Faults in Salt Mines—Their Impact on Operations

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ABSTRACT

Low angle thrust, tear and en'echelon gravity faults characterize the bedded salts of the Appalachian Basin. Gravity faults have demonstrated a throw of 57 feet in the Cleveland area. The mining layouts for flat lying beds of industrial minerals, in general, conform to property boundaries. Faults and their accompanying stress patterns force deviations from the original mine layouts, complicating haulage and ventilation routes as well as creating rock mechanics problems.

The petrofabrics and in situ stresses associated with the fault system can cause floor heave, roof slabbing and pillar spalling. In order to achieve the most stable type of mine opening, the shape size on orientation of these openings must conform with the in situ stresses of the fault system. Other aspects of the problem is rate of penetration of drills, fragmentation of the salt, quantity of explosives required and the amount of roof and rib scaling needed during the life of the opening.

INTRODUCTION

In 1957-58 an exploratory program was initiated in the industrial district of Cleveland, Ohio known as "Whiskey Island." A drilling program was designed to show the quality and thickness of the salt beds underlying the area. Results of the exploratory drilling delineated a bedded structure resembling a shallow half saucer, open to the south (Fig. 1).

The first indication of possible structural problems appeared when the two shafts, located some 600 feet apart, showed abnormally large variations in the correlation of the tops and bottoms of formations. After the connection of the shaft bottoms in the salt, and the initial drifts were developed, the first fault was encountered (Fig. 2).

GEOLOGY

This was a gravity type of fault with a throw of from 4 to 4 1/2 feet located in the area of the service shaft. None of the other mines then in existence in the northeast portion of the United States, had disclosed the presence of any faulting in their mine workings. Other structural features appeared which were not characteristic of the Detroit and/or Retsof Mines such as boudinage, micro thrust faults, grabens and gravity faults with throws measuring in inches. All of these gravity faults were parallel to the strike of the first fault encountered and approximately perpendicular to the axis of the Findlay-Cincinnati Arch.

Because of a very low percentage of extraction in the area of the shaft pillar, headings advanced rapidly. Within 16 months, a major discontinuity in the salt was encountered at a distance of 3,400 feet from the bottom of the service shaft (Fig. 3). At various points, attempts were made to penetrate this irregularity. Gradually the magnitude of this fault structure became apparent. An exploratory core drilling program, designed to delineate the size and character of the fault was developed. At the point selected for the coring, a vertical displacement of 47 feet was found to exist. Results of the coring program are shown in Figure 4. The first core of this program, core hole #6601, was drilled horizontally in the face of one of the drifts which had been driven in an attempt to penetrate the fault. This hole which had a total depth of 569.0 feet, curved downward due to the weight of the

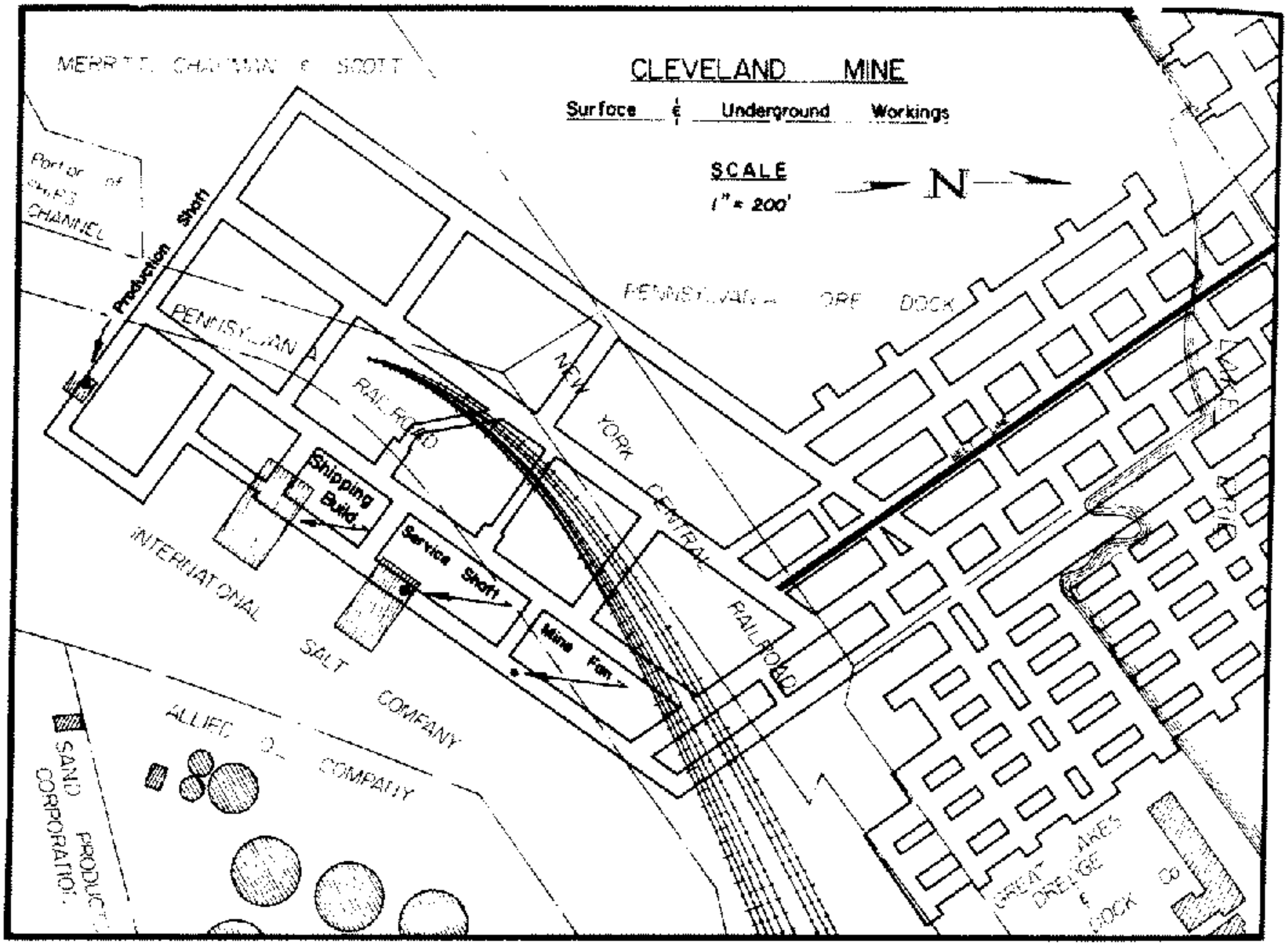

Figure 1.

drilling rods. After penetrating the two beds of salt shown (Fig. 4) and after several "twist-offs" of the rods had occurred, this hole was abandoned because of our fear of losing the tools in the hole. The trajectory of the hole was established by a deviational borehole survey. All holes were surveyed in a similar manner.

Drill Hole #6602, which was drilled upward at an approximate angle of 45° to the vertical, encountered no salt in its 101.5 feet of length. Due to the unknown proximity of the overlying water filled Oriskany sandstone, this hole was abandoned after filling it with an expanding cement. A third hole, C.H. #6603, was drilled downward in the same plane as C.H. #6601 and #6602 at an angle of about 45°. This hole disclosed two beds of salt in its original 110 feet of length. Good correlation could not be accomplished on the basis of the two holes which had encountered salt. Therefore, a fourth hole, #6604 was drilled upward at an angle of 20°, again in the same plane, but failed to encounter any salt. At this point, Drill Hole #6603 was re-entered and deepened to a depth of 210.2 feet with two additional beds being penetrated in its extension. Thus it was demonstrated that the block previously believed to be the up-thrown block was actually the down-dropped block.

To confirm this opinion, additional correlative data was required and thus Drill Hole #6605 was drilled into the floor of the drift. This hole encountered the normal sequence of beds at an elevation 47 feet below the level at which they were encountered on the near side of the fault. Thus, the conclusion has been tentatively drawn,

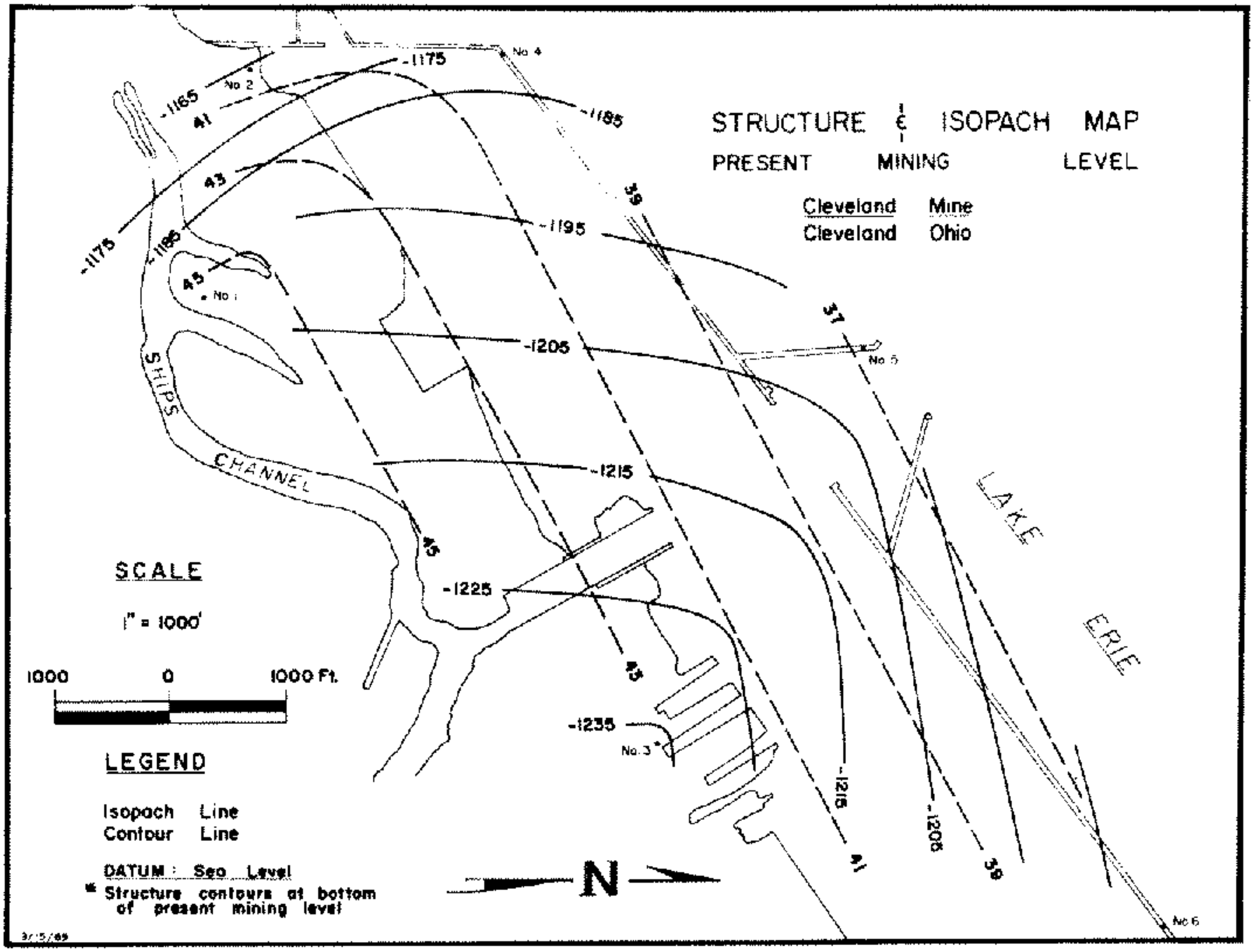

Figure 2.

that the area has been subjected to en'echelon gravity-type faulting.

Figure 5 is an isometric sketch of the exploratory program, extrapolated in three dimensions to cover conditions encountered in the three adjacent headings.

MINING

In establishing a mining pattern for the extraction of a low priced industrial mineral commodity such as rock salt, it is necessary to outline the mineral reserves sufficiently far in advance so that costly capital investments can be fully amortized and/or depreciated. Such a plan is generally based on a geological interpretation of the data obtained from an exploration program. The type and character of the mining and haulage equipment will be dictated long in advance, on the basis of the pattern that is established from this data. It is an unfortunate truth that has long endured in the salt mining industry, that most mining machinery and equipment used in salt mines has been originally designed and manufactured for the coal mining industry and subsequently modified to meet the conditions of the particular salt deposit which is to be exploited. When previously undisclosed faults of a magnitude such as that encountered in the Cleveland Mine are uncovered, it can cause severe disruption of mining operations and consternation in management.

Such anomalies can be particularly disrupting if the fault forms a barrier to a major portion of the

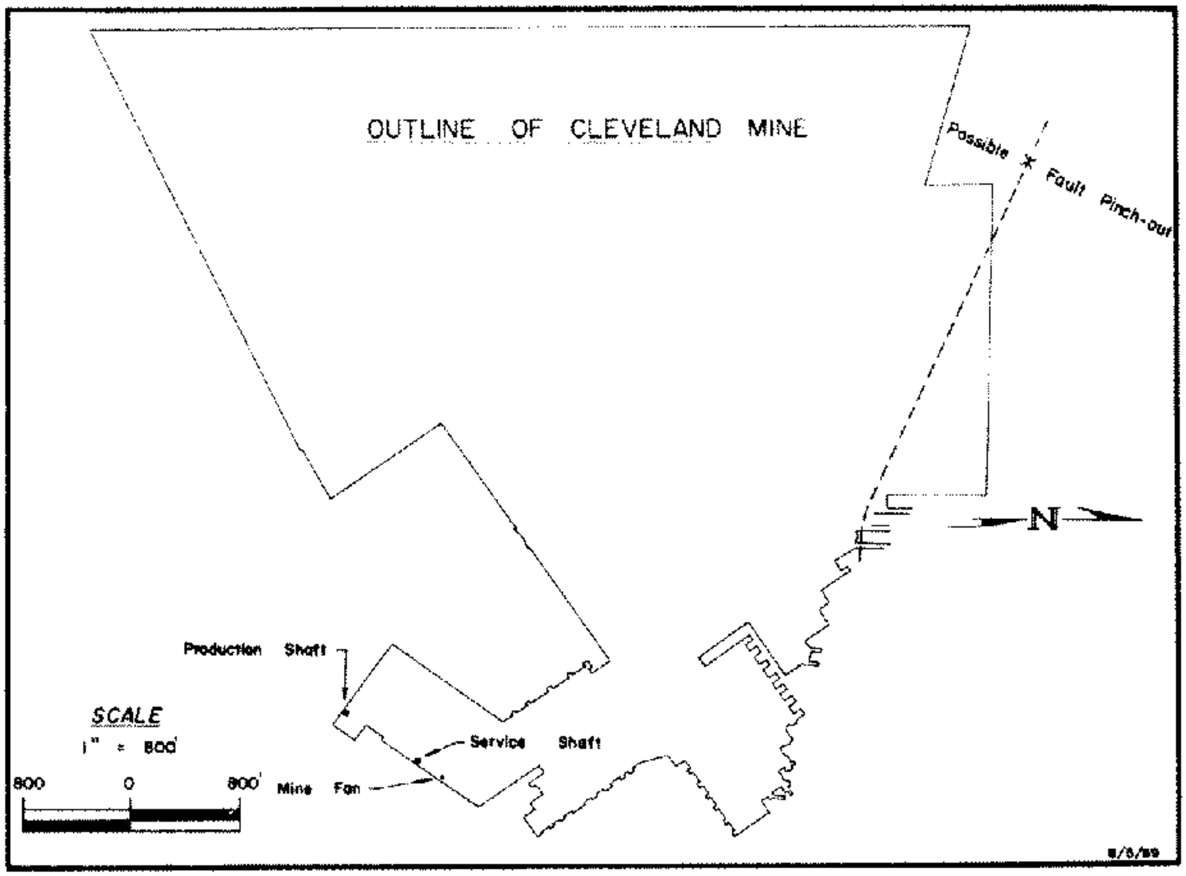

Figure 3.

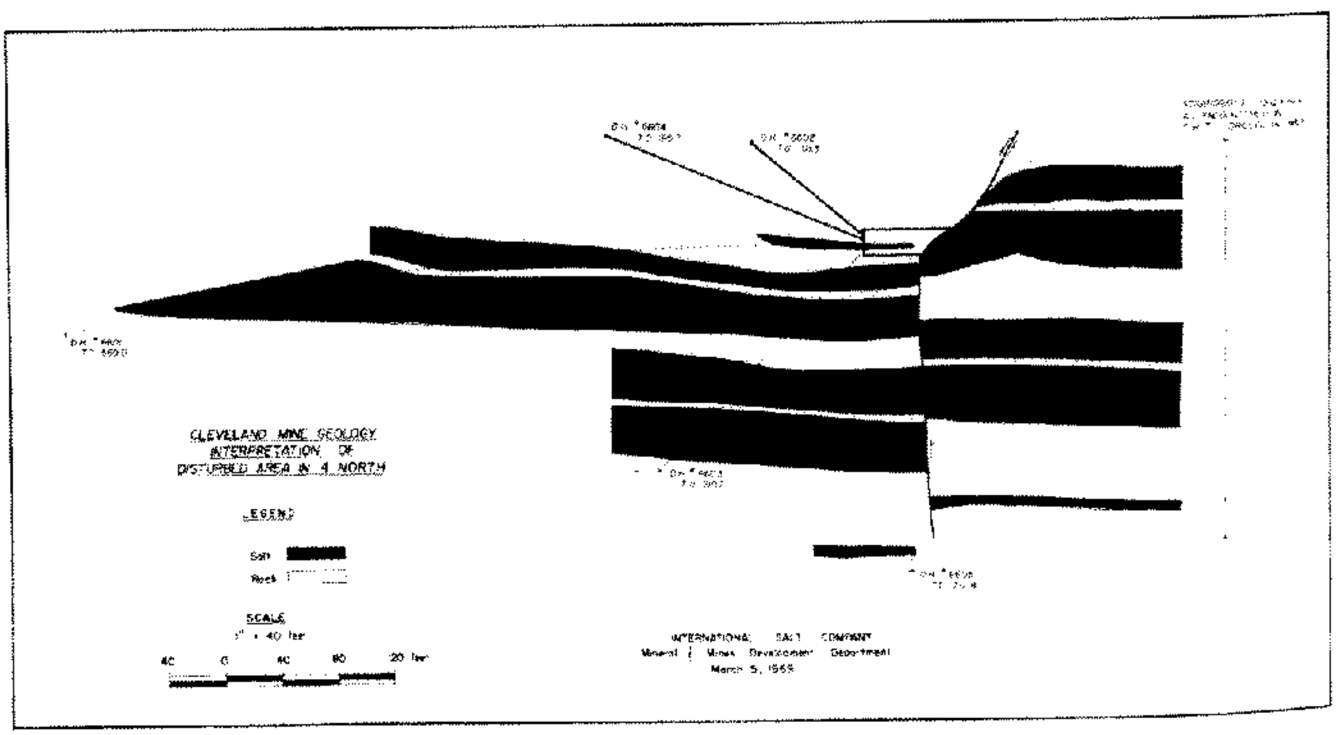

Figure 4.

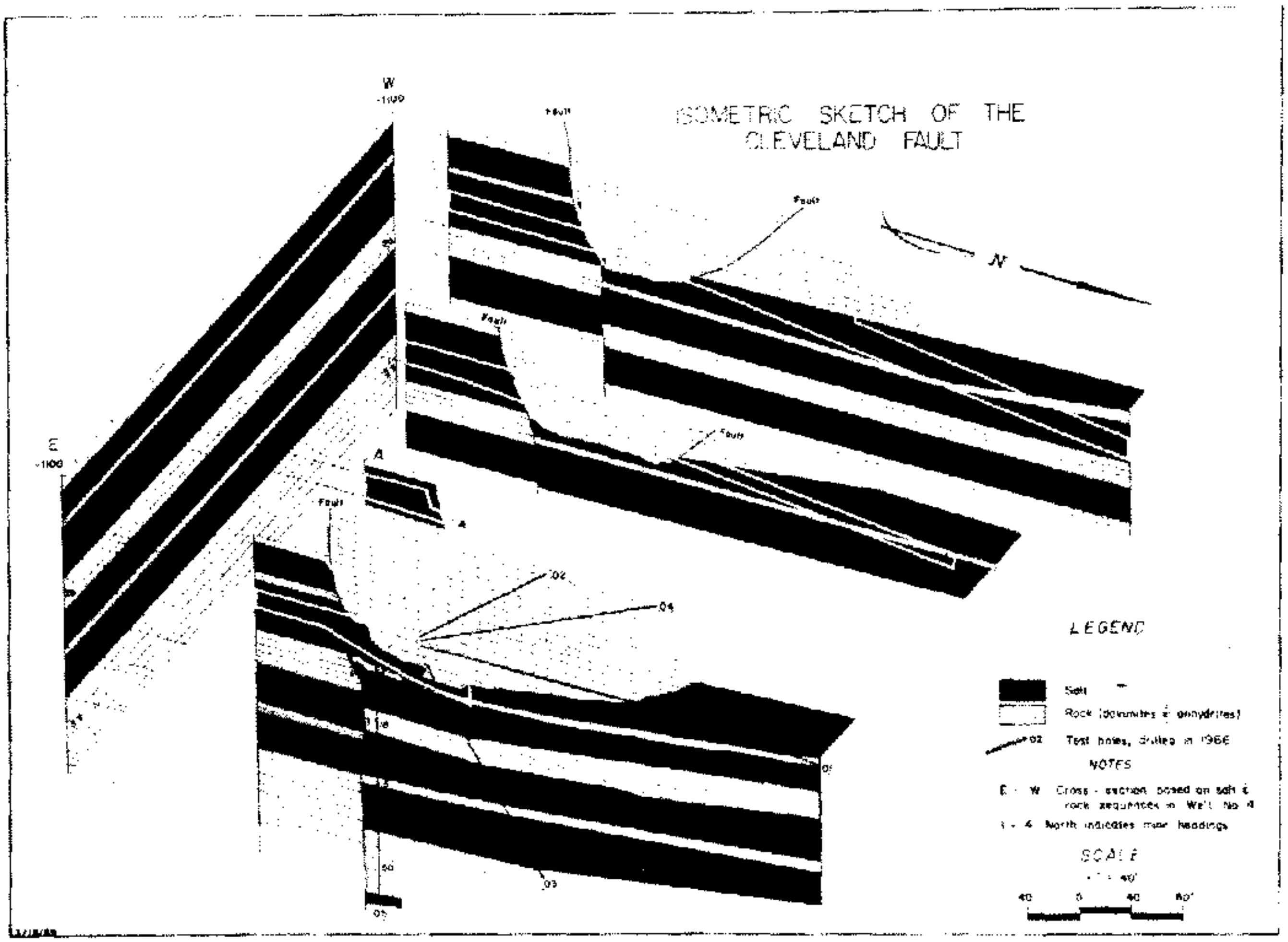

Figure 5.

ore reserves. Where a large tonnage, highly mechanized mine has been developed in an orderly manner, there is a strong possibility that most of the ore reserves on the near side of the fault will be exhausted by the time the solution to the geological anomaly has been resolved and a new mining pattern established. Fortunately, in the case of the Cleveland Mine, the State of Ohio came to the company's aid by leasing additional adjacent acreage which allowed the continuation of mining operations without interruption while plans were being formulated to penetrate the fault.

If it is necessary to curtail mining operations in order to penetrate the fault and develop the ore reserves in the area on the far side of the fault, mining costs on a per ton basis will be increased and service to customers will be jeopardized. In penetrating the fault itself, it may be necessary, as in the case of Cleveland, to secure additional special equipment of a type suitable for mining through the harder "rock" formations. This again has an adverse effect on the mining costs and may require special training of personnel and/or the hiring of a contractor.

The greatest impact on operations is probably in the laying out of the new mining pattern after the fault has been penetrated, in that sufficient material must be left in the form of a barrier pillar to insure the stability of the fault area. Rock movements must be closely monitored by the installation of convergence gauges and/or dilation pins or other instrumentation. In developing the far side of the fault, particularly in a room and pillar system, special consideration must be given to the organization of equipment. This usually means that the mine must be laid out in panels, each panel worked by a complete equipment unit consisting of a drill, undercutter and loader with the necessary haulage units. Travel time of equipment between faces and/or panels must be kept to a minimum.

The point at which the fault is penetrated must be in keeping with the center of mass, so that any increase in haulage costs will be kept to a minimum. Not only must consideration be given to the center of mass with respect to haulage, but also the location of the primary crusher, road grades, traffic patterns and the type and location of the haulage system after the primary crusher. If, as in the case of the Cleveland Mine, en'echelon faulting has occurred or is suspected, long-range planning must incorporate sufficient flexibility to cope with the numerous variations that may be encountered.

In salt mines, it is the general practice in the U.S. to use belt haulage after the primary crusher. As mining advances the working faces, the truck haulage distance is increased to a point where the truck haulage cycle is uneconomical. At this point, the crusher is relocated to a position closer to the working faces and the main line conveyors extended.

In an orderly progression, each of the panels is developed, mined, sealed off and the unit of mining equipment moved to the next panel. Care must be taken in the layout of panels in order to insure an adequate supply of fresh air across the active mining faces. Again, ventilation routes must be developed so that the shortest possible air travel is obtained.

The petrofabrics associated with these faults show a linear space lattice structure which has a definite influence on the stability and safety of the mine openings. It has been demonstrated that, where the orientation of the mine opening conforms to the major and minor in situ stress pattern, improvement in both the roof and pillar conditions will be experienced. Such layout of mine openings, in all probability will not conform with the legal boundaries of the mineral holdings and therefore results in irregular boundary configuration and a lower percentage of extraction. In addition to improved rates of penetration in the drilling of shot holes, increased rates of undercutter travel and rock fragmentation per pound of powder should result by adhering to the petrofabric orientation of the rock.

In the final analysis, the increased costs directly related to the disruptive effects of the fault or faults on the mining operations may be serious, but the critical factor is any new movement in the fault which may result from a differential stress across the fault and/or improper support of the fault. At the moment, we have little or no protection against the sudden unexpected collision with these faults in extending our headings. Horizontal exploratory drilling is of limited value, but is one's only insurance against water filled fault spaces. Research is currently underway to develop a method to detect the presence of these faults by use of electromagnetic energy, but even if successful, a useful tool is a number of years in the future.

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