Where Did It All Come From:
A Geological Look at El Potrero Chico, Mexico

Deep beneath the border between Mexico and the United States, you can find El Potrero Chico, “the little corral.” As you stand in midtown Hidalgo, Mexico, you can see the Potrero Chico in the horizon. As you get closer and closer to this miraculous formation, shadows cast down from the peaks above and engulf you. Soaring mountains of limestone stand in right front of you, tempting you to explore the profound beauty they enclose. Bountiful flora covers the area, wildlife thrashes in the hills, and magnificent rock extends as far as the eye can see. As a climber you should lend your attention to the Potrero Chico. For this unique landform, with its intense geologic history, proves to be a magnificent journey through time.

To ensure that you, the reader, come away with a firm grasp of the Potrero Chico’s creation, I am going to explain its history in reverse order. By explaining the creation of the Potrero Chico in reverse chronological order, I am creating a visual picture that allows the process to be seen more easily. Many progressions were a part of Potrero Chico’s completion, beginning with creation of salt and limestone. Spectators can see the limestone rock strata as it stands thousands of feet overhead, but the salt that used to fill the Potrero Chico is an entirely different story. In fact, salt deformation is most likely the single greatest factor in the formation of the Potrero Chico. Let us begin by first looking at the Potrero Chico as it stands today; what marvels do you gazing upon the immense landform?

(Insert Paragraph)
The gaping canyon passage in the north wall marks the last major geological event to take place on the Potrero Chico. Through physical and chemical processes, limestone slowly eroded over time. The United States Geological Survey states this claim towards physical degradation of limestone: “All materials that are exposed to the outdoor environment are subject to degradation caused by natural weathering processes.” Of course, forms of weather activity erode the Earth’s crust, and the Potrero Chico is no exception to powerful acts of Mother Nature.

On Earth’s surface various agents are engaged in the work of rock destruction. Rivers wear their channels; wind, when it has free play, scours the rocks over which it blows; These are all processes in which the agent is moving while in operation. When accomplished by moving or motionless agents, the various processes of rock destruction come under the head of erosions. Mechanical wear by rivers, wind, etc., is *corrasion*; chemical wear is *corrosion*. Many of the processes effected by agents which are essentially motionless are included in the term, weathering.

(Field Geology, P 1)
An overflow of water within the Potrero Chico created the canyon passage is it breached the edge and pored over. The actual speed of erosion depended on the velocity of the exiting water. It is hard for an exact date to be calculated for this event, but it is easy to infer that it happened within the last two hundred million years because of the occurrence of previously dateable processes. ‘As I walk into the canyon entrance I can see sharp fins and runnels, which are the typical patterns of surfaces erosion in the Potrero.’ (The Whole Enchilada, p 21) You will also notice the vertical striations that the rock strata create as they stand vertically on both sides of you. Actually, you are walking through a time machine as you walk into the Potrero,
because the vertical rock strata get older and older as you go. Although all of the rock you walk through is a variation of limestone, change does occur and is noticeable. From the creation of the canyon passage we go to the previous process of salt doming.

Throughout Northern Mexico you can find salt domes like Potrero Chico. This doming process creates the large bowls, or ‘corrals’, we can see from overhead.

In some parts of the world there are dome-shaped uplifts of stratified rocks associated with central plugs of salt. These structures are known as salt domes. The salt core generally stands vertical or nearly vertical and has a roughly circular or oval horizontal section, measuring from 1,000 ft. to 2 miles or so in diameter. It extends downward several thousand feet. Adjacent to the salt, the surrounding sedimentary strata, generally ranging in age from Cretaceous to Recent in the Gulf Coast domes, have been faulted and turned up at sharp angles against the sides of the plug and have been arched over it where instances proof have been found of a total displacement amounting to 5,000 ft. or over. The upthrust of many of these domes was intermittent.

(*Field Geology*, p 190-191)

The Potrero Chico is actually a more elliptical shape, rather than a circular bowl as indicated above. The total amount of displacement due to salt tectonics is only a few thousand feet in regards to the Potrero, instead of 5,000. The geologists responsible for writing *Field*...
Geology, explain that sharp angles are created in the rock strata as they are pushed vertically, altering their orientation. This evidence confirms the conversation before about the rock strata getting older as you walk in the canyon.

Figure 2 A salt dome right before it is about to protrude through the overlying rock.

The salt dome, in particularly, is massive and holds great potential power. The dome sits inside the soaring tall walls of the Potrero Chico, with no way to exist without an eroded canyon. The fascinating question that come to mind are: How can a mere substance like
ordinary table salt, sodium chloride, become concentrated in a massive bulge between strata of limestone? Where could salt become powerful enough to undergo this intensive process?

The sole reason for salt’s potential power its own density level. In “High Amplitude Studies of Natural Dome Salt and Hydrostatically Pressed Salt,” professors Lucas and Tittmann from Pennsylvania State University discuss salt tectonics in a few sentences:

Salt beds are formed when a thick bed of halite found a depth intrudes vertically into surrounding rock. Sense the density of salt is less than that of the surrounding material, it moves upward toward the surface forming large bulbous domes from 1-10 km across and as far down as 6.5 km.

Lucas and Tittmann are definitely right about the salt being a lesser density than the surrounding rock, which in case of the Potrero Chico is limestone. The molecular density of salt, or halite, is 2.17 g/cm$^3$ which is considerably less than the limestone’s average density of 2.4 to 2.6 g/cm$^3$ (Salt Deposits, p 243). Borchert and Muir go on to explain the process that occurs due to the differing densities in more detail.

The halite flows toward the fold crests, or areas of minimum load, and there seeks to penetrate upwards through the overlying sediments. As it does so, the differences in static pressure become accentuated, the penetrative power of the salt increases, and the dome is initiated. Salt will normally flow (upwards) into the dome
until the supply from the surrounding area is exhausted. So the height of the dome is largely governed by the thickness of the original bed of salt. If that was thick enough, then the domes will often reach right to the surface. The rate of upwelling domes is very variable; probably it is usually less than 2 millimeters a year.

As they rise they tend to dome up the overlying sediments.

You can see that salt is indeed very powerful. Having the lower density as described above it protrudes into the overlying rock layers, creating a dome. In order to breach the surface the salt must do this for a very long time, as indicated by the flow rate of only 2 millimeters a year. Alik Ismail-Zadeh et al. say, “Salt is so buoyant and weak compared to most other rocks with which it is found that it develops distinctive structures with a wide variety of shapes and relationships with other rocks by various combinations of gravity and lateral (tectonic) forces.” This statement agrees with that of Borchert and Muir, solidifying the points I have made about salt tectonics.

Massimi et al. explain the salt doming process with a slightly more scientific approach. Please pay close attention to the details and notice the flow between the density of salt and limestone. Massimi et al. exemplifies:

Salt structures appear to be rising diapirs of light rocks in a denser overburden. The rise of diapirs is caused by a balance between buoyancy and viscous forces. Thanks to this assumption the diapiric growth can be modeled using the Rayleigh-Taylor method,
describing the gravitational instability of a layered fluid. In this model the basic physical phenomenon of diapirs is explained by the differential instability of a lighter salt underlying a denser overburden. If the interface between two layers is perturbed, the underlying low density rock will move upward due to the density inversion. The growth rate of this structure depends on the density and viscosity contrasts as well as on the thickness of the two media.

You can see from the diagram (Brown, W., 2008) below the salt does indeed intrude upwards when it is compressed below largely dense overbearing rock strata. The diagram is accompanied with Brown’s analogy for salt dome creation due to density. “Just as a cork released at the bottom of a swimming pool will float up through water, wet salt can float up through denser, freshly deposited sediments,” he passionately puts forth as a relationship between a cork and the salt. Seeing the cork float to the top of the pool in my head really allows me to picture the process of salt dome creation.
I agree with all of the evidence provided from my acquired sources, in that, the salt gains all its pushing power from the overlying rock strata. As gravity pulls down on the limestone above, because of its higher density, the salt below thrusts upward. When salt pushes upward on the surrounding limestone rock strata, they are forced into the vertical orientation that we already have discussed. Why does the salt diapir, or dome, actually take the shape of a mushroom? We lend our attention once again to Massimi et al. for the answer. They say:

So we deduce that the change of the overburden viscosity with depth controls the ratio between the horizontal and vertical movement of the structural development. Alternatively an increase in overburden density with depth delays salt ascent because of the density contrast between diapir and overburden, and thus the buoyancy forces decrease as the salt ascends. Moreover, if the salt diapir reaches a level of equivalent density, it intrudes horizontally into the overburden and stops its vertical motion.

Understanding the process at which salt gets to the service is vitally important, yet there is still more to the creation of the Potrero Chico.

Now it is easy for you to see the dome of the Potrero Chico was shaped as it were. As the salt intruded far enough toward the surface, it began to reach a point of equivalent density
with the overlying limestone. The salt then began to intrude horizontally creating a bulging top to the diapir. All this conversation about salt makes me wonder where it comes from anyways. How does so much salt even get below limestone rock strata in the first place?

Salt near and around the Potrero Chico has an origin that dates back far beyond that of the overlying limestone. Even though our prior discussion has revolved around salt tectonics, I believe discussing limestone development next would greatly benefit your understanding. Plus, this choice fits the sequence of events anyways. Before the salt protruded upwards, it was merely an underlying layer to thousands of feet of limestone. Limestone is developed within a salt bearing body of water, normally the oceans. The Whole Enchilada explains that reasoning behind this occurrence as the following:

One hundred and twelve million years ago, a shallow cretaceous sea covered this area and most of northeastern Mexico. Similar to the present day Bahamas, deep waters of the open oceans passed landward into a quiet, shallow lagoon. These calm and peaceful waters owed their existence to the wave-resistant reef, which protected them from the open ocean to the east. (The Whole Enchilada, p 21)

In this ‘shallow’ sea, millions of small creatures lived and flourished. Some of them grew shells that were made of calcium, and it just so happens that calcium is a leading component in limestone development. Reefs provide a specific environment that allows limestone to develop. Scientists with Amethyst Galleries Incorporated agree in saying,
Limestones form usually close to the source of shelly debris although some significant transport can occur. Great sources for limestone are reefs. Reefs have been in existence for most of the history of life on Earth, but they have changed in the species that build them. Stromatolites, which are complex living structures of more than one organism (cyanobacteria and algae), formed the first reef like structures in the Cambrian Period. Early reefs in the Ordovician were composed of small crinoidal, bryozoan and brachiopod reef communities. In the Devonian, reefs became extremely large with tabulate and solitary corals starting to dominate, but brachiopods and crinoids still significant contributors. Some Cretaceous reefs really took on some huge proportions and were dominated by large, now extinct mollusks called rudist. Since those times, modern corals and bivalves (clams) have been the prime reef-building organisms.

When these creatures, like the rudists, fall to the sea floor over and over again, the beginning ingredient for limestone is created. Now you should just sit back for thousands of years and let time takes its course; eventually these deposits of marine animals will build up enough and begin to harden. Compaction of these organisms produces the introductory sequence to limestone. Once again, Field Geology lends a hand towards understanding the process.
During long continued sedimentation in a region, the strata already laid down are covered by an increasingly thick and heavy overburden which tends to compress them by its weight. The compression, although produced by a force acting downward, is undoubtedly transmitted in all directions, so the sedimentary material not only becomes more compact not only across, but also along, the bedding.

Compaction squeezes the limy mud until barely any water remains within. Once this process has occurred long enough, limestone is created. It should come of no surprise that you get multiple layers of limestone from this process occurring time and time again. The limestone actually covers the substance that I was telling you about before. It is ultimately the salt we are interested in, especially since salt was the sole reason for the creation of the Potrero Chico. So what about it? How did the salt actually get beneath those overburdening layers of limestone strata?

Salt is an evaporite that is left behind in a restricted marine environment. Of course salt is derived from a salt bearing form of water. Thanks to the shallow sea of the cretaceous period, we have plenty of it all around the Potrero Chico. Before the sedimentation rate of limestone was far too great for salt to be deposited, a very intriguing process occurred that left miles and miles of salt behind.

Landes of Ann Arbor, Michigan suggests, “The major bedded salt deposits occur in sedimentary basins... In spite of great thickness of many salt deposits, there is increasing evidence, such as the
presence of ripple marks, that the water depth most of the time
during precipitation of salt was relatively shallow.”

You can see the major locations of salt layers in North America in figure 4. The actual process at

Figure 4 All the major salt deposit layers (Landes, p5).
which salt is deposited can be seen in figure 5. There has to be that shallow amount of water in an
restricted marine basin in order for salt to ‘appropriately’ evaporate. Landes provides reasoning towards
the process of salt precipitation, which is how the salt layers beneath the limestone came to be.

Therefore, if the climatic conditions are such as to encourage extensive
evaporation where the waters are shallow and hence warmer than in
the open ocean, the greater evaporation of the water on the basin side
of the sill will result in a constant movement of water from the ocean
across the submerged peneplain and into the basin. The denser sea
water resulting from that evaporation sinks below the incoming fresher
water, and it cannot flow out over the sill. It becomes trapped in the
basin and the stage is set for an evaporite precipitation cycle to begin.
(Landes, 2010)

Can you see how the salt becomes a layer below the limestone yet? I can. Sea water becomes
trapped within walls, not letting anymore water in until the water in side has time to evaporate. When
the water evaporates it leaves behind the salt that settles to the bottom of the basin floor. This process
occurs again and again through episodes of flooding, or episodic flooding.

Figure 5 Shows the salt precipitation cycle in a restricted marine environment.
Now you can visually see the layer of salt below the overlying limestone rock strata. With the salt deposit now in place it is easier to see the creation of the Potrero Chico as the larger picture. The ‘little corral’ that is climbed in today derived from this vast layer of salt deep beneath the limestone we see today. Are we ready for a forward glance at the previously discussed processes? I believe you are ready, and I know just where to begin, right where we left off at the initial salt deposit.

Figure 6 shows an overview look at the processes that occurred to create the Potrero Chico.

Following along in figure 6, you can see the Potrero Chico develop into the magnificent landform it is to this day. The salt was deposited during the precipitation cycle, which takes place during evaporation in a restricted marine environment. Then, after sedimentation rates increase to meet that of the salt precipitation rate, and water depth become too great for episodic flooding to occur, the creation of limestone begins to be present. As calcium carbonate shell bearing organisms die in the now deeper ocean waters, they settle to the floor of the sea. Compaction occurs over and over again, hardening the limy mud into limestone. Once the limestone becomes very ‘heavy’, at about the same
time the seas recede, the less dense salt deposits moves upward. The salt intrudes vertically into the above limestone rock strata until the density of salt reaches an equivalent level with the overlying limestone. When this occurs, the deposit will take on the mushroom shape bulge, creating the dome. During its upheaval process, the diapir, or deposit, also pushed up the surrounding rock strata into a vertical orientation. After the salt diapir breached the surface atmospheric forces became at work. Physical and chemical erosion occurred on the north side of the dome, which was probably due to elevation. Finally, the great canyon passage climbers flourish to each year was created. Now you can see the creation of the Potrero Chico in forward and reverse chronological order.

After careful consideration, I have written a review of the appropriate sources that explain the processes of salt deformation, dome creation, salt precipitation, limestone development, and the overall creation of the Potrero Chico. Now when you walk through the gates, the canyon passage, into a museum of geological masterpieces, you will understand how they came to be. Looking up at the soaring peaks of limestone, you will really understand how they became that way. Once through the walls inside the ‘little corral’ you can now picture the entire bowl filled to the brim with salt, how it got there, and where that salt actually came from. With a deeper understanding of your surroundings, your visit to El Potrero Chico, Mexico will prove to be a more beneficial experience to your body and ‘mind.’ After all, the ‘little corral’, is world renowned, and it is not just for its great climbing opportunity.
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