The Salton Sea leaps out of the desert brown as a sparkling expanse of sapphire, suddenly filling the view from the left car window as we fly south along highway 86, all-terrain tires roaring on the hot california asphalt. The dusty green Chevy Suburban in which we're traveling is in its element; charging through the desert, trunk full of rock hammers, seats full of eager students, and Dr. Bob Gaines at the wheel.

Bob glances nonchalantly out the driver's side window over the blue expanse, I watch the reflective blue lenses of his Ray-bans flit back and forth between the road and the water in the rear view mirror. I'm waiting for him to share some impromptu factoid about the Salton Sea, to give the car a lesson in his trademark cadence of knowing enthusiasm, but it doesn't come.

I'm surprised by his reticence, the Salton Sea has quite the backstory. It was formed in 1905, when an engineering disaster accidentally diverted the nearby Colorado River into the valley for 2 years before the flooding could be quelled. This kind of tidbit seems like just the kind of car lesson Bob loves to give on field trips, but I guess we're not here for the Salton Sea. This weekend's trip is far more concerned with the basin that contains it— the so-called "Salton Sink."

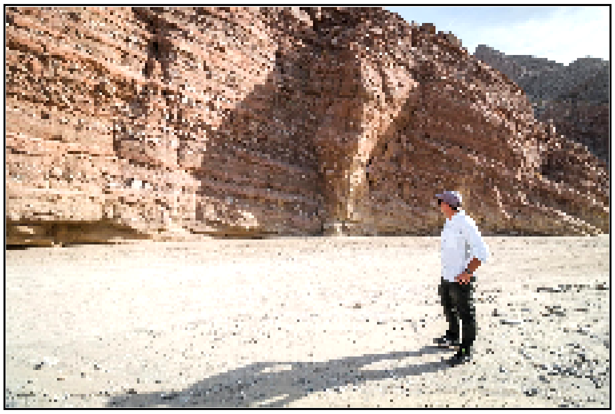
At 230 feet below sea level, the actively subsiding ground we're driving over is a product of the ongoing geologic setting of the Gulf of California, the latest sign of a continent that has been rending itself apart for the last 10 million years. Below us, the upwelling and diverging convection currents of magma in the mantle have begun to create new oceanic crust right under California and Mexico. This relentless spreading action is the same process that split the continents out of Pangaea 175 million years ago, and drove them into their modern configuration. Today, this process is ripping the Baja Peninsula away from mainland Mexico, and beneath our feet it is widening and deepening the Coachella Valley, preparing it to become the northernmost point in the Gulf.

We've come to the Anza Borrego desert seeking the sedimentary rocks that tell the story of a rifting continent. As the early gulf began to split and its center sunk into the ground, the rocks and sediments on the emerging hillsides suddenly had somewhere to go, and poured into the valley, layering strata in neat horizontal layers. As the rifting proceeded, the changing surface of the landscape caused the character of the sediments being eroded to change as well. In this way, the sediments created a record of the whole rifting event, a puzzle for enterprising sedimentologists to come along and solve. It was this puzzle that brought us here. Deciphering it was to serve as the culminating field exercise for GEOL 120: Sedimentology with Bob Gaines.

Sedimentology, or the study of sedimentary rocks, is chiefly concerned with translating the various traits of sediments into information about the rocks' formation. The underlying principle is that sediments are affected in characteristic, predictable ways by the rocks they come from and the things that happen to them during the process of weathering. Armed with knowledge of these signatures, it is the job of sedimentologists to construct a plausible story to explain their observations; to give the rocks a backstory befitting their current character.

The car lurches right, Bob's famously leaden foot relaxing from the accelerator as he forges across the lanes towards an oncoming exit. We turn right off the highway along a knobly sun-bleached road, putting the Salton Sea at our backs and heading for the hills. A few miles later comes another lurch, this time as we leave the asphalt entirely, transitioning to a sandy streambed that doubles as a 4X4 road. Bob shifts into four wheel drive, and but barely changes from his laid back posture and easy hand on the wheel as we traverse the rutted washes, moving up the stream bed towards the gates of a canyon ahead.

Within the canyon, we are surrounded by 200 foot cliff faces banded with the distinctive parallel layers of sedimentary rock. These layers slope away from us, such that the upstream side of each layer is lower than the downstream side. Because of this tilt, we can effectively climb upwards through the rock record as we drive up the dry river bed, looking at strata from their ancient bottom to their recent top, traversing 10 million years of geology within a few miles' drive.



100 yards into the canyon, Bob sticks his hand out the window and waves the other Geo department vehicle behind us to the side of the road. We are at our first stop. The canyon wall here is made up of cantaloupe-sized rocks embedded in a matrix of cemented sand: a conglomerate. Conglomerates are the product of debris flows— violent erosion events analogous to an avalanche, where mostly solid rock breaks away from a steep hillside and slides downward in a churning mass. The rocks within the flow experience high-energy collisions that rapidly break and round them, but such flows usually lasts only a few seconds or minutes before exhausting their momentum. The short transport time gives little chance for these rocks to be broken down into homogeneous pebbles and sand. What is left instead are rounded boulders that can be several meters across, entombed in a supportive cast made up of their own powdered remains.

A governing principle of sedimentology is that grain size equates to energy. The microscopic clay particles that make up smooth shales accumulate in only the most tranquil of environments, drifting to the deep seafloor in the absence of even the slightest currents to keep them aloft. On the other side of the spectrum, massive boulders are deposited in violent floods and debris flows—freight trains of churning rocks hurtling down a mountainside with enough energy to level trees, or houses. To find this high-energy deposit here, amongst the oldest rocks at the bottom of the sequence, suggests that the rifting process started dramatically—rapidly generating the harsh topographical relief needed for these flows to occur. This is a testament to the magnitude of the upheaval caused by this rift, and it is only the beginning. We still have miles of deposits yet to go.

Up the canyon we drive, the cars pitching and heaving over the rutted ground. I'm glued to the window in the back seat of the Suburban, watching the gently sloping layers in the walls pass by. The rocks are finer-grained now, layers of coarse sandstones intermingled with silt, reflecting that the gulf had flooded with a shallow sea where fine particles could settle, and that the sediments were weathering more before being deposited.

Above all else, Sedimentologists think about weathering: the ways in which rocks are physically and chemically broken down into sediments, and transported from mountains to the sea. Chemical weathering occurs when the natural acidic compounds in water react with rocks, dissolving some minerals and leaving others. On the physical side, water and gravity combine the give the added lubrication and momentum for rocks to travel downward. From cascading mountain streams to sluggish low-angle rivers, rocks are swept along in the flow, bashing into each other and breaking into perpetually smaller pieces. As long as there is slope, there is momentum to keep transporting and weathering sediments. When at last the rivers empty into the ocean, the momentum dissipates, and the sediments are deposited anew. So it is that the mountains of earth are slowly transported out to the sea. What comes up, must come down.

I snap out of my daydream to a catastrophe outside my window. The normally neat layers of sedimentary rock we were passing have been rudely interrupted by an immense pile of lithified rubble. The sediment layers reappear on the other side of this ugly mass, but are now grotesquely folded and warped, peeled back and heaped upon themselves like a 50 foot pile of dough. I bolt upright to inquire, but we're already stopping.

Assembled on a boulder overlooking the scene, we listen as Bob describes what happened here. "What you're looking at," he gestures to wreckage of rounded boulders and dark matrix on the right. "Is a massive, catastrophic landslide." Landslides of this magnitude are not uncommon in prehistory, but they exceed some of our modern understanding of physics. None of our models can account for how they were able to move as far as they did. This single slide has been mapped across the entire state park, all in all, it's runout extends over 20 *kilometers*! When this landslide came careening down from the mountains into the gulf, part of it cut down into the layers with enough force to peel back 70 feet of accumulating sediments and fold them back on themselves." It seemed things weren't quieting down much in the proto-gulf after all.

We leave the epic landslide behind, and drive onward. Outside the car window, the canyon changes. The solid rock seems to slump into soft, decaying soil. The steep canyon walls decline, shallowing into rounded hills devoid of vegetation, bone dry and encrusted in flakey clay. The hillsides are incised with jagged channels, the scars of rivulets that run over the surface instead of soaking into the dense, impermeable ground. I imagine that rainstorms here must produce epic flash floods, the unabsorbed water turning a rich and viscous brown as it sweeps up clay from the hills and paints it over every surface it touches.

Where the streambed curves, some walls still exist among the hills. The fast current on the outside of the river has more cutting power than the inside, allowing it to create vertical faces by undercutting the river bank even faster than the hills are worn down by rain. These walls that give us a window into the underlying structure of the badlands, and a chance to determine why they changed so dramatically from the sediments below them.

As we pull up to a wall, the details of it resolve into almost impossibly well-ordered layers. Beneath the veneer of clay painted on by the river, the sediments are stacked in perfect repeating beds with the color and width of 2X4 planks, each separated by a thin layer of dark silt. The consistency is astonishing.

The distinct layers within sedimentary rocks usually correspond to either single events or ongoing environments on land. Imagine a layer of fine silt that is deposited daily at the mouth of a river. This layer might be covered by an influx of coarse sand when the river floods, and then covered again as the slow trickle of silt resumes. A process like this might explain one of the layers we’re looking at now, but it can’t explain the perfect repetitive consistency of the wall as a whole. One would never find the exact same cycle of storms and fair weather repeating like clockwork over hundreds of thousands of years. The class is baffled.

Bob concludes that we need a little perspective, and so we set of up a faint trail to an overlook. It only takes a few hundred feet of elevation gain to see for miles over the rolling hills, and reveal the scope of the badlands we’re in. The hills stretch for miles, undulating off into the distance in mottled greys and browns, devoid of life but for the minuscule black forms of hikers like ants among them. In the distance, a mesa rises above the desert, capped by some resistant dark layer that has protected the weak material below it. If the same rhythmic layers underlie all of this, the deposit we were studying must be tens of thousands of feet thick. Whatever is happening here, to produce this much sediment with such regularity would require a dramatic change from the processes that laid down the sediments in the canyon.

We descend from the overlook single file, but not the way we came. Bob routes us down a precipitous drainage, into a side canyon cut by a tributary of the main streambed. Here, half buried in the soil, is a boulder the size of a house. Its interior is gnarled and swirled with the textbook texture of metamorphic rock, and it is shot through with a quartz vein that is wider than my body, the product of molten rock under pressure filling into a crack and jacking it apart. The edges of the behemoth rock are rounded, and nothing like it is nearby. It is clear that it detached from some ancient mountainside and fell here in an epic, almost cartoonish cataclysm. In technical terms, it is the largest sedimentary grain any of us have ever seen.

I try to get oriented in space and time, to think what this means for the story we're building. For this boulder to have fallen here, we must still be standing in sediments deposited in the early gulf, in an area near enough to the shore to catch a boulder like this hurtling down from a mountainside. And somewhere, somehow, there must have been a sediment source in this ancient seaway capable of producing billions of tons of sediment with almost perfect cyclicity.

As we would eventually learn, that source was The Colorado River, and the great piles of sand and silt before us were the excavated interior of the Grand Canyon.

Up until 5 million years ago, the Colorado River ran more west than south, draining the rockies straight into the Pacific and intersecting the ocean perhaps as far north as Monterey Bay. But as the as the rifting gulf widened and spread northward, the growing valley captured the flow of the river and diverted it south, setting it in its current-day course into the Gulf of California. The sediments below us, those that formed the walls of the lower canyon, had been the product of small-scale river systems; drainages that had developed within the early hills and mountains bordering the gulf, most collecting the rainwater of a few dozen square miles. At this scale, the character of sediments being carried by these streams was dictated primarily by storm events. Compared to these mild creeks, the Colorado River is in a league of its own. Draining the greater part of southwestern north America, the Colorado River watershed today is nearly 250,000 square miles. On this scale, individual storms matter not a whit. What did matter, were seasons.

Before the river was restrained behind dams, the flow of the Colorado varied widely over the course of the year. As the snowpack of the Rockies began to melt in spring, the river would swell and quicken dramatically, picking up sediments as it cut into its banks with flood waters. These entrained sediments gave the river cutting power as it crossed the Colorado Plateau, helping it slice through the rocks and level its own path towards the ocean. Upon arrival, these seasonal dumps would flood the floor of the gulf with great clouds of sediment, which settled into a uniform layer several inches thick across the seafloor. By contrast to these events, the sediment load of the rest of the year was trifling, a few centimeters of fine silt peppered on top of the coarse flood deposits. Year after year, this cycle brought the sedimentary sheddings of the entire southwest down into the gulf, piling so much weight on the crust that it hastened the subsidence already occurring, making room for season after season, foot after foot, mile after mile of sediments to accumulate. To the north of the delta, even the subsidence could not keep up, and the northernmost point of the rift became walled off by the relentless deposition of material. Isolated from the gulf, the water in the northern tip began to evaporate, leaving behind a barren desert depression that was sinking progressively lower below sea level, the Salton Sink.

When the northward movement of the San Andreas fault eventually exhumed the river sediments deposited in the early gulf, their high clay content and the arid climate of Anza Borrego made them poor hosts to plant life. With no roots to anchor the sediments or turn them into soil, these ancient river deposits became badlands, eroding slowly away one flash flood at a time.

With our feet weary and the light getting long, we load up into the cars, and head for camp.

The moonlight is bright enough to see the spider web of mud cracks beneath our feet, and pick out the individual clay plates curled up at the edges like flakes of chocolate. They crunch under our shoes with delightful rapport, a symphony of crackle that blends between our 8 pairs of feet into a low gruff noise like walking through icy snow. We’re picking our way single file through a wash near our camp. Our headlamps hang around our necks, unnecessary in the moonlight. Bob is leading without a word. Around us I can see the walls of the wash building higher, and as we round a turn I see them converge into an amphitheater: a dead end encircled by a 40-foot wall of stone, topped by a U-shaped lip where a waterfall must form during flood. Below that is a small basin, excavated by the force of the torrent.

A dark layer of rock, just visible in the moonlight, seems to run around the upper rim of the amphitheater, capping the walls with a thin dark streak that stands out from the sand-colored layers that surround it. Another similar stripe runs just in front of the basin, containing the depression like the rocky rim of a bathtub.

As Bob hoists himself over the rocky lip, he calls out “You guys might want to have a look at this rock ledge when you climb over it.” Students swarm to the scene, sweeping their headlamp beams across it and quickly raising a chorus of exclamations “They’re Fossils! Sea shells!” I hurry over to look, the sharp rock reveals itself to be a twisted mass of soldered-together grey shells, brittle and heavy. Kitty pries one from the embankment and says, tentatively “They almost look like oysters.”

“Bingo!” says Bob.

I look back up at the vertical walls around us, the dark bed that I had noticed forming the lip of the wash. The puzzle pieces click together in my head. The brackish water of the ancient gulf would have supported massive populations of oysters! Their millions of shells ,ust have accumulated together and formed a layer of their own on the seafloor. The hard calcium carbonate of the oyster shells had recrystallized and mineralized into a layer of rock far harder than the surrounding sandstone as the shells dissolved and re-cemented together into a interlocking mass of fossil limestone. This oyster layer formed a weather-resistant cap to the landscape, protecting the sandstone beneath it from rain and flash flood erosion. Where streambeds ran across it, the sturdy limestone provided a lip where flash floods had far more power to cut down than to cut back. Suddenly the mesa overlooking the badlands makes sense too—the dark layer at it’s top must be a similar oyster bed. In fact, given the perpetual upstream tilt of the sediment layers it must be the *same* bed. The mesa is a mile or so downstream of our camp, a perfect distance for the sloping oyster bed atop it to have descended almost to ground level.

I pocket a few nice samples, and join the procession back to camp, dreaming about the ancient seaway that supported so many millions of creatures.