer due to weathering -Low-angle cross stratification, lots of planar stratification as well -Medium grained

Unit F	-Yellowish cross-stratified siliciclastics -Similar to Unit D, but more weathered
Unit G	-Gray-weathering arenaceous limestone; wackstone -Less weathered than previous layers -Very fine, well sorted, subrounded grains; some quartz, muscovite, and rock fragments seen -Sand-filled burrows seen (Figure 67) -No clear stratification
Unit H	-Gray-weathering limestone, arenaceous fossiliferous grainstone -Less weatherable layer -Abundant rounded fossil fragments seen, angular quartz grains -Coarse grain size -Planar laminated -Depositional environment needs a strong enough current for planar lamination; would carry away the finer mud between grains -This indicates a sharp change in depositional environment, which probably was autocyclic due to the sharp contact; an allocyclic change, i.e., sea-level change, would be more gradual
Unit I	-Brown-weathering, fine-grained sandstone -Recessive -Layers of thin planar lamination interspersed with thick laminae -Carbonate cemented, allows recessive weathering because not as compact
Unit J	-Tan or beige-weathering limestone -Fine grained, probably a wackstone -Some fossil fragments seen -Burrowed at the bottom of the bed, but not as much at the top -Soft-sediment deformation (Figure 68) -Quiet water for soft-sediment deformation -Shallow water for fossils
Unit K	-Cream-weathering fossiliferous limestone -Fine grained; in thin section can see some rhombohedral crystals
Unit L	-Gray-weathering limestone, fossiliferous grainstone but very fine -Solution rills

	-Contains some stylolites (Figure 69); evidence of diagenesis -Ooids, rhombohedral crystals seen in thin section, in addition to fossil fragments in sparry cement -Shallow-water environment needed for ooids to form
Unit M	-Tannish-weathering calcareous sandstone -Medium grained, well sorted -Well stratified with large-scale, low-angle cross stratification and small-scale cross stratification -A few layers of arenaceous limestone in conformable layers due to a slight change in ratio of quartz and carbonate -Relatively strong current needed for cross stratification
Unit N	-Burrowed bed of gray limestone, arenaceous fossiliferous grainstone -Quartz grains and silicified rice-shaped foraminifera (Figure 70) -Burrows bring more gray-weathering material into the brown-weathering material (Figure 71) -Not clearly stratified
Unit O	-Tannish-weathering arenaceous limestone or calcareous sandstone -Medium grained -Same as Unit M, just more calcite -Considerable planar lamination plus cross stratification -Relatively strong current needed for cross stratification
Unit P	-Dark gray-weathering cherty limestone (orange chert) -Planar lamination
Unit Q	-Red-spotted, beige-weathering limestone with some quartz grains -Grading from wackstone and packstone to grainstone at the top -Fine grained becoming coarser upsection -No lamination
Unit R	-Gray-weathered limestone with some tan-weathering limestone interbedded -Mostly carbonate with some quartz grains, fossil fragments seen -Fine grained -Stylolitic; evidence of diagenesis in the form of pressure solution -No lamination
Unit S	-Gray-weathering limestone; grainstone -Ooids and long thin fossil fragments, some rounded quartz grains, in thin section

	saw imperfect hexagonal quartz grains -Medium to coarse grained with some finer layers -Depositional environment must have been shallow for ooids to form

Here are brief descriptions of the facies the units were grouped into and their depositional environments:

Facies 1	-Orangish brown-weathered limestone, quartz packstone -Burrows that stand in relief to surface -Possibly a hardground
Facies 2	-Gray to beige-weathering limestone -Mainly fine grained -No stratification -Fossiliferous and commonly arenaceous -Shallow quiet-water depositional environment
Facies 3	-Yellowish orange dolomitic quartz arenite -Considerable cross stratification -Considerable variation in lamina thickness -Possibly eolian depositional environment
Facies 4	-Calcareous quartz arenite -Medium grained -Significant planar stratification, some beds display low-angle cross stratification as well
Facies 5	-Arenaceous limestone -No clear lamination or stratification
Facies 6	-Gray weathering limestone, arenaceous fossiliferous grainstone -Medium to coarse grain size -Planar laminated -Depositional environment needs a strong enough current for planar lamination; would carry away the finer mud between grains -Ooids in one bed indicate shallow water depositional environment
Facies 7	-Dark-gray-weathering cherty limestone (orange chert) -Planar lamination

These units were grouped into the facies as follow:

- Facies 1 = Unit A
- Facies 2 = Unit B, Unit C, Unit J, Unit K, Unit L, Unit N,
- Facies 3 = Unit D, Unit F

- Facies 4 = Unit F, Unit I, Unit M, Unit O
- Facies 5 = Unit G, Unit Q
- Facies 6 = Unit H, Unit S
- Facies 7 = Unit P

As one can see, this outcrop has a great deal of cyclicity of limestone and sandstone and of no stratification, i.e., quiet water, and planar stratification or cross stratification. Most of the facies require shallow-water deposition also. We were able to follow the facies and units laterally over a valley and up a hill. This suggests that the area was undergoing allocyclicity because of the lateral extent of the cyclic changes. Therefore, sea-level fluctuations (transgression and regression) were probably the cause of the cyclicity. The depositional environment probably was a tidal area near shore, judging by the many fossils and ooids that form in shallow-water environments and the influx of much siliciclastic sediment, which would be transported from a source area onshore. It may have been a carbonate platform, because of the shallow-water environment. The alternation of sandstone and limestone could be due to the great increase in sand shutting off the carbonate factory. Sea-level fluctuations would bring the area closer and farther from the source of the siliciclastics controlling the influx and therefore causing the cyclicity. All of this occurred above a hardground that had been raised due to tectonism or a noncyclic limestone.

<u>Appendix: Figures</u>

Figure 1: Paleosol layer between Precambrian metamorphosed granite and Tapeats Sandstone; centimeter scale

Figure 2: Fresh surface of yellow-weathering rock; thumbnail is 1.5 cm for scale

Figure 3: Tool marks in fine green sandstone interbedded with the green Bright Angel shale; centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

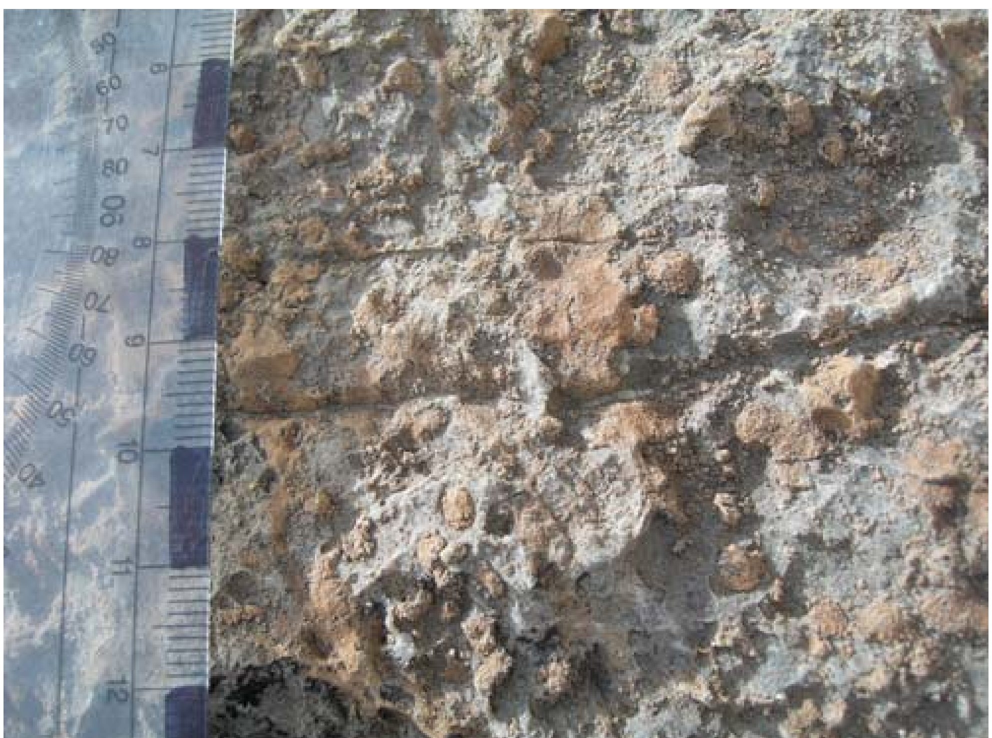


Figure 4: Subfacies of ribbon rock unit; ribbon rock with preferentially-dolomitized ooids, centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

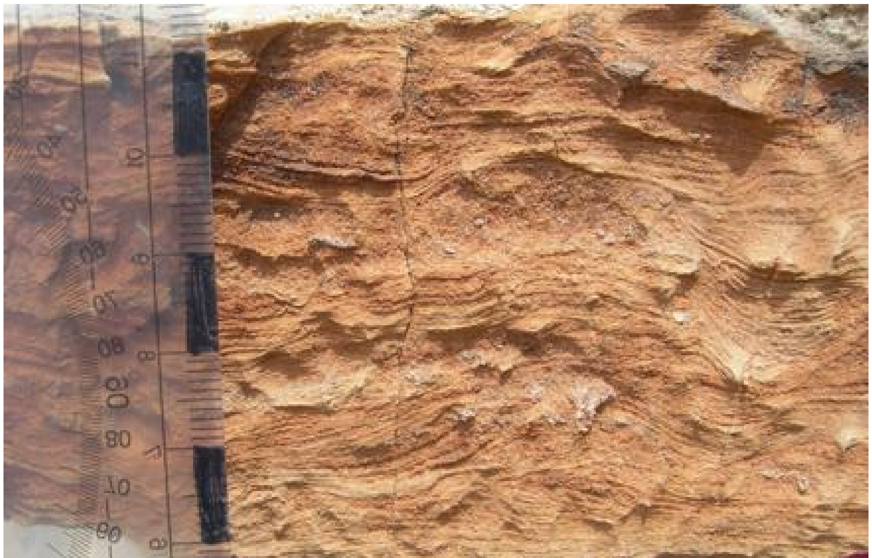


Figure 5: Subfacies of ribbon rock unit; thinly laminated, fine-grained dolostone with some small-ripple cross stratification, centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

Figure 6: Jointing and cavy weathering in the outcrop

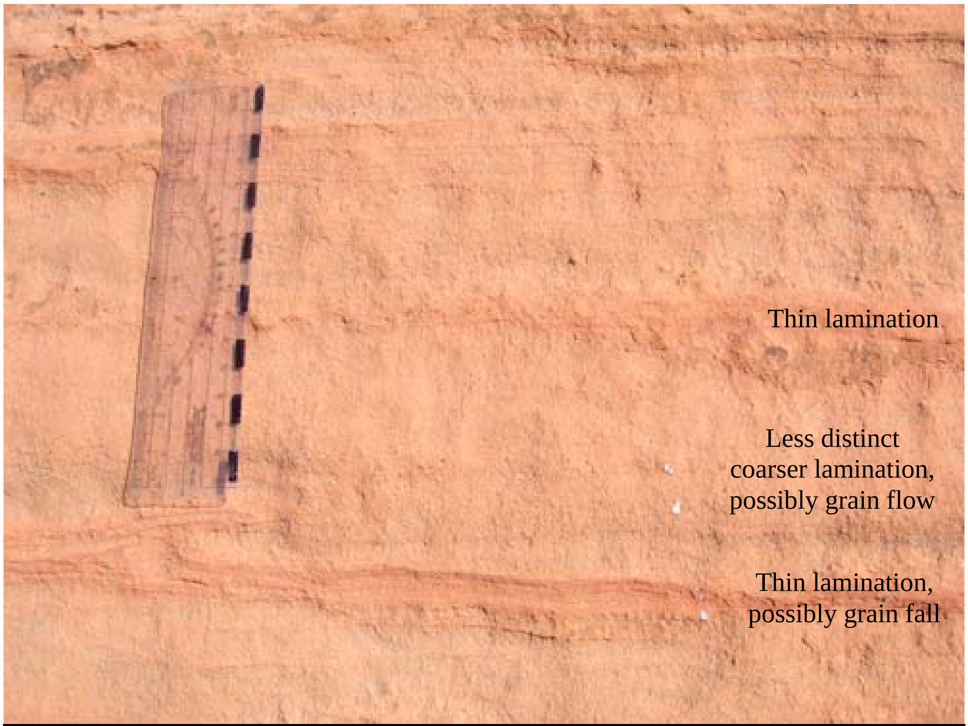


Figure 7: Packaging of layers with very thin lamination interbedded with packages of less distinct coarser laminae; possibly grain flow and grain fall environments; centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

Figure 8: Rib and furrow on top of bed and the blue arrow shows the direction of wind or current, centimeter scale

Figure 9: Unconformity between upper gray unit and lower orange unit, Sarah is 1.6 m

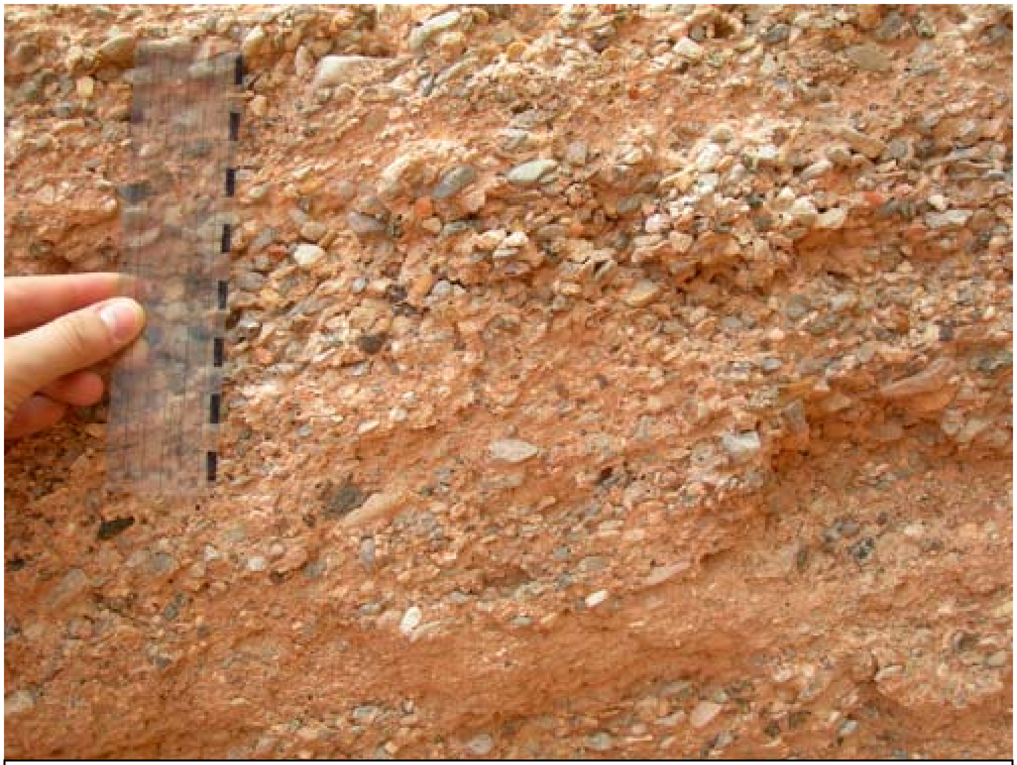


Figure 10: Planar lamination in coarse gray conglomerate, centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

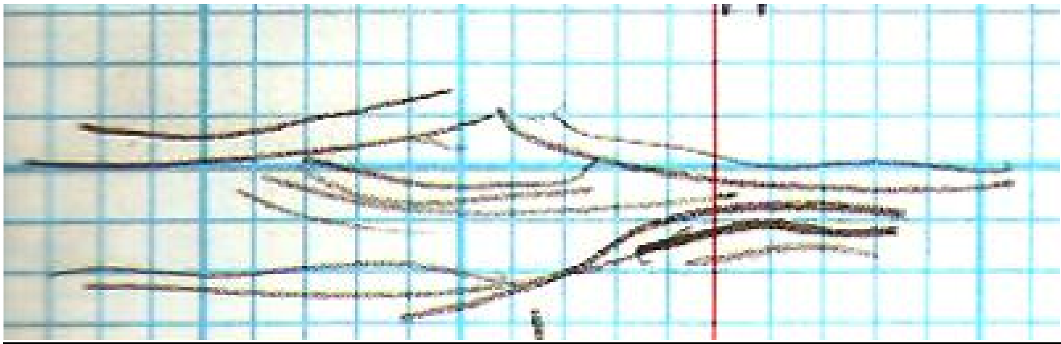


Figure 11: Sketch of combined-flow ripples seen in the green sandstone interbedded with the red shale

Figure 12: Layers of gypsum interbedded with the red sandstone and green shale, most gypsum layers are conformable with the other beds, but a few can be seen cut through laminae, centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

Figure 13: Low-angle climbing ripples in a red sandstone block of float, centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

Figure 14: Soft sediment deformation in a bed of red sandstone, centimeter scale

Figure 15: Two deformed beds with undeformed beds in between them, pencil is 14.5 cm long

Figure 16: Layer with small-scale troughy ripples that has some deformation; the exposed face is perpendicular to the depositional flow, centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

Figure 17: Large-scale cross stratification in Aztec sandstone in Red Rock Park, Scott (climbing at the bottom of the face) is 1.7 m

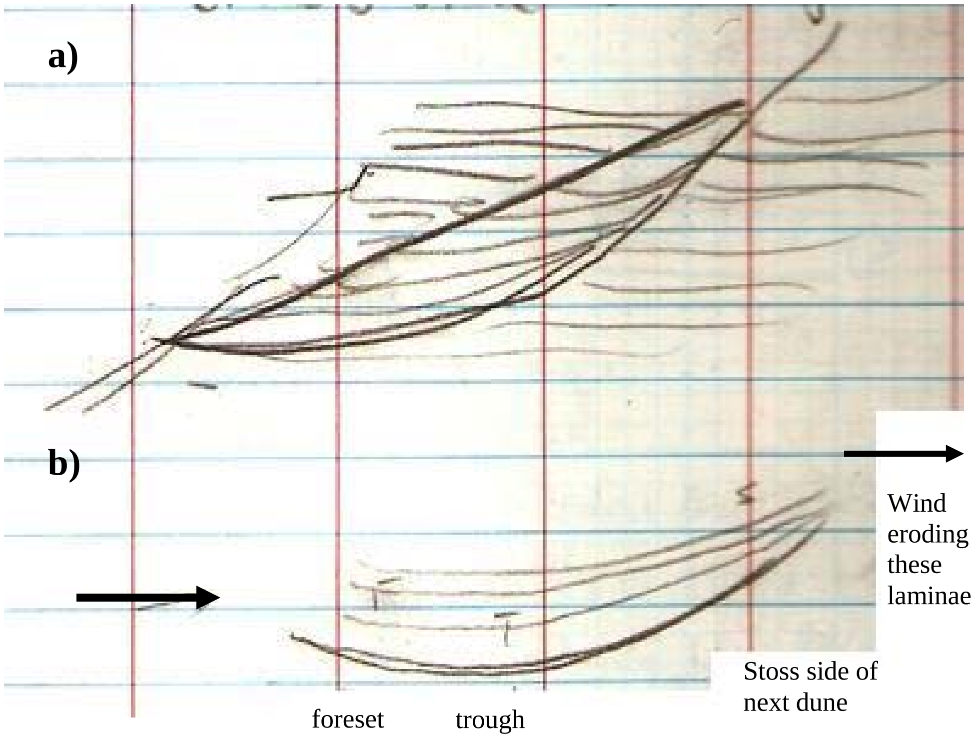


Figure 18: a) Sketch of the swoopy cross stratification seen on the exposed face of the outcrop b) Diagram of one theory explaining the “swoopy” look, arrow shows wind direction

Figure 19: Eagle Mountain with formations labeled. Photograph courtesy of Augusta Dibbell. Used with permission.

Figure 20: Planar lamination on quartz arenite highlighted by the desert varnish forming along laminae, centimeter scale

Figure 21: Dark reddish quartz arenite interbedded with the quartz arenite seen downsection (Figure 20), centimeter scale

Figure 22: Small-scale hummocky surface on thicker event beds interbedded with very fine sandstone or siltstone

Figure 23: Hummocky cross stratification in sandstone beds

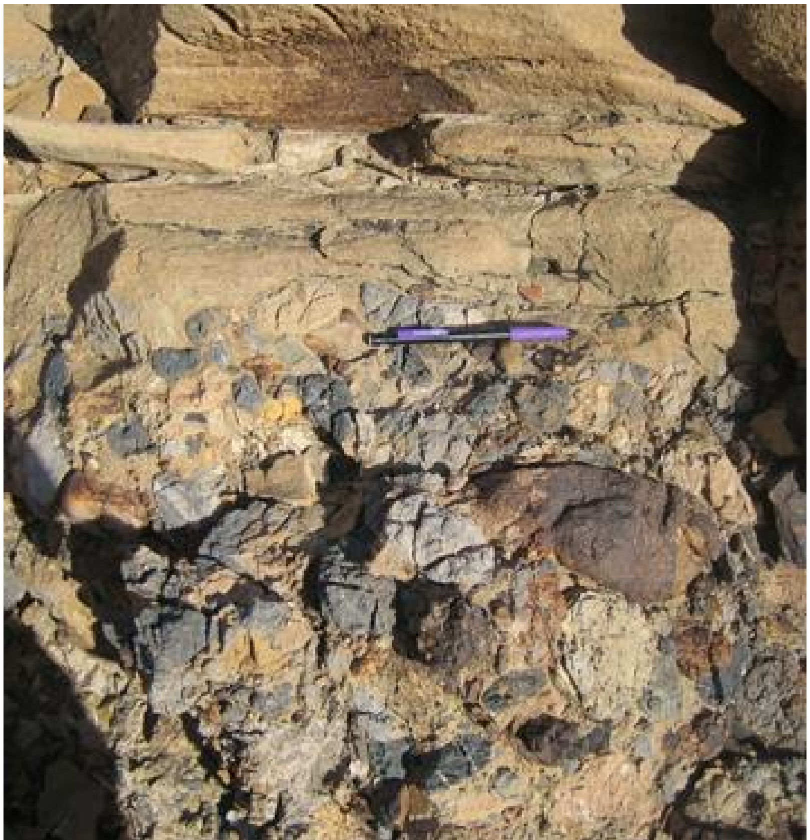


Figure 24: Contact between the orthoconglomerate and sandstone, pencil is 14.5 cm.

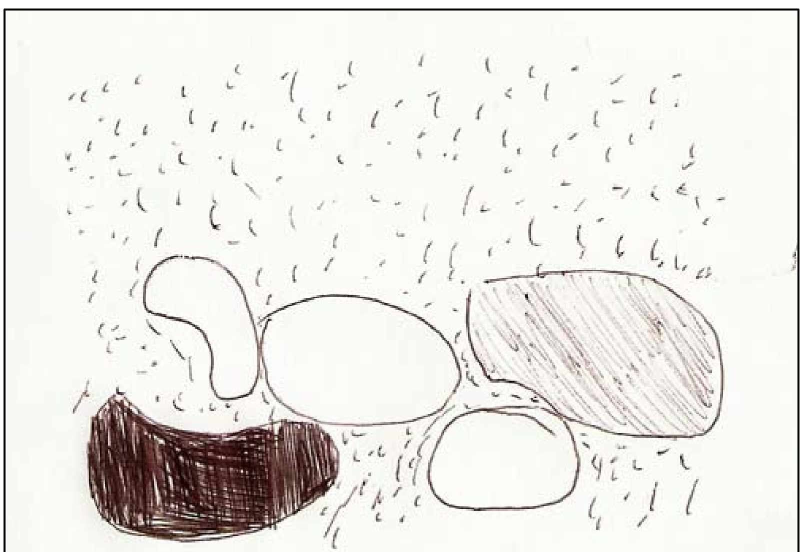


Figure 25: Sketch of detail in contact in Figure 24, sand goes around the uppermost pebbles of the conglomerate

Figure 26: Bright yellow limestone with solution rills right above planar-laminated, yellow sandstone, pencil is 14.5 cm

Figure 27: Bed of yellow medium to fine grained sandstone with some planar bedding and soft sediment deformation, above it is the layer of medium grained sandstone with oscillation ripples, ruler is 15.5 cm

Figure 28: Soft sediment deformation in a bed of yellow and red sandstone

Figure 29: Tecopa Lake beds, Allison is 1.6 m

Figure 30: Soft sediment deformation in a layer of the Tecopa Lake beds, centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

Figure 31: Cross stratification in a layer of the Tecopa Lake beds, centimeter scale

Figure 32: Unique weathering in China Ranch beds, quarter is 2.4 cm

Figure 33: Normally graded bed in China Ranch beds, quarter is 2.4 cm

Figure 34: Angular conformity between the China Ranch evaporite deposits and younger alluvium

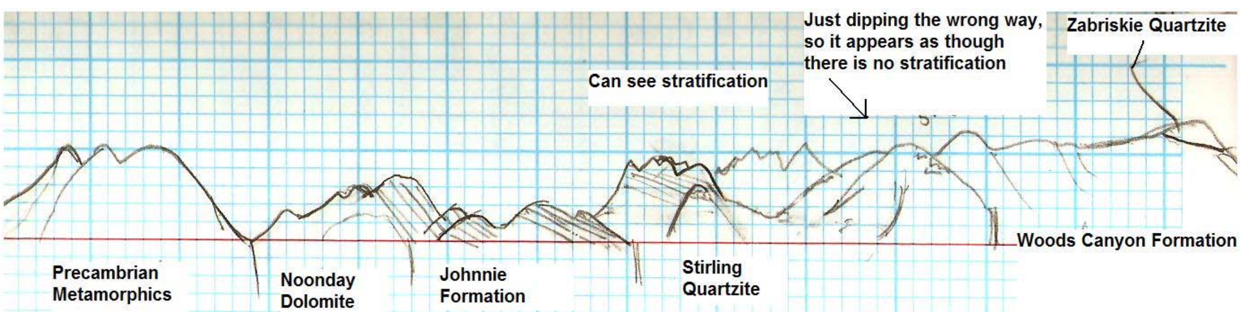


Figure 35: Sketch of the South Nopah Range with formations labeled

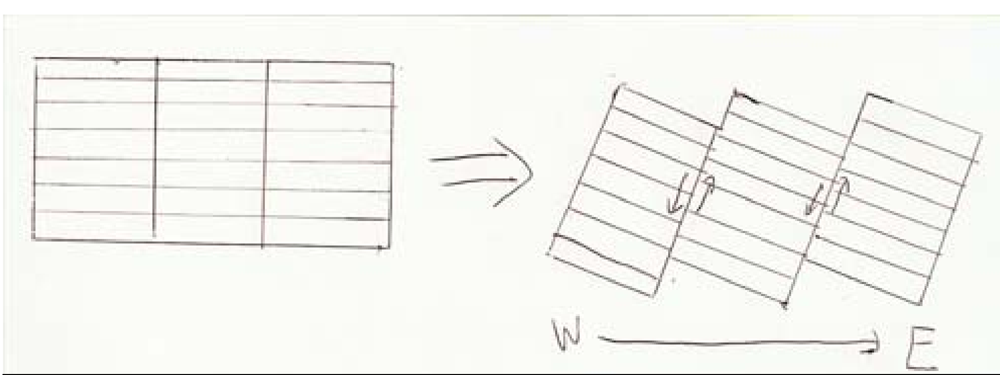


Figure 36: Diagram of classic block faulting which results in beds dipping to the east, as seen in the southern end of the Nopah Range

Figure 37: Cross stratification in arenaceous dolostone or dolomitic sandstone interbedded with quartz arenite which is coated with desert varnish (Unit 1), pencil is 14.5 cm

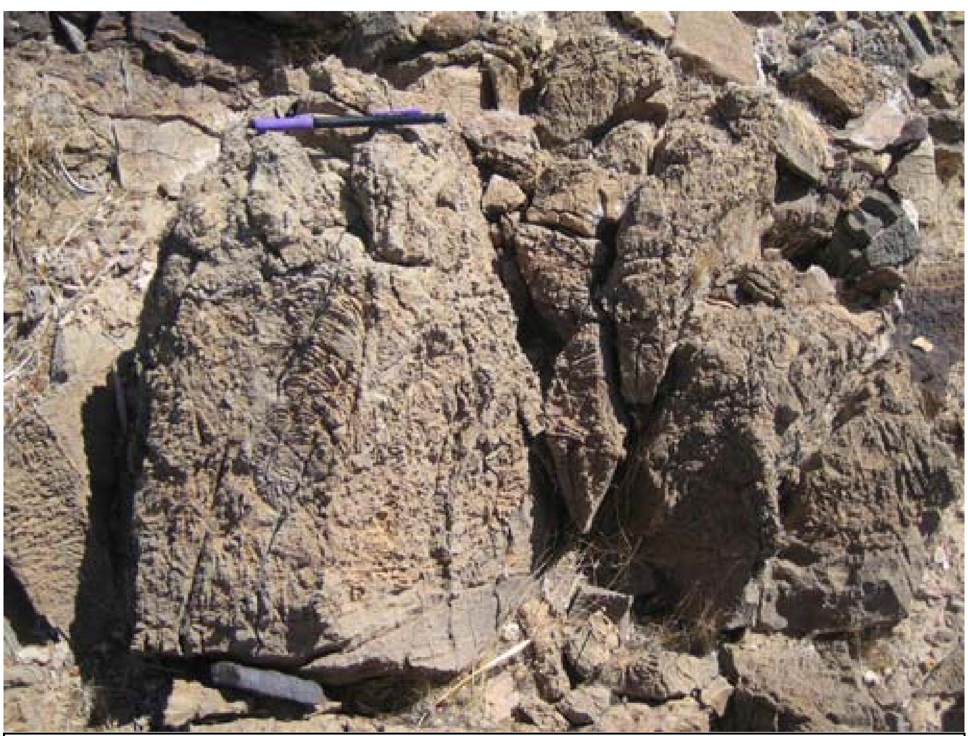


Figure 38: Microbial lamination in medium-gray-weathering dolostone (Unit 2), pencil is 14.5 cm

Figure 39: Interbedding of different dolostone subfacies in Unit 2 with desert-varnished quartz arenite, pencil is 14.5 cm

Figure 40: Stromatolites, i.e., microbial lamination in brown dolostone (Unit 3), centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

Figure 41: Boundary between two subfacies in Unit 3, lower is weathered light brown, and the upper is weathered a darker brown, Roxana is 1.6 m

Figure 42: Fine to very fine light-gray to white sandstone (Unit 4), pencil is 14.5 cm

Figure 43: Normally graded bed in coarse-grained quartz arenite (Unit 5), pencil is 14.5 cm

Figure 44: Brown-weathering sandstone event bed with hummocky cross stratification on top of the bed and planar lamination in the lower part, pencil is 14.5 cm

Figure 45: Paraconglomerate in the Johnnie Formation, perhaps with some intraclasts, centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

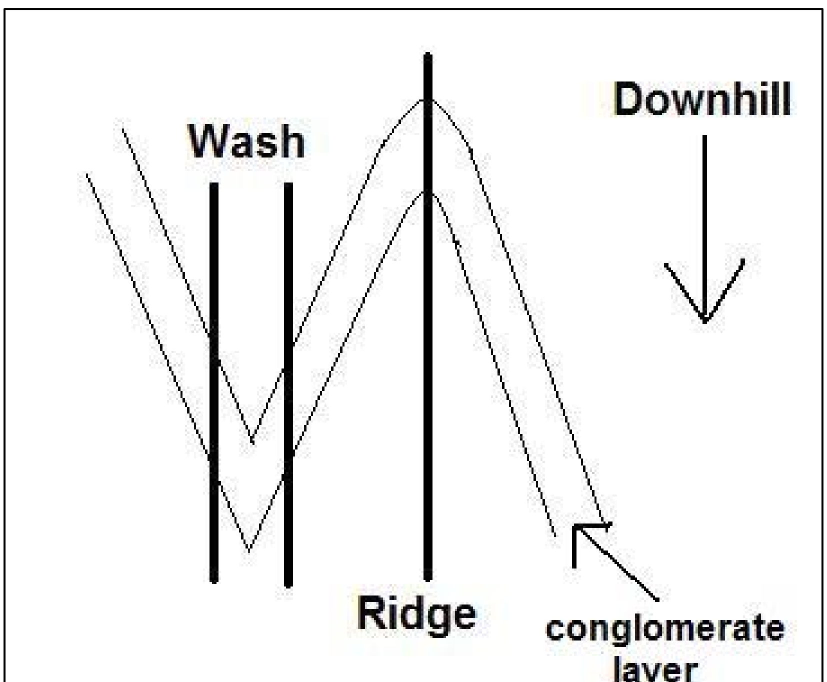


Figure 46: Rule of V's as seen in map view on the hillside

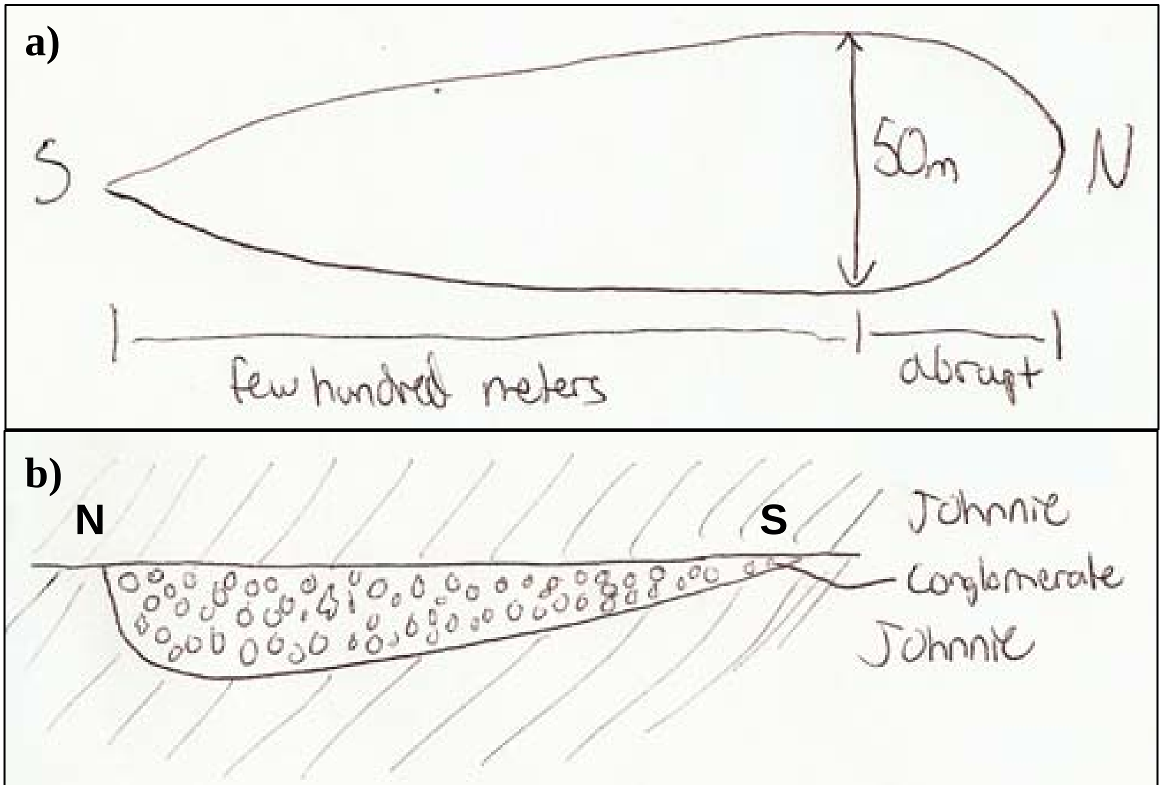


Figure 47: a) Diagram of the layer of paraconglomerate on the hillside in map view b) Cross section of the hillside showing the paraconglomerate in relation to the rest of the Johnnie, case of incised -valley fill

Figure 48: Large flute marks on the bottom of one of the siliciclastic event beds in the Kingston Peak formation, pencil is 14.5 cm

Figure 49: Large lone stone in Kingston Peak Formation, centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

Figure 50: Deformation of layers underneath lonestone, and laminae on top following the contours of the lonestone, centimeter scale

Figure 51: Smaller ripples in the current prevailing wind direction (yellow arrow) overlie and fill in larger ripples from a past prevailing wind direction (green arrow), ruler is 15.5 cm.

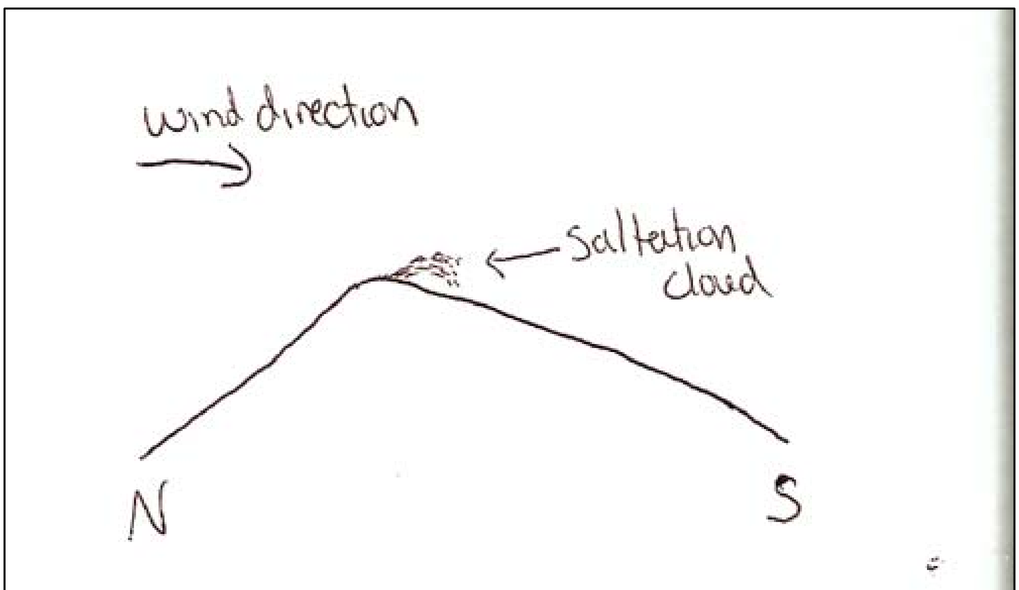


Figure 52: Sketch of the saltation cloud seen on the dunes

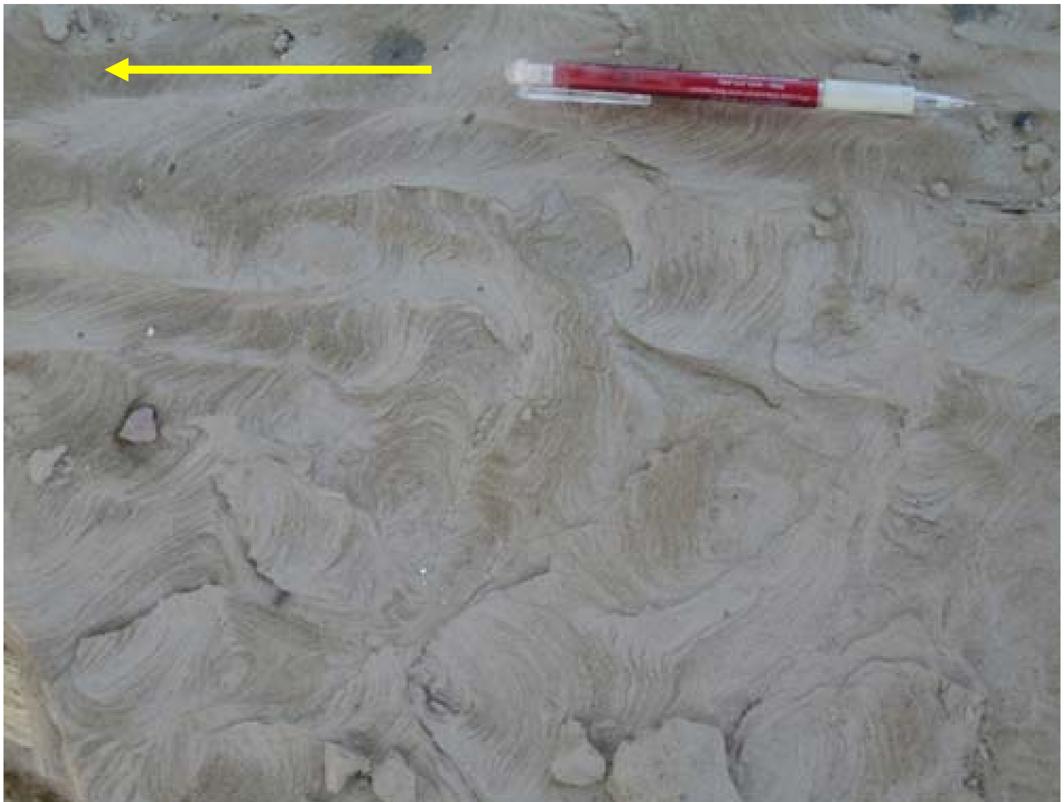


Figure 53: Rib and furrow on shore of Mojave River, yellow arrow is current direction, pencil is 14.75 cm

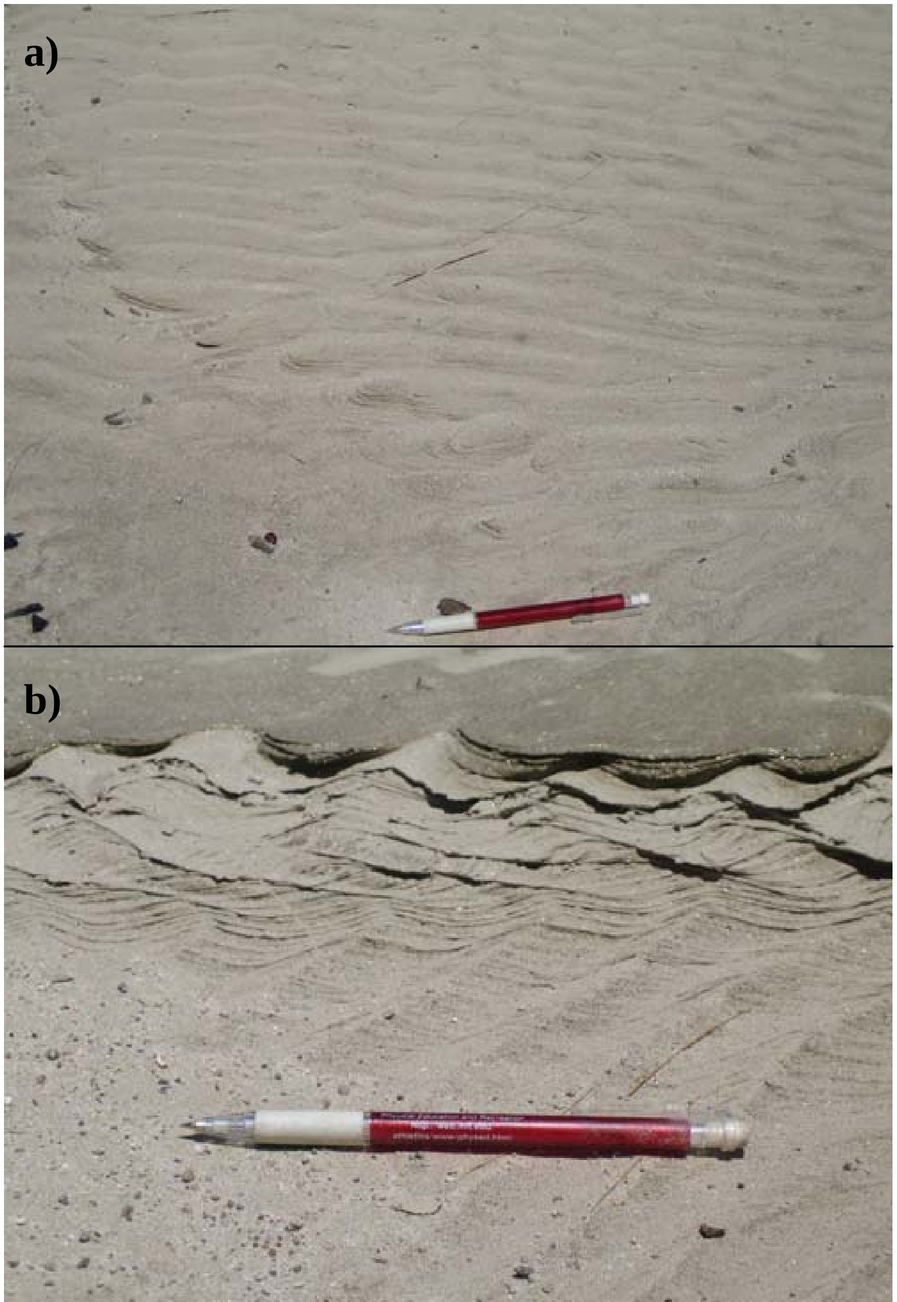


Figure 54: a) Oscillation ripples in the sand of the Mojave River shoreline
b) View of a vertical cut in the ripples shows they are climbing ripples, pencil is 14.75 cm

Figure 55: Three levels of terraces in the alluvium from the Mojave River, numbered oldest to youngest, John is 1.9 m

Figure 56: Pebble imbrication in the alluvium of an old terrace from the Mojave River, centimeter scale. Photograph courtesy of Augusta Dibbell. Used with permission.

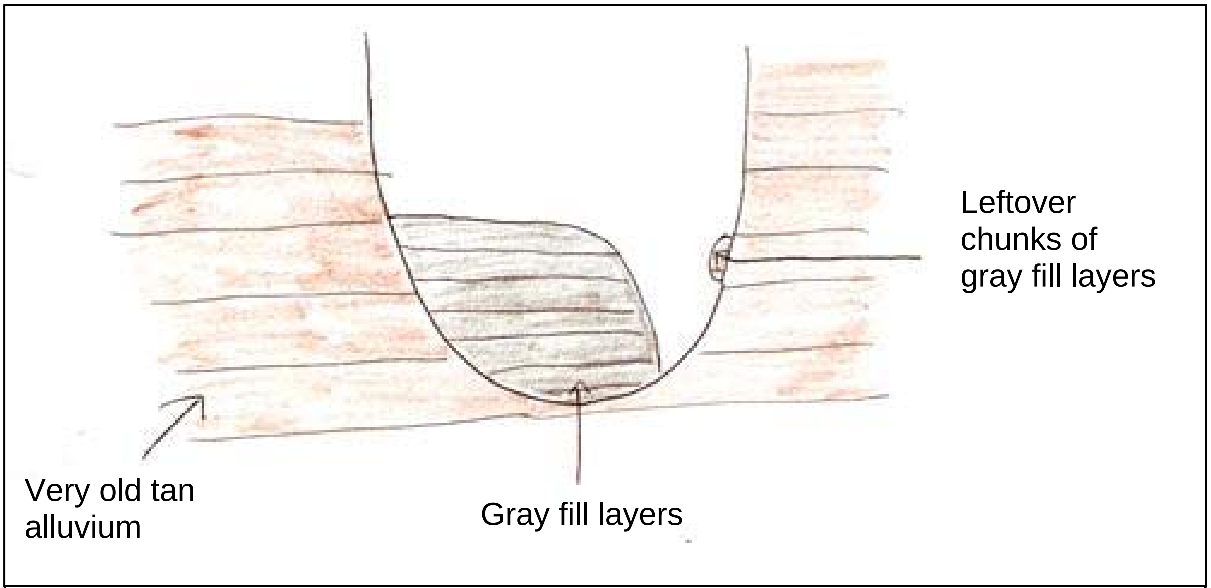


Figure 57: Diagram of a cross section of Afton Canyon according to theory that the topography formed by valley fill

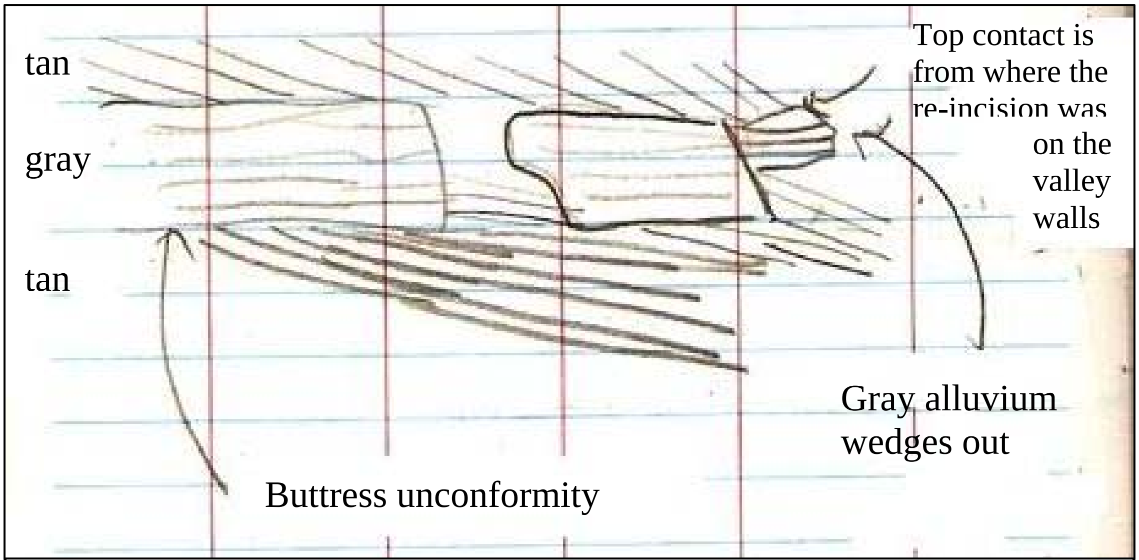


Figure 58: Sketch of buttress unconformity between the older tan and newer gray alluvium in Afton Canyon

Figure 59: Butte in Afton Canyon

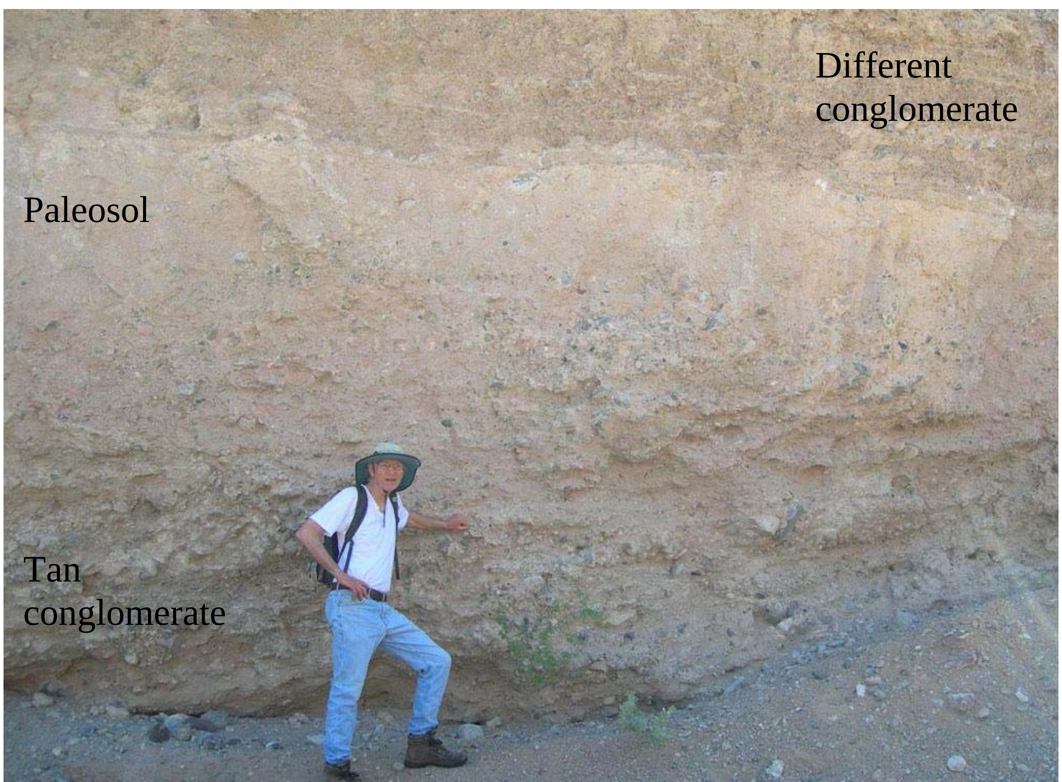
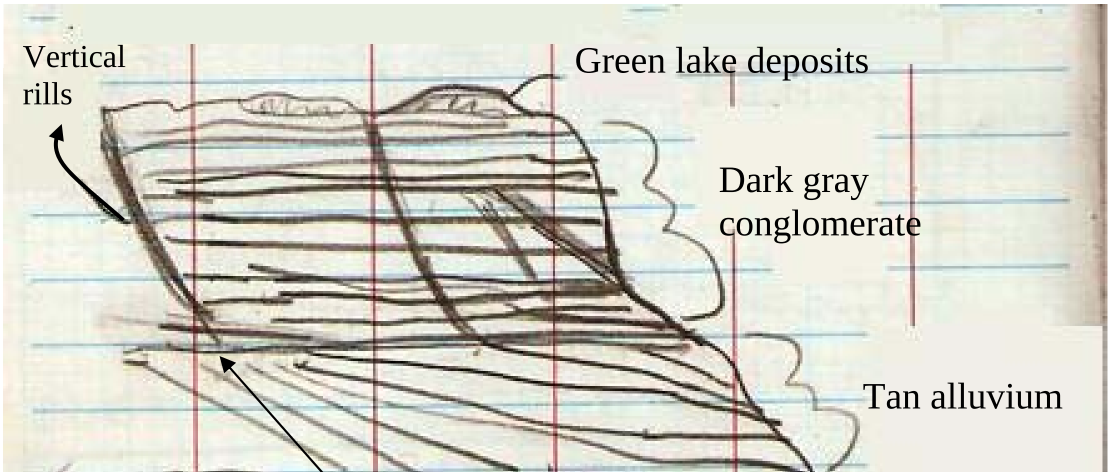


Figure 60: Paleosol that grades from the underlying tan conglomerate, John is 1.9 m. Photograph courtesy of Augusta Dibbell. Used with permission.

a)



b)

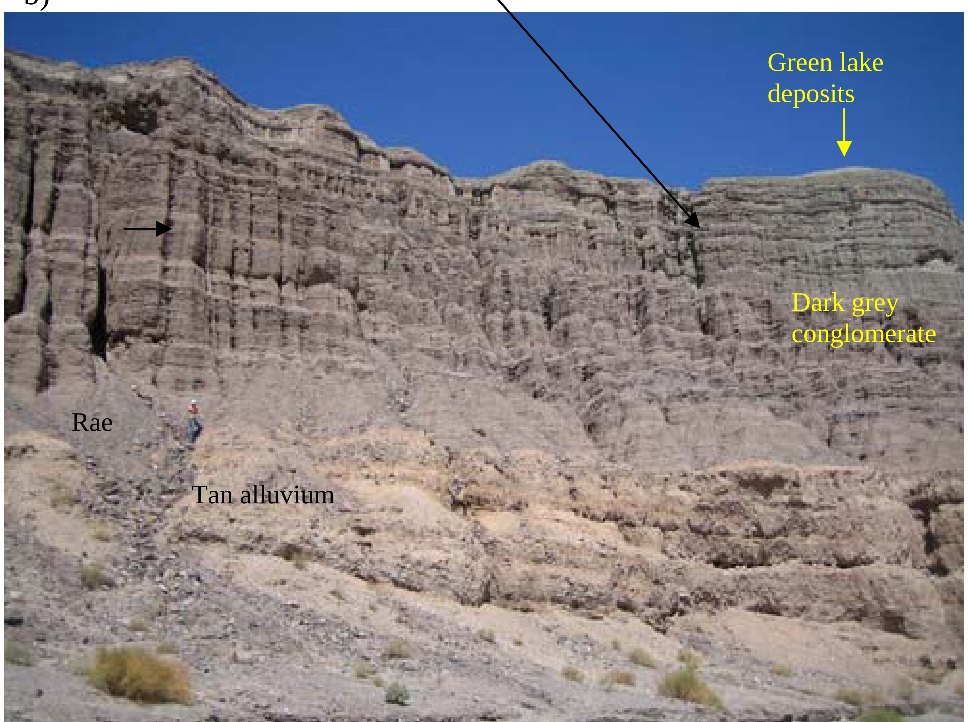


Figure 61: a) Sketch of large angular conformity between the dark grey conglomerate and tan alluvium, dip of layers in tan conglomerate is slightly exaggerated b) Picture of the angular unconformity slightly further up the wash, arrow between pictures shows connection, Rae is 1.7 m

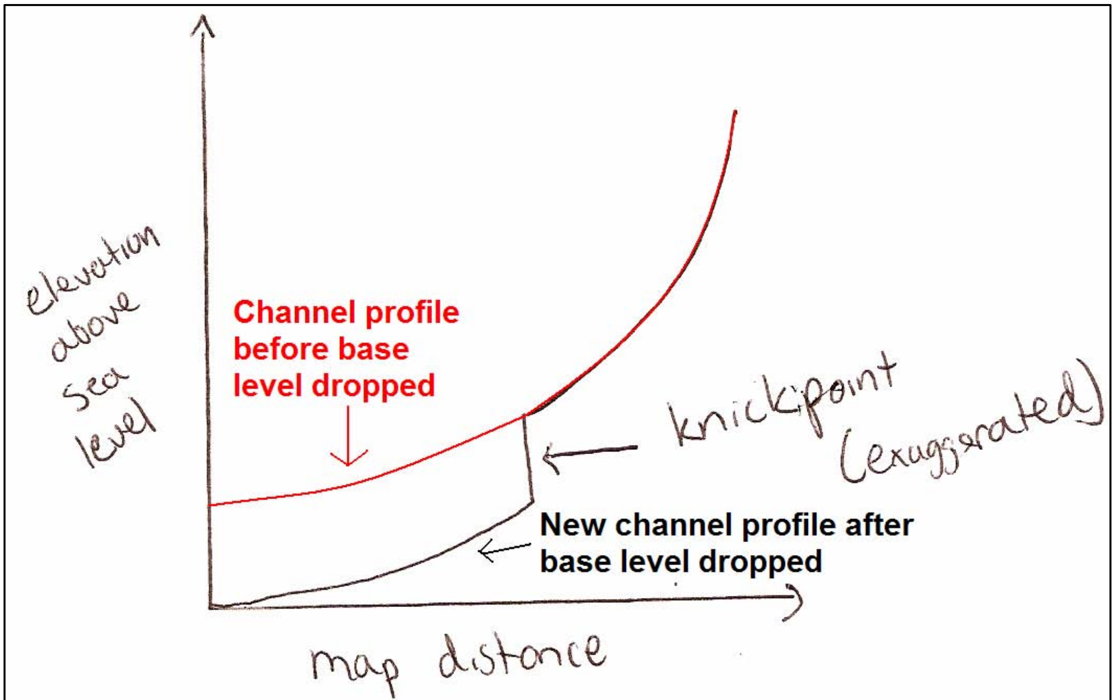


Figure 62: Graph showing how a basal drop causes a knickpoint

Figure 63: Steeply dipping stratification in the light green rock in Afton Canyon, Rae is perpendicular to the ground, Rae is 1.6 m

Figure 64: Amygdule in dark gray, fine-grained basalt, pencil is 14.5 cm

Figure 65: Burrows and planar lamination in orangish-brown-weathered limestone (Unit A), centimeter scale

Figure 66: Chert nodules in gray-weathering limestone Unit C, pencil is 14.5 cm

Figure 67: Sand-filled burrows in gray-weathering arenaceous limestone (Unit G), centimeter scale

Figure 68: Soft-sediment deformation in tan or beige-weathering limestone (Unit J), part of pencil showing in picture is about 11 cm

Figure 69: Stylolites in gray-weathering limestone (Unit L), centimeter scale

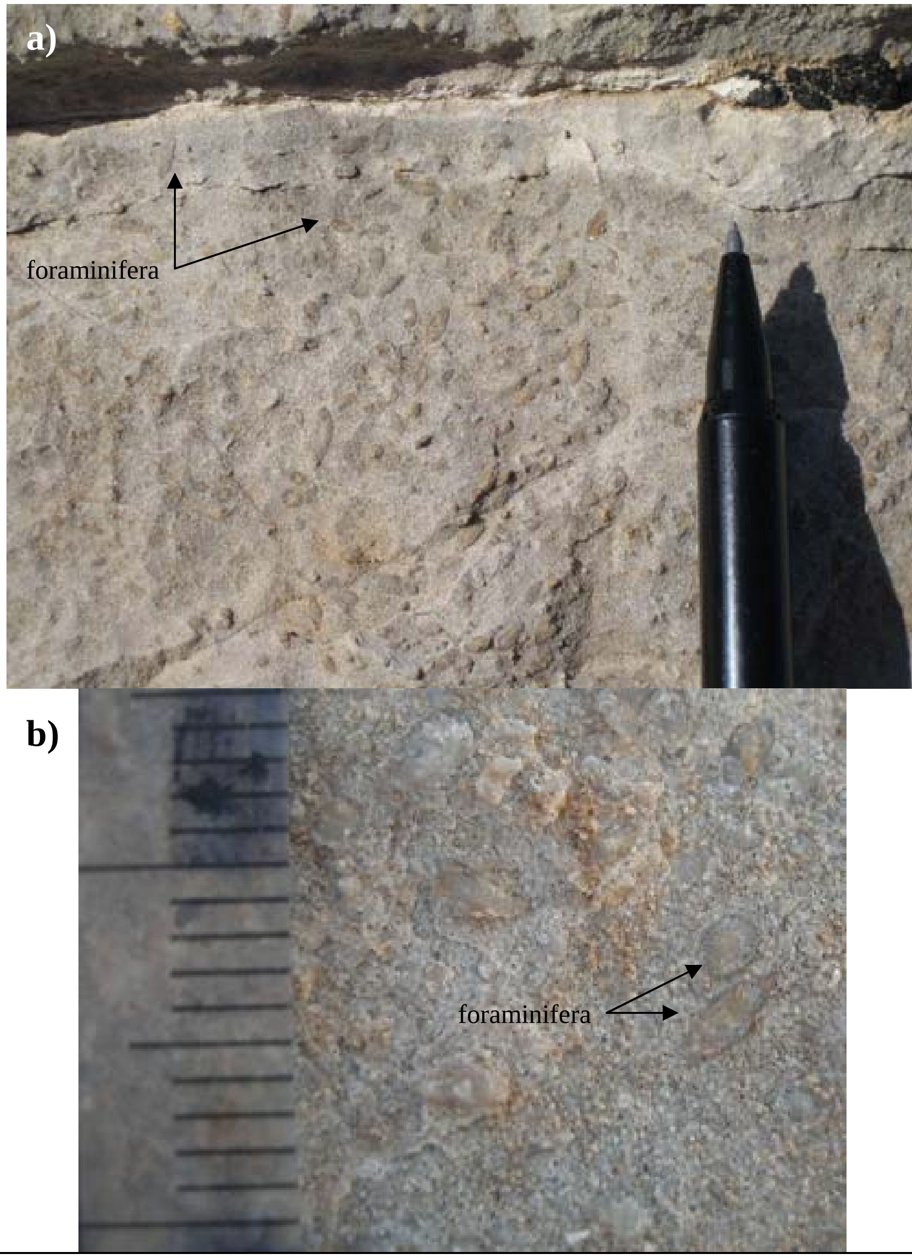


Figure 70: a) Silicified rice-shaped foraminifera in burrowed bed of gray limestone (Unit N), gray tip of pencil is 3 mm b) Closer picture of foraminifera, each line on scale is 1 mm. Photograph in b courtesy of Augusta Dibbell. Used with permission.

Figure 71: Burrows bring more gray-weathering material into the brown-weathering material in Unit N, pencil is 14.5 cm