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Jonathan Stercho
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Syracuse, NY 13214
Comment.CayugaSaltMine2023@dec.ny.gov

Re: Technical Review of Cargill's application for permit renewal and modification, Cayuga Salt Mine, 0-9999-00075/00001

Dear Mr. Stercho:

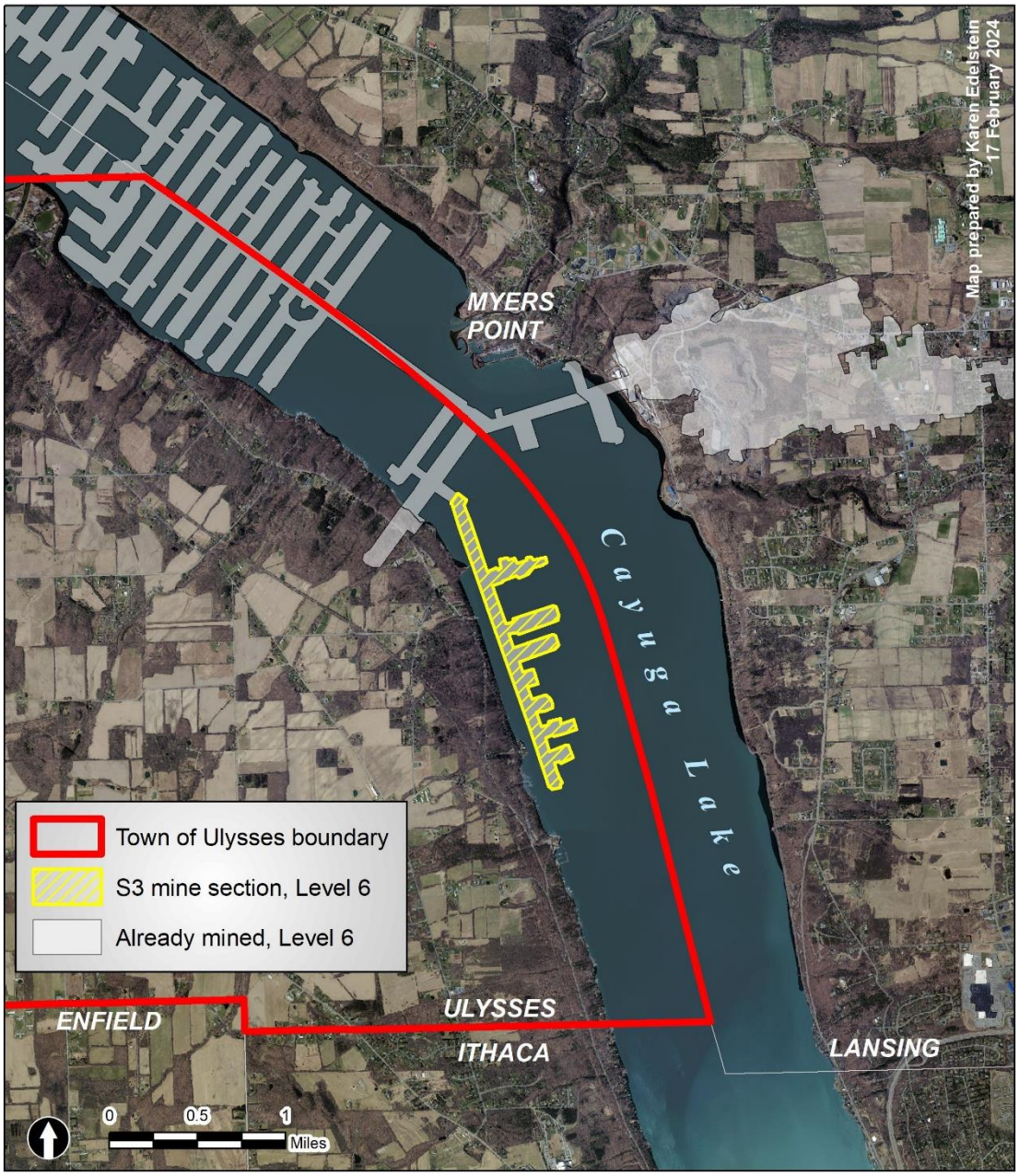
I submit the following technical review as additional support for the public comments prepared by Cayuga Lake Environmental Action Now (CLEAN). CLEAN asked me to perform an independent technical review of Cargill's application for permit renewal and modification relating to the proposed flooding of the S3 area, including DEC's Negative Declaration under SEQR.

I am a Professional Geologist (NY PG license 0258) and am familiar with the Cayuga Salt Mine, having been involved in providing comment on Cargill's operations previously. My CV is attached. In addition to the Cayuga Salt Mine, I am familiar with the Retsof salt mine in Livingston County, NY, which collapsed and flooded in 1994-95. During the period that I worked as an environmental scientist for the NYS Attorney General's Office between 2000 and 2012, I assisted in post-collapse characterization studies of the Retsof mine and its environmental impacts which are associated with upward and lateral movement of brine from the collapsed mine.

I have reviewed the available records regarding Cargill's renewal/modification application, including the DEC documents titled "0-9999-00075 Cayuga Salt Mine FEAF_Part 3_11.19.2024" and "0-9999-00075 Negative Declaration Narrative_11.19.2024" and other written sources cited herein. Some of the written sources I cite are the work of independent scientists; some are by other experts affiliated with the Cayuga Salt Mine and the failed Retsof salt mine. My review has focused in particular on the redacted version of a report entitled "Flac3D Stability Analysis of S3 Submains and E5 Panel, Cayuga Mine," prepared by Agapito Associates, Inc. for Cargill, Inc. dated April 12, 2022 (Agapito report). The Agapito report and associated modeling are referenced in the Negative Declaration as support for the conclusion that "the storage of water in the S3 main and the adjacent panels will not impact global stability" in the mine. In my opinion, based on the redacted Agapito report and other sources cited herein, the report and its associated modeling do not support such a conclusion. The report does not serve its stated purpose of demonstrating global stability, partly because pore water and its

negative effects on rock strength are not assessed, and partly because relatively strong rock layers above the mine are unrealistically modeled as elastic, "meaning they can accept unlimited load without failing."[1] Further, neither the Agapito report nor other information available from DEC or Cargill has assembled the information outlined here about the use of yield pillars when S3 was mined, the resulting pressure arches and destressing of rock within them, the presence and non-elastic response of joints and fractures within the bedrock above the mine, the in-migration of pore water through such joints and fractures, the formation of brine pockets, etc.

Geographic setting – map created for CLEAN by Karen Edelstein, showing S3 in yellow outline



[1] Quoted from the Agapito report at 3.

Agapito Report

The most serious problem is that Agapito's FLAC3D modeling of rock stability, as reported, fails to consider *pore water* within the rock, how it moves into and through the rock layers that Agapito modeled, and how such migration of pore water relates to the downward sagging (subsidence) of overlying rock, its overall weakening, and the deterioration of localized and global stability. In other words, the presence, variability, and effects of water within the many hundreds of feet of rock above the mine are not taken into account in Agapito's modeling. For example, the report says that:

> Agapito is not familiar with the hydrogeology of the Cayuga Mine, and details of hydraulic potential and its implications were beyond the scope of the study[2]

and says, without citation or reference to evidence, that the mining panels

> are isolated hydraulically from the overlying strata and Cayuga Lake.[3]

The Agapito report clearly recognizes the water (brine) that is intended to flood the S3 cavity within the mine, but this bulk quantity of water is distinct from the water within the joints, fractures, bedding openings, and other pores of the overlying rock. Neither Agapito's base model nor its flooded model acknowledges the presence of such pore water. On the contrary, Agapito notes only that "that the closest aquifer is about 1,200 ft above the No. 6 Salt."[4] While there may not be enough pore water in the overlying rock to be recognized as an aquifer, the presence of pore water has a substantial and widely recognized influence on rock properties and rock stability. For example, as noted in a recently published paper:

> In the last few decades, the influence of water on the mechanical behaviour of rock has been widely studied, and these studies verified that ***a small increase in water content can significantly reduce the strength [of] rock*** (Althaus et al., 1994, Zhou et al., 2016, Wong et al., 2016, Li et al., 2012, Ojo and Brook, 1990, Vasarhelyi, 2003, Van Eeckhout, 1976, Van Eeckhout and Peng, 1975, Colback and Wild, 1965). Broch (Broch, 1974) proved that even in igneous and metamorphic rock with low porosity, water-induced weakening effects are still significant. Althaus et al. (Althaus et al., 1994) and Li et al. (Li et al., 2012) found that a decrease in friction angle is an important factor in reducing the strength of wet rocks. They also reported that the pore pressure reduces the effective stress, thus causing a decrease in the rock strength (Althaus et al., 1994, Li et al., 2012).[5]

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[2] Id. at 38.

[3] Id. at 1. Id. at 38 indicates, more cautiously, that "the potential for paths between the [closest] aquifer and the mine workings is low."

[4] Id. at 38.

[5] Pan et al., "Analysis of rock slope stability under rainfall conditions considering the water-induced weakening of rock," *Computers and Geotechnics*, Volume 128, December 2020, 103806; emphasis added.

The authors of the paper continued as follows:

> Therefore, ***water is an essential factor that has to be considered in the stability analysis of a rock slope***. Due to the existence of joints and fractures in the rock mass, the weakening effect of rock mass when saturated can be more significant.[6]

Similarly, see Cheng, J., Liu, Y., Xu, C. et al., "Study on the influence of pore water pressure on shear mechanical properties and fracture surface morphology of sandstone," *Sci. Rep*. 14, 5761 (2024). https://doi.org/10.1038/s41598-024-55834-8. These authors focus on sandstone but their methods appear useful for the various lithologies that need to be included in a study that characterizes rock stability above the mine.

The Agapito report has been provided only in redacted form. Since the physical properties such as Young's modulus that were used for the modeling are among the redactions,[7] there cannot be complete certainty on whether Agapito ran its models with a range of values for the rock properties based on their water content. However, judging from the format of the redacted table, this was not the case; it appears that Agapito's base model and flooded model were assigned a single set of values without regard to the water content of the rock above the mine. The apparent failure to account for pore water above the S3 area is a critical oversight that calls into doubt the efficacy of the Agapito report's conclusions.

Further, the importance of the presence of pore water in the stability of the area above S3 is magnified by Cargill's use of small "yielding pillars" or "yield pillars" in this area. Mine pillars in general are pillars of unmined salt that are intended to help support the mine roof. All pillars, even large ones, will slowly deform or "creep" to some extent as the weight of the overlying rock pushes the mine roof downward – but small yielding pillars are deliberately too small to carry much load. By design, such pillars shift most of the weight onto more widely spaced pillars or abutments that are larger and stronger, thus creating a wide "pressure arch" in the rock above a mine which de-stresses the overlying rock within the arch.[8] The Agapito report fails to discuss this. It doesn't discuss the use and implications of yielding pillars when salt was mined in the S3 area and elsewhere under Cayuga Lake,[9] or how yielding pillars contributed to the 1994 collapse of the Retsof salt mine in Livingston County,[10] or how the resulting concerns about the stability

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[6] Id..

[7] Agapito report, Table 1.

[8] For background on this practice, see Agapito, J.F.T and Rankin, R.R., "Prefailure pillar yielding," *Mining Engineering*, November 2002, 33-38.

[9] For a 1993 overview of yielding pillars being used by Cargill for mining under Cayuga Lake generally (not just S3), see Petersen, G.; Plumeau, D.; and Rankin, J., "Practical Approach to Mine Design at the Cayuga Rock Salt Mine," *Seventh Symposium on Salt* (Elsevier), Vol. I, 259-264 (1993).

[10] Gowan, S.W.; Van Sambeek, L.L.; and Trader, S.M., "The Discovery of an Apparent Brine Pool Associated with Anomalous Closure Patterns and the Eventual Failure of the Retsof Salt Mine," *Proceedings, October 1999 Meeting of the Solution Mining Research Institute*, Washington, DC, 242-272; Gowan, S. W. and Trader, S.M., "Mine Failure Associated with a Pressurized Brine Horizon: Retsof

of Cayuga Salt Mine have not received the attention they need from regulators, the public, and third-party experts.

Given the key goal identified in the introductory paragraph of the Agapito report ("Cargill is interested in assessing the global stability in the flooded area, which if compromised, could potentially cause a sudden flood of the stored water into the active workings"), the following points from a widely cited paper by Whyatt and Varley need attention. They show the relevance not only of the yielding pillars and flooding in the immediate vicinity of S3 but also their effects on the overlying rock – including the "carbonate beam" rock which is a type of strong/brittle overburden. As pointed out by Whyatt and Varley, *yield pillars redistribute the stress in the overlying rock*, the effects of which extend upward from the mine into overlying rock and have important implications for the mine's global stability:

> Deformation of underground salt, trona and potash mines is generally time dependent, providing for gradual adjustment of strata to mining induced stresses. Time dependence can allow for higher extraction ratios provided eventual failure can be tolerated. However, this eventual failure can be violent if creep deformation can shift stress and potential energy to strong, brittle geologic units. The mine failure case studies reviewed here illustrate this process. Yield pillars and defects in bridging strata figure prominently in these cases. Yield pillars provide local and temporary support to the roof, temporarily delaying the cave; and allowing extraction ratios and overburden spans to increase beyond the long term capacity of overlying strata. Defects (faults, voids, thinning) of strong overburden strata reduce the critical span, sometimes to less than panel width. Analyses of many of these cases have focused on a cascading pillar failure mechanism, but recent work and this review point to failure of strong overburden strata as the essential element. The suddenness of failure and attendant seismic events pose hazards to miners and, in some cases, to those on the surface. Characterizing these failures is a first step towards recognizing and managing the risk of catastrophic collapse in underground mines.[11]

and

> The value of a set of case studies like these lies in their ability, through a composite view, to more fully reveal the mechanisms at work. The most important observation is that there is a strong correlation between dynamic collapse events and the presence of relatively strong, brittle bridging strata above the bed being mined.[12]

Salt Mine, Western New York," *Environmental and Engineering Geoscience*, Vol. VI, No.1 (2000), 57-70; Van Sambeek, L.L.; Gowan, S.W. and Payment, K.A., "Loss of the Retsof Salt Mine: Engineering Analysis," *Proc. of 8th World Salt Symp.* (Elsevier, 2000), 411-416.

[11] Whyatt J. and Varley F.,"Catastrophic Failures of Underground Evaporite Mines," *Proceedings of the 27th International Conference on Ground Control in Mining* (Morgantown, WV), 2008, National Institute for Occupational Safety and Health, 113-122, at 113.

[12] Id. at 117.

Whyatt and Varley's point about "relatively strong, brittle bridging strata above the bed being mined" is a direct contradiction of the Agapito report's aforementioned assumption that strong carbonate strata above the Cayuga Salt Mine can be "assigned elastic properties, meaning they can accept unlimited load without failing."[13] The distance of the strong carbonate strata above the Cayuga Salt Mine has not been shown to be protective against sudden collapse that propagates upward.

Whyatt and Varley also say:

> The cases reviewed here show a clear association between violent collapse and strong overburden strata. In these cases, failure of bridging overburden creates a shock load that drives rapid failure of pillars, all within a very few seconds. These cases also show that collapse events can occur where the mined horizon is not brittle and pillars are properly sized. Brittle overburden is sufficient. Yield pillars in ductile seams may delay collapse, allowing further mining that increases the potential energy released in the eventual collapse.[14]

While these cautionary concerns are *in addition to* the aforementioned concerns about the effects of pore water on rock strength, there is a noteworthy connection that relates to S3. The stress redistribution caused by yielding pillars creates destressed zones (i.e., zones of reduced stress and pressure) within the pressure arches above the mine pillars. The resulting pressure gradient tends to bring additional pore water into the rock above the mine, which in turn may weaken the rock and/or produce brine pockets of the type that contributed to the Retsof mine collapse. Such migration of water into the destressed zones above the Cayuga mine was recognized by mining consultant Gary Petersen, who advised Cargill to stop using yield pillars and return to large pillars. Petersen's opinions were paraphrased and quoted as follows in a 2018 report by DEC's consultant Boyd:

> In 2016 RESPEC designed large pillars for the C Anomaly that would reduce shear in the overlying salts and reduce shear to insignificant levels in the limestones.
>
> Mr. Petersen noted that due to the theory "... that the abnormal closure in U12, U40B and perhaps U24 could be due to hydraulic pressure within the de-stressed zone of the yield pillar panel design, it was wisely decided not to use the YPP (yield pillar panel) design to mine the northern reserves where the potential for high pressure/high volume aquiferic water in conjunction with large geological anomalies could bring water too close to the mining horizon. The concern being that the YPP design creates a low stress (destressed) zone above that panel that attracts higher pressure fluids in the rock strata, which given a

[13] Agapito report at 3.

[14] Whyatt and Varley, op. cit., at 120.

> geological conduit will flow into the de-stressed zone resulting in abnormal panel closure."[15]

and

> In addressing the big pillar design of RESPEC to undermine C Anomaly, Petersen continues "The big pillar design doesn't create a de-stressed zone above the panel, making it a much better design for potential water pressure situations." Thus "... the potential for developing a leak is much lower ..." and "We know from experience that the big pillar design is prone to shear the roof along the roof/pillar contact out over the room and in some cases results in a rather large roof fall."[16]

This relates back to the Agapito report's failure to address pore water. The S3 area uses small yielding pillars, which will likely result in increasing amounts of pore water above S3. The presence of pore water, and its ability to migrate through openings in the rock, is explained partly by the differences in how salt beds and strong/brittle overlying bedrock respond to stress. Salt responds to stress by slow deformation or creep. The strong/brittle overlying rock has a limited ability to deform elastically in response to the *changes* in stress resulting from the deformation and sagging of the underlying salt caverns. Beyond its elastic limit, strong/brittle rock may shift or slide along existing joints and fractures (as a type of "stick-slip" motion) and may also break along new fractures, thus destabilizing S3. Some of these fractures, old and new, will open up larger gaps or apertures in which fluids such as pore water can reside. Some of the fractures, where interconnected, will also provide new pathways through which pore water or brine or other fluids can flow, thus further destabilizing the de-stressed zone above S3.

In this manner, Cargill's recently disclosed need for borehole drilling is evidence that the combination of pore water and small yielding pillars is resulting in unanticipated conditions in the Mine. The most current chapter in this nexus of yield pillars, pressure arches, stress transfer, destressed zones, brine pockets, pore water, and degradation of overlying rock strength has not been fully disclosed by Cargill or DEC or their consultants. This "current chapter" consists of one or more boreholes drilled upward from the mine, apparently to depressurize and drain pore water or brine from rock above the mine. The effectiveness, drainage rate, stratigraphy, structural features, and other details associated with the borehole(s) have not been disclosed. Drainage from the borehole(s) appears to be substantially saline and constitutes a portion of the S3 brine disposal to which these comments are directed.[17]

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[15] Boyd report to DEC, February 22, 2018, at 6, citing Petersen, Gary, 2016, Cayuga Mine, Thoughts on Mining the Northern Reserves, prepared for David Plumeau, Cargill Deicing Technology, RockTec Solutions, August 27. One footnote omitted from Boyd's text.

[16] Id. at 7, which notes that large roof falls associated with Cargill's return to large-pillar mining "are local events and not a factor in, or represent, global instability." Note that the comments offered here are directed to the yield pillars which Cargill used when mining S3 and which *are*, as summarized herein, a factor in global instability of the mine.

[17] Currently available information implies substantial salinity of the drainage from the depressurizing borehole(s) but is not entirely clear on this point. The Boyd letter [report] to DEC, "Revised Planned S3

Three specific comments relating to the borehole(s) are as follows. First, a borehole of several inches diameter is unlikely to characterize or drain more than a tiny fraction of the overlying rock. This limitation, along with the existing range of uncertainties about stress transfer, brine pockets, pore water, overlying rock strength, etc., needs much greater characterization than currently exists. An EIS process, starting with reversal of the Negative Declaration, and an adjudicatory hearing would be appropriate next steps in such characterization.

Second, the source of the saline water/brine being drained by the depressurizing borehole(s) needs to be identified, and its rate of drainage and the variations in that rate need to be made available. Can this saline water/brine be age-dated? Can it be characterized by stable isotopes? Do its characteristics match those of modern Cayuga Lake water, or those of fossil groundwater? Do its characteristics match those of the upwelling saline water from the beach well on Bill George Road?

A finding that the borehole drainage is a reasonable match to lake water would raise additional questions that need resolution, including the question of whether the current drainage rate is merely a starting value for what will become an increasing and perhaps unstoppable leak from the lake into the mine.

Third, the many questions outlined above that relate to borehole drainage, and how the mining permittee has resolved or needs to be resolve these questions, may add up to a *material change* in current permit conditions. A mining permit should not remain silent on these various questions that stem from S3 yielding pillars and involve risks to mine stability. Adapting DEC's own words, confirmation is needed "that the observed behavior of the mine is consistent with the mine design."[18]

Other issues

DEC states in its Negative Declaration that DEC and its consultant Boyd regularly monitor closure rates and subsidence data in the 4-Level storage area where Cargill disposed of waste brine until February 2023. This is "required," according to DEC, because "the natural movement of unmined rock salt within the mineral deposit will eventually cause mine openings to close. The rate of closure is monitored via convergence stations and surface subsidence data by LiDAR."[19] Flooding of S3 will progressively put the convergence stations out of operation.

In more detail, physical closure or collapse at any level of bedrock above the mine tends to happen after the underlying supporting layer has sagged or fallen, thus no longer providing support from beneath. Sometimes upward propagation of rock movement happens quickly (in the extreme, as collapse), or sometimes it happens more gradually when a rock layer has enough strength to

Submain Sump, Cayuga Mine," August 2, 2023, at 4-5, lists the depressurizing borehole(s) as one of three contributors to the brine source for storage/disposal in S3, as follows: "The brine source for this sump will be the Number 1 shaft (averages 28 gpm), the No. 3 shaft, surface runoff concentrate, and U12 depressurizing boreholes. The total flow to the planned sump will be 30–35 gpm."

[18] DEC's 0-9999-00075 Negative Declaration Narrative_11.19.2024, at 2.

[19] Id.

temporarily bridge the gap after underlying support is gone. In any case, rock movement at mine level is currently detected by convergence stations that detect the earliest (deepest) warning of abnormally high rock movement. Such early warning in the S3 area would be lost if convergence stations are put out of service by flooding, the reason being that abnormally high rock movement at mine level may not result in ground-level subsidence or failure until seconds or hours or months later.

For this reason, LiDAR or ground-level surveying provides *late* warning that is not an adequate substitute for the mine-level monitoring that will be lost due to flooding. In contrast, continued monitoring apparently remains possible in at least certain parts of the 4-Level storage area because the brine is stored in ponds, not to the ceiling as is proposed in the S3 Zone after it is flooded. Mine-level instrumentation is also superior to LiDAR or ground-level surveying because of its capability for automated continuous monitoring. Such real-time monitoring can, for example, immediately report exceedance of a user-specified limit.

Audible "pops" heard by miners are an additional issue. Popping noises heard by miners in the S3 area before mining ceased there several years ago[20] can also be categorized as acoustic emissions or microseismic activity. They are associated with stick-slip rock movement and are thus very relevant to movement or breakage of rock in the vicinity of S3. Such "pops" need further study using modern methods of acoustic emissions analysis,[21] along with existing microseismic monitoring,[22] before brine storage occurs/continues in the S3 area.

Another S3 issue is Cargill's rejection of a prior study by their frequent consultant RESPEC in favor of Agapito's study and report – which might be construed as seeking a preferred outcome. As described in the Agapito report,

> Cargill retained Agapito Associates, Inc. (Agapito) to assess the effect of the planned flooding on the global stability of the subject panels. Previously, Cargill commissioned a study of panel flooding by RESPEC of Rapid City, South Dakota. While Cargill did not provide the resulting RESPEC report to Agapito, Cargill specified input parameters assumed in the previous study so that the results of the Agapito and RESPEC work could be directly compared by Cargill.[23]

I understand that the RESPEC study or report has not been made publicly available, nor is it clear whether the report was made available to DEC. I understand that RESPEC concluded at least in part that flooding the S3 area would cause the first 15 feet of claystone roof rock over the S3 Zone to lose 95% of its strength. Regardless, without both reports, is impossible to compare

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[20] See Boyd report to DEC dated March 8, 2012, at 3 ff.

[21] For example, L. Ding, Y. Zhao, Y. Pan and Y. Fan, "Investigation on acoustic emission characteristics of fault stick-slip under different lateral pressures," *Scientific Reports* [*Nature* Portfolio] 14, 6718 (2024), doi.org/10.1038/s41598-024-57076-0.

[22] See, for example, Boyd report to DEC, "2022 Annual Report Review," April 2023, at 8-9. See also https://deepgeothermalheat.engineering.cornell.edu/cubo-science-intro/cornells-seismic-network/

[23] Agapito report at 1.

the validity of the two studies. These need to be directly compared in a manner that allows DEC as well as both RESPEC and Agapito to see each other's work while also allowing the public and third-party experts to review the work.

Conclusion

In summary, based on my review, the modeling study in the Agapito report is not an adequate analysis; it does not serve its stated purpose of demonstrating global stability, partly because pore water and its negative effects on rock strength are not assessed, and partly because comparatively strong rock layers above the mine are unrealistically modeled as elastic. Furthermore, neither the Agapito report nor other information available from DEC or Cargill has produced a careful synthesis that combines the aforementioned subject matter with the well-known *subsidence* process wherein rock layers above a mine gradually sag/subside downward toward the cavity of an abandoned mine. A key component of subsidence is its ongoing distortion of the overlying layers, resulting in continual micro-scale rearrangement of existing joints and fractures in rock, some of which undergo stick-slip movement, and some of which remain sealed while others widen or become open as pathways through which water/brine can flow. The above-quoted paper by Whyatt and Varley covers important parts of this, and it demonstrates how the S3 yield pillars put the overlying rock, including the overlying carbonate beam, at risk of collapse. Such risk is apparently higher than in more recent mining where large pillars have been used.

In explaining the 1994 collapse of the Retsof salt mine, Van Sambeek, Gowan, and Payment said that, "The site conditions relating, in particular, to the potential for catastrophic flooding of the mine were unknown and were not foreseeable prior to the collapse."[24] The opinions I offer here on the Cayuga Mine and S3 flooding are meant to avoid a "not foreseeable" or unforeseen outcome. Much has been learned and published since the 1994 Retsof collapse. The papers published and lessons learned should be, but mostly have not been, built into the pending DEC decision on S3 flooding. Much remains to be done in assembling and assessing the information needed to support the decision. An EIS process, starting with reversal of the Negative Declaration, and an adjudicatory hearing would be appropriate next steps. In taking these steps, DEC should evaluate whether the emerging information on depressurizing borehole(s) justifies or constitutes a material change in the permit conditions.

Sincerely.

Raymond C. Vaughan, Ph.D., P.G.

[24] Van Sambeek, Gowan, and Payment, op. cit., at 413.