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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	L/s	liter per second
cm^3	cubic centimeter	m	meter
°C	degree Celsius	m^3	cubic meter
g	gram	m^3/t	cubic meter per metric ton
kg	kilogram	md	millidarcy
km	kilometer	mm	millimeter
kPa	kilopascal	pct	percent

METHANE CONTENT OF GULF COAST DOMAL ROCK SALT

By Steven J. Schatzel[1] and David M. Hyman[1]

ABSTRACT

Large-scale methane releases in domal salt mines have resulted in ignitions and mine fatalities as recently as 1979. Several past studies have implied that hazardous methane occurrences in U.S. salt domes are distributed neither uniformly nor randomly, but are geologically controlled and potentially predictable.

A first step by the Bureau of Mines in addressing the problem of methane in domal salt mines required development of a new test to determine volumes of gases in solid salt samples. This report considers the results achieved when 80 domal salt samples were tested for gas content by dissolution in a controlled atmosphere chamber. Criteria were organized to delineate salt types based on geological occurrence. Outburst samples range from 0.014 to 7.4 cm^3 CH_4/100 g NaCl, anomalous salt samples from 0.0027 to 2.6 cm^3 CH_4/100 g NaCl, and normal salts from less than 0.0003 to 0.31 cm^3 CH_4/100 g NaCl. The presence of higher hydrocarbons was most common in samples containing larger quantities of methane. The presence of higher hydrocarbons appears to be useful in detecting methane hazards where some methane may be lost before gas content testing. An exploratory rotary and/or core drilling program, dissolution testing for gas content, and up-to-date geologic mine mapping could allow a mine operator to assess methane hazards in domal salt.

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INTRODUCTION

Large volumes of methane have been introduced into domal salt mines as a result of an outburst of salt following a face blast. Outbursts following blasts that release methane gas have been known to occur in four of the Five Island domal salt mines of the Louisiana gulf coast (fig. 1). Although rigorous well-documented gas outburst data do not appear in the literature, a Mine Safety and Health Administration study suggests that a large outburst expelled about 13,600,000 kg of salt. Gas was released at an estimated pressure of about 8,000 kPa and expanded to a volume of approximately 2,800 m^3 at underground atmospheric pressure (1).[2] Although outbursts appear to have accounted for the majority of methane hazards in these mines, other mechanisms do exist for the release of methane into the mine environment.

The Bureau has conducted extensive research in coal mines aimed at reducing methane hazards by removing methane from the coal prior to or during mining. Reducing methane hazards in domal salt

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[2] Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

FIGURE 1. - Location of domal salt mines on Louisiana gulf coast.

mines presents problems very different from coal because of different gas occurrence, retention, and release properties. Salt domes are not permeated with a natural macroscopic fracture network occurring at regular intervals analagous to coal cleat, which can transport gas throughout the ore body. Nonfractured domal salt with few impurities is considered to be impermeable by many authorities although values from essentially zero to about 600 md have been reported (2). These gas transport limitations eliminate or seriously complicate the potential for methane drainage in salt domes. Whether the methane originates in gas-bearing strata outside the salt stock and migrates into the dome and/or is the result of diapiric metamorphism of included sediments is subject to debate. Problematic methane emissions have been associated with certain unusual or anomalous features (e.g., included nonsalt bands, interconnected void zones, outbursts) (3).

Some aspects of salt dome mining methods are poorly suited to dealing with methane hazards. Discerning intake and return air is difficult in many areas of domal salt mines because of their relatively large openings. In coal mines, which have much smaller openings, stoppings provide very effective separation of air sweeping through the workings and continue to serve their purpose in all but the most severe crisis situations.

BACKGROUND

Owing to their unusual structure and the association with petroleum occurrences, salt domes have historically been the subject of scientific and economic interest. Geologic investigations of salt domes are extensively reported on in domestic and foreign literature. However, methane occurrences within the salt dome seem to be uniquely a mining and cavern development and utilization concern. Generally, methane occurrences are not widely reported in detail in the literature.

Foreign literature does document some work in quantifying methane content in domal salt rock. Although some methane contents have been reported, related geologic information has not been reported, which limits the usefulness and applicability of this work. Detailed information concerning the experimental method and the apparatus have not been reported. Little geologic context was given for the salt samples from which the gas content data were obtained.

Domestic studies of salt domes are frequently studies of geochemistry, internal structure and banding, external structure, cap-rock evolution, salt dome growth, outbursts, and the relationships among a variety of anomalous salt dome internal features (3-7). The authors directly or indirectly imply that hazardous methane occurrences are distributed neither uniformly nor randomly but are geologically controlled. Qualitative evidence exists for the distribution of methane in the dome to be nonuniform. Large volumes of organic source material that frequently precede methane formation are not common in the halite-rich Gulf Coast salt domes. The same transport limitations affecting methane drainage would resist uniform distribution or escape of any gases present in a salt dome. Geologic structure and its associated gas content variability must be addressed when determining the methane content of domal rock salt samples.

In evaluating gas content data of domal salt, caution must be exercised to avoid misinterpretation by directly extrapolating the gas content of a small sample to mine-room emission. Because samples generally do not completely include or are not entirely composed of particular geologic features that may vary in their associated methane content, sample size can have some effect on the methane content of that sample. A higher degree of permeability may be associated with some features such as impure salts appearing as traceable dark bands in the mine. Some bands have been suggested to be the result of differential movement between a spine of salt and the surrounding strata or differential movement between salt spines in a single salt stock (3). These edge and central anomalous zones can be migrational pathways for brines and gases in the dome, and in some areas of domal salt mines brine seeps can be observed to parallel banding (3). Thus, the methane content of such a sample would not represent the amount of methane released into the mine during mining. However, such a sample may still be enriched in methane beyond the majority of "normal" salts. One of the goals of current Bureau research is to study and quantify possible relationships between rock sample gas content and gas emissions during mining.

Methane enriched domal salt generally consists of (1) dark banded or argillaceous salts, (2) outburst ejected or related salts, and (3) petroleum occurrences in the dome interior. Correlations, if any, will be examined between recognizable salt "types" together with geologic context and gas contents. Ultimately, gas content tests together with lithologic and geologic associations could be a useful predictive tool for the mining industry. An exploratory and/or core drilling program, dissolution testing, and up-to-date geologic mine mapping could allow a mine operator to assess the potential for encountering methane gas.

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EXPERIMENTAL TESTS AND PROCEDURES

CRUSHING METHOD

The first step in addressing the problem of methane in domal salt mines required development of a new test to determine the amount of gas in a solid volume of salt. Two tests were developed by the Bureau and are described by Hyman (8).

Crushing salt to release methane upon disaggregation was the first method investigated. The disaggregation of salt in a ball mill was thought to be a good analogy to continuous or conventional salt mining. Some of the experimental apparatus is used routinely for determinations of coal gas content. Certain modifications were necessary for adaptation to salt crushing. The grinding action of the ball mill was enhanced by decreasing the volume of grinding media, by welding fins to the inner wall of the ball mill, and by decreasing the sample size. A second port was added to the ball mill lid to allow for purging of the mill atmosphere with an inert gas that is not detected by a gas chromatograph. The purging of the chamber retards any gas reactions and reduces the interference of background gases.

Preliminary results of gas determinations using the modified crushing apparatus exhibited a considerable scatter of data indicating equipment problems. Remedial action included redesigning the ball mill. The simpler and cheaper dissolution method was adapted in favor of the crushing method.

DISSOLUTION METHOD

Dissolution in a controlled atmosphere has been cited as a means of gas content determination in foreign literature and preliminary tests had been conducted by the Bureau (8) (fig. 2). The noncorrosive construction of the dissolution chamber allows for easier maintenance and decreases preparation time between tests. The present laboratory apparatus is simple and has a great deal of site and scale flexibility potential. Whatever the scale, the proportion of chamber void space to sample size is much smaller in the dissolution apparatus as compared with the crushing apparatus. The result is higher concentrations of released gases present within the dissolution chamber, which decreases the effect of error producing factors over the course of the experiment. The experiment is conducted at a chamber pressure slightly higher than atmospheric to prevent outside contamination of the chamber atmosphere. Operating the apparatus near atmospheric pressure also decreases errors in chamber gauge readings and decreases errors in normalizing to Standard Temperature and Pressure (STP) (0° C, 760 mm Hg) conditions.

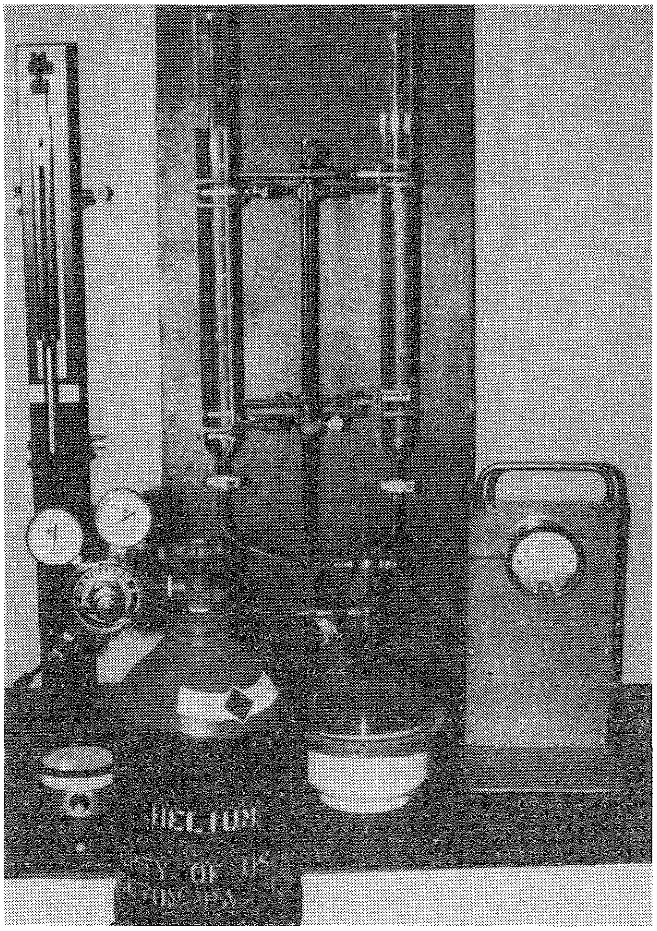

FIGURE 2. - Laboratory apparatus for dissolution testing.

ESTIMATIONS OF ACCURACY FOR THE DISSOLUTION TEST

An indication of the dissolution test low-end resolution was sought early in its development. Chemical reagent sodium chloride (NaCl) was obtained as an experimental control. The reagent is approximately 99.98 pct pure NaCl. The reagent is artificially produced in a chemically controlled environment, which precludes the accumulation of methane. Two samples of reagent were weighed out at near the minimum sample size for the dissolution chamber. This is thought to be the poorest operating condition for the experiment. Gas volumes were then computed by a data reduction procedure established for all experimental samples. The procedure calls for multiple gas samples before and after dissolution of a single salt sample to be drawn from the chamber atmosphere. The analysis shows 0.0002 pct methane in one of the three gas samples following dissolution of one of the salt reagent samples (table 1). The other samples had no detectable methane.

For a conservative estimate of the gas analysis detection limit, "worst" conditions were interpreted. Instead of averaging the gas samples from a particular time during the test procedure, the only gas sample showing methane content was used. Determination of the methane content per unit mass of reagent was calculated using the same worst case conditions as applied to the methane detection limit. Data reduction indicated 0.0003 cm^3 CH_4/100 g NaCl to be present. This is considered an estimate of the low-end experimental resolution and must be exceeded to be reported as significant.

TABLE 1. - Gas composition analysis of two experimental control salt samples, percent

	O_2+AR	N_2	CO_2	CH_4
Sample 1:				
Before dissolution.....	0.57	1.78	0.015	ND
	.53	1.72	.014	[1]<2
After dissolution......	.46	1.13	.023	.0002
	.47	1.17	.022	ND
	.46	1.15	.022	ND
Sample 2:				
Before dissolution.....	1.24	4.30	.016	ND
	1.47	5.10	.012	ND
After dissolution......	1.61	4.68	.020	ND
	1.62	4.70	.021	ND
	1.63	4.71	.021	ND

ND Not detected. [1] Parts per million.

NOTE.--Carbon monoxide and higher hydrocarbons were not detected.

Errors resulting from measurements during all phases of the experiment and combined arithmetically in data reduction have been found to produce a total methane content error of about 5 pct.

APPLICATION OF METHANE CONTENT TESTING AS PART OF A METHANE PREDICTION STRATEGY

A field test of methane hazard evaluation procedure was planned. In a Louisiana domal salt mine, plans were made for two holes to be core drilled at nearly horizontal angles from within mine workings. The first hole was to be drilled in an area that was projected from a zone that had emitted very small amounts of methane during mining. The second hole was oriented to intercept a continuous zone of anomalous argillaceous salt known to have been related to increased methane emissions.

Mine emission rates for methane from normal salt and the same band of anomalous argillaceous salt were measured below this mining level while driving a development decline. Normal salt emitted less than 0.16 m^3/t. Measurements of mine emissions of methane in the anomalous salt ranged from 0.47 to 2.18 m^3/t (9). Average gas contents of samples of the two types of salt from the two Belle Isle core holes were 0.0046 and 0.021 cm^3 CH_4/100 g NaCl, respectively.

Both holes were to be monitored for emissions during drilling. Any gas flows encountered would be measured and sampled for gas composition analysis. The cores were to be tested for gas content and compared to determine the possibility of potential methane hazard prediction by gas content.

DISCUSSION OF TEST RESULTS

A histogram of methane contents for all samples tested is presented in figure 3. The horizontal scale shows methane content on a five-cycle logarithmic axis required to accommodate all of the data points. The vertical scale shows the number of samples in each methane content interval.

The various domal salt rock lithologies were grouped into three major classes based on geological association and methane emission history during mining. The types were defined as follows:

1. Normal salt--white to gray, transparent to translucent, very rich in

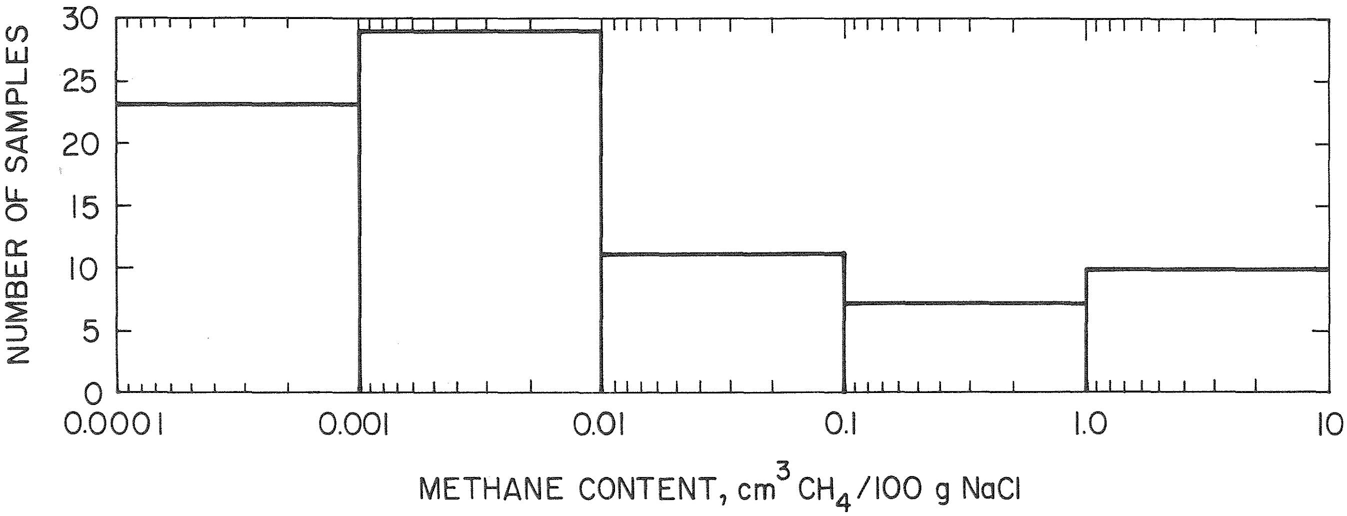

FIGURE 3. - Distribution of methane contents for 80 domal salt samples tested.

sodium chloride, few impurities, generally medium grained.

2. Outburst salt--usually white to gray, sometimes with greatly increased crystal size and randomly oriented (presumably recrystallized), sometimes showing curved cleavage traces continuous over a few centimeters, gas bubbles sometimes included in the salt mass. The essential criterion for all outburst salts is that they are physically associated with an outburst.

3. Anomalous salt--includes central and edge anomalous zones, dark and relatively continuous, frequently with brine and gas seeps, occasionally with petroleum seeps, argillaceous and/or sandy. This type also includes lithologies such as sandstone breccias and sylvite as bands that can be relatively continuous or may be discontinuous and pinch out over along-strike distances of 30 to 70 m. Other non-NaCl materials are included in this type (e.g., potassium salts, gypsum, anhydrite, quartz, clay, etc.).

Figure 4 shows these lithologic types with some additional delineations. Core samples of normal salt and anomalous salt intercalated in normal salt are categorized using the same criteria as the other samples. The cored samples were obtained from two holes during in-mine drilling to be discussed in a later section. The reagent-grade salt control samples are also shown. Samples having less methane than 0.0003 cm^3 CH_4/100 g NaCl, the estimated experimental low-end resolution, are plotted at the intersection of the abcissa and the ordinate although they are considered to have essentially zero methane content.

Some overlap of methane contents can be seen between the salt types. However, anomalous salts and outburst salts represent the great majority of high-methane-content salts. Normal salts represent the majority of low-methane-content salts. Some of the normal salts indicated methane contents of the same magnitude as the reagent control samples. Outburst samples range from 0.014 to 7.4 cm^3 CH_4/100 g NaCl. Anomalous salts range from 0.0027 to 2.6 cm^3 CH_4/100 g NaCl. Methane contents for normal salts vary from less than 0.0003 to 0.31 cm^3 CH_4/100 g NaCl.

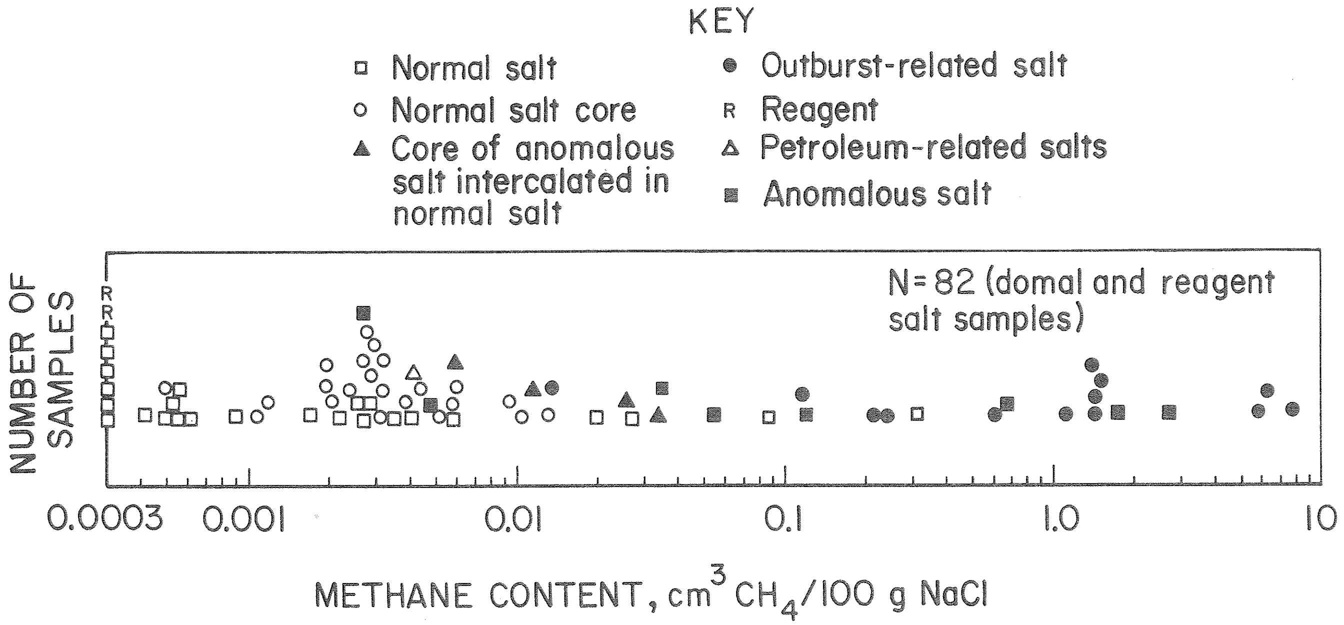

FIGURE 4. - Salt type categorization and corresponding methane content of 82 samples tested.

Certain sets of physical characteristics of domestic domal salt that can be shared by more than one salt type have been noted in the literature as sometimes being related to methane and other hazardous conditions. Kupfer (3) has stated that some features often indicative of hazardous conditions in salt mines are frequently spatially related. Ceiling slabbing, increased crystal size, contorted cleavage boundaries, and gas seeps are other characteristics that have been suggested as precursors to hazardous mining conditions. Because one of these features can precede any or all of the others, whenever possible these features were used during geologic mapping and sampling to aid in the recognition of methane enriched salts. Depth of mining, the presence of higher hydrocarbons (where the molecular hydrogen to carbon ratio is less than 4), and carbon dioxide enrichment were examined for correlation with methane enrichment. The presence of higher hydrocarbons appears to be significant and it is generally associated with relatively high methane content. This trend is presented in a tabular format in the appendix.

Carbon dioxide enrichment of some high methane content salts was observed; however, a numerical value for carbon dioxide contents lacked meaning since carbon dioxide was being exsolved from the brine in the dissolution chamber as its salinity increased. Nonuniform amounts of solvent and solute introduce additional variables. Potential improvements in the dissolution method involve more effective degassing of the distilled water.

A methane content histogram (fig. 5) shows the number of samples containing higher hydrocarbons within each interval. The frequency of occurrence of higher hydrocarbons in the samples increases with increasing methane content. This indicates that if a dissolution test yields a relatively low methane content but higher hydrocarbons are present, the mine operator should be alerted to a possible methane enriched zone nearby.

Histograms were generated for the individual salt types to determine the gas content distribution among the sample type populations. The samples containing higher hydrocarbons are also shown. All but one of the 54 normal salt samples tested contained less than 0.1 cm^3 CH_4/100 g NaCl (fig. 5*B*). Of all the salt samples classified as normal, 43 pct

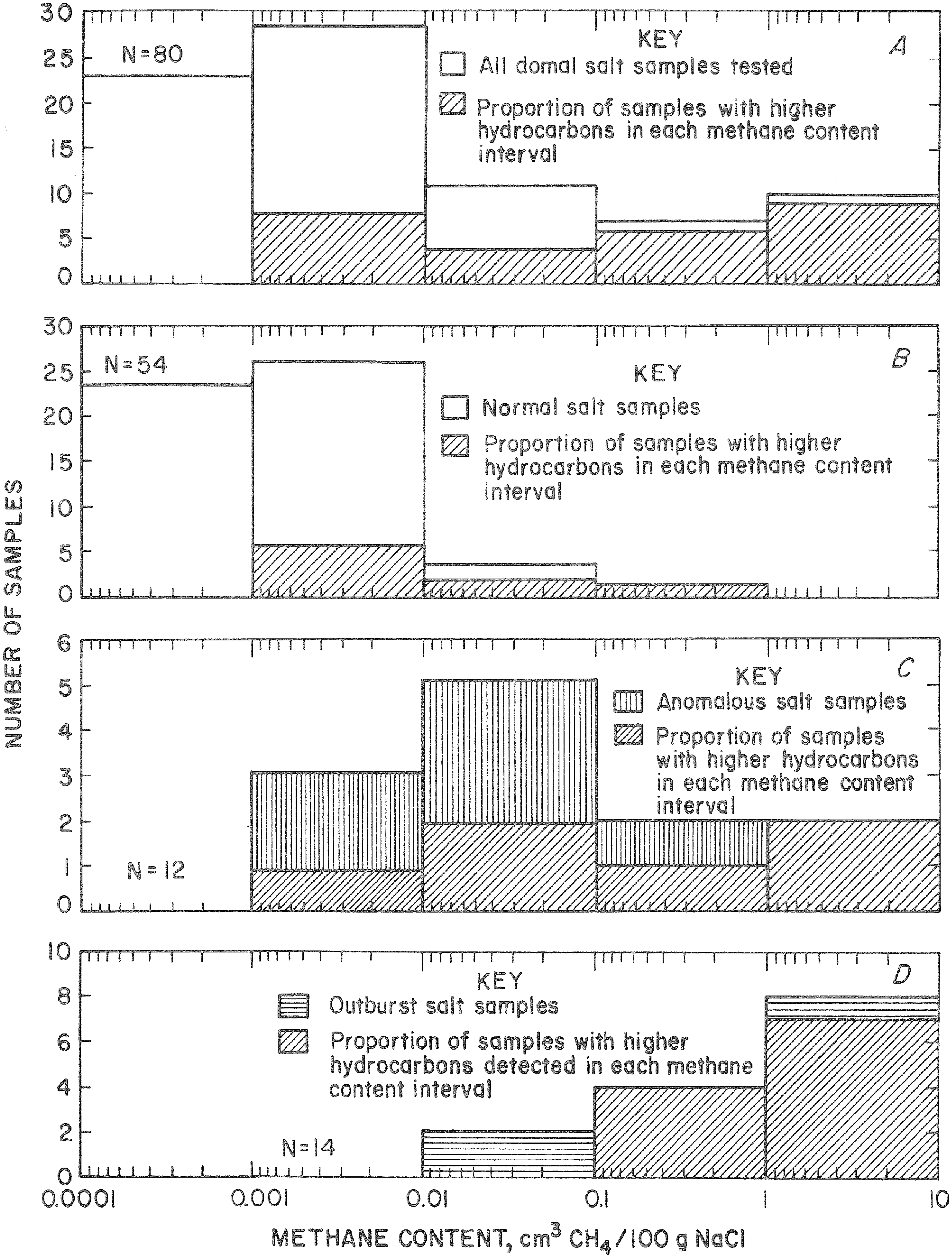

FIGURE 5. - Methane content distribution and samples containing higher hydrocarbons in each interval. *A*, All domal salt samples; *B*, normal salt; *C*, anomalous salt; *D*, outburst salt.

contained less than 0.001 cm^3 CH_4/100 g NaCl. No higher hydrocarbons were observed within this interval. Forty-eight percent of the normal salt samples tested contained between 0.001 and 0.01 cm^3 CH_4/100 g NaCl with 23 pct of those samples showing higher hydrocarbons. Only 7 pct of the normal salt samples contained between 0.01 and 0.1 cm^3 CH_4/100 g NaCl with two of the four samples in this interval showing higher hydrocarbons. One normal salt sample was between 0.1 and 1.0 cm^3 CH_4/100 g NaCl and it showed higher hydrocarbon content. Of the 54 normal salt samples tested, 17 pct contained higher hydrocarbons.

The methane contents of the anomalous salts are shown in figure 5*C*. A petroleum-seep-related salt sample is included here because it is geologically closely related to the anomalous zones included in this class. The gas contents of the 12 anomolous salt samples are plotted with three of the samples between 0.001 and 0.01 cm^3 CH_4/100 g NaCl. Of those three samples, one showed higher hydrocarbons. The next higher methane content interval, 0.01 to 0.1 cm^3 CH_4/100 g NaCl contained five of the anomalous salts. Two of these showed higher hydrocarbons. Two samples were between 0.1 and 1.0 cm^3 CH_4/100 g NaCl with one sample containing detectable higher hydrocarbons. In the 1.0 to 10 cm^3 CH_4/100 g NaCl group were two of the samples. Both of the samples in this interval contained higher hydrocarbons. Overall, 6 of the 12 anomalous salt samples contained higher hydrocarbons.

Outburst salts accounted for 14 of the samples tested, 11 samples indicating the presence of higher hydrocarbons (fig. 5*D*). The lowest gas content interval of the outburst salts was from 0.01 to 0.1 cm^3 CH_4/100 g NaCl where two of these samples were present and where no samples were determined to have a higher hydrocarbon content. Higher hydrocarbons were present in all four of the samples from 0.1 to 1.0 cm^3 CH_4/100 g NaCl and seven of the eight samples in the 1.0 to 10.0 cm^3 CH_4/100 g NaCl interval (fig. 5*D*).

Anomalous salt samples show a wide range of methane contents. These samples share the 1.0 to 10.0 cm^3 CH_4/100 g NaCl interval with outburst salts and the 0.001 to 0.01 cm^3 CH_4/100 g NaCl interval with normal salts. Most of the anomalous salt samples were collected in areas thought to be associated with edge or central anomalous zones which may represent relatively continuous liquid and gas transport paths and/or reservoirs within the dome structure. This could allow for high methane contents where gas was trapped within the hand sample until released during dissolution. However, since these zones appear to have the potential to transport gases, samples might allow the escape of gas before dissolution testing resulting in low experimentally determined methane contents. Therefore, a low gas content sample might not reflect potential gas emissions from that zone during mining operations.

The proportions of each domal salt type making up the total salt sample population within each gas content interval is presented in figure 6. The interval from 0.0001 to 0.001 cm^3 CH_4/100 g NaCl contains only normal salt samples. Anomalous salts account for about a tenth of the samples between 0.001 and 0.01 cm^3 CH_4/100 g NaCl with the remainder being normal salt. The area bounded by 0.01 and 0.1 cm^3 CH_4/100 g NaCl represents a group of samples composed of four normal salt, five anomalous salt, and two outburst salt samples. Between 0.1 and 1.0 cm^3 CH_4/100 g NaCl are samples of all three salt types. The samples between 1.0 and 10 cm^3 CH_4/100 g NaCl consist of outburst salt, except for one anomalous salt sample.

It was apparent from the analyses that those samples with higher methane contents had a greater frequency of higher hydrocarbons than those with relatively low methane contents. Higher hydrocarbons can be a useful methane hazard indicator in samples where methane may escape before testing.

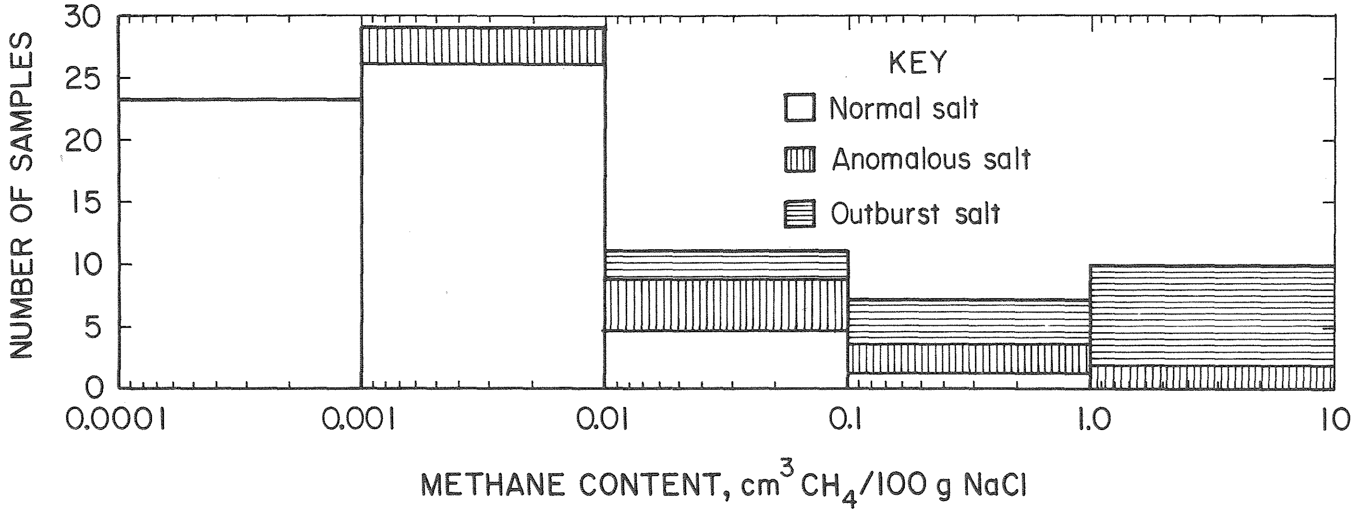

FIGURE 6. - Salt type composition for each methane content interval.

Methane content, methane emissions, and outburst hazards in coal have generally been found to increase with increasing depth of mining (10). The same relationship has been suggested for domal salt mines where methane related mine disasters and mining depths have increased in recent years. Potential energy stored in the salt mass can be greater at greater depths as gas pressures for a given STP gas content will increase with depth. Gas content pressures were not determined in this study.

A plot of methane contents of domal rock salt samples and corresonding depths is presented in figure 7. Although samples taken from the shallowest mining depths have low methane contents with generally low variability, a trend of increasing methane content with increasing depth is not clear. The sample population presented in this report was not sampled in an unbiased manner with respect to depth. Since all salt types discussed are included in this plot and a high degree of methane content variability has been shown between the types, the data may involve variables that have not been accounted for. Plotting methane content against depth for a single salt type may be more useful in evaluating the relationship between methane content and depth. Of the three salt types sampled, the normal salts were the most abundant and could most easily be found in different mines at various depths. Mine operators tend to develop mine openings in normal salt and avoid anomalous zones. A plot of normal salt methane contents versus depth is presented in figure 8. No direct relationship between depth and gas content is apparent. There does not appear to be a relationship between increased occurrence of higher hydrocarbons and increased depth.

FIELD TEST OF METHANE PREDICTION STRATEGY

Two core holes were drilled horizontally from the 427-m level in the Cargill Inc., Belle Isle Mine (fig. 9). Hole 1 was drilled into an area of anticipated normal salt. Hole 2 was oriented to intercept a projected band of anomalous argillaceous salt.

Hole 1 was drilled in April 1982 to a depth of 47 m. Methane from the hole was continuously monitored at the vent hose outlet (fig. 10). Methane concentrations were measured only during core retrieval when the hole was flushed with brine drilling fluid, which displaced the gases out of the hole and through the vent hose. Methane concentrations were always below 0.15 pct and returned to zero after flushing the hole. At no time during the drilling of hole 1 were any measurable methane flows detected.

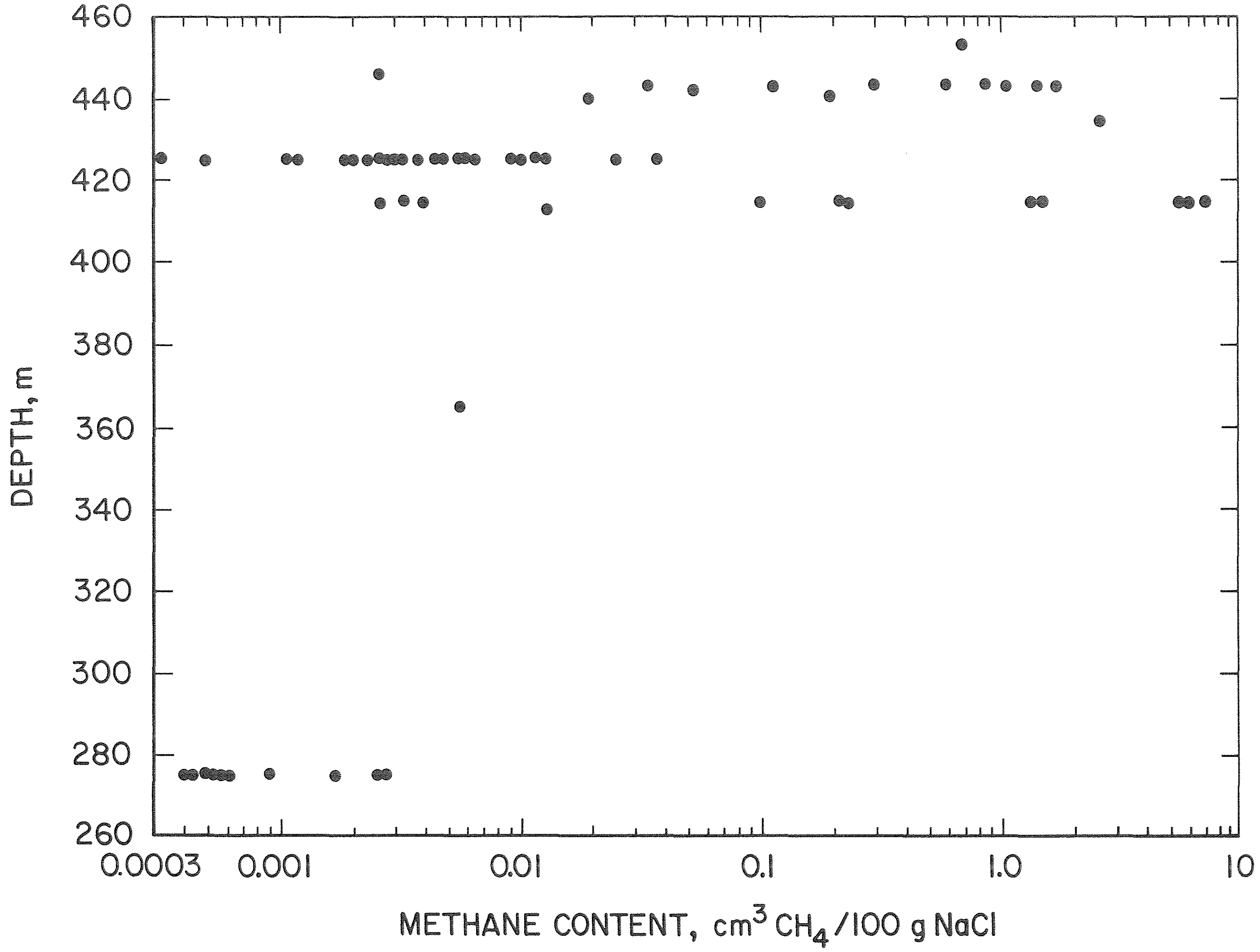

FIGURE 7. - Methane contents of domal rock salt samples and corresponding depths.

Hole 2 was drilled in July 1982 to a total depth of 38 m. The continuous methane monitor used during the drilling of hole 1 was inoperable throughout the hole 2 study. A transition zone of anomalous argillaceous salt bands intercalated in normal salt was encountered about 6 m before the projected location of the anomalous zone (fig. 9) and before the cut core was retrieved, a petroleum-type odor was noticed. Checks for gas were made more often in this zone. When the core was retrieved, well-defined bands of white salt and black argillaceous salt were observed. The presence of methane near the collar of the hole was indicated and increased in concentration approaching the open ended drill steel where flowing gas could be detected but not quantified. Methane concentrations in the hole were measured with a hand held methanometer and were between 90 and 95 pct.

Unfortunately, these events occurred at the end of a regular work shift preceding production blasting in another area of the mine. The hole was not completely shut in preventing any in-hole pressure buildup because under similar circumstances cemented standpipes have been ejected. Following the blast, personnel returned to the drill site to collect samples for gas composition and check the behavior of the flow. The methane concentration averaged 93 pct and the gas flowed at 0.33 L/s.

Extenuating circumstances unrelated to the drilling study forced only one-half shift of additional drill site access. The hole was left open overnight. The

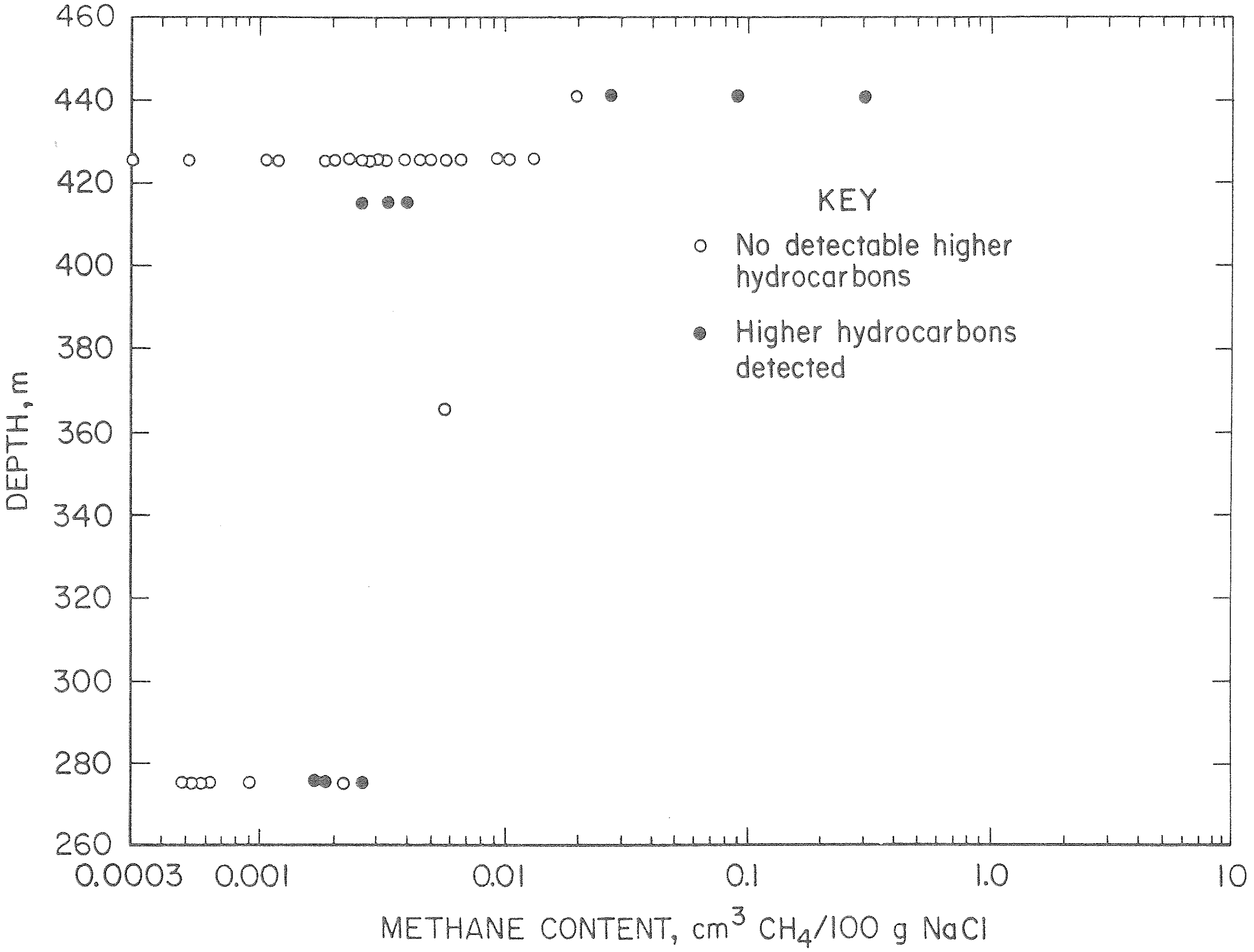

FIGURE 8. - Methane contents and higher hydrocarbon occurrence with respect to depth for normal salt samples.

following day the gas flow had dropped to 0.03 L/s. When the hole was shut in, the gas pressure rose to 138 kPa. Additional pressure was apparently relieved by a crack in the cement around the standpipe at the hole collar. Gas could be heard hissing even when the hole was shut in.

At least one sample for gas content determination was selected from each 3.05 m of core removed from the hole. Gas contents for hole 1 averaged 0.0048 cm^3 CH$_4$/100 g NaCl with a standard deviation of 0.0036 cm^3 CH$_4$/100 g NaCl. The methane contents of the core from hole 2 where no methane production was encountered resemble that of normal salt in hole 1. These samples averaged 0.0044 cm^3 CH$_4$/100 g NaCl with a standard deviation of 0.0034 cm^3 CH$_4$/100 g NaCl. Four samples were removed at the interval from which the methane flow was generated and where the salt became banded. These samples averaged 0.021 cm^3 CH$_4$/100 g NaCl with a range of 0.0060 to 0.039 cm^3 CH$_4$/100 g NaCl. Higher hydrocarbons were found in one of these samples.

The data indicate that the transition zone had enough permeability to support a flow although no gas flow was detected in the normal salt in either hole drilled. In-mine geologic mapping indicated that the band of anomalous salt could be projected from one mining level to another. The boundaries of methane content enrichment are well defined and appeared to

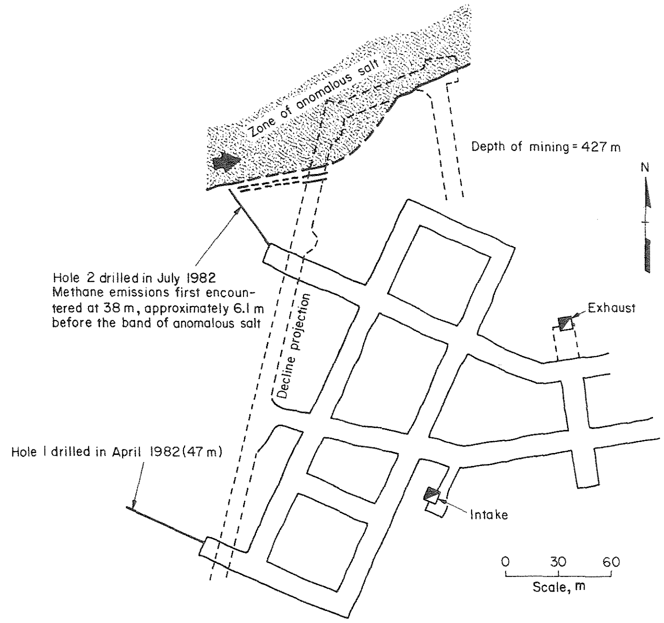

FIGURE 9. - Location of holes 1 and 2 and the band of anomalous salt projected to the 427-m mining level.

coincide with the dark argillaceous bands in the core.

Although methane contents of core samples from the transition zone collected in hole 2 were not as enriched as some anomalous salt samples, they were enriched beyond the vast majority of normal salt core samples and in one instance contained higher hydrocarbons. Three of the four samples were within a methane content interval overlap zone of the three salt types between 0.01 and 0.1 cm^3 CH_4/100 g NaCl. A more continuous sequence of anomalous salt begins abruptly about 6 m deeper and continues on for many more meters. The forced termination of hole drilling halted the collection of more samples in this zone (fig. 9). Preliminary data taken at several locations through this anomalous zone indicate that methane content is higher at the center of the zone than at its edges.

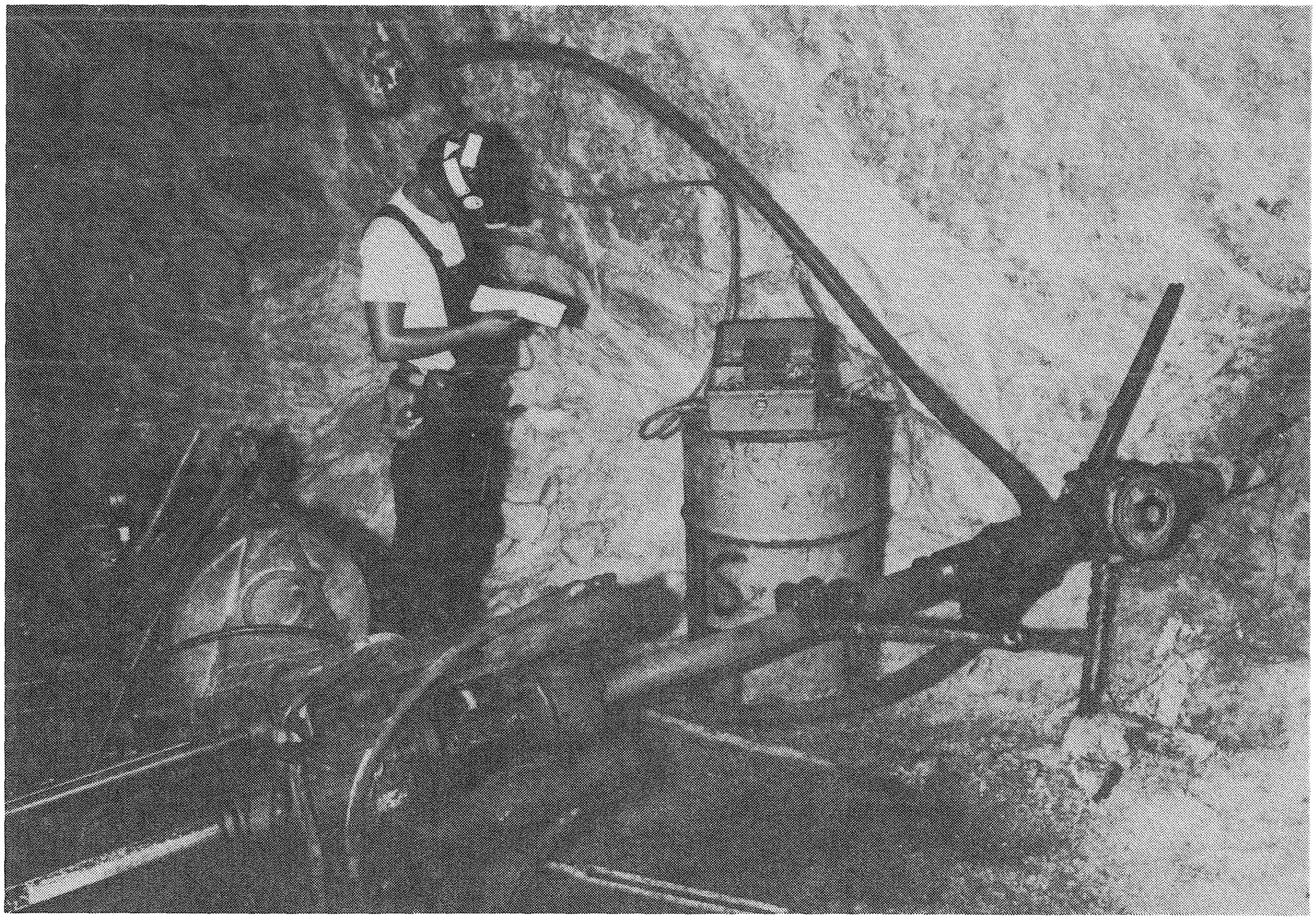

FIGURE 10. - Continuous monitoring of methane at vent hose outlet.

RESULTS AND CONCLUSIONS

Gas movement in salt is not nearly as well defined as gas movements in coal but some characteristics are apparent. The physical features required for rapid gas movement, particularly a regular fracture network, do not occur in salt domes. Methane occurrences in domal salt are nonuniform. Variability of five orders of magnitude in methane content indicates that the methane does not equilibrate in the salt body and may be limited to migration along localized gas transport paths. Thus, determination of gas content can provide important information concerning potential methane hazards, especially when coupled with geologic mapping.

Normal salt methane contents have been found to be relatively low. Over 90 pct of the normal salt samples tested contained less than 0.01 cm^3 CH_4/100 g NaCl. There are wide ranges of methane enrichment in normal versus outburst type salts. Many criteria have been put forth as being associated with outburst salts (increased crystal size, included gas bubbles, contorted cleavage surfaces, disking of a core sample, etc.) but these features were not always evident in the outburst salt samples tested. For the purposes of this study, physical association with an outburst was the essential criterion for the type classification. However, where a potential outburst zone is being breached by mine workings for the first time, physical association cannot be used and physical features are unreliable. The dissolution test can provide pertinent information to distinguish potential outburst salt. There are no other methods currently available. The methane content of outburst salt is usually high. The outburst salt samples had a methane content higher than nearly all of the normal salts included in this paper.

Anomalous salt samples, predominantly from what was identified as one mine's edge anomalous zone, have highly variable methane contents possibly because of the ability of these zones to transport gases. Methane contents of samples of anomalous salt ranged from 0.001 to 0.01 cm^3 CH_4/100 g NaCl, a methane content interval occupied by mostly normal salt and from 1.0 to 10 m^3 CH_4/100 g NaCl where the largest group of outburst samples is found. It is unclear whether anomalous salts that are discontinuous and not associated with edge or central anomalous zones are methane enriched.

Edge and central anomalous zones will emit much higher levels of methane than normal salts (<0.16 m^3/t versus 0.47 to 2.18 m^3/t) (8). They are generally undesirable sites for mine workings because they will probably not be of production grade and have potential for increased methane emissions.

Drilling indicates that normal salt does not produce a measurable gas flow. Edge and central anomalous zones have produced gas flows in some mines. The initial gas flow from a 7.6-cm-diam drill hole in a band of argillaceous anomalous salt was 0.33 L/s with methane concentrations averaging 93 pct.

The presence of higher hydrocarbons is common in high methane content salts and infrequent in low methane content salts. They may be especially useful in the anomalous salts where methane may escape from the sample before laboratory testing.

Although shallow domal salt mine levels had generally low methane contents, no trend of methane content increasing with depth can be seen from the 80 salt samples tested. Carbon dioxide enrichment may coincide with methane enrichment but does not appear to be as variable as methane.

The integration of an exploratory rotary and/or core drilling program, gas contents from dissolution testing, and up-to-date geologic mine mapping could allow a mine operator to assess the potential for encountering methane gas.

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APPENDIX.--SAMPLE DATA BASE PRINTOUT

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    SAMPLE    MINE   SALT TYPE   DEPTH*   CH4 CONTENT   HIGHER HYDROCARBONS
    NUMBER                                (CM3/100G)
------------------------------------------------------------------------------
     10.254   W      OUTBURST    C             0.0140
     44.195   W      NORMAL      C             0.0034   C2H6
     45.201   W      NORMAL      C             0.0027
     46.196   W      ANOMALOUS   C             0.0041   C2H6, C3H8, C4H10
     47.195   W      NORMAL      C             0.0040   C2H6
     65.155   Z      ANOMALOUS   D             1.8000   C2H6, C3H8, C4H10, C5H12
     68.254   Z      NORMAL      D             0.0170
     69.159   Z      NORMAL      D             0.0270   C2H6
     70.161   Z      ANOMALOUS   D             0.0540   C2H6, C3H8, C4H10
     71.147   Z      NORMAL      B             0.0057
     75.153   Z      ANOMALOUS   D             0.0027   C2H6
     76.160   Z      ANOMALOUS   D             0.7000   C2H6, C3H8, C4H10, C5H12
     77.254   Z      ANOMALOUS   D             2.6000   C2H6, C3H8, C4H10, C5H12
     80.189   W      OUTBURST    C             1.6000   C2H6, C3H8, C4H10
     80.190   W      OUTBURST    C             1.4000   C2H6, C3H8, C4H10
     81.255   W      OUTBURST    C             5.7000   C2H6, C3H8, C4H10, C5H12
     82.255   W      OUTBURST    C             1.5000   C2H6, C3H8, C4H10
     83.252   W      OUTBURST    C             7.4000   C2H6, C3H8, C4H10, C5H12
     84.255   W      OUTBURST    C             0.1200   C2H6, C3H8
     85.256   W      OUTBURST    C             0.0140
     86.253   W      OUTBURST    C             0.2200   C2H6
     87.256   W      OUTBURST    C             6.1000   C2H6, C3H8, C4H10, C5H12
     88.257   W      OUTBURST    C             0.2400   C2H6
     89.274   X      NORMAL      B             0.0006
     90.274   X      NORMAL      B             0.0006
     91.273   X      NORMAL      B             0.0000
     92.273   X      NORMAL      B             0.0028   C2H6
     93.272   X      NORMAL      B             0.0000
     94.272   X      NORMAL      B             0.0005
     95.271   X      NORMAL      B             0.0000
     96.355   X      NORMAL      B             0.0004
     97.356   X      NORMAL      B             0.0000
     98.361   X      NORMAL      B             0.0005
     99.361   X      NORMAL      B             0.0000
    100.027   X      NORMAL      B             0.0000
    101.362   X      NORMAL      B             0.0006
    102.362   X      NORMAL      B             0.0009
    103.363   X      NORMAL      B             0.0017   C2H6
    104.363   X      NORMAL      B             0.0000
    105.028   X      NORMAL      B             0.0000
    106.364   X      NORMAL      B             0.0000
    107.003   X      NORMAL      B             0.0000
    108.004   X      NORMAL      B             0.0000
    109.005   X      NORMAL      B             0.0026   C2H6
    110.006   X      NORMAL      B             0.0000
```

* DEPTH: A < 230 M < B < 380 M < C < 434 M < D

SAMPLE NUMBER	MINE	SALT TYPE	DEPTH*	CH4 CONTENT (CM3/100G)	HIGHER HYDROCARBONS
111.032	Y	OUTBURST	D	1.5000	C2H6
112.032	Y	OUTBURST	D	1.1000	
113.033	Y	NORMAL	D	0.0890	C2H6
114.033	Y	NORMAL	D	0.3100	C2H6
115.034	Y	OUTBURST	D	0.6200	C2H6
116.035	Y	ANOMALOUS	D	0.0350	
117.038	Y	ANOMALOUS	D	0.1200	
951.351	X	NORMAL	B	0.0000	
1001.210	Z	NORMAL	C	0.0021	
1002.214	Z	NORMAL	C	0.0020	
1003.214	Z	NORMAL	C	0.0130	
1004.166	Z	NORMAL	C	0.0070	
1005.168	Z	NORMAL	C	0.0039	
1006.168	Z	NORMAL	C	0.0053	
1007.168	Z	NORMAL	C	0.0110	
1008.169	Z	NORMAL	C	0.0024	
1009.175	Z	NORMAL	C	0.0032	
1010.175	Z	NORMAL	C	0.0050	
1011.176	Z	NORMAL	C	0.0008	
1012.172	Z	NORMAL	C	0.0029	
1013.174	Z	NORMAL	C	0.0032	
2001.243	Z	NORMAL	C	0.0027	
2002.244	Z	NORMAL	C	0.0030	
2003.245	Z	NORMAL	C	0.0110	
2004.246	Z	NORMAL	C	0.0066	
2005.250	Z	NORMAL	C	0.0090	
2006.252	Z	NORMAL	C	0.0019	
2007.258	Z	NORMAL	C	0.0011	
2008.259	Z	NORMAL	C	0.0047	
2009.260	Z	NORMAL	C	0.0012	
2010.263	Z	NORMAL	C	0.0028	
2011.236	Z	ANOMALOUS	C	0.0120	
2011.237	Z	ANOMALOUS	C	0.0260	
2011.238	Z	ANOMALOUS	C	0.0060	
2011.251	Z	ANOMALOUS	C	0.0390	C2H6

* DEPTH: A < 230 M < B < 380 M < C < 434 M < D

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