W023582-062317 - Freedom of Information Law Request

Freedom of Information Law Request Details

✓ Extend 3 wks

Freedom of Information Law Request Details

Type of Record(s) Requested:	Other
Description of Record(s) Requested:	All reports on the operation of Cayuga Salt Mine from year 2000 to the present including but not limited to those submitted to DEC by Cargill and including all CDs, all maps as AutoCad or Adobe Acrobat files, all extensometer and closure readings as Excel or other digital files, all consultant reports including but not limited to those reports from ESC, RESPEC, Rock Mechanics Assist and RockTec Solutions, and any other materials submitted as part of the annual report submission process including materials only sent to John T. Boyd company and not copied to a DEC office.
NYSDEC Office processing the Request:	Region 7: (Central New York) Covers the counties of: Broome, Cayuga, Chenango, Cortland, Madison, Onondaga, Oswego, Tioga and Tompkins **If your request pertains to just one Region, select that Region. If your request pertains to more than one Region, select Central Office. If you're unsure which Region your request pertains to, select Central Office. The Department will route your request to the appropriate Region(s)**
Legal Review Required:	If this field is marked Yes, it must be routed to the Office of General Counsel for review prior to the release of any documents.
Preferred Method to Receive Records:	Electronic copies
Amount of Payment:	
Date Payment Received:	

Exemptions

Region 2 Activity Creation

Region 9 Activity Creation

Message History

Date

YIELDING PILLARS and PRESSURE ARCHES AT THE CAYUGA ROCK SALT MINE

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ABSTRACT:

Even though pillars were 88 feet square and only 8 feet high, with entries 32 feet wide to give an extraction ratio of only 46%, the standard room-and-pillar layout at depths in excess of 2,500 feet resulted in undesirable roof conditions.

A plan was conceived for using small pillars which would yield and shed load onto massive abutment pillars, thus reducing roof stresses in the mining area.

Two test areas were mined, the latest giving 90% extraction in a panel 600 feet long and 200 feet wide. Pillar stubs were as small as 12' x 28'; entries became 46 feet wide. Nominal pillar load was 32,000 psi, giving a "safety factor" of 0.16, but there are no signs of roof or pillar failure. The test panel was very productive, largely because of short equipment moves and low-cost pillar robbing.

Simple instrumentation showed that the pillars did yield, the load was shed onto abutments, and an arch must have formed.

Further instrumented tests are being run to adapt the principle of the yielding-pillar/pressure arch to the various requirements of both development and production panels.

GEOLOGICAL SETTING:

The mining horizon is one of several beds of rocksalt interspersed with beds of shale and dolomite. They are part of the Late Silurian Syracuse formation.

Although some of the upper beds are severely distorted, the #6 salt is fairly consistent in thickness, and it dips gently to the south, at about 100 feet per mile.

Thickness of cover varies from 2,300 at the shaft near Lake Cayuga, to more than 3,000 feet under the hills to the east of the lake.

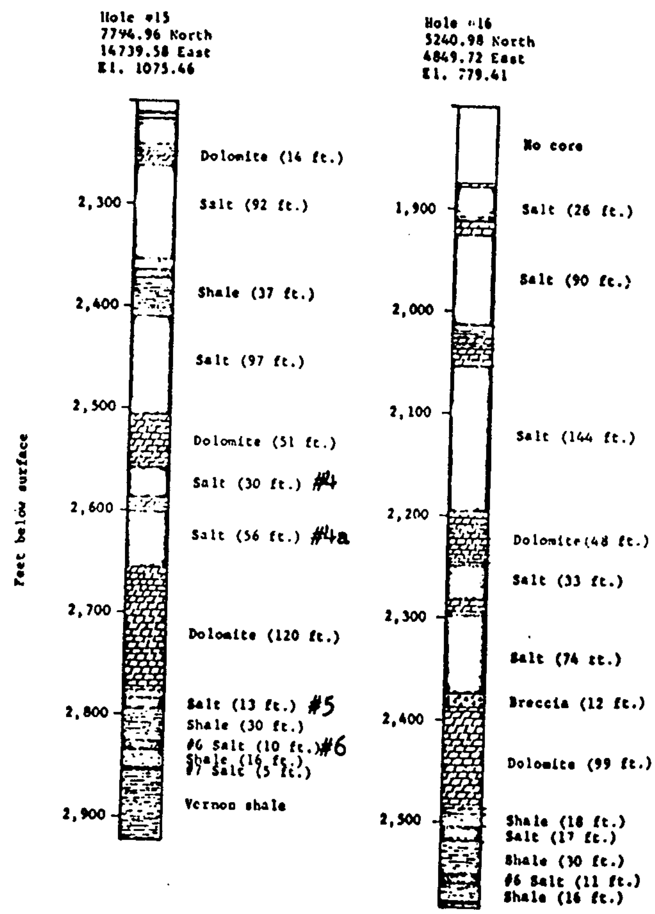


Fig. 1: Geological Cross Sections

MINING METHOD AND EQUIPMENT:

Conventional equipment is used in a room-and-pillar layout.

Seven foot and eight foot roofbolts are installed on 4 to 5 foot centers, then the salt face is undercut with a Joy 15 RU undercutter to a depth of 14 feet. A Fletcher face jumbo is used to drill 24 1-3/4" holes in entries 32 feet wide and 8 feet high, then the holes are loaded with either Troja-

Exhibit 3

mite "C" or Tovex 90, and they are blasted. Broken salt is hauled to a Stamler feeder-breaker with Wagner ST-5A LHD vehicles, then it is conveyed to a preparation plant where it is crushed and screened, then hoisted to surface.

Daily production is around 3,300 tons.

ORIGINAL MINE DESIGN:

Mining in the #4 salt simply followed the thick rolls of that contorted salt bed, so both pillars and stopes varied greatly in width.

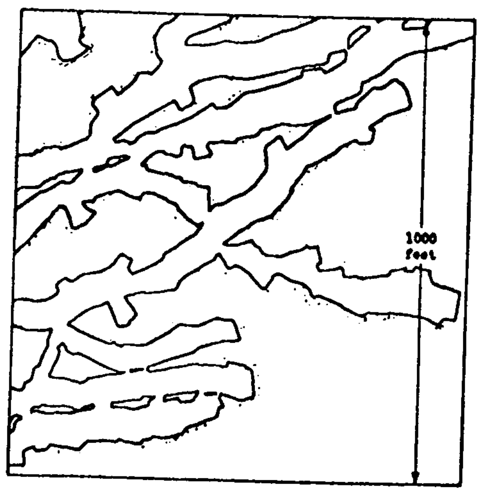


Fig. 2: Map of part of the #4 level, showing how both pillars and stopes varied in width.

The layout in the #6 salt was more systematic. Entries 32 feet wide and pillars 88 feet square gave about 46% extraction, which, at a depth of 2,400 feet, gave an average pillar load of about:

$$\frac{2,400 \times 1.1}{.54} = 4,890 \text{ psi}$$

This gave a nominal pillar safety factor of about 1.0, since the compressive strength of rock salt is generally assumed to be around 5,000 psi.

To achieve a more commonly accepted theoretical pillar safety factor of 2.0, we would have had to aim for a pillar load of 2,500 psi, which would have meant zero extraction. However, even with a safety factor of 1.0 we experienced no pillar failures, so we could not apply that particular theory.

In the early years of mining there were few ground-control problems, perhaps because we were mining beneath an "umbrella" of workings in the #4 salt, but that is part of another story. Ground conditions became more difficult in recent years, and in May of 1975 a month's production was lost when the entire mining front was closed by MESA. A new mining front was established perpendicular to the first, but one year later this front was also threatened by numerous roof failures.

Mine design seemed to be inadequate. Entries for travelling, conveying and ventilation must stay open for tens of years, whereas only a year or two of stability was being achieved.

MODE OF ROOF FAILURE:

The floor did not heave and the pillars did not fail, but apparently the load was too great for the roof rocks.

In most places a foot or two of salt is left in the roof, and vertical loading results in sideways motion of the salt in the roof. If there is a free face, due to overbreak perhaps, the salt moves towards it. If there is no free face, a low-angle shear develops along one rib and the salt is thrust sideways and downwards. In an entry 32 feet wide there can be as much as a foot of sideways motion - sufficient to shear 3/4" bolts, both mechanical and resin-grouted.

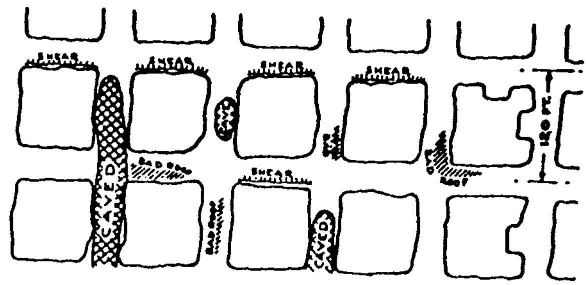


Fig. 3: Map of typically bad ground

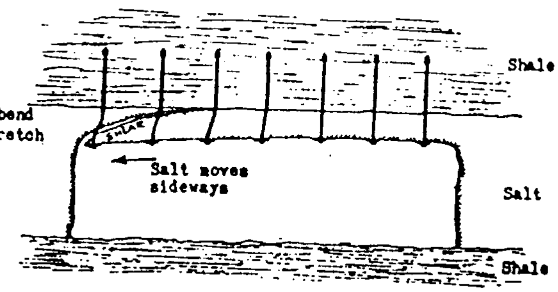


Fig. 4: Cross-section of typical roof failure

The salt layer then breaks up and falls, and similar activity continues up into the overlying shale. Height of failure seems to be related to mining depth, as shown in the next sketch:

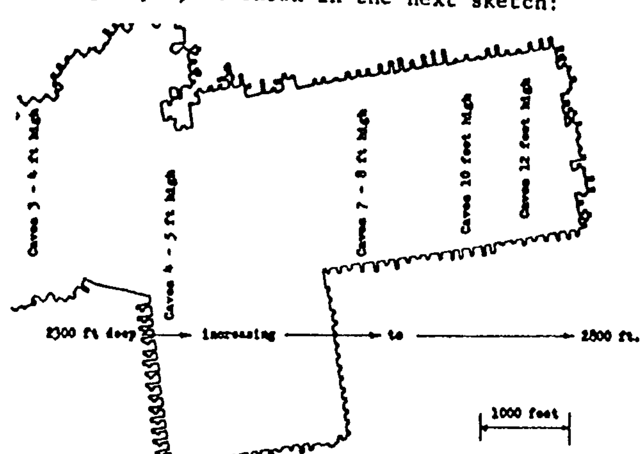


Fig. 5: Height of roof failures increases with mining depth

orientation, but they do most often begin between pillars and not in the intersections.

YIELDING PILLARS - A POTENTIAL CURE FOR THE PROBLEM:

Since we were already very deep for salt mining, with an extraction ratio and pillar dimensions already unfavorable for efficient mining, we could see only one possible solution.

We had to design pillars so small that they would yield under load, instead of being so stiff that they would overload the roof rocks and cause roof failures.

At the same time we would have to have "abutment pillars" available, strong enough to support the load shed by the yielding pillars.

And presumably there would be some critical width within which the overlying strata would bridge or arch onto the abutment pillars, but beyond which the bridge or arch would collapse.

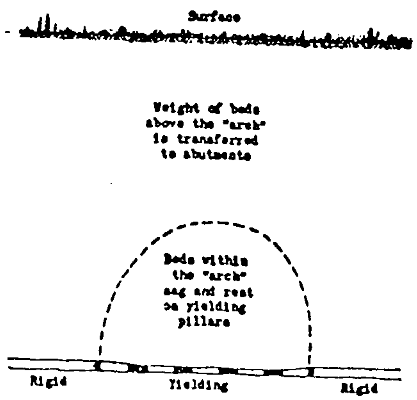


Fig. 6: Principle of yielding pillars and pressure arch.

In our case we suspected that a layer of dolomitic shale would help by providing a "beam" about 100 feet thick (see Fig. 1).

Then a rather delicate balance would have to be achieved. The yielding pillars must support the rock within the "arch", and the mining panel must be wide enough to allow good mining productivity, but it cannot be too wide, or the arch will be too high, then the yielding pillars will be overloaded.

We had no reliable theory to work with, so we had to get our design information from experiments in the mine. And we had to do it without impeding production.

COULD WE CAUSE PILLARS TO YIELD AND SHED THE LOAD ONTO ADJACENT, STIFFER PILLARS?:

We were reasonably sure that the behaviour of pillars - yielding, or stiff, or very rigid, would depend upon the width:height ratio, and we had an idea that the ratio for a yielding pillar should be around 3:1 - which meant that the yielding pillars should be something like 24 to 30 feet wide.

By fortunate coincidence, we could get pillars of that size by simply driving standard 32 ft. entries through the middle of standard 88 foot square pillars - leaving four stubs each 28 feet square.

So the plan was made to split four of the large pillars, close enough to the mining front for the faceequipment to do the work, and to get some easy salt.

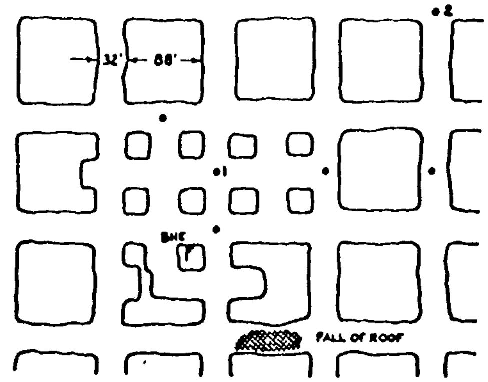


Fig. 7: Layout of split pillars, showing convergence points and borehole extensometer (BHE)

INSTRUMENTING THE TEST:

In theory we were stretching our luck. We were already having problems with 46% extraction and 88 foot square pillars, but we were going to reduce pillars to 28 foot squares and boost extraction ratio to 79%, thus boosting nominal pillar load to 13,600 psi.

Our plan was to make those small pillars shed the load onto larger adjacent pillars, so relieving some of the stress in the roof amongst the small pillars, but we had to make sure this was happening.

We used two simple forms of instrumentation:

Convergence measurements:

Small reference points were installed in roof and floor, so that the distance between them could be measured to the nearest thousandth of an inch, with a Reed-type extensometer. Subsequent measurements show how much the distance between roof and floor has changed, and at what rate.

Convergence measured in this way includes roof sag, pillar yield and floor heave, but were able to determine that the movement was mainly pillar yield amongst the small pillars, and roof sag amongst the large pillars.

Graphs of convergence measurements show the effects of mining, and they show if trends are decelerating toward stability or accelerating toward failure.

Borehole extensometers:

For a pillar to yield it must not have a rigid core, but the core of a rigid pillar must not yield.

To check the behaviour of our pillars we installed borehole extensometers in both 28 foot and 88 foot squares. The design is simple, but effective. A hole is drilled into the pillar, then wires are anchored at various depths in the hole with their ends hanging out of the collar of the hole. Periodically we measure the distance from a mark on each wire (perhaps a split shot) to a reference point at the collar of the hole.

Measuring to the nearest 1/100 of an inch is precise enough, because the rock salt does move so much.

Measurements taken at the collar of the hole show the relative movements of the anchors, so we can tell if the inner parts of the pillar are rigid or moving.

RESULTS OF THE PILLAR-SPLITTING TEST:

The results of the experiment are shown most clearly by graphs.

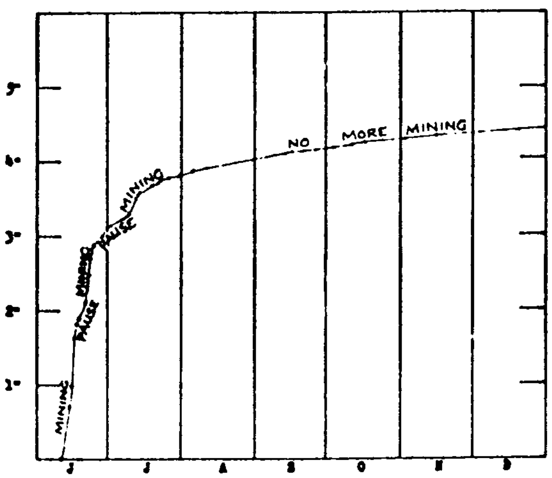


Fig. 8: Above, shows how the convergence rate at Point 1, which was typical of the area of split pillars, responded to the mining of each pillar, and to each delay, and settled down to a moderate trend after mining ceased.

The graph indicates that the small pillars did yield, and the moderate long-term trend shows that the pillar could not possibly be supporting the nominal load of 13,000 psi, so that load must have been shed onto adjacent, larger pillars.

There is normally some continuing convergence everywhere in the mine. The rates vary, and they seem to be related to the load on the salt.

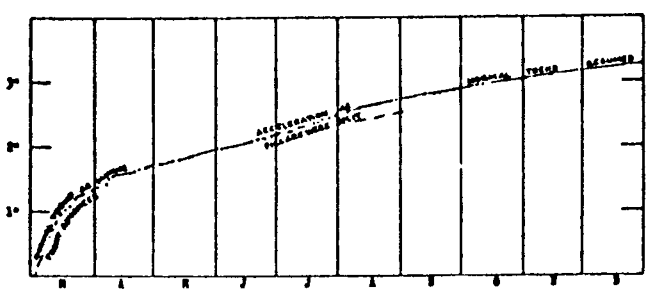
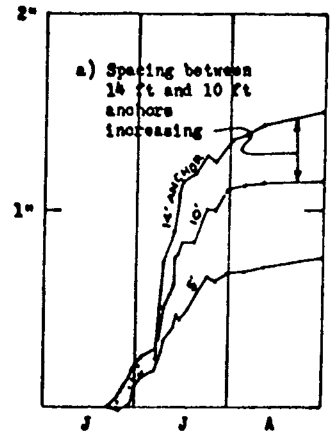


Fig 9: Above, shows how splitting the pillars affected a convergence station some 200 feet from the test. There was an immediate response when splitting began, and rates diminished when splitting ceased. These were direct indications that the load had been shifted from the split pillars and onto a wide zone of the larger pillars.

This was also evidence that pillars 88 feet square were not big enough to serve as abutment pillars, which are meant to accept and restrict the spread of the transferred load.



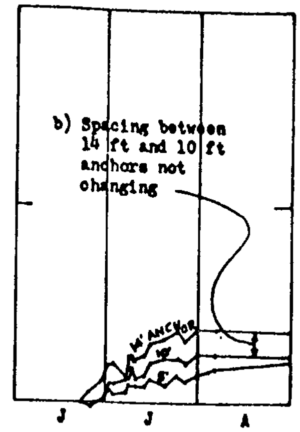


Fig. 10a: At left, above, shows the apparent movement of borehole extensometer anchors within a 28 foot square pillar. Since the deepest anchors moved apart, the core of the pillar must have been yielding.

Fig. 10b: At right, above, shows the relative movement of anchors within an 88 foot square pillar. It shows that the outer 10 feet of the pillar was moving into the entry, but the greater width of the pillar had lent rigidity to its core.

Visual observations were in agreement with the measurements:

> The first cuts into pillars were difficult and noisy, suggesting that the skins of the big pillars were highly stressed.
>
> Roof conditions were unusually good in the new entries through the pillars, probably because of low pillar load.
>
> Roof conditions deteriorated in the entries around the test area, including a roof fall just south of the test area (Fig 7).

A LARGER TEST PANEL:

Results of pillar splitting were so encouraging that we planned a larger test panel, with nine entries 32 feet wide to be driven eastward about 200 feet, so developing a row of "transition" pillars each 40 feet by 88 feet, and two rows of pillars each 28 feet square.

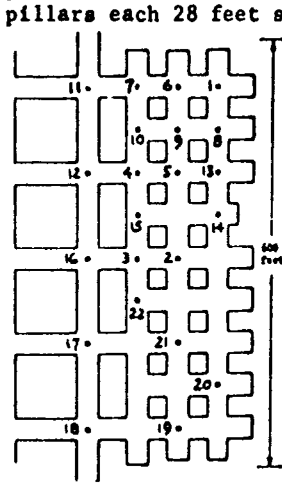


Fig. 11: Shows the layout of the NE test panel, and the location of the convergence points

factor of 0.37, our only problem was that the miners were upset when we stopped the panel. Short equipment moves made it easy for the miners to earn a production bonus, but we had to stop for a while, to assess the stability of this new panel.

Convergence measurements showed that conditions stabilized quickly.

Since this panel was well away from the production front, we thought that we would see how far we could push the yielding-pillar/pressure arch concept - by reducing the size of the 28 foot square pillars.

At first we did not want to expose the cutter operator, so we tried just blasting slabs off the pillars, but blasting was not very successful without the undercut.

Because convergence rates settled so quickly after the blast, we did bring the cutter in, but we monitored two or three extensometers continuously while cutting and mucking.

At first we were somewhat concerned at the rates of convergence during the undercutting of each pillar, but soon we were pleased and amazed by pillar behaviour. (See Fig. 12).

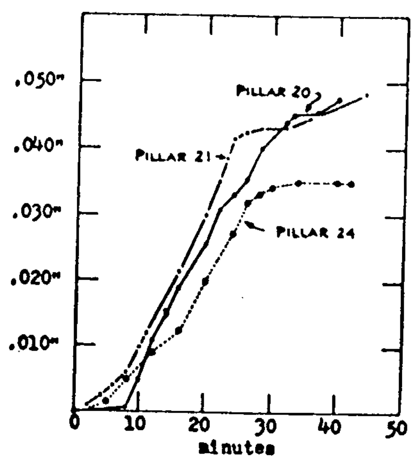


Fig. 12: Above, shows convergence rates measured at intersections adjacent to three different pillars as they were undercut. Note that the responses to beginning and finishing the cuts were almost immediate, indeed by watching the dial we could tell when the machine was cutting salt and when it was idling. Note too that total convergence was almost exactly the same for all cuts, and remember that the changes are in thousandths of an inch over a total height exceeding 100". We were pleased very much by the consistent and predictable behaviour of the salt.

We did not finish two of the pillars, because of a feeder-breaker moveup in the production panel, but ended up with stubs as shown in the next sketch.

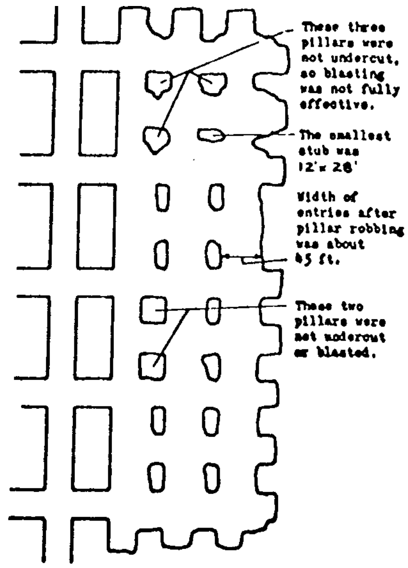


Fig. 15: Map of NE test panel after pillar robbing

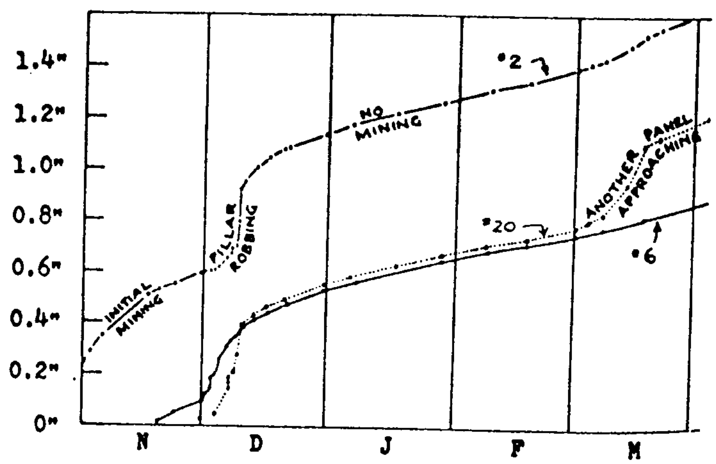


Fig. 14: Shows how the rates of convergence accelerated during pillar-robbing, but decelerated to steady, long-term trends soon after mining ceased. The rates, we believe, depend upon the height of the "arch", which depends mainly upon local geology and width of panel.

CONCLUSION:

Although the extraction ratio in the test panel is about 90%, giving a nominal pillar load of 32,000 psi and a pillar safety factor of 0.16, there are no signs of pillar or roof failure. The pillars have indeed yielded and shed their loads onto more massive abutments. There is an arch. The mining operation was very productive, like an assembly line. We were very pleased with the measurements, because they have given us so much control over rock behaviour.

We believe that we simulated shallow mining conditions at a depth exceeding 2,500 feet. We don't have all the answers yet, but we are working on further simple, instrumented tests to adapt the principle of the yielding-pillar/pressure arch to development and production needs.