# Blowouts in Domal Salt

R.L. Thoms and J.D. Martinez
*Institute for Environmental Studies, Louisiana State University, Baton Rouge, Louisiana 70803 USA*

**ABSTRACT**

"Blowouts" are known to occur in many U.S. Gulf Coast salt domes. A blowout refers to a moderately violent to violent ejection of salt, reportedly accompanied by release of gas, which produces a cavity in the salt. When blowouts occur in room and pillar salt mines they usually are precipitated by routine blasting of an advancing wall or face. The aftermath of a blowout is a cavity and a significant amount of granulated and small pieces of "crackle salt" which are ejected onto the mine floor. The cavity frequently is a vertically inclined, elongated opening into the mine ceiling, and is called a "chimney" by miners. Blowouts and their possible causes and significance relative to the increasingly important practice of storage in mined openings in salt domes are discussed in some detail.

## INTRODUCTION

Blowouts are a relatively well known phenomenon in room and pillar mines of U.S. Gulf Coast salt domes (Cameron, 1949; Belchic, 1960; Hoy and O'Neil, 1960; Hoy et al., 1962; Obert and Duvall, 1967; Kupfer, 1976; Martinez, et al., 1977). They also have been noted in potash mines (Obert and Duvall, 1967; and Hoy et al., 1962).

All of these authors noted the presence of gas in association with blowouts in salt. In fact, blowouts sometimes are referred to as "gas outbursts", particularly by investigators with previous experience in coal mining (Obert and Duvall, 1967). The type of driving energy associated with blowouts also has been speculated to be strain energy associated with overburden loading. Further, it has been suggested that a blowout is simply the release of a passive pocket of loose salt existing in the salt stock prior to exposure by mining.

Each of these concepts will be considered in turn in reverse order. Then a mechanism for blowouts will be proposed which will employ the more commonly accepted gas driven release concept as the dominating feature for U.S. Gulf Coast salt domes in particular.

## POSSIBLE MECHANISMS FOR BLOWOUTS

Blowouts in salt may be classified as a special type of rock burst in the sense that a violent expulsion of rock is involved which can result in an engineering problem (Obert and Duvall, p. 582). Further, blowouts may be classified as a megascopic phenomenon in salt domes since they are associated with large scale geologic trends in the salt stock. This is in contrast to more localized macroscopic features which can be partially analyzed for mechanical behavior by testing of laboratory or bench scale rock salt specimens.

The possibility that blowouts in salt domes are the result of a simple release of a passive "pocket" of loose salt in the ceiling can be readily dismissed by noting an observation by Cameron (1949) and a later observation by the same person, now H. Cameron Belchic (1960) in her description of a blowout in the Winnfield salt dome in north central Louisiana: "Such a pocket was tapped during the course of mining operations, resulting in the violent release of dry gas under high pressure, which filled the room with fine salt, blown down from a pocket over 100 feet above the roof of the mine. This pressure surge forced the belt off the ventilating fan at the surface. In other instances gas has heaved the floor up with great force."

Although blowouts may be classified as rock bursts, they are unlike more conventional bursts driven by strain energy associated with geostatic stresses due to overburden alone. Obert and Duvall (1967) have noted that this type of rock burst is seldom encountered at a depth of less than 2,000 feet, unless large tectonic forces are present that act in a direction approximately parallel to the surface. Further, the mechanical characteristics of the rock associated with such bursts can be described as "hard, strong, and brittle."

The burst described by Cameron (1949, 1960) and others (Hoy, et al., 1962) occurred in a mine at a depth of 811 feet below surface level. Moreover, the salt domes of the U.S. Gulf Coast are generally considered to be of buoyancy driven genesis (Atwater and Forman, 1959; Kupfer, 1976) as contrasted, for example, to tectonic affected salt diapers in Iran. Obert (1964), measured the stress state in a Gulf Coast salt dome (probably Winnfield) and characterized it as hydrostatic in character and of a magnitude due to overburden. Thus geostatic stresses due either to overburden or tectonic forces acting parallel to the surface were inadequate to act as a sole source for the amount of strain energy necessary to cause the Winnfield blowout described by Cameron.

The mechanical properties of rock salt can be described as relatively weak and time dependent, i.e., viscoplastic. Thus, rock salt is a poor rock for maintaining a relatively high strain energy density as compared to the "hard, strong, and brittle" rocks prone to conventional rock bursts (Obert and Duvall, 1967, p. 584). To further accentuate the relative independence of blowouts from the mechanical properties of evaporite rocks in general, it may be recalled here that blowouts occur also in potash, an even weaker material than rock salt.

The preceding discussion strongly implies that the dominating energy source for blowouts in the U.S. Gulf Coast salt domes is entrapped gas. This obvious conclusion has been generally accepted in the Gulf Coast region for a considerable length of time. Only recently has it become subject to review; and then, primarily because it potentially affects the increasingly important practice of storage in salt dome mines and caverns.

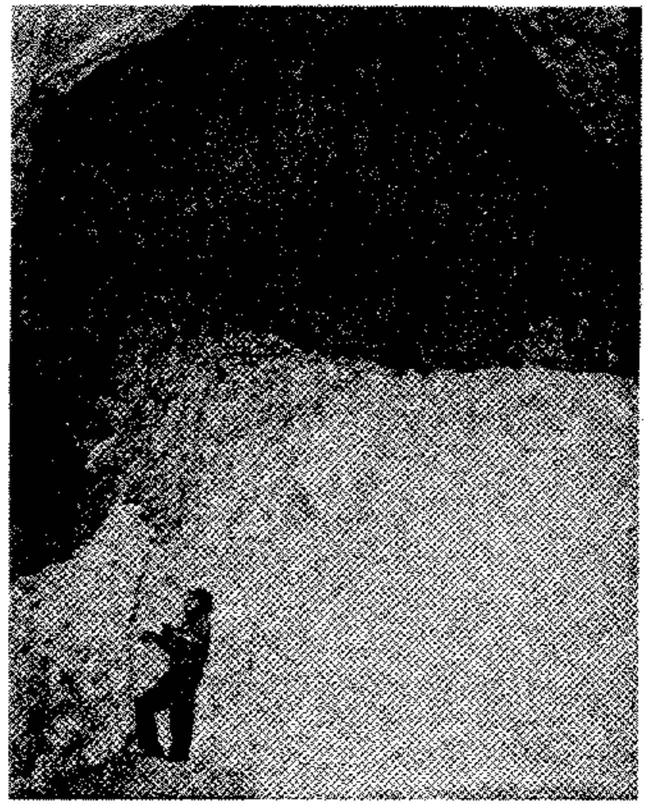

**Figure 1.** Blowout in Winnfield Salt mine. After Hoy and O'Neill (1960).

## BLOWOUTS AS GAS OUTBURSTS

Apparently considerable amounts of gas were encountered in the Winnfield salt dome mine (Cameron, 1960). It also was subject to considerable moisture infiltration. In 1965 it was flooded due to a leak that progressively enlarged (Martinez, et al., 1976). According to W.H. Cameron, former mine manager, the leak that flooded the mine was not associated with a blowout (personal communication, 1977), and thus it will not be discussed further herein.

The presence of gas in mines is not a favorite subject around active salt mines. Recently, even small blowouts in salt mines have caused considerable additional work for operators because of increased interest in their occurrence by nonmining personnel.

The Winnfield mine obviously is inactive; and further, a relatively complete body of literature exists on this mine because of the previously cited works of Cameron (Belchic) and data generated by **Project Cowboy,** carried out by the Atomic Energy Commission from December, 1959, to March, 1960. (Reports on **Project Cowboy** were generously loaned to the authors by Mr. W.H. Cameron, 1977–78). Therefore, the Winnfield mine will be used as the primary example to discuss blowouts as a dominantly gas outburst feature in Gulf Coast salt domes.

Figure 1 depicts a relatively large blowout in the Winnfield salt dome (after Hoy and O'Neil, 1960). It is unlikely that this is the same blowout referred to by Cameron (1949), since almost a decade had elapsed between reportings. Hoy et al. (1962) quoting W.H. Cameron, reported a volume of salt of 150 × 50 × 20 feet ejected onto the floor from one such blowout. A man was said to be overcome by the released gas at the time of the blowout, and typically, the ejected salt "crackled" underfoot when walked upon.

The crackling sound associated with salt ejected from a blowout can be attributed to release of entrapped gas as the salt is strained or heated. In Winnfield the gas most frequently encountered was $CO_2$ (Cameron 1949, Belchic 1960), although $H_2S$ reportedly was also encountered at one location (W.H. Cameron, personal communication, 1977).

The character of gas in blowouts generally varies between salt deposits and even between sites within one salt dome. Hoy et al. (1962) reported the results of a gas analysis of some Winnfield crackle salt and noted the main constituent to be $CO_2$ (46.9%) with lesser amounts of $H_2O$ (17.3%), $N_2$ (18.4%) and other gases: CO (4.8%), $O_2$ (4.4%), $SO_2$ (3.7%), $H_2$ (1.8%), $CH_4$ (1.5%), A (0.4%), $S_2H_2$ (0.4%), other hydrocarbons (0.4%). They also noted that methane gas had been reported in potash mine blowouts. Further, Obert and Duvall (p. 609, 1967) state: "The gas in evaporite deposits include carbon dioxide, nitrogen, and methane. In some instances, the methane content is high enough for the product to be explosive."

Figure 2 is a "features" map of the Winnfield salt mine. Belchic (Cameron) (1949, 1960) and Hoy et al. (1962) note that the blowouts depicted schematically in Figure 2 occurred near the edges of the dome, although gas and moisture were distributed generally in lesser amounts throughout the dome. The more frequent occurrence of blowouts near the edge of the dome can be attributed to several possibilities: 1) the entrapment of gas producing materials into the peripheral gouge zone and surface of the salt stock at some stage in its diapiric evolution, 2) high gas content in original salt beds now forming the periphery of the stock, and 3) coupling of gas pressured zones and geostatic stress concentrations at the mine and salt stock boundaries.

Kupfer (1976) had discussed the "spines" of movement

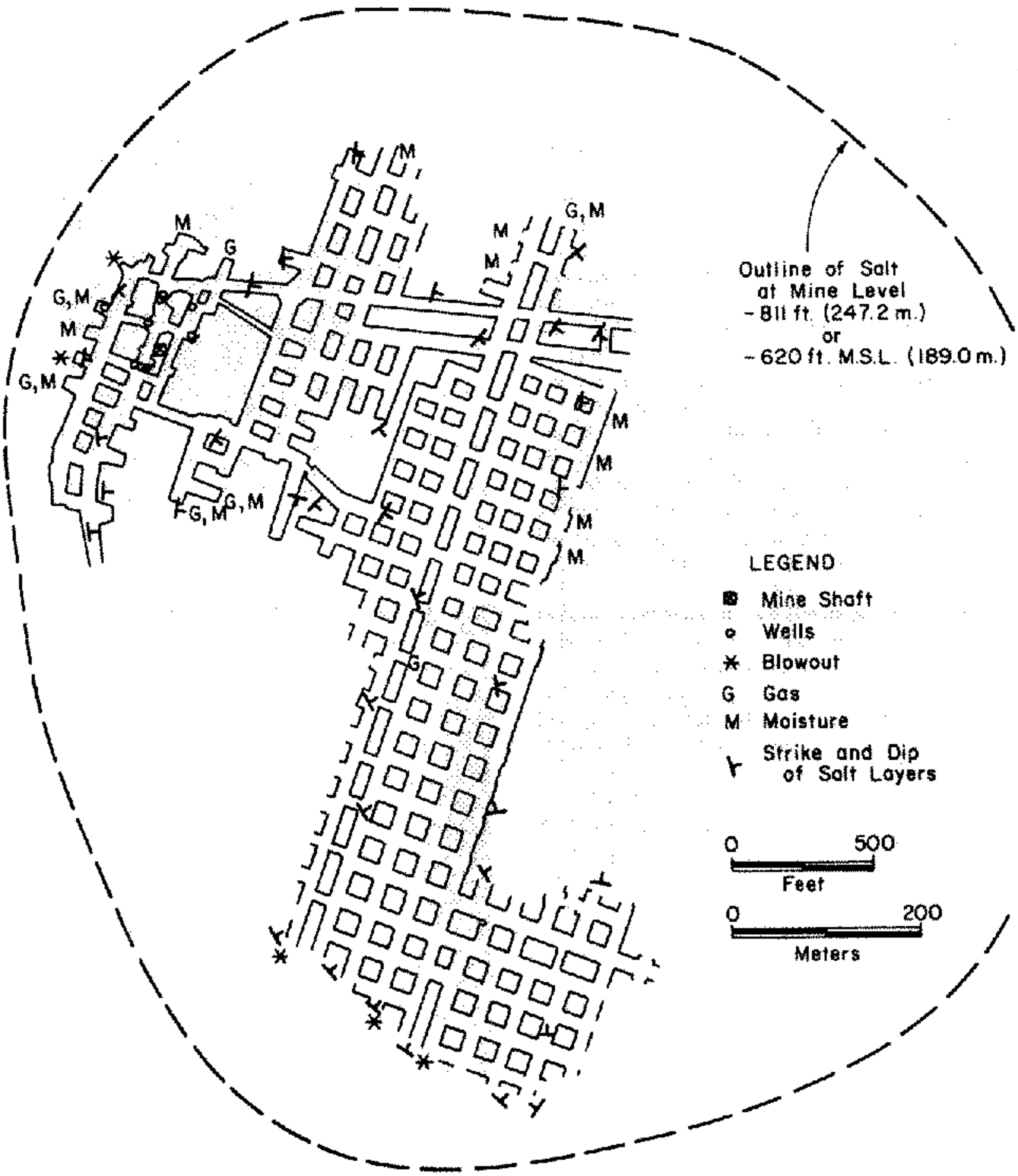


**Figure 2.** Features in the Winnfield Salt Dome mine (flooded, 1965). Modified from Cameron (1949), Shreveport Geological Society Guidebook (1960), and Hoy, Foose, and O'Neill (1962).

concept relative to the occurrence of unusual features within the five currently active south Louisiana salt mines. He has noted unusual features appear to be located in or near suspected "shear zones" within the salt stocks, and includes among such features "natural-gas seeps, oil pockets, small gas-induced explosions, increased abundance of impurities and a tendency for the salt to exfoliate". In his discussion, Kupfer notes shear zones which separate spines of movement, where the term "spines" refers to possible salt movement features associated with a series of "unit" salt cylinders moving at different speeds within the total salt stock. Kupfer also suggests that spines of all sizes can occur such that for an extreme example of large spines, the salt stock can be identified possibly as having only two major units.

As mapped by Hoy et al. (1962), the Winnfield salt stock does not indicate movement of large spines because if a single unit cylinder of salt stock were to flow upward, the layering in that unit should dip inward toward the approximate center of the cylinder. This inward dip is indicated, for example, in models of diapirs in Ramberg (1968) and Dixon (1975). Hoy et al. (1962) also note that the salt layering generally dips inward to the center of the Winnfield salt stock from almost all points within the mine. They interpret this as the upward and partly outward movement of the salt during diapiric emplacement controlled the internal salt structure of the stock. Figure 2 depicts the dip of the salt layering at a representative number of locations within the mine as mapped by Hoy et al. It may be noted that internal shear zones between major spines are not evident from this map.

Gas and moisture apparently were noted in many areas of the mine (Fig. 2), in addition to the blowout zones (Cameron, 1949). In newly opened rooms moisture and gas escaped from the floor, walls, and ceiling, but gradually tapered off. Much of the gas was detected seeping upward from the floor through the more permeable (?) anhydrite "bands" (5 to 25% anhydrite, Cameron, 1960). (Hoy et al. (1962) refer to "salt layers which are presumedly more permeable.") Occasionally masses containing over 80% anhydrite occurred in slabs up to eighteen inches in length. The anhydrite banding was generally steeply inclined throughout the mine, which reflected the diapiric upward flowing evolution of the salt stock in its "mature" stage. Figure 3 depicts the character of the anhydrite banding in the Winnfield mine.

Belchic (1960) noted that "on several occasions when blast holes were drilled into walls, small gas pockets were tapped which violently ejected tools or dynamite." Some holes, located on corners or back walls of rooms, developed salt stalactites from steadily dripping brine. Holes in pillars eventually stopped flowing, thus indicating the gas and brine could be "bled off" from zones of salt surrounded by open faces.

**Figure 3.** Anhydrite banding in the Winnfield Salt mine. After Cameron (1949).

## BLOWOUT CAVITY CONFIGURATIONS

Most cavities resulting from blowouts in salt mines are vertically inclined, elongated openings extending upward into the mine roof, and thus are referred to as "chimneys" by miners. Other blowout cavities may be almost hemispherical. Chimney openings may range from approximately three or four up to thirty feet in diameter; and usually appear to taper to a smaller diameter inward (or upward) into the salt.

Blowout cavities in south Louisiana salt mines are shown in photographs, Figures 4 and 5. The blowout cavity of Figure 4 is an elongated opening or chimney, however it has an interesting curved "hornlike" configuration not found in many chimneys. Figure 5 depicts a relatively shallow, but larger diameter, roughly hemispherical blowout cavity in a second south Louisiana mine. It can be noted that this cavity occurred in the wall of the mine rather than in the roof.

The blowout cavity in the Winnfield dome (Fig. 1) extends into the wall of the mine. The man in the photograph appears to be looking upward into a chimney. Hoy et al. (1962) depict a similar blowout cavity (possibly the same one) and note: "The opening extends upward and out of sight more than 100 feet above the mine level." Approxi-

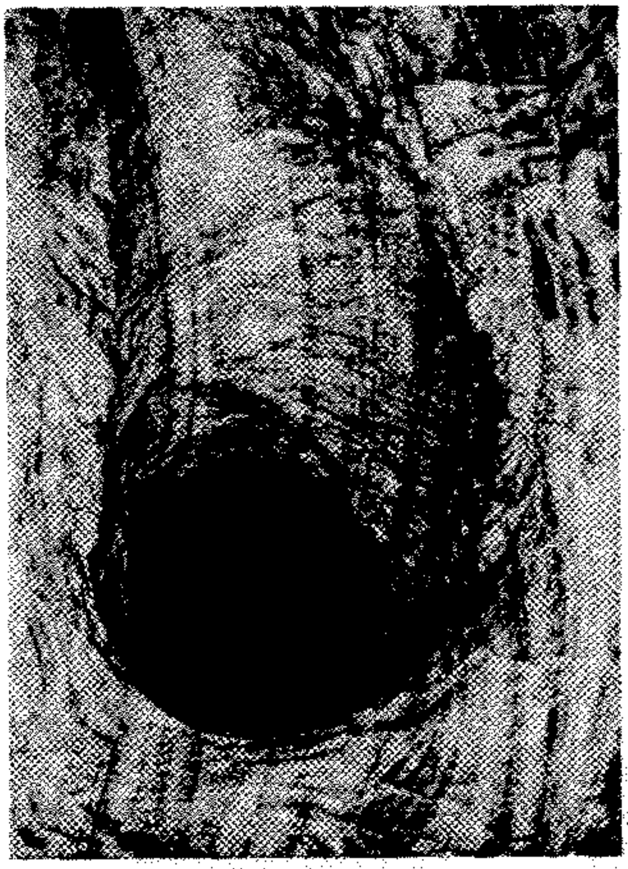

**Figure 4.** Blowout in South Louisiana salt mine A. After Martinez, et al. (1977).

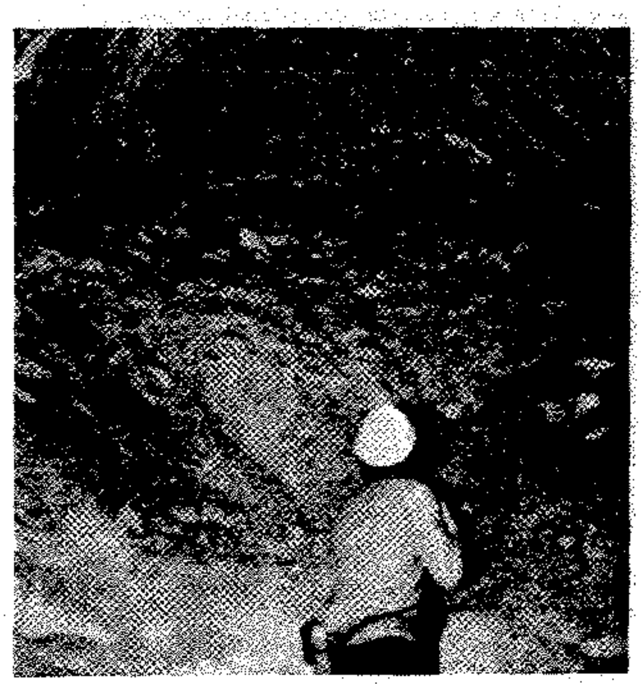

**Figure 5.** Blowout in South Louisiana salt mine B. After Martinez, et al. (1977).

mately 7,500 tons of salt were produced which filled the previously noted space of 150 × 50 × 20 feet. The extent of the chimney into the roof thus was not determined completely. An estimate of the chimney height can be obtained based on the following simplistic assumptions: 1) the chimney "diameter" averaged 30 feet, and 2) the crackle salt ejected onto the mine floor occupied the same volume prior to the blowout. The implied calculation yields an estimated chimney height of 212 feet. The interested reader obviously may perform many variations on this estimate; while noting that assumption one is conservative, whereas two is not.

A number of factors probably affect blowout cavity configurations. The most frequently occurring blowout cavity is the steeply inclined chimney into the mine roof. Blowout cavities into the wall are less common and cavities into the floor are rarely reported. Belchic's report (1960) on the "floor being heaved up with great force" in the Winnfield mine is exceptional. Furthermore, blowouts consistently occur with blasting; although one has been rumored to occur spontaneously. Also, there are reports of blowouts occurring in conjunction with solution mining.

## FACTORS AFFECTING BLOWOUTS

Figure 6 depicts factors that are proposed to account for the typical chimney configuration of blowout cavities. Gas pressured zones A, B, and C are nearly vertical and elongated because of the dominantly vertical flow patterns and

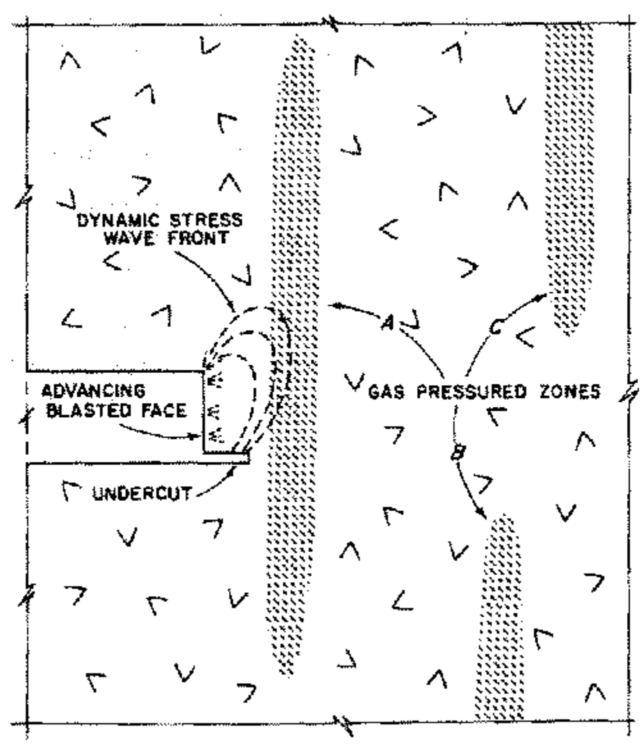


**Figure 6.** Interaction of stress wave and pressured zones in domal salt at and in front of an advancing blasted face.

extensional strain associated with the buoyancy driven salt stock. Ramburg (1968) and Dixon (1975) have developed centrifuged models of domes which exhibit layering and extensional strain in the vertical direction. The layering demonstrated in their models are generally consistent with the typical internal structure observed in salt mines (e.g., Fig. 3).

A typical dynamic stress wave associated with routine blasting of an advancing face is guided in a forward and upward direction by the undercut of the face (Fig. 6). The salt below the floor level in front of the face thus is relatively undisturbed.

Rock salt is a strain rate dependent material, i.e., it behaves in a brittle mode when loaded rapidly. Thus, the interaction of the stress wave front and the gas pressured zones A and, eventually, C of Figure 6 precipitates a blowout of the momentarily brittle rock salt. Zone B is uncoupled from an intense stress wave loading, and therefore a blowout in the floor does not occur. It is possible that the gas in nearby pressured zones below the floor surface may gradually seep out over a period of several days.

The direction of the cavity "run" is typically in the direction of the vertically inclined gas pressured zones. The direction also could be partly influenced by local material anisotropy consistent with the structural configuration of anhydrite rich layers in the salt.

It appears from Figures 1 and 4 that the configurations of the blowout cavities were influenced as previously described by effects related to the local structure of the salt as reflected by layering. The cavity surface of Figure 5 is not particularly revealing.

## BLOWOUT RISKS AND THEIR REDUCTION

Blowouts have been considered a relatively minor risk in Gulf Coast room and pillar salt mining because they consistently occur with blasting when the area is clear of personnel. Obviously problems can occur when exceptionally large blowouts occur if an associated gas is explosive.

It must be emphasized at this point that the frequency and magnitude of blowouts in U.S. Gulf Coast salt domes depend strongly upon the character of the individual domes. That is, the history of reported numbers and magnitudes of blowouts varies widely between domes. Furthermore, as previously noted, certain zones within domes are blowout prone, whereas others are not. Thus site specific assessments necessarily must be included in consideration of blowout risks.

The possibility of serious risk associated with blowouts has received more general attention recently because of the increasing use of mined openings in salt domes for storage purposes. In this case the possibility must be considered that blowout cavities might form abrupt and unplanned connections between storage caverns and other caverns or the dome surface.

Usually few problems are associated with connectivity of caverns with the same stored product. However more serious consequences are obvious depending upon the respective usage of caverns that possibly could be connected by blowout cavities.

The more frequent and generally vertical chimneys as previously described might pose connectivity between relatively close caverns in an "above and below" configuration. Horizontal "runs" of cavities reportedly have been so small that they are unlikely to form a lateral connection between caverns at the same elevation with an intervening wall of rock salt of 100 feet or more.

Traditionally blowout risks have been reduced simply by identifying blowout prone areas within a particular mine, mainly on the basis of experience, and then avoiding those areas (Obert and Duvall, 1967, p. 610). Apparently geophysical techniques have not been developed (or at least reported) that can be employed to give warning of potential blowout areas.

The geology of specific domes can be mapped and used to extrapolate trends of unusual features zones laterally into unmined areas. Such zones exist, regardless of their origin, e.g., Kupfer (1976).

As noted previously (and by other investigators), because of the diapiric evolution of salt domes, unusual features can be anticipated to occur at least locally (over several hundreds of feet) in a nearly vertical orientation. The vertical extent of unusual features, such as blowout prone zones, within salt domes has not been fully explored. However, based on relatively localized knowledge within a mine, blowouts also can be reduced at lower levels by avoiding risk areas tentatively identified by extrapolation of blowout prone zones from upper mine levels.

Another possible, but more speculative, method of reducing blowouts at an eventual lower cavern level would be to drill gas drain (or "bleeder") holes in the floor of blowout prone areas. If storage is planned for a cavern then the holes should be outfitted so as to insure one way drainage in a desired direction. Furthermore, appropriate precautions should be taken in drilling drain holes so as to minimize risks associated with tapping a gas pressured zone.

The drilling of drain holes, as proposed above, could prove ineffective unless pressured zones were directly intercepted. The very existence of the zones implies relative impermeability of the locally surrounding salt. Slant holes, as contrasted to vertical holes, would have a higher probability of intercepting vertically inclined zones.

Although gas pressure has been designated as the dominating energy source for blowouts in this study, the possibility of geostatic stress coupled effects should not be ignored. Such effects could interact with gas pressured zones to increase the severity of blowouts. Accordingly, "de-stressing" procedures such as these described by Obert and Duvall, (1967, p. 603) to reduce more conventional rock bursts also should be considered.

## CONCLUSIONS

Blowouts and their effects have been relatively well known in evaporite deposits for some time. In the U.S. Gulf Coast the frequency and magnitude of blowouts depends strongly upon the particular salt dome under consideration. Neighboring domes, separated by only a few miles and in the same basin, may have entirely different blowout histories.

The vertical extent of blowout zones within salt domes should be explored. This potentially rich area of research should yield useful results which would impact strongly on planning for long term optimum utilization of salt domes for storage purposes. This exploration should extend below depths currently being mined by room and pillar methods.

A more complete understanding of blowouts could be obtained by combining information gained from all enterprises working in or around salt domes, e.g., sulphur and oil production, brine operations, room and pillar mining, and the rapidly increasing storage industry. For example, blowouts from within the salt stock of domes have been noted for a considerable period of time in the oil industry.

Vaughn (1925), in a discussion of relative dome character in "The Five Islands, Louisiana," noted that, "Any prediction as to the future of Belle Isle (salt dome) as a producer of oil and gas would be hazardous. However, the high gas pressure and oil so commonly found within the salt body itself would seem to indicate that there is a pool of oil somewhere in the immediate vicinity." Vaughn also noted the salt of Belle Isle to be "impure" relative to the salt of Jefferson, Avery, and Weeks Island; and he suggested this as a reason for the caprock existing over Belle Isle, whereas only Jefferson Island has caprock (at a lower depth) among the other "Islands."

In conclusion, the mere occurrence of blowouts in salt domes has not, and should not, deter many kinds of storage in specific domes. However, in general, blowouts are worthy of additional study relative to long term storage and overall optimum utilization of salt domes.

## ACKNOWLEDGEMENT

This work was partially supported by the United States Department of Energy under Subcontract with the Office of Waste Isolation, Union Carbide Corporation, Nuclear Division.

## REFERENCES

Atwater, G.I. and Forman, M.J. 1959. Nature and Growth of Southern Louisiana Salt Domes And Its Effects On Petroleum Accumulation. Am. Assoc. of Pet. Geol., Bull. 43:2592–2622.

Belchic, Harriet C. 1960. The Winnfield Salt Dome, Winn Parish, Louisiana, *Guide Book*. 1960 Spring Field Trip, Shreveport Geological Society.

Cameron, Harriet. 1949. The Winnfield Louisiana Salt Dome, M.S. Thesis, Louisiana State University.

Dixon, J.M. 1975. Finite Strain And Progressive Deformation In Models Of Diapiric Structures, Tectonophysics. 28:89–124.

Hoy, R.B., Foose, R.M. and O'Neill, Jr., B.J. 1962. Structure of Winnfield Salt Dome, Winn Parish, Louisiana, Am. Assoc. Pet. Geol. Bull. 46(8):1444–1459.

Hoy, R.B. and O'Neill, Jr., B.J. 1960. Investigation of On-Site Inspection Techniques for High Explosive Tests In A Salt Dome, Final Report, Project Cowboy, Winnfield, Louisiana. Stanford Research Institute report for U.S. Atomic Energy Commission, SRI Project No. SU-2993.

Kupfer, D.H. 1976. Shear Zones Inside Gulf Coast Salt Stocks Help To Delineate Spines of Movement, Am. Assoc. Pet. Geol. Bull. 60:1434–1447.

Martinez, J.D., et al. 1976. An Investigation Of The Utility Of Gulf Coast Salt Domes For The Storage Or Disposal Of Radioactive Wastes; Report ORNL-Sub-4112-25, Institute for Environmental Studies, Louisiana State University, 317–320.

———. 1977. An Investigation Of The Utility Of Gulf Coast Salt Domes For The Storage Or Disposal Of Radioactive Wastes; Report Y/OWI/Sub-4112/37 to the Office of Waste Isolation, Institute for Environmental Studies, Louisiana State University, 161–204.

Obert, L. 1964. In Situ Determination of Stress in Rock, Mining Engineer, August, 51–58.

——— and Duvall, W.I. 1967. Rock Mechanics And The Design of Structures In Rock. John Wiley & Sons, Inc., 582–610.

Ramberg, H. 1968. Experimental and Theoretical Study of Salt Dome Evolution. UNESCO, Geology of Saline Deposits, Proc. Hannover Symp., Earth Science, 7. (See also Third Symp. on Salt, 1:261–270, 1972).

Vaughn, F.E. 1925. The Five Islands, Louisiana, Am. Assoc. Pet. Geol. Bull., 9:756–797.