Cote Blanche Island Mine, St. Mary Parish, Louisiana: Salt Diapirism and Geology of the Louann Salt (Jurassic)
Cote Blanche Island Mine, St. Mary Parish, Louisiana
Salt Diapirism and Geology of the Louann Salt (Jurassic)

A Field Trip of the Southeastern Geological Society

14 October 2016

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Northwest Florida State College

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*On the Cover – Two students from Northwest Florida State College in Cote Blanche Mine, 14 November 2014
Introduction to Fieldtrip and Acknowledgements

For most of us, visiting a deep, subsurface mine is something like an otherworldly experience. When I first entered Cote Blanche Salt Dome, after a 2-minute, 1,500-foot (0.28 mile) vertical descent down the mine shaft, I was immediately struck by the deep silence of the mine. It seemed so heavy as to be felt. But the silence quickly vanished as the carts and machines and chatter began. Still, exploring the mine was unlike any other geologic field trip in which I have participated. It was as if we had gone to the Moon or to Mars. And for the geologist, who most especially appreciates the origin and age of this salt, its significance in the history of Pangaea, the origin of the Gulf of Mexico, and the intrusive, diapiric structure of the dome—what can you do but shake your head in amazement. If you think I exaggerate or dramatize, okay. But just wait till you go “way down in the mine” (Johnny Cash).

Many people have made this field excursion possible. Special thanks are due to Don Brumm, VP of Operations, at Cote Blanche, for his kind permission to enter the mine and assistance in making this SEGS trip a reality. Thanks also to Tara Hart, Manager of Corporate Affairs for Compass Minerals, who provided much company literature on the mine (including in the three appendices of this field guide). And Cote Blanche Mine Engineer Michael Nixon gave the SEGS an informative presentation on the mine at our pre-trip evening dinner in New Iberia. Thanks also to all the staff at Cote Blanche Mine for their hospitality and guidance in exploring the mine.

Compass Minerals reviewed an early draft of this field book, and provided corrections and additions to the mining portion of the text. Compass Minerals, however, cannot guarantee the accuracy of any information herein that is not directly related to Cote Blanche Mine and its operations. This field book is a production of the Southeastern Geological Society (SEGS) and is intended solely for the general use of SEGS members who participated in the visit to Cote Blanche on 14 October 2016.

Schedule and Driving Directions

The SEGS will assemble in the parking lot of Holiday Inn Express & Suites, New Iberia-Avery Island (318 West Highway 90 Frontage Road, New Iberia, Louisiana, 70560; Phone: 337-408-2700) on Friday, 14 October 2016, at 6:45 AM, and depart at 7:00 AM for the mine. We will caravan to the mine, taking US-90 east to SR-318, then south on SR-318 (which turns into SR-83) to Cote Blanche Crossing—a short, cable-drawn ferry over the Gulf Intracoastal Waterway (we stay in our vehicles for the crossing)—then a short drive on Cote Blanche Road to the mine. We need to allow ~45 minutes travel time from
New Iberia to Cote Blanche, for the ferry crossing and possible delays on the highway (from sugar cane harvesting). An early start is also necessary in order to catch the last, return cable ferry off the island.

Cote Blanche and the Fives Islands of the Louisiana Coast
Cote Blanche is one of the Five Islands located south of, and parallel to, US-90 between New Iberia and Morgan City, Louisiana (Figures 1, 2). The Five Islands include Jefferson, Avery, Weeks, Cote Blanche, and Belle Isle islands. The “islands” are forested hills that rise between 23-52 meters (75-171 feet) above the surrounding marsh land of the Louisiana coast. All are surface expressions of salt diapirism, and the flanks of all of these subsurface salt pillars have several fields each of petroleum reservoirs. All five of the islands have also supported active salt mines at some point, but only three are currently active (viz., Avery {Cargill Corporation}, Weeks {Morton Salt}, and Cote Blanche {Compass Minerals}).

Figure 1 – The Five Islands of Coastal Louisiana (figure 1 of Kupfer, et al., 1995).
The Five Islands domes are aligned, with a linear trend/strike of ~N42W. Each of the four northernmost domes are about 7.3 miles (11.8 km) apart, and there are two additional, probable residual salt structures (viz., Bayou Carlin and Bayou Sale) between Cote Blanche and Belle Isle, making the spacing and alignment of these structures all the more striking. Some structural control seems certain. The Five Islands parallel one of the many NW-SE trending fracture trends of southern Louisiana (Kupfer et al., 1995; Fisk, 1944), and a salt ridge has been postulated as the source of the Five Island domes (Kupfer et al., 1995; Kupfer, 1982). Below is a brief account of some of the more interesting aspects of each of the Five Islands (summarized from Kupfer et al., 1995 and recent sources).

**Jefferson Island.** Discovered in 1894, with salt mining beginning in 1923, Jefferson is the northernmost of the Five Islands, with a surface elevation 23 m (75 feet). It is perhaps most remembered for the mine flooding disaster of 20 November 1980, in which a Texaco oil rig in Lake Peigneur (which overlies the mine) accidentally drilled into the Diamond Crystal Salt Company mine at a depth of 400 m (1,300 feet),
apparently the result of drill coordinate error. For the next several hours, the shallow lake drained into the mine, creating a vortex, rapidly widening the drill hole, drawing in the drilling barge and many other cargo barges, and creating a 50-foot high (perhaps higher) waterfall. Water flowed into the lake from the Gulf of Mexico through Delcombe Canal, breaking local shrimp boats from their moorings in the town of Delcombe. Up to 60 or more acres of adjacent land collapsed into the lake. Although no lives were lost in the event, 55 miners had to be quickly evacuated from the salt mine.

**Avery Island.** Salt springs were known on Avery from pre-Columbian times, and salt was processed by evaporation around the turn of the 19th Century. Open pit mining of salt occurred for a short time during the Civil War. Subsurface mining was resumed in 1869 and has continued to the present. Surface elevation of Avery is about 48 m (157 feet). Many will know Avery Island as home of the Tabasco Pepper Sauce Factory and the Tabasco Country Store. Produced on Avery Island since 1859, this favorite condiment is a product of Avery Island salt, French vinegar, and capsicum red peppers. The seeds of these peppers are taken from plants grown on Avery Island, but they are exported and cultivated in Central and South America, where the peppers are harvested. The sauce is produced at Avery Island, requiring more than 3 years for fermentation of the salty pepper mash, which is mixed and steeped in vinegar before bottling. (**Bonus Question for next Geology final exam: “What does Tabasco Pepper Sauce have to do with the breakup of Pangaea and the origin of the Gulf of Mexico?”**).

**Weeks Island.** Weeks has a surface elevation 52 m (171 feet), and mining began in 1902. Since 1947, the Morton Salt Company has owned and operated the mine. In the late 1970’s, the U.S. Federal Government purchased the mine then operating for use in oil storage as part of the Strategic Petroleum Reserve (SPR). Filling of the mine began in 1980 and was completed in 1982 with 72 million barrels of oil (Morton Salt then opened a new mine in the dome). A sinkhole developed in the mine in 1994, the petroleum was evacuated, and the old mine was stabilized with brine.

**Cote Blanche.** Rising to a surface elevation of 30 m (97 feet) on the north shore of Cote Blanche Bay, Cote Blanche (Fr. “White Coast”) is the last of the Five Islands to be developed for salt mining, beginning in 1961 (but officially opening in 1965). The mine opened at a fairly deep level, at 403 m (1,322 feet) (the top of dome is at 640 feet depth), and subsequently moved up to a shallower level (342 m/1122 feet). Cote Blanche mine was considered, but not used, for the Strategic Petroleum Reserve. (The SPR is presently
stored in four coastal domes: two in Texas (Bryan Mound and Big Hill), and two in Louisiana (West Hackberry and Bayou Choctaw).

The nearly round island of Cote Blanche is covered by Late Pleistocene alluvial sediments (the Prairie Complex) and loess (the Peoria Loess), and Holocene coastal marsh. The Sangamonian-Wisconsinan age Prairie Complex directly overlies the top of the salt, indicating that the latest movement of the dome was in the Late Pleistocene. The southeast side of the island has modern wave-cut escarpments. Steeper slopes on the north side of the island is nearly coincident with a subsurface “overhang” structure along the northern flank of the otherwise elliptical dome Oil and gas have accumulated under the overhang (Figures 3-7). According to Halbouty (1979, p. 91):

Some wells penetrated the top of the salt at less than 1,000 feet and drilled through more than 14,000 feet of salt before encountering Miocene sands. Other boreholes close to the scalloped flank of the salt plug have drilled in and out of the salt as many as three times to a depth of 8,000 feet.

**Belle Isle.** The southern-most of the 5 Islands, and accessible only by boat, Belle Isle rises to a surface elevation 24 m (48 feet). Salt was discovered here in 1896, but mining attempts were not very successful. Cargill Corporation opened a mine in 1961-2, but the mine had problems with trapped natural gas. In 1979, a gas explosion claimed the lives of 5 miners. Mining was discontinued in 1983. The mine was closed in 1984, and flooded with seawater in 1985.

Additionally, there are 19 salt domes in the Northern Louisiana Salt Basin (Figure 8), southeast of Shreveport, which have been variously exploited for salt, oil and gas, and caprock quarrying. The Winnfield Dome, for example, on US-84 between Winnfield and Natchitoches, has been mined not only for halite, but its caprock of anhydrite, calcite, gypsum, and other minerals (Spearing, 2007; Martinez, 1986).

**Overview of the Jurassic of the Northern Gulf of Mexico Basin**

The origin of the Gulf of Mexico Basin (a smaller ocean basin nearly surrounded by continental crust), and its relation to surrounding terranes in the Caribbean and South America, remain difficult geologic problems. But the opening the Gulf was certainly related to the initial, Triassic-Jurassic rifting of the North American continent (Laurentia) from the Pangean supercontinent. Crustal thinning during the continent-to-continent divergence produced several rift basins (grabens), transform
Figure 3—Google Earth image of Cote Blanche Island, showing Intracoastal Waterway (top), Cote Blanche Road (leading to the mine at lower left), and waterway connecting the mine area to the Intracoastal.

Figure 4—USGS Topographic map of Cote Blanche Island. Kemper and Marone Point 7.5 minute Quadrangles.

Figure 5—Cote Blanche Island Salt Dome showing the “overhang” morphology of the upper, and northern, part of the diapir (from Murray, 1961, p. 221).
Figure 6—Cote Blanche Island Salt Dome showing oil traps/accumulations created by stratal truncation in angular unconformity against the salt; and the protruding, "overhang" structure of the northern side of the diapir (depth scale in feet) (from Halbouty, 1979, p. 100).

Figure 7—Isometric block diagram of Cote Blanche Island Salt Dome, described as: "...a mature, cylindrical, elliptical stock with small size (15 km²), asymmetric overhang, tilted axis, and monoclinic symmetry. Data from 44 wells" (depth contour in feet below MSL) (from Jackson and Talbot, 1986, p. 308).
Figure 8—Salt Diapir Provinces of the Northern Gulf of Mexico Basin. Black areas are domes or dome fields (from Ewing, 1991).

boundaries, as well as oceanic crust, in the Gulf from the Late Triassic to the end of the Middle Jurassic (Callovian Stage). The early rifting of the Gulf Basin has been likened to the separation of the Saudi Peninsula from Africa and opening of the Red Sea Basin, in which more than 1000 meters of evaporites accumulated during the Middle Miocene (Bird et al., 2011; Nelson, 1991).

Like the well-known Triassic basins of the Atlantic Seaboard, the Triassic rift basins of the Gulf (such as the South Georgia Basin, which extends across much of southern Georgia and north Florida), were filled with continental siliciclastics (“red beds”) and intrusive volcanics. These basal sediments of the Gulf Basin have been referred to the Eagle Mills Formation. But by the mid-Jurassic, extensive evaporite deposits began to fill and cover the rifted terrains. The salts thickened, presumably as the distended continental crust cooled, subsided, and accommodated thicker accumulations. Overlying the Eagle Mills in the northern Gulf from Texas to the Florida panhandle, this
evaporite sequence includes the Werner Anhydrite (Werner Formation) and the Louann Salt. The Werner Formation occurs only in southern Arkansas, northern Louisiana, and adjacent areas of east Texas and Mississippi. It consists of anhydrite beds and conglomeratic, siliciclastic red beds. The Louann Salt is far more extensive. By the early Late Jurassic, eolian and fluvial-deltaic facies spread across the northern Gulf (Norphlet Formation), followed by fully transgressive conditions that flooded the Gulf for the entire Late Jurassic, with a variety of marine facies developing across the basin (Smackover, Haynesville, Cotton Valley formations) (Salvador 1991a, b) (Table 1).

Oil was discovered in Jurassic strata of the northern Gulf Basin, first in Arkansas (1936), then in Louisiana (1937), Texas (1944), Mississippi (1953), Alabama (1967), and finally the very productive Jay Field of northwest Florida (1970) (see Braunstein 1974a, b, for early summaries). Ventress et al. (1984) presents a collection of papers from the Third Annual Research Conference of the Gulf Coast Section of SEPM on the Jurassic of the Gulf Rim, which also highlights oil and gas production in the Jurassic.

Jurassic evaporite deposits in the Gulf are thick and extensive, but not uniformly distributed. Within the entire Gulf Basin, there are two major areas. A northern region extends from northeastern Mexico, north through Texas, and east across Louisiana, Mississippi, Alabama, and the Florida panhandle, reaching the continental shelf and slope of these northern Gulf states. Several distinctive salt basins with diapiric salt structures are found across inland areas from Texas to Mississippi. This northern salt is primarily referred to the Louann Salt. A southern salt region in the Gulf Basin includes part of the deep Gulf of Mexico (Sigsbee Plain), south to the Bay of Campeche; and into parts of Veracruz, Chiapas, and Tabasco, Mexico. This southern salt basin is usually referred to as the Campeche Salt Basin, and its salt deposits include the Isthmian Salt and the Challenger Salt (Salvador, 1991a).

On the continental shelf, the easternmost extent of the Louann Salt appears to be the DeSoto Canyon diapir province of the Florida shelf. Twenty four salt structures have been identified here, including the 70-km long anticlinal, Destin Dome (Ewing et al., 1991). Subsurface salt may extend further east under the abyssal plain, west of the Florida Escarpment.
<table>
<thead>
<tr>
<th>Period</th>
<th>Stage</th>
<th>Formations</th>
<th>Facies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Jurassic</td>
<td>Tithonian</td>
<td><em>Cotton Valley</em></td>
<td>silici-clastics,</td>
</tr>
<tr>
<td></td>
<td>Kimmeridgian</td>
<td><em>Buckner/Haynesville</em></td>
<td>carbonates</td>
</tr>
<tr>
<td></td>
<td>Oxfordian</td>
<td><em>Norphlet/Smackover</em></td>
<td></td>
</tr>
<tr>
<td>Middle Jurassic</td>
<td>Callovian</td>
<td><em>Werner/Louann</em></td>
<td>some silici-clastics/</td>
</tr>
<tr>
<td></td>
<td>Bathonian</td>
<td>- - - - - - - - - -</td>
<td>mostly</td>
</tr>
<tr>
<td></td>
<td>Bajocian</td>
<td>- - - - - - - - - -</td>
<td>mostly</td>
</tr>
<tr>
<td></td>
<td>Aalenian</td>
<td>- - - - - - - - - -</td>
<td>evaporites</td>
</tr>
<tr>
<td>Lower Jurassic</td>
<td>Toarcian</td>
<td>- - - - - - - - - -</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pliensbachian</td>
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<td>Sinemurian</td>
<td>- - - - - - - - - -</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hettangian</td>
<td><em>Eagle Mills</em></td>
<td>basaltis/diabase</td>
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<tr>
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<td>Rhaetian</td>
<td><em>Eagle Mills</em></td>
<td>rift basin</td>
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<tr>
<td></td>
<td>Norian</td>
<td><em>Eagle Mills</em></td>
<td>siliciclastics,</td>
</tr>
<tr>
<td></td>
<td>Carnian</td>
<td><em>Eagle Mills</em></td>
<td>red beds</td>
</tr>
</tbody>
</table>

*Table 1*—Generalized Triassic-Jurassic stratigraphy of the northern Gulf of Mexico Basin (this sequence rests unconformably on Paleozoic basement)

**Geology and Mineralogy of the Louann Salt**

The Louann Salt formational name was proposed by the Shreveport Geological Society and Ralph Imlay (Imlay, 1940) for a section of rock salt between 6631-7488 feet in the Gulf Refining Co. #49 Louis Werner Saw Mill Company well, drilled in the Louann District of Union County, Arkansas (although stratigraphic and facies associations of the salt were misinterpreted at the time; Dockery and Thompson, 2016, p. 111).

Although the Louann was once suspected as Permian in age, the discovery of Triassic plant fossils and palynomorphs in the underlying Eagle Mills Formation make a Permian age for the Louann Salt all but impossible. Sparse and poorly preserved palynomorphs of mid-late Jurassic age have been reported in the Louann from samples in calcite caprock of the Challenger Salt Dome in the Sigsbee Knolls area. Another
poorly-preserved assemblage of 24 palynomorph species (including gingkos and cycads) has been recovered from five salt domes in east Texas and Louisiana, and assigned to the Late Triassic to Early Jurassic (Jux, 1961). The siliciclastic (and largely eolian) Norphlet Formation overlies the Louann, but is unfossiliferous. But the Smackover Formation, which overlies the Norphlet, contains Late Jurassic (early-middle Oxfordian) ammonites (Imlay and Herman, 1984). Based on stratigraphic relations, Bishop (1967) placed the Louann in the Lower to Middle Jurassic. And Imlay (1940) assigned the Louann Salt to the late Callovian (late Middle Jurassic) to mid-Oxfordian (early Late Jurassic) stages (see Lindberg, 1988).

Thicknesses of the Louann Salt are difficult to estimate. The base of the rock salt is rarely encountered, and most of the formation is affected by diapiric flow and intrusion, which has severely altered the original, “mother salt” bed. Estimates range from 1000 meters in the East Texas and Northern Louisiana salt basins, 1200 to 1500 meters for the Mississippi salt basin and coastal belt from southeast Texas to southern Louisiana (this would include the Cote Blanche area), and up to 3000-4000 meters in the Texas-Louisiana continental slope area. Up to 2000 meters of rock salt may be in the southern area in the Gulf of Campeche.

The stratigraphic position of the “mother salt” layer of the Louann is presently as much as 18 km deep (60,000 feet; 11.2 miles), although it is assumed that no salt is left at that level (having long since been mobilized and evacuated in concert with sedimentation), and no salt was actually that deep (the original position having subsided with sediment loading) (Kupfer et al. 1995).

The Louann Salt is composed primarily of medium- to coarsely-crystalline, translucent light-medium gray, to opaque white, halite (up to ~98%), with lesser anhydrite (up to 10%), and minor sylvite. The darker gray bands of halite are generally richer in anhydrite (Kupfer et al., 1995). Pyrite, quartz, and dolomite occur in trace amounts. Carnalite (KMgCl$_3$·6H$_2$O) and various Borate Group minerals have also been reported form the Louann (Gann et al., 1987; Dockery and Thompson, 2016). On average, halite crystals are between 5-15 mm (generally 0.5 to 1cm) in length, but some are larger (“pegmatitic salt”). Halite crystals are usually interlocked, equigranular, and slightly elongated. Recrystallization is common. Larger crystals are usually associated with moisture, bubble-like inclusions of methane gas, or clastic sediment. A common rock salt texture at Cote Blanche (but rare in the other Five Island Domes) is poikiloblastic salt (a descriptor normally used in metamorphic rocks), in which small salt crystals are
embedded in larger crystals (metacrysts). The anhydrite (CaSO$_4$) occurs as small, disseminated, euhedral crystals. Sylvite (KCl/“potash”) is typically red or pink color. Some salt contains interstitial brines (connate water, trapped in the salt during its formation) which evaporate upon exposure, leaving residual iron oxide stains (limonite), coloring the salt yellow or red (and not to be confused with the pink-red color of sylvite). Halite stalactites may form in areas where the brines drip (Kupfer et al., 1995).

Salt at Cote Blanche and other domes is typically layered, and although ductile flow and recrystallization are common, the prominent layering is still thought to be primary stratigraphic bedding. Layers range from 1-25 cm in thickness, with interbedded lighter and darker layers (white, light and dark gray, tan, and black). Darker layers are generally thinner (1-5 cm), but thicker (1 m or more) dark beds are occasionally found. Darker layers may contain 2-4% anhydrite, clay particles or other impurities, or may simply be darker due to the internal refraction/reflection of light by the translucent halite. Some beds display a chemical grading, from darker (anhydrite-rich) to white salt. Folding is common and vertical layers may be isoclinaly folded around vertical axes. Ceilings display a variety of folding complications, and several generations of folding have been recognized. All folding is obviously related to diapiric intrusion, with both folds and bedding in nearly vertical orientation (75-90°) (Figure 9). The appearance of folding at Cote Blanche and the other 5 Island Domes has been likened to pulling the center of a handkerchief through a small ring, which would result in numerous, radial, vertically-plunging, “drape folds” (Kupfer et al., 1995). At Cote Blanche, there appears to be dominant fold trend, described as a “vertical, elliptical cylinder, open to the northwest.” The limbs of the fold are broader and more open on the north side of the mine, but converge toward the south side (near the fold axis) (Figure 10) (Molinda, 1988).

More than 50 varieties of salt can be extracted from seawater by evaporation (MacIntyre, 1970), and there is no simple evaporitic sequence. Slight variations in initial brine composition or concentrations can yield many combinations in mineral evaporite phases (Table 2). However, evaporitic concentration (with regular replenishment) of normal marine seawater is necessary, so some type of basin restriction (i.e., restriction of water exchange/circulation with the larger ocean) is required to accumulate marine evaporites such as the Louann Salt. The early Gulf of Mexico Basin was just such a setting. The Louann must have precipitated from restricted, hypersaline waters entering the proto-Gulf of Mexico intermittently from embayments, straits, or channels.
connecting the Gulf to Panthalassic (Pacific) waters through what is now central Mexico (the Atlantic Ocean, as such, being essentially non-existent at this time; Salvador, 1991a).

Most modern evaporites are found in arid, coastal, supratidal settings, as in the carbonate mud flats (sabkhas) of the Middle East. But many ancient evaporite deposits, including the Louann Salt, are very thick and extensive (“saline giants”), with no modern counterpart facies. Marine basin models of evaporite precipitation are necessary to account for them. If, for example, a given volume of seawater is allowed to evaporate, but the original volume is continually replenished with normal marine seawater, the brine can become sufficiently concentrated to precipitate halite and other evaporite minerals. The formation of saline giants in the past may have required circumstances similar to this (Kendall, 2010).

<table>
<thead>
<tr>
<th>Evaporite Mineral</th>
<th>Hardness</th>
<th>S.G</th>
<th>Required concentration of seawater (34.7‰ salinity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaSO₄ · 2H₂O (gypsum)</td>
<td>2.0</td>
<td>2.32</td>
<td>3.8x</td>
</tr>
<tr>
<td>CaSO₄ (anhydrite)</td>
<td>3.5</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>NaCl (halite)</td>
<td>2.5</td>
<td>2.16</td>
<td>10.6x</td>
</tr>
<tr>
<td>NaSO₄ · 10H₂O (glauberite)</td>
<td>2.5-3.0</td>
<td>2.81</td>
<td></td>
</tr>
<tr>
<td>MgSO₄ · 7H₂O (epsomite)</td>
<td>2.0</td>
<td>1.67</td>
<td>70x</td>
</tr>
<tr>
<td>KMgCl₃ · 6H₂O (carnalite)</td>
<td>2.5</td>
<td>1.60</td>
<td></td>
</tr>
<tr>
<td>KCl (sylvite/“potash”)</td>
<td>2.5</td>
<td>1.99</td>
<td>90x</td>
</tr>
</tbody>
</table>

Table 2—Some common evaporite minerals (with hardness and Specific Gravity) and the concentration of normal seawater (by evaporation) necessary for their precipitation.
Figure 9 — Illustration of Jefferson Island dome, showing internal flow and folding (figure 5.37 of Murray, 1961).
Figure 10—Structure map of Cote Blanche salt stock, showing generalized bedding plane trends and fold axis logic map of Jefferson Island dome (figure 10 of Molinda, 1988).

Salt Diapirism in the Northern Gulf of Mexico Basin

The literature on Gulf Coast salt structures is enormous. Some of the older compilations include Murray (1961b), Bouma et al. (1978), Halbouty (1979), and chapters in Salvador (1991). More recent summaries can be found in Rowan (2006), Jackson et al. (2008), Buster and Holmes (2011), Hudec and Jackson (2011), Alsop et al. (2012), and Jackson and Hudec (2016).

The low density of most evaporite minerals make them susceptible to ductile strain under relatively low compressive stress. Halite, by far the most abundant of Gulf Basin salts (comprising 90-98% of evaporite deposits), has a density of 2.164 g/cc. Usually, impurities (such as anhydrite, with a SG of 2.960 g/cc) make most halite slightly denser on average (e.g., 2.2 g/cc, if containing 5% anhydrite). The viscosity of halite decreases with increasing temperature, and halite is a good heat conductor, making ductile flow with burial almost inevitable. The driving forces of salt mobilization (halokinesis) are
gravitational, and include surface slope, sediment loading, and buoyancy differences between denser sediments and the underlying salt. Vertical movement of salt under such stress typically results in piercement salt structures (domes) (Figure 11). Preexisting or syn-deformational faults are commonly associated with salt structures (Nelson, 1991). Indeed, perhaps most of the abundant growth faults (listric faults or “down-to-the basin” faults), so common in the Gulf, are related to salt mobilization (Gallaway, 2011).

The variety of structures that can result from salt mobilization is amazing, and is in some ways analogous to intrusive igneous bodies. Original, tabular salt lithosomes may be transformed into anticlines, pillows, walls, rollers, stocks, nappes, massifs, detached sheets (which, on the continental slope may coalesce to form larger, “allochtons”), and a variety of piercement (diapiric) forms (salt domes), to name just a few (Jackson and Talbot, 1986; Figure 12, 13, 14). And internal flow and folding structures develop within the larger intrusive bodies. Salt mobilization may result in salt-withdrawal basins in the area of salt evacuation. Or, doming may result in radiating, vertical fault systems, creating keystone grabens over the domes (Nelson, 1991). As salt domes or walls move and even evacuate their former locations, adjacent, deformed sedimentary strata may collapse into the area once occupied by the salt, creating a peculiar structural unconformity called a salt weld. In some cases, flowing salt may reach the surface and flow as salt glaciers on the ocean floor or even on land (if conditions are sufficiently dry). As domes approach the surface, overhang structures (as seen at Cote Blanche; Figures 5-7) may develop. This common phenomenon may result from a buoyancy equilibrium that is reached between the rising salt and the thinning (and therefore less dense) overlying sediments (Nelson, 1991).

Xenoliths have sometimes been encountered in salt domes. Duex and Lock (1992) describe a 18-inch block of altered ultramafic porphyry (pyroxene-hornblende peridotite) from the 1000-foot level in the Weeks Island mine, possibly of Cretaceous age or pre-Jurassic age. Locke and Duex (1996) also describe a serpentinite (meta-peridotite) xenolith from Weeks Island mine. Although igneous xenoliths have not been reported at Cote Blanche, various other inclusion are common, and include sand (stringers and pods), black clay balls, and marls. All are usually brecciated (angular), and most are thought to be secondary inclusions from salt mobilization. Paine et al. (1965) report Oligocene foraminifera from sand samples collected in Belle Island Dome, with a probable displacement of 7 km (22,000 ft.). Continuous sand beds are very useful in mapping the otherwise complex folded structure of the salt (Molinda, 1988).
Salt domes have been the subject of intense interest since the surprising (at the time) 1901 discovery of oil associated with the Spindletop Dome, located near Beaumont, Texas. More than 90% of Gulf Coast salt domes are associated with oil or gas, which is commonly trapped in folded/faulted sandstone against the impervious salt. Many Gulf Basin domes are in distinct salt diapir provinces, each with similar styles of salt structures (Ewing, 1991). These may be related to salt deposition in Jurassic sub-basins that formed by crustal thinning during the opening of the Gulf (e.g., horst and graben structures), but deep sediment burial and salt movement may have obscured the effects of any primary basins.

Many salt domes are capped by relatively insoluble and variable deposits of calcite, gypsum, anhydrite, and sulfur, called caprock. These diagenetic minerals form as meteoric waters dissolve the native halite and gypsum of the dome, leaving various diagenetic residues. Caprock minerals are highly variable and internally gradational, but ideally consist of an upper calcite zone, a middle transitional zone of gypsum and sulfur, and a lower anhydrite zone. Several trace minerals may also be present. In some cases, the breakdown of petroleum, gypsum, and anhydrite by anaerobic (sulfur-reducing) bacteria can release sulfur and sulfide, creating sulfide minerals. Groundwater then oxidized by bacteria and/or groundwater to elemental sulfur.

Caprock sulfur can be sufficiently abundant to be mined, and was so as early as 1894 in southwestern Louisiana, with the first underwater mine in operation by 1932 in Lake Peigneur over Jefferson Island Dome. The sulfur was melted using steam and compressed air. The amber-to-brown colored fluid was then flowed through wells to the surface for cooling into solid yellow blocks of sulfur (a technique is called the Frasch Method). According to Ellison (1991), 36 salt dome caps have been mined for sulfur since the 1894 mine (29 in the U.S. and 8 in Mexico), but few are presently in operation. Caprock is not well developed at Cote Blanche, perhaps because the top of the dome was not brought into contact with groundwater, or has not long been in meteoric waters (Murray, 1961, p. 236).
Figure 11 — Three phases of salt dome growth (figure 2 of Kupfer, 1986).

Figure 12 — Types of salt structures (figure 1 of Jackson and Talbot, 1986, p. 306).
Figure 13—Generalized cross-section of the northern Gulf of Mexico margin from central Texas through the Texas-Louisiana shelf and slope, onto the Sigsbee (abyssal) Plain. Salt domes in black. Compare to Figure 14 below for a more recent conception of salt mobilization (figure 2 of Martin, 1977).

Figure 14—Schematic cross-section across the Louisiana continental shelf and slope, illustrating some of the complexity of salt diapirism. The “mother salt’ has evacuated its initial position at the base of the stratigraphic sequence. Compare to older conception of salt dome development in Figure 13 above (from Hutchinson, et al., 2011).
Salt Domes and Coral Reefs in the Northern Gulf of Mexico Basin

Salt domes are frequently associated with reef development of various types (algal, sponge, coral). If the dome penetrates to sufficiently shallow depths in tropical to subtropical waters, the dome may raise the seafloor into shallow, warm, and non-turbid waters so as to provide a substrate for reef growth of various types. There are many examples in the Gulf of Mexico Basin. The modern Flower Garden Banks on the outer continental shelf of Texas-Louisiana, is a National Marine Sanctuary and hosts the northern-most coral reefs in the Gulf of Mexico. The East and West Flower Garden Banks host lush coral growth (but lower diversity than tropical, Caribbean reefs) over two salt domes. Nearby banks, such as Stetson Bank, also host limited coral-algal buildups (Rezak et al., 1990, 1985). Another modern coral reef in the northern Gulf is the Middle Ground Reef of the central Florida continental shelf, but this reef developed over paleokarst limestone ridges, not salt structures. Cote Blanche Dome is not associated with any reef development because it was uplifted in the Late Pleistocene, when the overlying area would have been neither in neither tropical water nor a shallow marine setting.

The Oligocene Epoch was a time of extensive salt dome intrusion and associated coral reef development in Texas and Louisiana. The well-known Heterostegina Zone of the Late Oligocene, petroleum-producing Anahuac Formation, is typically a calcareous shale. But around salt domes and other topographic highs it grades into a coral reef facies (the “Het Lime”), and is exposed in outcrop at Damon Mound Dome (Brazoria County, Texas). Reefal facies are also encountered in the Het Zone of the Texas subsurface over Boling Dome (Wharton-Fort Bend counties), Nash Dome (Fort Bend County), West Columbia Dome (Brazoria County), Barbers Hill Dome (Chambers County), Stratton Ridge Dome (Brazoria County), Fannett Dome (Jefferson County), and Sugarland Dome (Fort Bend County). In Louisiana, Mississippi, and Mobile Bay, Alabama, the Heterostegina Zone reef facies forms a rimmed carbonate shelf (Krutak and Beron, 1990, 1993).

The Paleocene was similarly a time of reef growth associated with salt diapirism in the Gulf Basin. The Late Paleocene Salt Mountain Limestone is primarily a subsurface unit reported from Mississippi to Florida, but it is exposed in Clarke County, Alabama, where the Klepac Salt dome has raised it to the surface along the Jackson Fault. A coral-algal-sponge reef and associated fossiliferous limestone well-exposed here in outcrop (summarized in Bryan, 1997). And in the La Popa Basin of Nuevo Leon, northeastern Mexico, some of the best-exposed salt diapirs in the world are associated with
Paleocene reefs. Here, six carbonate buildups (called lentils) are within the Potrerillos Formation, and developed syn-deformationally with the intrusion of the El Papalote Salt Diapir (evaporites of the Late Jurassic Minas Viejas Formation), which is exposed in outcrop in this desert climate. The lowest lentil is of Late Cretaceous (Maastrichtian) age (and includes rudist bivalves), and the upper 5 lentils are Paleocene in age (Figure 15). Most notable is the Late Paleocene La Popa Lentil, a limestone massif and coral-algal-sponge reef, much like the Salt Mountain Limestone of Alabama (Giles and Lawton, 2000).

In southern Mississippi, a distinct algal facies (with some coral) developed in the Jackson Gas Rock, a Late Cretaceous (Maastrichtian), petroleum-producing, chalky limestone that developed over the Jackson Dome, one of several igneous intrusions in the northern Gulf (Dockery and Thompson, 2016).

Mining and Economic Geology at Cote Blanche
There are three vertical shafts into the Cote Blanche mine, each designated for specific functions (personnel and emergency, personnel and equipment, and production hoisting). Mining is presently at the 1,500 foot level, with future projections at 1,300, 1,600 and 1,700 feet. Mining strategy entails the use of a checkerboard-like, “room and pillar” system (Figure 16). The “rooms” are the mined/open areas, and the “pillars” are square blocks of salt left for support. Rooms are generally 15-30 meters (50-100 ft.) wide and 7.5 meters (25 ft.) high. Pillars are 30-60 meters (100-200 ft.) to a side. As an active salt face is mined, it is first horizontally undercut, at floor level, to keep the floor flat after blasting. The face is drilled and blasted (Figure 17). The ceiling is called the “roof” and the side walls the “ribs”. After blasting, both roof and ribs must be “scaled”, a process of removing loose hanging slabs of salt. Scaling is periodically necessary in older parts of the mine as expansion joints (fractures) develop in response to stress and ductile strain (flow) into the opened area. Faulting is not common at Cote Blanche. The dome is, however, thought to consist of two, possibly three, major salt spines where anomalous salt would be expected to be found. Mining does not take place in these areas.

Additional rooms are created by mining a ramp 50 feet further down, then vertical holes are shot downward from the original floor, a process called benching. At this point, the roof becomes too high (75 feet) to adequately scale, and the rooms may be closed to further mining. New levels are usually planned at 60 m (200 ft.) depth intervals, and are connected by ramps. All equipment in the mine, including trucks and
heavy equipment, must be brought through the main mine shaft. This requires disassembly (even cutting), then reassembly in the mine (summarized from Kupfer, et al., 1995). Mined salt is trucked to conveyor belts, lifted to the surface, placed directly on barges, and shipped through the Intra-Coastal Waterway and Mississippi River to northern states primarily for use in de-icing roads. Some salt is used in water-softeners, animal feeds, and other applications (see Appendices for additional information provided by Compass Minerals, and see the Compass Minerals website at: [http://www.compassminerals.com/](http://www.compassminerals.com/)).

**Figure 15**—Geologic map of the El Papalote Diapir, La Popa Basin, Nuevo Leon, Mexico. Lentils are reef facies associated with salt dome intrusion (dark blue, Late Cretaceous; light blue, Paleocene; salt diaper is Jm) (figure 1.1 of Giles and Lawton, 2000).
Figure 16—Geologic map of Cote Blanche mine at the 1,365-foot level (figure 6 of Molinda, 1988).
**Salt Life — Field Notes for the Descent**

The Louann Salt is nowhere exposed in outcrop. To sample one of the most important rock formations in the Gulf Coast Basin (with regard to basin history and economic geology) is an exceptionally unique field opportunity for SEGS geologists. Cote Blanche Salt Dome has been mined since the 1960’s, but has only rarely been accessible to geologists. Participants will collect beautiful halite crystals (NaCl) of various sizes, textures, and color. The pink-red potassium salt, sylvite (KCl), is also present (but not abundant) at Cote Blanche, and we will hopefully be able to collect this potash mineral as well. Sulfur and petroleum residues may be seen on the rock salt in places.

Field trip participants will participate in a brief site hazard training (and must sign a U.S. Department of Labor Certificate of Training form), and will be supplied with lights, safety glasses, hard hats, and other safety equipment. You will also be required to wear a numbered brass tag (to record and identify all personnel in the mine at any given time). Entry into the mine requires a 2-minute vertical descent down a large mine shaft to approximately 1500 feet (more than ¼ - mile below sea level). SEGS members will be escorted by miners through the extensive mine in 4-wheel transport carts holding 4 or 5 people each.
Clothing and Field Equipment. Heavy field boots/steel-toed shoes are required, preferably shoes that include metatarsal protection. The mine gets warm (~90°F), but is obviously very dry. Long field pants are necessary. Shirts with at least short-sleeves are permitted (no tank tops). Long-sleeve T-shirts or field shirts are recommended. Even a flannel shirt is not uncomfortable in the mine. Field equipment should include rock hammer, chisels, and sample bags (larger Ziploc bags are very useful to protect salt samples from moisture/humidity when you return to the surface). Cell phones are not permitted in mine, and therefore cannot be used in the mine as a camera. It is not recommended that expensive or high-quality cameras be brought into the mine because of the high concentration of powdery salt dust. Old or disposable cameras are recommended, and have a Ziploc bag in which to keep it. In any case, a gas meter may be required in order to take any pictures, and mine personnel may insist that only a special group of us be designated to take photos during the trip (which we could all share later). So we may have to coordinate this, but maybe those of us with old “cheapie” cameras could step up and volunteer. Even eyeglasses may be adversely affected by the salt dust. So you may want to bring an old pair if possible (*Personal Note: I had pair of eyeglasses on which the protective coating was corroded in the mine. When I went to replace then, the optometrist asked me if my glasses had been recently exposed to salt! ~JRB). Standard field safety, geological good sense, and courtesy are expected in the mine. Do not proceed to sample any areas until directed by your guide, and stay very close to your group. You should never be out of site of the other participants. Heavy equipment will be nearby and in use. Enjoy the Cote Blanche experience!
References


Bishop, WF, 1967, Age of pre-Smackover formations, north Louisiana and south Arkansas. AAPG Bulletin 51(2):244-250.


Attached Appendices provided by Compass Minerals and Cote Blanche Mine:

Appendix I — Cote Blanche Fact Sheet

Appendix II — Welcome to Cote Blanche

Appendix III — Cote Blanche Mine Overview — Michael Nixon, Mine Engineer
COTE BLANCHE FACT SHEET

WHO WE ARE

- The Cote Blanche salt mine has operated since 1961 and is among the largest private employers in St. Mary Parish.
- It is located on Cote Blanche Island, which is approximately 1,000 acres. It is the youngest of the five “salt dome” islands in the area that rise 75 feet or more out of the surrounding marshes.
- The mine has more than 180 employees whose families live, work, play and go to school in St. Mary and Iberia parishes.
- The mine’s employees, vendors, suppliers and contractors contribute an estimated $2.7 million per year to the local economy.

WHAT WE MAKE

- Cote Blanche salt mine produces more than three million tons of rock salt per year. The salt is used primarily by governments and contractors for deicing public roads. It also is sold to manufacturers that make plastics, detergents, disinfectants and other important products.
- Cote Blanche salt mine is the largest producer of Louisiana’s three major salt mines.
- The salt mine produces nearly 15% of America’s highway deicing salt.

SAFE PLANT, SAFE DRIVERS

- Safety comes first at the Cote Blanche salt mine, with all employees participating in numerous trainings throughout the year to ensure positive safety performance.
- The Cote Blanche Mine rescue team claimed four awards from the 44th Annual Southern Mine Rescue Competition. The team earned the Dwight C. Bonin Memorial Award for finishing first in the Southern Salt Division. The members also picked up the Salt Institute Southern Regional Mine Rescue Association’s traveling trophy for first place in the overall Southern Salt Division. Finally, the team won first place in the smoke contest and finished third in the field competition.
- The rock salt produced at the mine is used to keep Americans safe as they travel through winter snow and ice. The mine’s salt is used on roadways in 18 states from Georgia to Minnesota.
HISTORY

- Geologists believe that 300 million years ago a narrow saltwater ocean covered what is now Texas, Louisiana and Mississippi. When the sea evaporated, it left behind a vast sheet of salt that then was covered by thousands of feet of sediment. Since the density of salt is generally less than that of surrounding material, the salt moved upward during geological shifts, forming domes. Thousands of years ago these upthrusts breached the surface marsh in several places. When more water turned the marsh into the Louisiana coast, the upthrusts became five islands – now named Cote Blanche, Avery, Weeks, Belle Isle and Jefferson.
- Inhabitants have gathered salt from brine springs along the Louisiana coast for centuries. The first salt mine in North America began in 1862, when workmen on nearby Avery Island enlarging brine springs to produce more salt for the Confederacy hit solid salt at a depth of 16 feet. The salt works were destroyed by Union forces the following year, but after the war, a mine shaft was sunk through 58 feet of a solid salt dome to a depth of 90 feet. Salt mining in the area has continued ever since.
- Although geologists were aware of the salt deposit at Cote Blanche Island due to oil exploration early in the 20th century, it wasn’t until 1961 that Carey Salt began excavation of the Cote Blanche salt mine. The mine became part of the Compass Minerals family in 1990.

HOW IT WORKS

- Cote Blanche Island miners work 1,500 feet underground – the equivalent of four football fields, end-to-end, and straight down. Miners cut into the rock salt face using specialized equipment, then drill holes into the face and use five tons or more of explosives per day to break the salt into small pieces. Front-end loaders and trucks load and haul the salt to equipment that crushes, screens and sorts the rock salt to the required sizes. Then the salt is hoisted to the surface and loaded onto barges for shipment.

CONTACT US

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For more information, visit www.CompassMinerals.com

KEY PERSONNEL

Don Brumm
VP Operations

Toyla Charles
Local Human Resources Representative

Jim Scialabba
Local EHS&S Representative
ABOUT COMPASS MINERALS

- The largest salt producer in North America and the U.K.
- A leading supplier of highway deicing products
- A key producer of high-quality salt for consumers and industry throughout North America
- The leading sulfate of potash specialty fertilizer producer in the Western Hemisphere
- Number one producer of dry dispersible powder micronutrients and phosphorus
- Provider of secure records management services in the U.K.
OUR VISION

To be the best **essential minerals** company delivering when and where it matters
At Compass Minerals, we have the ability to do something essential. Through the responsible transformation of the earth’s natural resources, we help keep people safe, feed the world and enrich lives. We embrace this responsibility with a passion for quality, consistency and reliability. What we do each and every day makes a real difference.
COMPASS MINERALS LOCATIONS

- Nine production locations
- Four packaging facilities
- Three sales offices
- Two storage facilities
ABOUT COTE BLANCHE

• The Cote Blanche salt mine has operated since 1961

• Our team is comprised of more than 180 people with an average tenure of 11 years

• Five employees with more than 40 years at Cote Blanche
  - Henry Lewis (50 years)
  - Danny Landry (48 years)
  - Irvin Boutte (48 years)
  - Wilbert Olivier (42 years)
  - Rickey Olivier (41 years)

• We produce more than three million tons of rock salt per year used primarily by governments and contractors for deicing public roads. It also is sold to manufacturers that make plastics, detergents, disinfectants and other important products.

• Cote Blanche salt mine is the largest producer of Louisiana’s three major salt mines.

• The salt mine produces nearly 15% of America’s highway deicing salt.
• Gumbo Cook-Off – sponsored by New Iberia Chamber of Commerce
  - Team employees compete against 100+ teams for the “Best Gumbo”

• United Way
  - More than 50% of our employees participate in the annual fundraising campaign

• Annual Charity Day
  - Donate $1 for every ton of salt mined in a day
  - Donations to the area’s two largest food banks, St. Mary Outreach in Morgan City, and Solomon House in New Iberia
THE COTE BLANCHE COMMUNITY

• Close cooperation with area mines
  - Mine rescue collaboration
  - Barge operations – best practice sharing
  - South Central District MSHA safety conference
  - Salt industry scales best management practice with MSHA participation

• Mine Rescue Team
  - Effective emergency preparedness with two mine rescue teams
  - Progressive improvement at mine rescue competitions
  - Added a second team this year after going with only one team for six years
  - New trailer purchased in 2015
BACKGROUND

• Cote Blanche Mine is operated by Compass Minerals
  - The largest salt producer in North America and the U.K.
  - A leading supplier of highway deicing products
  - The leading sulfate of potash specialty fertilizer producer in the Western Hemisphere
  - Number one producer of dry dispersible powder micronutrients and phosphorus
  - Provider of secure records management services in the U.K.

• Cote Blanche is a salt-producing mine in South Louisiana
  - Located around 50 miles South of Lafayette and 120 miles West of New Orleans

• The salt deposit is in salt dome form

• Around 500 diapirs exist in the region
  - Most accessible domes have been mined or are currently being mined
HISTORY

- Geological investigations date back to the early 1900s
- Mining has been carried out on the 1,100’ and 1,300’ levels
- Mining the 1,500’ level currently
- Future potential mining 1,300’ level extension, 1,600’ sub level and 1,700’ level
- Life of mine exceeds 50 years
GEOLOGICAL MECHANICS

- Salt is ductile and liable to flow
- The salt has intruded up through overlying rock
  - Uplifted from the main salt deposit c.5miles deep
  - Typically forms a column and expresses as a dome
    - Hydrocarbons can be sequestered and accumulate near the margin of the dome
GEOLOGICAL SETTING

- Salt (Halite, NaCl) is a sedimentary deposit

- Evaporation and deposition occurred during the Mesozoic era (c.250 – 65Ma)

- The Basal Louann Salt is several miles thick and is extensive
  - The basal salt is typically overlain with a subsequent sedimentary sequence to include limestone, marl, chalk, mudstone and sandstone and alluvium
    - These rocks are world renowned for containing oil with around 1.6mbpd produced from the Gulf of Mexico

- Salt, when in dome form, is also economically extractable by either conventional or solution mining
The salt is thought to have uplift in the Pleistocene era (ice age).

The top of the dome is between 350’ and 1,500’ from ground surface:
- Dome roof surface is uneven in nature
- Some overhang is thought to occur to the North/North East
LOCAL GEOLOGY – SPINES

• The salt diapir typically did not rise in a single simple mass
  - The salt invariably rose at different velocities
    ▪ This can create salt spines/salt spine complexes

• Where the salt spines meet, boundary shear zones are created
  - These are thought to play a part in anomalous areas within salt domes
  - This has not been encountered at Cote Blanche
GEOLOGY – FAULTING

• Faulting at Cote Blanche not seen locally

• Boundary shear zones between spines
  - External shear zone at edge of dome
  - Inter-slicing where the edge of the salt dome meets the country rock

• Sedimentary inclusions thought to increase towards the edge of the dome
  - Knowledge on dome limits critical to safe economic mining and dictates the mining plan
GEOLOGY – FEATURES

• The original sedimentary beds would have been horizontal in nature
  - The original beds have been upturned in the uplift
• Beds typically at angle c.75 degrees
  - This is characterized by the appearance of near vertical bedding
  - The dark bands are anhydrite (CaSO4)
    ▪ Even small chemical quantities of anhydrite can change the visual appearance of the salt
LOCAL GEOLOGY – EXPLORATION

• Local geology determination is through surface seismic, surface drilling and in seam seismic exploration

• Determination of mining boundaries is critical to safe economic extraction
  - Prescribed distances are adhered to for diapir roof distance
  - Mining does not continue towards potential geological features
MINE INFRASTRUCTURE

- Island accessed via ferry

- Mining currently at the 1,500’ level
  - 200’ is left between mining horizons

- Access via three shafts
  - #1 (8’ shaft) to 1,300’ level used for personnel and emergency
  - #2 (14’ shaft) to 1,500’ level for personnel, materials and under-slinging
  - #3 (16’ shaft) to 1,500’ level for production hoisting
MINE DESIGN

- Room and pillar operation
  - Development 30’, bench a further 45’
  - Total mined height 75’
  - Room width 50’
  - Room centers 150’
- Extraction ratio 56%
  - \[
  \frac{(150 \times 150) - (100 \times 100)}{(150 \times 150)}
  \]
- Rock mechanics allows for self-support
  - Some remedial spot bolting is used
MINE CYCLE

- Drill and undercut
- Charge and blast
- Load
- Haul
- Dump
- Scale
PROCESSING AND TRANSPORT

• All crushing carried out underground
  - Primary, secondary crushing

• Mill and screening plant
  - Separated into product piles (chemical, highway, medium, course, feed)

• Hoisted to surface using #3 (16’) shaft

• Either directly to barge (1,500t), surface stockpile or surge bins

• Quality tested in lab