Exhibit 1

Cavern Integrity Report
H. C. Clark, Ph.D.

Cavern Integrity Analysis

Finger Lakes LPG Storage, LLC

January 15, 2015

H.C. Clark, Ph.D.

I. Introduction

Finger Lakes LPG Storage, LLC (FLLPG) has applied for a permit to store liquid petroleum gas (LPG) in two underground galleries—known as Gallery 1 and Gallery 2—in the Watkins Glen Brine Field along the west side of Seneca Lake.[1] I was asked to prepare this technical report analyzing whether there are any risks to the integrity of the caverns proposed for LPG storage that are not addressed by FLLPG's application materials or the draft permit conditions published by the New York State Department of Environmental Protection (DEC) in connection with this project. In my opinion, there are serious questions remaining about the solution-mined salt caverns in this area and their future integrity, and the data gaps are serious enough to warrant denial of the permit. Moreover, even if sufficient new studies are performed to supply the missing information, and the application materials are revised to provide a comprehensive and accurate picture of the caverns and their geological context, it will be impossible to respond in a timely and effective way to any problems that may develop, unless significant additional conditions are included in the permit.

My report examines the geology of the area and its solution-mined caverns, with special focus on Galleries 1 and 2, the caverns bordering Galleries 1 and 2 on the south and north, and the high-angle strike-slip (tear) fault along the eastern boundary of the project. A thorough understanding of the surrounding geology is critical because that geology will be the container for LPG, and the caverns were not simply hollowed from a homogeneous and isotropic mass (that is, a uniform material with the same properties in all directions). The geology where these caverns have been dissolved has been folded, thrust faulted, and cut by vertical faults, leaving a complex geology that has controlled the development of the Watkins Glen Brine Field. The development, shape, and behavior of the caverns are, in large part, a product of that geology, acting over the history of each cavern, and for most of them, it's a very long history.

Questions about how this geology is involved with the caverns of the Watkins Glen Brine Field are important because problems involving salt storage caverns, wells, and mines have been documented over many years.[2] Examples of such problems in both bedded salt formations and domal salt include:

- Mid-1990s collapse of the Retsof, NY, bedded salt room and pillar mine, where a 500-foot-by-500-foot block of ceiling fell, leading to the flooding and closure of the mine.
- Yaggy bedded salt storage cavern leak and 2001 fire at Hutchinson, KS.
- Salt mine collapse in 1974 forming the 300-foot-diameter Cargill Sink at the Hutchinson, KS, bedded salt mine.

[1] "The Watkins Glen brine field, located in Schuyler County, is in the south central part of New York State, along the west shore of Lake Seneca . . . . It is approximately four miles north of the Village of Watkins Glen." (Jacoby, 1962: 506) As used in this report, the "Watkins Glen Brine Field" or "Watkins Glen" refers to that area, including the wells and galleries in the Town of Reading that FLLPG proposes to use for LPG storage.
[2] Reports of these and other problems follow the list of references at the end of this report.

- Explosion at Mt. Belvieu, TX, when stored LPG leaked from salt dome through corroded well casing, then to town sewer system.

- Ongoing collapse of Oxy3 Cavern at Bayou Corne, Louisiana, where a solution mined cavern in the Napoleonville Salt Dome has breached the salt wall, and subsequent collapse has chimneyed to the surface, creating a sinkhole that continues to expand.

Although the caverns listed above do not represent precise analogues of the FLLPG Galleries, the history should remind us that accidents do happen, and when they do, they can be very serious. No two caverns are exactly alike, if only because the local geology is different, and each requires careful study, controlled solutioning, and meaningful and frequent monitoring—to avoid the problems of these examples.

The basic question presented by FLLPG's application is whether or not there is adequate evidence of long-term cavern integrity—so DEC and the public can have confidence that problems encountered elsewhere will not happen at Seneca Lake—and the answer is no. The evidence is inadequate because much of the information that a geologist would ordinarily expect to find about the surrounding geology and features of the caverns is missing, incomplete, or incorrect. Moreover, the information that *is* available indicates that Galleries 1 and 2 and surrounding caverns—some more than half a century old—show effects of age and anomalies suggesting that long-term integrity may not be possible.

Documents supporting FLLPG's application for the underground storage permit were heavily redacted before public release, so public information about the site area is available largely from published articles and an application released by the New York State Electric Gas Corporation (NYSEG) for compressed air energy storage (CAES) nearby. That information was enough to raise a number of preliminary questions about the project, but it was not enough to answer them. [redacted]

To summarize the critical issues I identify:

- A professional geologist assessing the integrity of solution-mined salt caverns proposed for hydrocarbon storage will begin with the applicant's maps and cross-sections, which are supposed to depict the geology of the area, including stratigraphy and faults, as well as the extent, contours, and developmental history of the caverns. Comprehensive and accurate maps and cross-sections serve three crucial functions: (1) they allow analysts to flag issues that may become serious problems; (2) they help to identify where additional study or monitoring is needed; and (3) they expedite response when something goes wrong, by enabling analysts to understand quickly what happened and what corrective action is needed. FLLPG's application lacks the comprehensive and detailed maps and cross-sections that provide the framework for an adequate assessment of cavern integrity.

- Some readily available and relevant data (for example, from publications by Charles Jacoby, the geologist who developed these caverns) is missing [redacted] and some of the visually displayed information is incorrect. When the omissions are cured, and the mistakes are corrected, the need for further study is immediately apparent. The map and cross-sections should be supplemented with the results of additional studies I identify below as well as known sources of information, both published and from company files evidently available to FLLPG.[3] Cavern integrity analysts should not have to comb through thousands of pages of application materials—as I have had to do—to piece together a comprehensive picture of the geology and storage cavities. It is dangerous and irresponsible not to have the resource readily available, if a problem develops in the future.

- For example, there are zones or planes of weakness in the walls and roofs of these caverns—such as thrust faults, fractures, and high-angle strike-slip faults—that are not shown on the maps and cross-sections. Some of these faults served as pathways for communication between wells in the past or for accidental transmission of fluids to the surface, and some have been linked to roof collapse. FLLPG insinuates that the documented Jacoby-Dellwig Fault does not exist or is sealed. Full studies of faults and fractures should be required, all such zones of weakness should be evaluated as potential pathways for communication, and the complete results of that analysis should be described and portrayed graphically in revised application materials, including in a monitoring plan.

- The caverns of the Watkins Glen Brine Field have grown outward and upward, and this growth will continue. Outward cavern growth may lead to communication with nearby caverns or fault zones. [redacted] Upward growth may lead to partial roof failure or complete collapse—as is evident from the rubble piles in the caverns of the Watkins Glen Brine Field. Sonars from 2009 and 2011 show that the roof of FLLPG Gallery 2 (Cavern 58)—which previously was abandoned because of a prior collapse—has reached the Camillus shale, appears to be sinking at the center, and may be unstable. This uncontrolled growth is partially depicted in the limited sonar slices shown on the cross-sections and [redacted]

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[3] The 2010 Reservoir Suitability Report submitted by FLLPG refers to "US Salt company files" (2010-5-14, BSK to DEC – NOIA Response Reservoir Suitability Report (redacted) at 1). Companies routinely maintain records of project development and performance over the lifetime of a project and after it has ended, so FLLPG may have access to additional historical documentation from company files. Such detailed records are important in understanding what has happened if there is a failure of some sort—such as a cavern roof fall—and in deciding how to address the problem.

[4] [redacted]

[redacted] but a full complement of sonar comparisons, typical of cavern evaluations in the cavern development industry, is needed.

- The project borders are suspect. On the southern border of the FLLPG galleries (the site of the Arlington Storage Company, LLC ("Arlington") gas storage expansion project), the roof of Cavern 30 failed, and [redacted] Bordering caverns should be thoroughly evaluated, [redacted] These caverns should be fully characterized, and their ongoing measurement should be included in the monitoring program. The Federal Energy Regulatory Commission ("FERC") has required more extensive monitoring of Cavern 30 than previously was required for gas storage at the Arlington facility, as a condition of the approval issued for expansion. Enhanced monitoring should be required for both of the FLLPG Galleries and all neighboring caverns and galleries.

- The monitoring program planned is minimal, and much of it—including the subsidence leveling program that seems to monitor the weather, rather than the intended cavern roof subsidence—is inadequate. If the informational gaps and errors are addressed in revised documentation, and FLLPG's application is granted, DEC should require enhanced monitoring, providing real-time, continuous measurements, as additional conditions of the permit.

As a professional geologist, critically reviewing the FLLPG project, I would expect to see, at the beginning of an analysis, geologic maps and cross-sections fully describing the brine cavern field; the geology involved; operations, such as hydraulic fracturing, that created the passages between the caverns; and faults, folds, and fractures that have been involved the cavern development process. Then, I would expect to examine detailed studies, measurements, and discussions of specific issues introduced by a review of the basic data. FLLPG has provided enough information to raise safety questions and to create conflicts with published articles about the caverns to be used in this project and anomalous features of the surrounding geology. Ordinarily, I would expect a storage permit applicant to provide responses to those questions and resolution of those conflicts. Only after all the questions about cavern integrity are answered, would I expect to see development of a monitoring plan, using currently available technology, to serve as an early warning of impending cavern failure. The FLLPG application and draft permit conditions defeated all of my expectations and failed to conform to standard industry practices I have observed over decades as a professional geologist.[5] In my opinion, FLLPG understates cavern integrity risks, and the incomplete and inaccurate information in its application leads me to conclude that the Galleries cannot be used safely to store LPG, even with the monitoring required in the current draft permit conditions.

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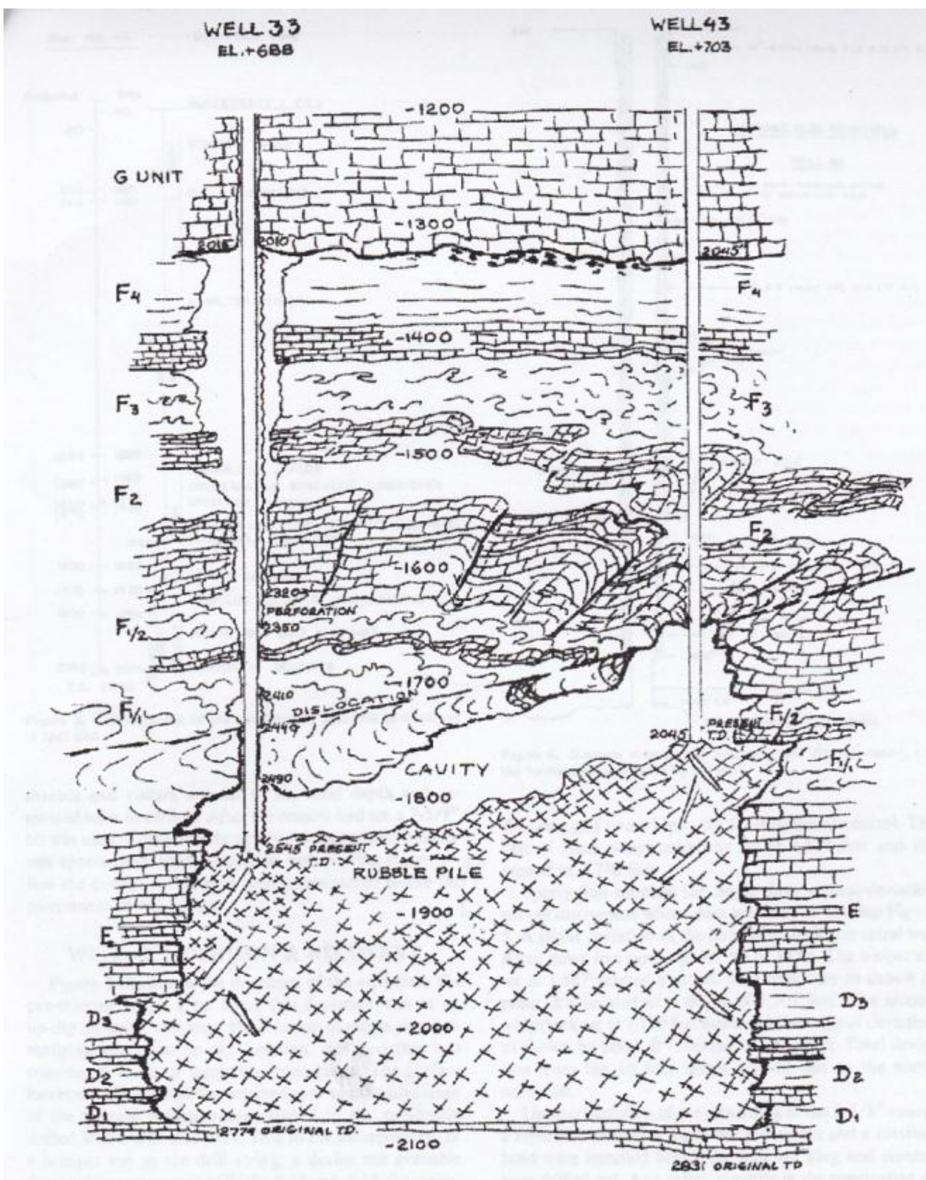
[5] I have been an academic and consulting geologist and geophysicist for nearly 50 years. My curriculum vitae is attached to this report as Exhibit F.

II. Overview of Relevant Geology

To place my analysis in context, it is important to understand the salt cavern solutioning process in its geological context. Making caverns like those in the Watkins Glen Brine Field is a matter injecting fresh water into a well, dissolving the bedded salt, and withdrawing the resulting brine. The geologic cross-section in Figure 1 below shows an injection well and a withdrawal well typical of the multi-well caverns at the Watkins Glen Brine Field. (Jacoby, 1973). In fact, this is a cross-section of two of the wells involved in Gallery 1 of the FLLPG project—Wells 33 and 43—now part of a mega-cavern joining Wells 33, 43, 34, and 44.

Figure 1: Wells 33 and 43
Source: Jacoby, 1973

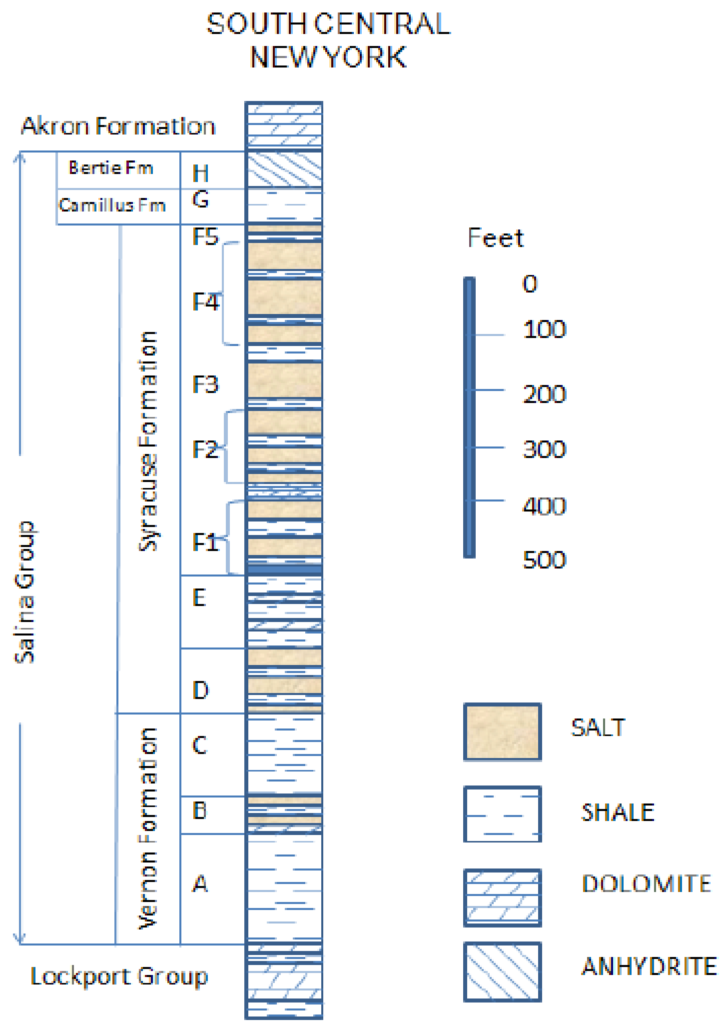


Both wells were first drilled, then fresh water was pumped into one under pressure—creating a hydraulically fractured connection along a fault plane connecting the two wells, and solution of the cavity followed. The wells still exist and can be opened for logging and to lower sonar devices or other equipment used to monitor cavern pressure, salinity, and seismic events with periodic or continuous measurements.

The stratigraphy (rock layers) shown in Figure 1, like that of the Watkins Glen Brine Field generally, involves salt beds (shown with the letters and subscripts) and interbedded layers of shale, limestone and dolomite (shown by the patterns). The cross-section illustrates the folded rocks and salt layers, along with thrust faults—one is just below elevation -1700 with the notation "dislocation." The original hydraulic fracture in this example was near the bottom of the cavern, and as solutioning of the cavity progressed, rock layers—which did not dissolve—were undermined and fell into the cavern, creating the "rubble pile." The tubing through which the fresh water was injected and the brine was removed was cut off as the process moved upward (and cut off pipe pieces are depicted in the rubble pile).

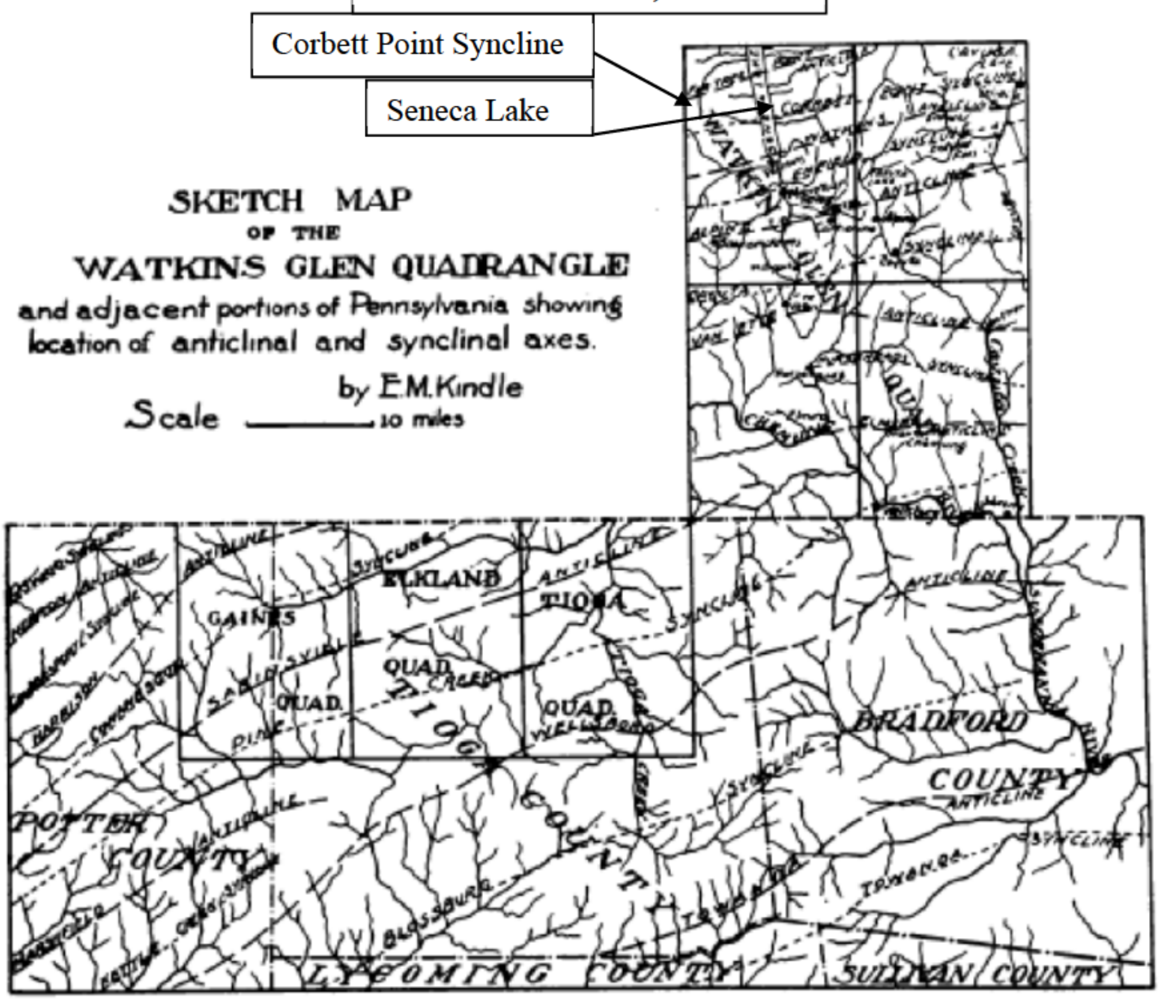
The caverns of the brine field are solutioned in bedded salt of the Silurian Syracuse Formation, sandwiched between Vernon shales below and Camillus shale (shale, dolomite and gypsum) above. The stratigraphic column in Figure 2, below, from the proposed NYSEG CAES plan, describes the nearby rock section (PB Energy Storage Services, 2011:5). Here, the interbedded salt and rock layers are designated by letters, then numbers and numbers within (like F1/1 and F1/2). The nomenclature has changed through the years and the lettering in Figures 1 and 2 may not match exactly.

Figure 2: Column of Rock Layers
Source: PB Energy Storage Services, 2011



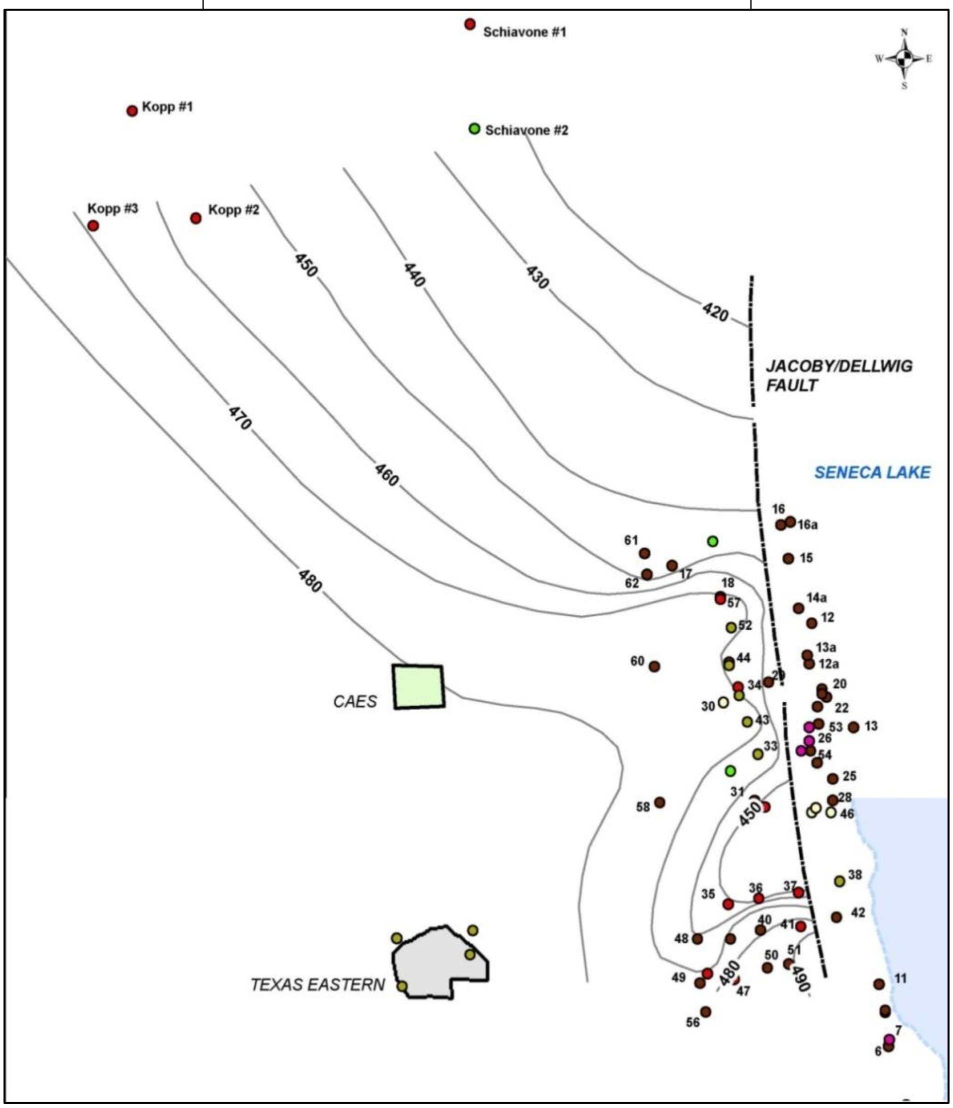
Within the Syracuse formation, salt layers are interbedded with shales and dolomites that resist solutioning, but not gravity, and fall from the walls and roofs of these caverns, leaving all the caverns here at least partially filled with rock rubble. The alternating salt and rock beds were originally laid down in a shallow interior sea that was oftentimes limited in its connection to ocean exchange—thus the salt. Devonian rocks complete the section to the surface as gently folded east-northeast trending anticlines (areas bowing up like the arch) and synclines (areas bowing down like a trough) (here the Corbett Point Syncline), the signature of Appalachian tectonism left behind. These structures in the vicinity of Seneca Lake have long been well known, and Figure 3 below illustrates their relationship to Appalachian geology to the south of Watkins Glen.

Figure 3: Map of Geology
Source: Kindle, 1904



The Syracuse Formation beneath these folds was not treated so gently. The Appalachian push from the south used the salt layers, being quite malleable, and the shale, still holding a lot of water, like a skateboard's rollers, floating the Devonian rocks over folded, thrust faulted and tear faulted Silurian beds, leaving often thickened salts and shales pushed up and over one another in stacks of repeated sections, cut again by high-angle strike-slip faults (Jacoby and Dellwig, 1973). The FLLPG site-specific, thrust fault thickened, salt, and the effect of the high-angle strike-slip fault, are shown on Figure 4 below, a salt isopach (thickness) map of the vicinity from the NYSEG CAES application (PB Energy Storage Services, 2011). This is the complex that makes up the walls, floors, and roofs of the caverns in the Watkins Glen Brine Field, most of which are about a half-century old. Those walls, floors, and roofs reflect both the area's long-term geologic history and events that occurred during individual cavern development.

Figure 4: Salt Isopach Map
Source: PB Energy Storage Services,



III. Assessment of Cavern Integrity

My assessment of cavern integrity is organized around a map showing Watkins Glen Brine Field wells and gallery outlines and three cross-sections created by FLLPG to outline its plan. I begin with an overview of the caverns in the area, move to an examination of the cross-sections provided in the application, and then consider faulting and other geological features affecting the caverns and concerns about cavern growth. I offer observations at each stage in the context of additional information that I have obtained from public sources. My report concludes with a set of recommendations for studies, tests, and monitoring.

A. Gallery Map

[redacted] How are these caverns related or could they become related; that is, what happens to the rest if there is a problem at one? To answer that question, it is essential to understand a lot more information [redacted]—some of which I add in this report.

[redacted] There needs to be a comprehensive study of all the caverns in the brine field and development of a "state of the brine field" map that includes geology as well as information about each cavern and how it is related to others.

[redacted] Much of this added information was developed by International Salt geologist Charles Jacoby. He was able to use geologic mapping of structural grain and associated planes of weakness to plan pairs of wells, where fractures would develop along preferred pathways between the pressured and the interceptor well. Most of the caverns in the Watkins Glen Brine Field were formed by this hydraulic fracturing from one well to another, and the coalescent history has resulted in some complex, large elongate cavern shapes. [redacted]

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[6] [redacted]

[redacted] There is a lot more about hydraulic fracturing pathways that would be good to know, and a lot more hydraulic fracturing was done or attempted at the Watkins Glen Brine Field. This missing information would illuminate weaknesses in the rocks that created the pathways for hydraulic fracture flow and may explain present cavern growth behavior.

Charles Jacoby wrote a number of papers about geology and cavern research and development, including articles with a number of examples of well behavior in the Watkins Glen Brine Field and descriptions of the geology that influenced this behavior. Table 1 below is a partial list of well pairs subject to hydraulic fracturing that were documented by Jacoby. [redacted]

Table 1: Well Pairs and Hydraulic Fracture Connections

Year	Well Pumped for Fracture	Target Well	Connected?	Well Unintentionally Connected	Note	Reference
1956	28	27	Yes			Jacoby, 1962, 1969
1955	25	23	No		Fluid pumped through Well 25 went to "vacuum"	Jacoby, 1962
	41	42	No	37		Jacoby, Dellwig, 1973
	40	39	No	42		Jacoby, Dellwig, 1973
1962	33	32	No	34 (north)		Jacoby, Dellwig, 1973, Jacoby, 1965
	29	34	No	32	Fluid traveled south along Jacoby-Dellwig Fault	Jacoby, Dellwig, 1973
1962	29	34	No	surface	Fluid reached surface 1/2-mile north, along Jacoby-Dellwig Fault.	Jacoby, Dellwig, 1973
1962	33	34	Yes		Thrust fault caused fluid to reach well at unintended location.	Jacoby, 1965
	30	31	Yes		Thrust fault caused fluid to reach well at unintended location.	Jacoby, 1969
	33	43	Yes			Jacoby, 1973
1963	35	36	Yes			Jacoby, 1969
1963	37	38	Yes			Jacoby, 1969

Jacoby's knowledge about the regional structural grain (the near east-west Corbett Point Syncline) allowed him to plan locations of connections where there had been only apparently random connection before. He was able to take advantage of the east-west weaknesses of folding and thrusting as long as there was not an easier path for hydraulic fracturing fluid flow. An unexplained change in the behavior of attempted fracturing, as fracture operations moved north and approached Seneca Lake, led him to recognize the role of north-south tear faulting. Several wells failed to fracture to an east-west target well and instead connected with a well to the south or north. [redacted]

Comparison of geophysical logs from wells near this change in fracture path described a vertical fault plane with about 1200 feet of horizontal displacement (and related smaller faults), as well as thrusts (Jacoby and Dellwig, 1973). This tear fault, or high angle strike-slip fault, is the Jacoby-Dellwig Fault, shown in Figure 4, above). East of the Jacoby-Dellwig fault, thrust development of the salt section is reduced. [redacted] The significance of this tear fault is in part that, when fracturing Well 29, fluid travelled along this fault and flowed out at the surface a half-mile north of the initial fracture.

[redacted]

[redacted]

B. Cross-Sections of the Caverns

The FLLPG Reservoir Suitability Report includes three cross-sections. The first, cross-section AA', shows caverns along the southern border of the FLLPG property and includes Cavern 58, or FLLPG Gallery 2. The second, cross-section BB', is through the caverns of

[7] [redacted]

[redacted]

[redacted] For example, the salt isopach map in Figure 4 shows the detail of the section in the area of this cavern project, and that cumulative salt thickness, built by thrust faulting, should be shown [redacted] The significance of the thrust faults in this region is that, as nearly horizontal bedding plane features, they represent horizontal planes of weakness that have functioned as pathways for hydraulic fracture fluid flow. The faults, related hydraulic fracture connections, and the differences in salt, shale, and dolomite layer properties influenced the creation of all of the caverns of the Watkins Glen Brine Field, including the caverns that FLLPG storage proposes to use for storage. The salt caverns here are not solutioned out of a homogeneous and isotropic mass, and the caverns reflect this geology. The differences in the salt and rock remain, along with the folds, fractures, and faults that are part of the walls and roofs of these caverns.

[redacted] Showing rock and salt layers as solid, intact materials, where a cavern in fact is filled with broken rock, is inaccurate and misleading. It is important to know what these cavern systems look like, how and where these caverns are connected, and how the geology may affect the system including these caverns.

Each of the three cross-sections is examined below, with reference to mark-ups attached to this report as Exhibits B–D.

1. Cross-Section AA' (revised 8-28-14)

This west-to-east cross-section begins at the left edge of the diagram with Cavern 58, or FLLPG Gallery 2, and then depicts the subsurface along the southern border of FLLPG property, incorporating the Arlington natural gas Caverns 30, 31, 28, and 27. The inset on the lower left shows the stratigraphic context of the interbedded salt and rock in the detailed cross-section at the top. The letters with subscripts on the left edge and near the right edge name the interpreted layers of salt (shown as white), and the interbedded rock layers (shown as a red pattern). Typically, rock core description data and/or geophysical logs are superposed or referenced on a cross-section to support the interpretations and allow independent verification, but that is not the case here. The addition to cross-section AA' of the log data developed by Jacoby (in his published papers) and the logs for Well 58 (included in the application, *e.g.*, 2010 Reservoir Suitability Report, Exs. 5 and 6) would be helpful.

Cavern 58 will be discussed in more detail later, but some basic information requires immediate correction. Two rock layers are depicted abutting Cavern 58 in unlikely locations. One layer is shown a third of the way up in the new cavern being solutioned above the collapsed original and passing through the 2011 and 2013 sonar outlines (likely a drafting error). The other rock layer, shown beneath and apparently supporting the new Cavern 58, conflicts with the underlying information in the application. The implied structural support beneath the new Cavern 58 raises an important question: Is the layer real, making its future over the previous Cavern 58 rubble pile somewhat precarious? Or, is the new Cavern 58 floored on the rubble of the lower Cavern 58 roof collapse, and the continuous bed pictured an error? According to the well status report in the Reservoir Suitability Report, the base of the new Cavern 58 is "top of rubble,"[8] making the depiction as solid rock an error. The phrase "top of rubble" here and at several places on the cross-section indicates that there is rubble between the old and new cavern floors and that, as Cavern 58 has been solutioned, the relatively insoluble interbedded rock has fallen and filled the base of the cavern. A complete cross-section should show the volumes now filled by this rock. The rubble-filled historic cavern outline for Cavern 58 is shown on Exhibit B.

a. Caverns 27, 28, 30, 31, and 46

Moving to the east on cross-section AA', the galleries of Caverns 30 and 31and Caverns 28 and 27 are part of the Arlington natural gas storage expansion project recently approved by the Federal Energy Regulatory Commission. This proposal was the subject of detailed comments, and most of the comments and FERC's responses are available for review. FERC has asked for "a new sonar survey of Gallery 2, through all three cavern wells, to obtain the current size of the gallery, the size and shape of the rubble pile, and the shape of the roof around each well."[9] That is, for the gallery involved with the 400,000-ton roof fall described by Jacoby, Arlington not only must develop measurements of the currently open cavern, but also must obtain measurements that fully characterize the size and shape of the rubble pile at the bottom of the complete gallery. The latter measurement likely will require seismic testing, because sonar cannot penetrate the rubble.

Information missing from cross-section AA' is available from Jacoby studies of these specific caverns. The 1967 cross-section of these caverns (Jacoby, 1969), shown below in

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[8] 2010-5-14, BSK to DEC – NOIA Response Reservoir Suitability Report (redacted) (Ex. 9 at 2).

[9] FERC, Order Issuing Certificate and Reaffirming Market-Based Rates, 147 FERC ¶ 61,120, at ¶ 31 & Engineering Condition 3 (May 15, 2014).

Figure 5, below, was developed after their initial hydraulic fracture connection. It provides a clearer picture of the actual situation here, in contrast with the current open space measured by recent sonars above beds depicted as continuous on FLLPG cross-section AA’. The information on this Jacoby cross-section should be disclosed on cross-section AA’, but it is not.

Figure 5 shows the outlines of the caverns, the hydraulic fracturing connections between caverns, thrust faulting and tear faulting, in addition to the more detailed stratigraphy here that Jacoby developed from core samples and geophysical logs. The notation in the middle of the rectangular shape at the base of Cavern 30, “Fallen Rock Mass,” describes a 400,000-ton block that fell from the roof (outlined by sonar). I have sketched the cavern outlines developed from the 1967 sonars on cross-section AA’ and have attached the marked cross-section as Exhibit B to this report, to allow comparison.

Figure 5: Wells 27, 28, 30, and 31
Source: Jacoby 1969

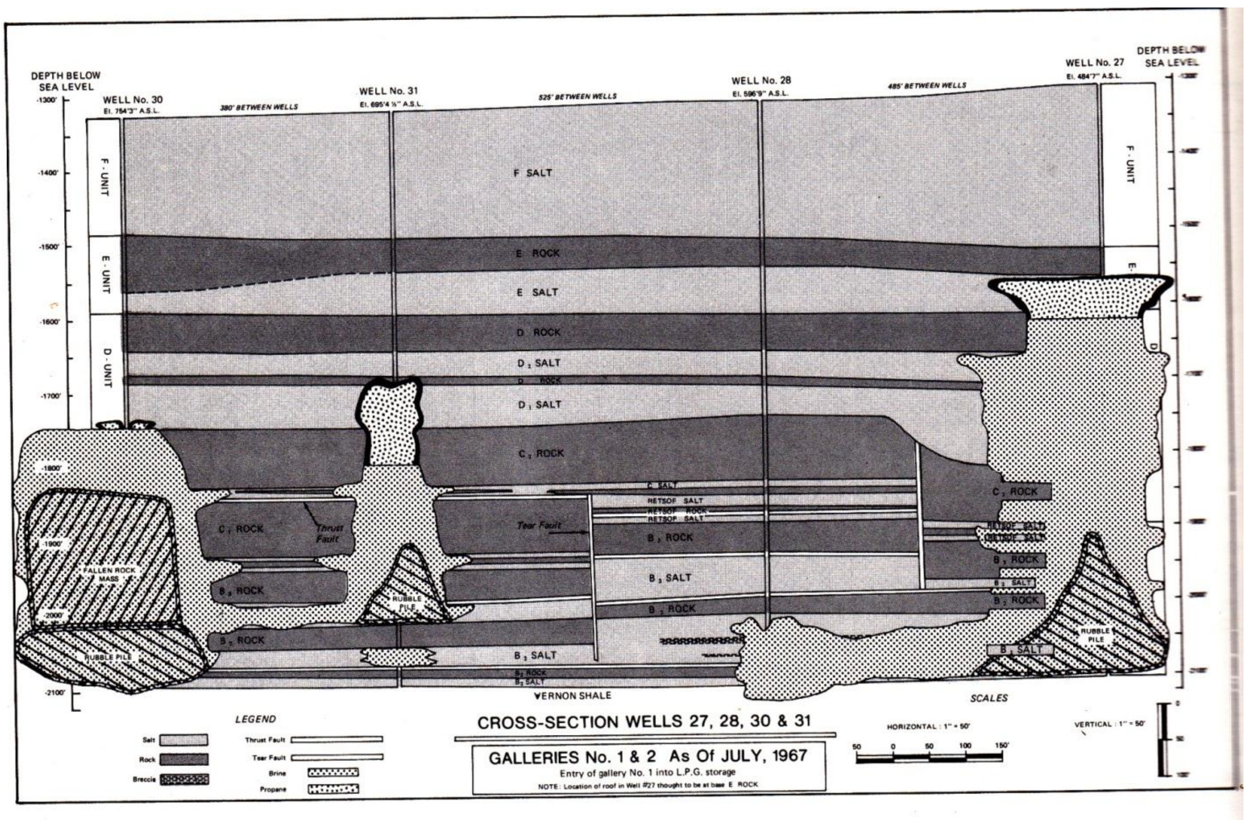


Figure 3.

Also, on FLLPG cross-section AA’, note the “Top of Rubble” arrows between Caverns 30 and 31 and the “Estimated Location of Pressure Connection” arrow between the two caverns—two features that help to reconcile the Jacoby cross-section with cross-section AA’(in addition to the depths shown on the Jacoby cross-section). Corresponding locations of “Top of Rubble” and “Estimated Location of Pressure Connection” appear on cross-section AA’ for

Caverns 28 and 27, enabling the match with the Jacoby cross-section there, as well. Additional published sonar measurements (Jacoby, 1973) of Cavern 27 provide information about the upward path of the cavern roof.

There is a cautionary tale about Cavern 27, the basis for the Jacoby research paper related to this additional sonar. Cavern 27 sonar was used to guide the drilling of Well 46 to recover LPG that had migrated upward, as roof fall developed out and away from the original Well 27. He noted that additional LPG might be trapped above weakened rock leaves of the then-present cavern roof. This rock is now part of the rubble pile noted on AA'.

Figure 6: Wells 46 and 27
Source: Jacoby, 1973

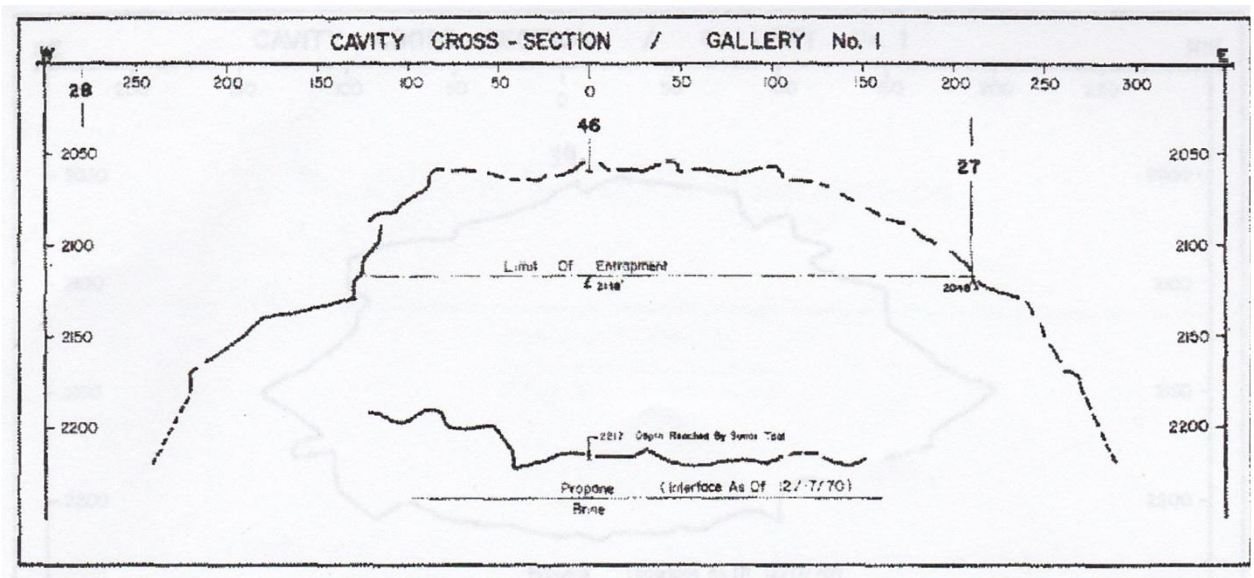


Figure 8. Cross section of the salt storage cavity through Gallery No. 1 (E-W).

Figure 6 (Jacoby 1973) shows Wells 46 and 27. Well 46 was drilled to recover trapped LPG and likely did not extend to the depth shown on cross-section AA'. Cross-section AA', with the addition of information from these sonar studies, would provide a picture of the cavern advancing from Jacoby's initial work, through the Well 46 experiment, and on to the present roof outline.

My mark-up of cross-section AA' in Exhibit B shows cavern outlines and the Jacoby-Dellwig Tear Fault, shown in Figure 3 above between Caverns 31 and 28 and in Figure 4 parallel to the shore of Seneca Lake. Thrust faulting shown on the Jacoby cross-section and discussed in his 1973 article with respect to the thickened salt in Well 27 also should be added to cross-section AA'. The locations of the thrust faults were developed from the repeated signatures shown on gamma logs from Wells 27, 28, 30, and 31 and discussed in several Jacoby papers. Jacoby discussed subsidiary faulting related to both of the major faults shown on his cross-section, and that faulting should be recognized and plotted on cross-section AA'. The original sonar information and the geophysical logs that were the basis for Jacoby's cross-sections and interpretations—and that are necessary to provide a complete account of the geology in the area covered by cross-section AA—are likely in salt company files available to FLLPG. Once completed, the revised cross-section AA' should show the thrust faults and tear faults that explain the variations in salt and rock layers shown on the 8/28/14 cross-section AA' now in the application.

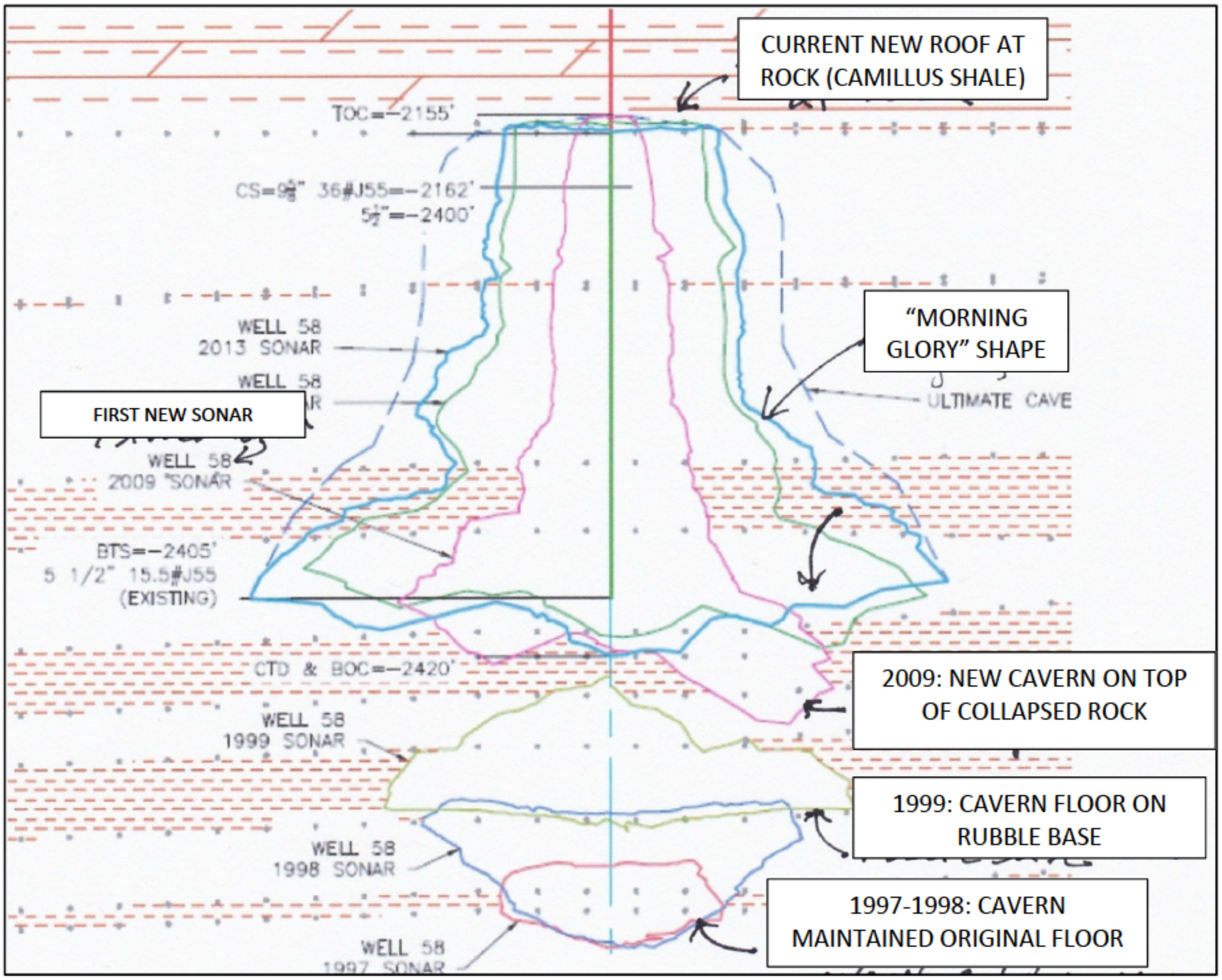
In response to a Notice of Incomplete Application with questions from DEC about faults, FLLPG discussed only the Camillus shale above the interbedded salt and rock layers and repeated the conclusion that thrust faults do not involve the Camillus.[10] But the thrust faults and tear faults that are part of the overall geology, [redacted] The appropriate time to present interpretations of beds above and below the deformed salt is after all the geological information is presented visually in the cross-sections.

b. Cavern 58

Figure 7 below is my mark-up of the portion of cross-section AA' depicting Cavern 58, which is FLLPG Gallery 2. This cavern has been a focus of concern for a long time. It could be described as the combination of two caverns: (1) the new one with its roof at the Camillus shale, the upper bound of the interbedded salt and rock layers, and with its base outlined by the 2009 sonar, with a "morning glory" shape, and (2) the original attempt at cavern development, below the new one, as outlined by the 1997–1999 sonars, which now is filled with rubble, the result of a roof collapse and consequent abandonment. FLLPG shows them as isolated on cross-section AA', but in fact they are connected, as I show on Exhibit B.

[10] 2010-05-14, BSK to DEC – NOIA Response (redacted) at 8.

Figure 7: Clark Mark-Up of Cavern 58 Cross-Section
Source of Cross-Section: FLLPG (filed Oct. 23, 2014)



[redacted] [redacted] The 1997 sonar survey (lowermost outline on Figure 7) captures the status of the cavern's solutioning at that time. The open cavern sequence continued as shown on successive sonars from 1998 and 1999. The base of the 1999 sonared cavity was flat, illustrating the accumulated rubble from the collapsed rock layers (red pattern) and that cavern development was progressing upward from that rubble base as solutioning continued. The next routine sonar logging attempt found a catastrophic change—outlined in a series of documents describing the situation and summarized in a letter dated May 24, 2001, from US Salt to DEC:

---

11 [redacted]

> Reports and conversations with Larry Sevenker prior to the last loggings appeared that the cavern at Well 58 was progressing normally. The latest logging indicated that the roof of the cavern had collapsed and filled with rubble. Mr. Sevenker further reported that it appeared that the upper formations may have been in a fractured and faulted zone and that a small magnitude earthquake could have damaged the cavity.

Other (partially redacted) documents disclosed by DEC pursuant to a Freedom of Information Law Request (but not included in the documents released to the public for this proceeding) make it clear that the Cavern 58 project ended because of concerns that questionable geology ("fractured and faulted zone") in the immediate vicinity made it unwise to place a cavern there.[12] The cavern had collapsed, and continued to collapse each time they pulled up tubing and tried to work again, so the well was plugged and sealed.

FLLPG attempts to discredit Mr. Sevenker [redacted] This explanation fails for several reasons. First, the cavern developers were "[u]nable to sonar survey due to cavity conditions" (Jan. 8, 2001 report); [redacted] Second, the presence of open hole from the top of the abandoned area to the top of the salt was known at the time and disclosed on the plugging report. [redacted] Cross-section AA' shows the "original" cavern at its original position; what is there now has been solutioned above the original cavern. [redacted] Exhibit B demonstrates that neither alternative is correct; rather, the new cavern was solutioned above the old. The serious questions remaining about the integrity of Cavern 58, given its earlier catastrophic collapse, cannot be explained away by impugning the reputation of a geologist with first-hand knowledge of the event.

[12] These documents include the letter quoted above; page 3 of a report dated January 8, 2001, on the inability to use sonar in Well 58 (apparently from the files of DEC petroleum geologist William Glynn), and the 2003 plugging report and cover letter from the consultant, Mr. Sevenker. These documents are collected and attached to this report as Exhibit E.

[13] [redacted]

Moreover, there is evidence not only of past cavern failure but also of current roof instability. The sonars in cross-section AA' show that the roof in 2009 is higher than in 2011 and that, by 2013, the roof is visibly sagging. [redacted]

[redacted]

[redacted]

The sagging occurs even as the extent of the roof grows, adding to the risk of collapse. Finally, Cavern 58 extends to the Camillus shale; there is no salt layer to provide support for the roof.

c. Summary of Cross-Section AA' Issues

Summarizing the review of FLLPG cross-section AA': the depiction of rock and salt layers beneath sonar outlines of Caverns 58, 30 and 31, and 28 and 27 as continuous is incorrect and misleading; there are rubble-filled caverns here that have been solutioned upward through time, and this area should be shown not as a continuous red pattern and white area meant to characterize intact rock layers, but rather with a rubble symbol, [redacted]

[redacted]. The fact that there is [redacted], but no such attempt with respect to Caverns 30 and 31 and 28 and 27, increases concerns about FLLPG's misrepresentation of conditions in the caverns.

My concerns about a broader analysis of the caverns bordering proposed FLLPG Gallery 2 mirror my concerns, [redacted] and are reflected in FERC's insistence upon further study of the rubble piles and conduits as a condition of approving Arlington's gas storage expansion. Complete and accurate information about caverns bordering the FLLPG project is crucial because the Arlington caverns holding and cycling compressed natural gas could fail—in turn jeopardizing the integrity of the adjacent FLLPG caverns. Exhibit B shows the southern border of the proposed LPG storage caverns to be far more complicated and potentially compromised than shown in cross-section AA'. DEC should analyze the new information that FERC has required from Arlington before determining whether to grant FLLPG a permit for LPG storage.

Finally, more study is needed not only of Cavern 58's rubble-filled base but also of its unsupported rock roof. FLLPG has gone to some length to demonstrate the healing power of salt, but it now has at least two caverns with flat or sagging rock roofs. FLLPG's claim that thrust faulting does not appear to affect the Camillus shale [redacted]—two things not expected in a uniform shale. [redacted] Thus, FLLPG's own records about the rock roof raise serious and unanswered questions about Cavern 58's suitability for LPG storage. DEC's permit determination should be deferred until after it has a full and correct understanding of Gallery 2 and the bordering caverns, and until that additional study is complete, the application lacks sufficient data to show that the reservoir is adaptable for storage purposes.

C. Cross-section BB' [redacted]

[redacted]

[14] [redacted]

[redacted]

1. **FLLPG Gallery 1**

[redacted] Specifically, the Jacoby (1973) cross-section, reproduced above as Figure 1, illustrates the early history of the cavern originally created when Well 33 was hydraulically fractured to Well 43, [redacted]

First, the Jacoby cross-section in Figure 1 shows a thrust fault cutting (at depth 2449) just above the cavern that existed at the time, which was formed by the connection of Wells 33 and 43. That fault forced the rock and salt beds up and over one another within the Silurian section, [redacted] The thickened salt mass found in Well 34 was noted by Jacoby (1969) in discussing the northern involvement of thrust faulting. [redacted] While the fault and folds shown in Figure 1 are largely now part of the rubble pile, they are also part of the walls of the cavern. [redacted] these faults are planes of weakness that could serve as fluid pathways or influence future cavern deformation.

[redacted] The Jacoby cross-section clarifies that, as salt was dissolved, the rock layers above the former salt were no longer supported and fell to the bottom, forming the rubble shown. That process began at the base and moved up, [redacted] with accumulated rubble below.

[redacted]

[redacted]

Jacoby shows the top of the original cavity as 2490 total depth at Well 33, [redacted] Figure 1 also shows an apparently well cemented casing at Well 43, but void space around the casing at Well 33 from the cavity as it existed then up to about 2010 depth. [redacted]

[redacted] Beginning with the area beneath Cavern 44, the Well Status and Condition Report lists "Top of rubble, bottom of existing cavern" as 2423 feet for Well 44, [redacted] For Cavern 34, the Well Status and Condition Report lists the "Top of rubble, bottom of existing cavern" as 2383 feet,[16] [redacted]

[redacted]

[15] 2010-5-14, BSK to DEC – NOIA Response Reservoir Suitability Report (redacted) (Ex. 9 at 2).
[16] *Id.* at Ex. 9 at 1.

[redacted]

[redacted]

[redacted]

[redacted]

The discussion in the previous paragraphs raises a question about the connections of the mega-cavern in the upper open cavern space. Where and how did they all become connected in the first place? The answer is: at the level of the rubble pile “tunnel” and not intentionally. The Jacoby (1973) cross-section discussed earlier shows the base of the cavern connecting Wells 33

[17] [redacted]

and 43, near the base of the Syracuse, and then subsequent solution up from there. The hydraulic fracture that connected Well 33 to Well 43 was apparently a second event. Here, Jacoby (1965) described an unintended fracture connection where Well 33 fractured to Well 34, rather than the intended target, Well 32.

> Well # 33 was an injection well with an intended target of Well # 32 across a distance of 735 feet. Unexpectedly, it connected with Well # 34, or almost due north, a distance of 745 feet. Within 24 hours after the fracture had been initiated, brine was being produced by the target well. The volume of brine produced quickly reached a point where it was proportional to the volume of water injected. The quality of brine with respect to calcium and magnesium chlorides was extremely high, thus being relatively poor for the production of evaporated salt. Pump pressures remained extremely high despite the fact that large quantities of salt were extracted. No second plateau ever developed.
>
> It was surmised that fracturing fluid had passed horizontally along a faulted zone with at least a portion of the travel route being in shale layers.

Jacoby's articles demonstrate that there was a hydraulic fracturing operation that connected Wells 33 and 43 (illustrated in Jacoby, 1973) and an operation that connected Well 33 to Well 34 (described in Jacoby, 1965). Both of these fracture pathways were near the base of the Syracuse, but they had to have taken independent routes in order to develop pressure for each connection. These routes were involved with the zones of weakness related to faulting.

Jacoby wrote more about the role of faulting between Wells 33 and 34, describing the pressure variation experience:

> In fracturing Well 33 to 34, alternate buildup and recession of pumping pressures indicated that the solution channel was being *closed by rock movement from time to time*. In the light of subsequent geologic information, the occurrence of intermittent collapse should have been unexpected, inasmuch as in this area of the brine field the *major thrust has broken up*, into and through the No. 3 salt. Faulting above the cavity created by solution between Wells 33 and 34 *may have resulted in a weakness* which led to the *observed periodic collapse and pressure buildup*. It is over this area that the major thrust bifurcates at several points, creating a series of planes of weakness in the section overlying the solution zone.

(Jacoby, 1973) (emphasis added).

Observations such as these, made by the US Salt geologist involved with the creation of these caverns, make it clear that a time sequence describing the role of geology in the history of each cavern is necessary in order to give an accurate portrayal of the current situation. Information like the presence and position of the major thrust fault and bifurcated thrust faults, along with the rubble-filled caverns developed in a time sequence and other information, [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

> [redacted]

[redacted] similar modeling of other features of Gallery 1 should be done as well. Without more study, the data on Gallery 1 is insufficient to demonstrate that the reservoir is suitable for LPG storage.

2. Gallery 10

[redacted]

> **DEC Comment 9b.** Page 9 of the May 14, 2010 Reservoir Suitability Report states "there was no pressure encountered on well 52 . . . ." In other parts of the application (i.e., Gallery 1 & Gallery 2), Finger Lakes says that encountered pressure during well re-entry is an indication of tightness for the proposed storage galleries. Conversely, is "no pressure encountered" an indicator of Gallery 10 not being tight?
>
> ***Finger Lakes Response:*** *It is assumed that the cavern does leak and will be monitored as explained in response to DEC Comment 9d below.*[22]

Well 52 presents additional challenges. [redacted] In response to DEC's question about the cavern at Well 52, FLLPG replied:

> [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted].

A professional geologist examining a project expects to see accurate, clearly identified, and consistent data on cross-sections that can be traced to underlying information; [redacted]

[redacted]

[redacted]

[redacted]

[redacted] more data is needed to show that the Gallery 1 reservoir is safe for LPG storage.

D. Cross-section CC' [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Cavern 29 is the cavern close to or in the Jacoby-Dellwig Fault, [redacted] This cavern was the injection well that was supposed to create a hydraulic fracture connection with Well (now Cavern) 34. Instead, Well (now Cavern) 29 fractured [redacted] both to what is now Cavern 32, some distance to the south (toward the viewer perpendicular to the cross-section), and to the ground surface about a half-mile north (away from the viewer perpendicular to the cross-section). This north-south fracture, considered in light of geophysical logs, mapping of the salt thickness, and Appalachian-related features in the area, led Jacoby to identify a near vertical strike-slip fault with about 1200 feet of offset—the Jacoby-Dellwig Fault (Jacoby 1973). The fault, along with related north-south tear faults, is a zone of weakness, it has served as a fluid transmission pathway in the past, and it may do so again. It therefore is important that the major and minor faulting be fully characterized, that its role as a fluid pathway be evaluated, and that the Jacoby-Dellwig fault be included in the cavern system monitoring plan.

FLLPG addresses the Jacoby-Dellwig Fault as follows:

> [redacted]

[redacted]

[redacted] Either ongoing or periodic pressure tests would be valuable sources of information, if a problem occurs.

[redacted]

[redacted] Whether a fault exists is determined by examination of regional data, and there are multiple studies of the Jacoby-Dellwig Fault (Jacoby and Dellwig, 1973; Jacoby, 1965; Jacobi, 2002; FERC Arlington, 2014). That the Jacoby-Dellwig Fault is not sealed is indicated by the movement through it of fracture fluid a half-mile north and a half-mile up to the surface. Moreover, the hydraulic fracture pathway from Well 29 to Well 32 had to pass through the Jacoby-Dellwig Fault, which is located between the two wells. If the fault is sealed and cannot account for the uncontrolled hydraulic fractures from Well 29, then we lack an explanation for the fluid movement. Either there are other yet unidentified pathways from the well or fluid escaping a cavern can travel randomly and emerge anywhere there is a pressure differential (including to the ground surface); neither alternative is comforting, and both cry out for additional study.

[redacted] If Cavern 29's development was influenced by the north-south Jacoby-Dellwig Fault or related faults, there may be other linear features nearby—and the linear east side of a large part of Gallery 1 is certainly one feature that should be investigated. All the relevant sonar surveys should be made available for this purpose. The characterization of the Jacoby-Dellwig Fault and related faults is important since it represents an area of weakness and a potential fluid pathway.

IV. Conclusion and Recommendations

The caverns that FLLPG proposes for LPG storage are part of the geology from which they've dissolved—and over their history, each has responded to that geology. Galley 1 (the mega-cavern of connected Caverns 33, 43, 34, and 44), was solutioned a half-century ago [redacted] Gallery 2 (Cavern 58), collapsed once and is being solutioned again above the rubble of what was there before.

[redacted] All of these issues, summarized here and described in more detail in this report, have been the subject of concerns expressed by DEC in repeated NOIAs, and FLLPG's responses have only raised more questions that require further inquiry.

The deficiencies identified in this report can be addressed only through the submission of revised documents, including maps and cross-sections reflecting complete and accurate information, which will require additional data collection and performance of technical studies. At least the following documents should be filed:

- A comprehensive and accurate map of the Watkins Glen Brine Field.

- Revised cross-sections, with complete and correct depictions of the underlying geologic and cavern information. Preparation of the cross-sections will require:

    - (i) collection and compilation of relevant historical information about the wells and caverns and their geological context, including information from published literature and information in affiliated company files;

    - (ii) performance of additional technical studies, including seismic surveys (modified refraction, reflection, and vertical seismic profiling), to fill data gaps identified in this report, such as the shape and volume of rubble-filled portions of all caverns; [redacted] the relationship between Cavern 29 and the Jacoby-Dellwig Fault, and the pathway from Cavern 29 to the ground surface;

    - (iii) incorporation of that information into cross-sections that accurately illustrate geologic features and fully characterize the caverns, including the rubble piles and conduits, with comprehensive Keys to all features displayed; and

    - (iv) submission of all data underlying the cross-sections [redacted] in well-organized and meaningfully labeled electronic files.

  Specifically, the cross-sections should provide full historical comparison of all sonar information, superposed on common axes (derived from underlying full sonar histories of each cavern developed using historical data superposition), and the data displayed should enable the reader to ascertain: the total extent of caverns, including hanging ledges and areas created by solutioning or hydraulic fracturing that are now under rubble; cavern growth over time; fault involvement with well and cavern development; intended and unintended hydraulic fracture paths; and other factors or anomalies that may be disclosed during additional study. All thrust and high-angle strike-slip faults, including the Jacoby-Dellwig Fault, should be located, characterized, and identified on the cross-sections.

- Documentation showing the full three-dimensional extent and historical development of the caverns, to supplement the cross-sections—that is, the detailed information underlying the representative cross-section diagrams. Several full sonar surveys have been made over the lifetime of each cavern. Each of these surveys involves synthesis of sonar data points into a series of vertical and horizontal slices that provide a three-dimensional picture of the particular cavern at that point in time. Often, the sonar acquisition firm provides not only the current sonar data, but also superposes the sonar slices with historical sonar data for the same slices, allowing comparison and evaluation of trends over the time period of the surveys. Examples of the value of these comparisons can be seen for the vertical sonar slices shown on the cross-sections and noted historically by line color and the date next to each. All of the sonars for all of the caverns should be produced for the record and expert review.

- A revised Reservoir Suitability Report or other narrative comprehensively and accurately describing the facts underlying the completed and corrected cross-sections and the three-dimensional studies.

- A written plan for monitoring all thrust and high-angle strike-slip faults and for addressing any anomalies or problems identified through review of the cross-sections and three-dimensional studies.

Ideally, the issues conference would be postponed until the foregoing documents are filed, members of the public (including experts) have an opportunity to review them, and the new information can be incorporated into petitions for party or amicus status. Without the revised documents, FLLPG has not provided sufficient data to demonstrate that the Galleries it proposes to use are appropriate for storage, the serious cavern integrity risks that I have identified cannot be ruled out, and therefore DEC should refuse to issue FLLPG a permit for LPG storage.

If the revised documents are submitted, and a permit ultimately is issued, DEC should require additional monitoring of the storage facility. The present monitoring plan focuses on periodic measurements, mostly of the condition of the wells and the effects of moving LPG and brine in and out of the caverns, and the caverns are to be evaluated by occasional pressure tests and sonars of the open portion of the caverns. This is 2015, and technology is available for making continuous measurements that will signal a problem before it becomes a disaster. Further, real-time monitoring measurements should be recorded and made available to DEC and the public. Below is a list of recommended monitoring requirements, which should be added as conditions of the permit, to ensure that any changes in the caverns that increase the risk of leakage or other problems are identified and addressed as soon as possible.

- Install borehole seismic sensors similar to those being used at Bayou Corne to track and study events related to the failed cavern there, to measure other caverns, the rock chimney, and gas and fluid movement in the subsurface. These sensors could be installed in cavern wells considered for plugging or wells developed specifically for monitoring. Install recording strain gauges (sensitive tape or material that can be locked against a cavern wall to measure the tiniest flexure or strain) in these or additional deep boreholes.

- Measure pressures, salinity (or chloride concentration), temperature, and other easily measured variables at injection and withdrawal and monitoring wells.

- Install gas sensors in the aquifer(s) above the caverns.

- Install active sonar and other means to monitor cavern changes (like roof, wall, and floor creep). Install means to monitor rock and salt fall.

- Expand the leveling network to include the caverns of the comprehensive map. Add dedicated subsidence measurement monuments designed to minimize effects such as weather. Add horizontal and tilt measurements over FLLPG Gallery 1. Add active, continuous level monitoring for extended periods—like the subsidence monitoring done in the Houston subsidence province.

Without the addition of these monitoring requirements as permit conditions, DEC cannot ensure that emerging cavern integrity problems will be timely identified and therefore should not issue the permit.

REFERENCES

Jacoby, C.H., 1962, International Salt Brine Field at Watkins Glen, New York, Proceedings of the First Symposium on Salt, Cleveland, Ohio, 506–520.

Jacoby, C.H., 1965, Effect of Geology on the Hydraulic Fracturing of Salt, Proceedings of the Second Symposium on Salt, Northern Ohio Geological Society, Cleveland, Ohio, 311–320.

Jacoby, C,H,, 1969, Correlation, Faulting and Metamorphism of Michigan and Appalachian Basin Salt, AAPG Bulletin, V 51, 136–154.

Jacoby, C.H., 1969, Storage of Hydrocarbons in Bedded Salt Deposits Formed by Hydraulic Fracturing, Proceedings of the Third Symposium on Salt, Cleveland, Ohio, 463–469.

Jacoby, C.H. and Dellwig, L.F., 1973, Appalachian Foreland Thrusting in Salina Salt, Watkins Glen New York, Proceedings of the Fourth Symposium on Salt, Houston, Texas, 227–233.

Jacoby, C.H., 1973, Recovery of Entrapped Hydrocarbons, Proceedings of the Fourth Symposium on Salt, Houston, Texas, 267–275.

Jacoby, C.H., Szyprowski, S., Paul, D.K., 1973, Earth Science Aspects in the Disposal of Inorganic Wastes, Proceedings of the Fourth Symposium on Salt, Houston, Texas.

Jacoby, C.H., 1973, Use of Abandoned Solution Mined Cavities for Storage of Plant Wastes, Transactions Society of Mining Engineers, AIME, V. 254, 364–367.

Jacobi, R.D., 2002, Basement Faults and Seismicity in the Appalachian Basin of New York State, Tectonophysics, V 353, 75–113.

Kindle, E.M., 1904, A Series of Gentle Folds on the Border of the Appalachian System, The Journal of Geology, V 12, 4, 281–289.

Looff, K.M., Loof, K.M., 1999, Possible Geologic Influence On Salt Falls Associated with the Storage Caverns at Bryan Mound, Brazoria County, Texas, SMRI Spring 1999 Meeting, Las Vegas, Nev., 269–286.

Munson, D., Bauer,S., Rautman, C., Ehgartner, B., and Sattler, A, 2003, Analysis of the Massive Salt Fall in Big Hill Cavern 103, Sandia Report 2003-0703.

Nieto, A. and Young, R.A., 1998, Retsof Salt Mine Collapse and Aquifer Dewatering, Genesee Valley , Livingston County , NY : In: Poland Symposium Volume: Land Subsidence, (J. Borchers, Ed.), Spec. Pub. 8, Assoc. Engineering Geologists, 309–325.

PB Energy Storage Services, 2011, Compressed Air Energy Storage NYSEG Seneca Lake Project, Geology, https://www.smartgrid.gov/sites/default/files/doc/files/Exhibit%2013.10%20Geology%20Part%201.pdf.

Rickard, L.V., 1969, Stratigraphv of the Upper Silurian Salina Group, New York, Pennsylvania, Ohio, Ontario, Map and Chart Series Number 12, New York State Museum and Science Service, 57 pages.

USGS Fact Sheet 017-98, 1988, Effects of the 1994 Retsof Salt Mine Collapse in the Genesee Valley, New York, USGS, 4 pages.

Reports of Salt Cavern Problems

Yaggy
http://www.kgs.ku.edu/Hydro/Hutch/Refs/Hutch_KBA_final.pdf

Yaggy and Cargill Sink
http://www.thelivingmoon.com/45jack_files/03files/Endangered_Earth_Sinkhole_Hutchison_Kansas.html

Retsof
http://pubs.usgs.gov/circ/circ1182/pdf/14Retsof.pdf

https://www.dot.ny.gov/conferences/itgaum/repository/2H_Gowan_Cause%20of%20the%20Retsof%20Collapse.pdf

Mont Belvieu
http://www.thelivingmoon.com/45jack_files/03files/Endangered_Earth_Sinkhole_Hutchison_Kansas.html

Tersanne and others
http://arxiv.org/ftp/arxiv/papers/1302/1302.2582.pdf

Gulf Coast cavern problems
http://www.geostockus.com/wp-content/uploads/Subsidence-Sinkholes-and-Piping2000a.pdf

Big Hill
http://prod.sandia.gov/techlib/access-control.cgi/2003/030703.pdf

Bayou Corne
http://ucmwww.dnr.state.la.us/ucmsearch/FindDocuments.aspx?idx=xwellserialnumber&val=180708

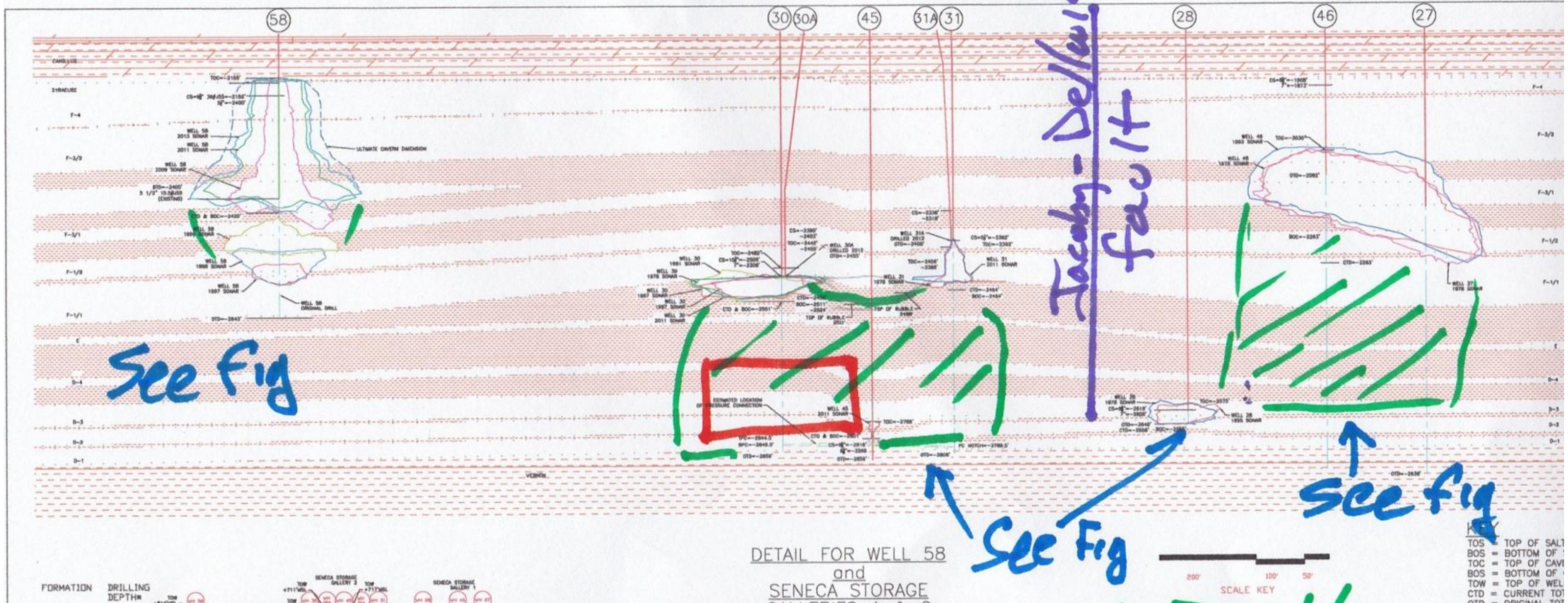
Exhibit A

Markup of Gallery Map

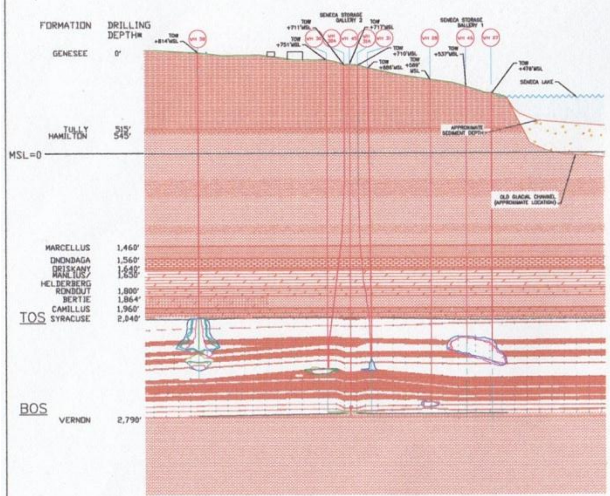
[redacted]

Exhibit B

Marked Cross-Section AA'



DETAIL FOR WELL 58 and SENECA STORAGE GALLERIES 1 & 2



SECTION A–A' LOOKING NORTH

*DEPTH DOWN FROM SURFACE (AT WELL 34)

SCALE KEY

SCALE KEY

KEY

TOS = TOP OF SALT
BOS = BOTTOM OF
TOC = TOP OF CAV
BOS = BOTTOM OF
TOW = TOP OF WEL
CTD = CURRENT TOT
OTD = ORIGINAL TOT
TPC = TOP OF PRE
BPC = BOTTOM OF
BTS = BOTTOM OF
CS = CASING
SCS = SURFAC
BTS = BRINE
CENTERLINE OF
FIRST RECORDE
SECOND RECOR
THIRD RECORDE
FOURTH RECOR
FIFTH RECORDE
SIXTH RECORDE
SEVENTH RECOR
EIGHTH RECORD
SHALE & LI
LIMESTONE
SALT
SHALE
FOSSILIFERO LIMESTONE
SANDSTONE
LIMESTONE & DOLOMITE
SHALE & DO

NOTES:
1. DISTANCES BETWEEN WELLS ARE MEASURED FROM DRAWING 2000-00-01-11
2. DEPTHS ARE MEASURED IN FEET FROM GROUND LEVEL.
3. DEPTHS ARE SHOWN AT TRUE VERTICAL DEPTH (TVD)
4. DATA IS TAKEN FROM LATEST SONAR AND LOGS.
5. WELL 59 IS LOCATED BEHIND WELL 46 FROM THIS PERSPECTIVE

SELECT WELL DATA WATKINS GLEN, NY, USA

WELL #; & OPERATING COMPANY	DATE DRILLED	TD. FROM GL	ELEV @ GL	STATUS	FUTURE USE	API #	NAD 83 LAT/LONG	LAST SONAR DATE	DIRECTIONAL SURVEY DATE	OTHER LOGS & DATES
WELL # 27 AKZO	4/27/1957	2636	476	P & A	NA	31-097-03891-00-00	42.415855 / 76.890917	4/26/1978	NA	NA
WELL # 28 ASC	4/20/1996	2649	569	ACTIVE/NG	NG	31-097-03892-00-00	42.415697 / 76.892684	11/16/1995	NA	NA
WELL # 30 ASC	1997	2664	751	DRILLEDOUT/STRAT	NG	31-097-61188-00-01	42.415855 / 76.896163	Nov-11	Dec-11	DEC-11 SBT/HR VERTILOG
WELL # 30A ASC	6/20/2012	2455	710.6'	NEW STRAT	NG	31-097-26500-00-00	42.416242 / 76.895591	N.A.	JUN/15/ 2012	JUL/2012 TRI-COMBO/SBT/HR VERTILOG
WELL # 31 ASC	2011	2606	686	DRILLEDOUT/STRAT	NG	31-097-61189-00-01	42.415919 / 76.894687	Nov-11	Dec-11	DEC-11 SBT/HR VERTILOG
WELL #31A ASC	MAY 24 2011	2400	710.4'	NEW STRAT	NG	31-097-26501-00-00	42.416310 / 76.895174	N.A.	MAY 21 2012	MAY 2012 TRI-COMBO/SBT/HR VERTILOG
WELL # 45 ASC	2011	2670	717	DRILLEDOUT/STRAT	NG	31-097-61201-00-01	42.415541 / 76.895471	Nov-11	Dec-11	DEC-11 SBT/HR VERTILOG
WELL # 46 ASC	Nov-70	2062	537	ACTIVE / NG	NG	31-097-61202-00-00	42.415579 / 76.891766	12/21/1993	11/18/1970	NA
WELL # 58 FL	2009	2642	814	ACTIVE / SALT	BUTANE	31-097-21467-00-01	42.416054 / 76.899519	3/26/2013	9/3/2009	GR/N,SBL/MICRVERT 10/09 GR/SBL,HRVERT 3/24/11
WELL # 59 ASC	9/23/1996	2042	538	ACTIVE / NG	NG	31-097-21618-00-00	42.415686 / 76.891759	11/17/1995	11/17/1995	DU NEUT/HI-INDUCT/ DENS/X-Z/CBL/DU INDUCT LOGS 11/95

NO.	DATE	REVISION	BY	CHK	APPR.
0	5/12/10	DRAWING RELEASED	JMR	L.D.	L.D.
1	6/23/10	TITLE INFORMATION CHANGE	JMR	L.D.	L.D.
2	9/26/10	ADDED ESTIMATED CAVERN SHAPE: WELL 58	JMR	L.D.	L.D.
3	4/6/11	UPDATE CAVERN SHAPE: WELL 58; FORM. EL.S	JMR	L.D.	L.D.
4	4/19/11	CHANGED ALL DEPTHS TO BELOW SURFACE	JMR	B.M.	B.M.
5	3/12/12	UPDATE SONAR WELL 30	JMR	B.M.	B.M.
6	12/6/12	ADD WELLS 30A & 31A, ADD WELL INFO	JMR	B.M.	B.M.
7	5/2/13	UPDATE SONAR WELL 58 & WELL DATA	JMR	B.M.	B.M.
8	7/16/13	UPDATE TITLE BLOCK, ADD WELL DETAIL INFO	JMR	B.M.	B.M.
9	8/28/14	UPDATE ULTIMATE WELL 58 OUTLINE	JMR	B.M.	B.M.

INERGY

FINGERLAKES LPG STO

VERTICAL SECTION A–A' (
SOUTH BRINE FIELD SEN
GALLERIES 1 AND 2, AND

SCALE	PROJECT NO.	
AS NOTED	-	2000-00-01-

Exhibit C

Marked Cross-Section BB'

[redacted]

Exhibit D

Marked Cross-Section CC'

[redacted]

Exhibit E

Documents Released Pursuant to DEC Freedom of Information Request

Well 58 (Planned Storage Well) Unable to sonar survey due to cavity conditions.

Date	01-08-01
Elevation	813'
Top of Salt	2144'
Top of Cavity	[redacted]
Cavity High Point	NA
7" Casing	2472'
4-1/2" Casing	2477' pulled for sonar, then re-set
Total Depth	2478'
Deepest Depth	2478'
Max Avg Diameter	NA' at NA depth
Sonar Volume	[redacted] (old sonar surveys, now cavity filled w/ shalt rubble)

Well 58 was the well drilled to develop a future gas storage cavity. The cavity was in the mid-stages of development and progressing in the creation of a cylindrical cavity from the earlier sonar surveys. The cavity had new cavity development and the older cavity of October 1998 had been nearly filled with shale and salt rubble in the shot period between earlier sonar surveys. The hanging casing were cut off and re-positioned above the rubble. Well 58 operated with injection only in the 7" casing, as the 7" and 4-1/2" casings were above the rubble pile and close together. This adjustment produced a higher saturation and reduced the demand to be re-injected in the 3 - 4 gallery.

The well 58 cavity had a cylindrical configuration with a nearly flat rubble bottom and a domed cavity roof. The cavity bottom had been at the depth of the flat cavity roof of the October 1998 sonar. [redacted]of cavity has been filled with shale and salt rubble. The hanging casings were set near mid cavity to allow for more rubble fill and improved brine concentration produced from well 58.

After starting up the well, both the flow rate and brine concentration had improved. The present attempted sonar survey shows a cavity volume to be complete filled with shale and salt rubble. Development of the cavity has terminated. Review of the core description and earthquake activity in the area, it is believed that a disturbance in the formations resulted in the faulted shale and salt rubble to completely fill the cavity and render the cavity useless for development for storage. A protective pad in the roof of the cavity would not have stopped the rubble in the fault zone from filling the cavity. During the work-over the 4-1/2" tubing was pulled and re-set and again lifted off bottom and re-set. As soon as the tubing was withdrawn or raised and lowered again, a 1-11/16" gamma ray tool could not enter any cavity, as the cavity filled with rubble after each movement of the tubing. The sonar tool could only indicate rubble material behind the 7" casing. Only near the top of the rubble pile at [redacted] a small void was noted behind the casing for several degrees of rotation. The rubble filled in after withdrawing the tubing and then re-setting. Upon completing the work-over the wellhead was reinstalled and the piping connected, but the valves were closed.

The top of salt was recorded at 2144' and the top of the rubble pile at [redacted] which leaved [redacted] of roof salt remaining for cavity support. A 9-5/8" cemented casing had been set at 2167' depth. The remaining salt roof should not be mined and mining operations have been terminated. The well will be further evaluated and consideration given to the plugging and abandonment of the well 58. The 4-1/2" and 7" hanging casings should be withdrawn before starting any plugging operations. A 9-5/8" bridge plug should be planned to be set near the top of salt and the well plugged using 2/7/8" tubing for placement of cement and withdraw the tubing in stages to completely fill the casing with cement for plugging.

USSALT

May 24, 2001

New York State Department of Environmental Conservation
Division of Mineral Resources
Bureau of Oil & Gas Regulation, Room 290
50 Wolf Road
Albany, New York 12233-6500

Attn: Kathleen F. Sanford
Chief, Permits Section

RE: Solution Salt Mining Well No. 58
API #31-097-21467

Dear Ms. Sanford:

I must apologize for not replying earlier, but vacation times and availability of people to cover these periods caused the delay.

Reports and conversations with Larry Sevenker prior to the last loggings appeared that the cavern at Well 58 was progressing normally. The latest logging indicated that the roof of the cavern had collapsed and filled the whole cavern with rubble. Mr. Sevenker further reported that it appeared that the upper formations may have been in a fractured and faulted zone and that a small magnitude earthquake could have damaged the cavity.

We have enclosed seismic local log that Mr. Sevenker obtained indicating small earthquake activity.

Our intentions for this well are to plug and abandon on the advice of our consultant, Mr. Sevenker. He clearly states in his report that the roof movement is unusual and renders the cavity unusable for continued development or storage. We will submit the Notice of Intention to Plug and Abandon form as soon as we have planned dates for these operations.

RECEIVED
MAY 29 2001
BUREAU OF OIL & GAS REGULATION

Sincerely,

Alan Parry
Plant Manager

AP:s
Enclosure

P.O. Box 110 Salt Point Road Watkins Glen, NY 14891 (607) 535-2721 Fax (607) 535-2953

Bob Traver ext. 220

85-15-8 (1/86)—27b

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION
DIVISION OF MINERAL RESOURCES

PRINT OR TYPE IN BLACK INK

PLUGGING REPORT

THIS APPLICATION IS A LEGAL DOCUMENT.
READ THE APPLICABLE AFFIRMATION AND ACKNOWLEDGEMENT CAREFULLY BEFORE SIGNING.

NAME OF OWNER (Full Name of Company, Organization or Individual): U S Salt Company

LEASE OR UNIT NAME AND NUMBER	TOTAL DEPTH	PLUGGING PERMIT NO.
Well #58	2478'	02-13101P

COUNTY	TOWN	API WELL IDENTIFICATION NUMBER
Schuyler	Reading Center	31-097-21467

LOCATION DESCRIPTION (7½ Quad)	LATITUDE (FT. S of)	LONGITUDE (FT. W of)
Reading Center	880,470'	414,560'

PLUGGING PERFORMED BY	DATE OF PLUGGING
Universal Cementing	10-14-03

DIVISION OF MINERAL RESOURCES WITNESS	DATE WITNESSED
prior to plugging Debbie Rathbun	10-09-03

DETAILS OF PLUGGING

Filling Materials and Plugs	DEPTH-FEET From	DEPTH-FEET To	CASING RECORD Size-In.	Weight#/ft.	Put In Well-ft.	Pulled Out-ft.	Left In Well-ft.
~~4-1/2"~~	~~2477~~	~~Surf~~	~~4-1/2"~~	~~10.5~~	~~2477'~~	~~2218'~~	~~259'~~
7"	2472'	Surf	7"	20.0	2472'	2215'	257'
9-5/8"	2167'	Surf	9-5/8"	36.0	2167'	0'	2167'
13-3/8"	169'	Surf	13-3/8"	61	169'	0'	169'
9-5/8" Bridge Plug	2154	---	9-5/8"	36	2154'	0'	2154'
Class A Cement	2154	Surf	9-5/8"		2154'	0'	2154'

	YES	NO
Have pits and other excavations been filled?	X	
Have the following been removed? Equipment	X	
Debris	X	
Has casing been cut off below plow depth?		X
Has well-site been restored to condition similar to adjacent terrain?	X	

If any of these questions are answered NO, give timetable for completion of reclamation.

REMARKS Due to rubble filling the cavity the 4-1/2" hanging casing was cut off at 2218' and the 7" hanging casing cut off at 2215'. From these depths the 4-1/2" and 7" casing were removed. A 9-5/8" bridge plug was set at 2154'. Cementing with 800 sacks Class A through 2-7/8" tubing being withdrawn in stages was the method of plugging the well from the bridge plug to the surface. The cement filled the 9-5/8" casing to the surface. The 9-5/8" wellhead flange will remain as an elevation survey bench mark. The area is to be returned to the surrounding conditions and the concrete pad filled in after plugging is complete.

FOR USE BY INDIVIDUAL:

I hereby affirm under penalty of perjury that information provided in the report is true to the best of my knowledge and belief. I am aware that false statements made in this report are punishable as a Class A misdemeanor pursuant to Section 210.45 of the Penal Law.

X [signature] — Signature of Individual
Larry Sevenker — Print or Type Name of Individual
10-17-03 — Date

FOR USE BY ORGANIZATION OTHER THAN AN INDIVIDUAL:

I hereby affirm under penalty of perjury that I am ______ (title)

of ______ (organization); that I am authorized by that organization to make this report; that this report was prepared under my supervision and direction; and that the information provided in this report is true to the best of my knowledge and belief. I am aware that false statements made in this report are punishable as a Class A misdemeanor pursuant to Section 210.45 of the Penal Law.

X ______ Signature of Authorized Representative
______ Print or Type Name of Authorized Representative
______ Date

LARRY SEVENKER

Consulting Engineer

4148 Loire Dr.
Kenner, LA 70065

(504) 468-1909

October 17, 2003

Mr. Frank Pastore
US Salt Company
P.O. Box 110
Watkins Glen, NY 14891

RE: Cement Bond Log Evaluation Well 58

Dear Frank:

Well 58 was drilled and completed on October 17, 1992 for operation as an individual well for gas storage. At the completion of the required cavity size and before converting the well to natural gas storage, an earthquake in the area resulted in shale filling the entire cavity with rubble. The cement bond log was run prior to plugging and abandonment to confirm the isolation of the cavity from any fluid migration behind the casing into the formation above the cavity or from the surface. Before the bridge plug was set in the 9-5/8" casing below the top of the salt, the 4-1/2" and 7" hanging casings were cut off and removed and then the well plugged to the surface. The bridge plug was set at 2154' and plugging was by the pumping cement down the 2-7/8" tubing and withdrawing the tubing from the cement in three 543' stages and the last 525' stage. After the tubing was withdrawn the cement was returned to the surface to complete the plugging operation. Universal pumped 800 sacks of Class A cement to plug well 58 to the surface. Universal's cementing ticket number 533749 is attached. Good circulation with cement returns were observed at the surface.

US Salt plans to push in the earth and rock berm around the concrete pad to restore the well 58 site to the surrounding conditions. The cement in the 9-5/8" casing settled back top to 6" above the concrete pad floor. The well 58 elevation survey bench mark will be re-established on the 9-5/8" casing flange for subsidence surveys and well location.

The following is a summary of the well construction and cement bond evaluation.

Well 58 API# 31-097-21467
Drilled: October 17, 1992

Elevation:			813'	
Conductor Casing:	13-3/8"	61.0#	169'	Cemented w/ 150 sacks Class A
Top of Salt:			2144'	
Surface Casing:	9-5/8"	36.0#	2167'	Cemented w/ 775 sacks Pozmix
Top of Cavity:			[redacted]'	Cavity filled with rubble

Protection Casing:	7"	20.0#	2472'	Hanging Casing
Hanging Casing:	4-1/2"	10.5#	2477'	Hanging Casing
Total Depth:			2478'	
4-1/2" Casing Pulled			2218'	
4-1/2" Casing Left in Hole			259'	
7" Casing Pulled			2215'	
7" Casing Left in Hole			257'	
Cement Bond Log	October 13, 2003			

Well 58 has excellent to very good cement bond above the salt interval to provide protection and isolation of the salt brine from the surface formations. Also the conductor string of casing was cemented from setting depth to the surface for added protection. Bed rock was encountered at 2' depth and no water bearing formation was detected below the surface.

Well 58 Cement Bond

Cement Bond Evaluation

2300' - 2183'	Open hole	9-5/8" casing at 2183'
2183' - 2150'	Excellent bond	Top of Salt at 2150'
2150' - 1660'	Excellent bond	
1660' - 1578'	Excellent bond	Marcellus Shale
1578' - 1372'	Excellent bond	
1372' - 1360'	Very good bond	
1360' - 1200'	Excellent to very good bond	
1200' - 1188'	Very good bond	
1188' - 1129'	Excellent to very good bond	
1129' - 1110'	Fair to poor bond	
1110' - 1010'	Excellent bond	
1010' - 974'	Good bond	
974' - 965'	Excellent bond	
965' - 938'	Good bond	
938' - 914'	Good to fair bond	
914' - 810'	Excellent to very good bond	
810' - 746'	Good to fair bond	
746' - 730'	Good bond	
730' - 722'	Fair to poor bond	
722' - 678'	Very good bond	
678' - 640'	Excellent bond	
640' - 590'	Very good bond	
590' - 505'	Good to fair bond	
505' - 485'	Poor bond	
485' - 464'	Very good bond	
464' - 430'	Poor bond	
430' - 324'	Very good bond	
324' - 288'	Good bond	

288' -	222'	Poor bond	
222' -	150'	Excellent to very good bond	13-3/8" casing at 169'
150' -	100'	Good bond	
100' -	40'	Excellent bond	
40' -	Surf	Above fluid level	

Due to the cavity being filled with shale rubble, the hanging 4-1/2" and 7" casing required cutting at 2218' and 2215' respectively in order to be pulled from the well. The Baker bridge plug was set at 2154' depth. Plugging and abandonment was from the bridge plug to the surface.

There is excellent to good cement bond above each fair to poor bonded section to provide isolation from the surface or the cavity. The bridge plug was set in the salt section of the 9-5/8" casing and cemented through the 2-7/8" tubing, which was withdrawn in stages to completely fill the casing with 800 sacks of Class A cement.

Plans are to fill in the concrete containment pad with dirt and rock from the surrounding berm and restore to the existing surface grade. An elevation bench mark is to be established in the 9-5/8" casing flange for elevation surveys.

Baker Oil Tool, Allegheny Wireline, I&S Well Service and Universal Cementing crews conducted an safe and excellent preparation and plugging operation on well 58. The project should be classified as a text book example for plugging and abandonment of a salt brine well.

If you have any questions or comments please contact me.

Sincerely,

Larry Sevenker
Consulting Engineer

Exhibit F

Curriculum Vitae of H.C. Clark

H.C. Clark
2300 Bolsover
Houston, Texas 77005
hcclark@rice.edu

Consulting Geology and Geophysics
Rice University [1966-1989], Geology and Geophysics, retired faculty

PhD, Geophysics, Stanford University, 1967
MS, Geophysics, Stanford University, 1966
BS, Geology and Geophysics, University of Oklahoma, 1959
Teaching: courses in geophysics and geology, geologic hazards, engineering geology and geophysics
Research Interests: Current - Geophysical techniques applied to the study of shallow features, geophysical measurements and hydrogeologic problems, sustainability and agriculture; Past - paleomagnetism, geophysical measurements and crustal studies, analysis of geologic hazards
Texas Registered Professional Geoscientist 1977.
Municipal Solid Waste and Resource Recovery Advisory Council of the Texas Commission on Environmental Quality, 2003-2013, representing the Public Director of Student Advising at Rice in 1979 and served in various combinations with Susan Clark until retiring in 1989.
Organizations: American Geophysical Union, Society of Exploration Geophysicists [and Near Surface Section], Houston Geological Society, Geophysical Society of Houston, Board of Directors-Houston Urban Gardeners

Consulting Projects

Browning Ferris CECOS Gulf West Hazardous Waste Landfill, Chambers Co., Seismic study of active fault, groundwater geology
BFI 521 Municipal Landfill, Fort Bend Co., Texas, Geology, groundwater, active faulting and salt dome
BFI McCarty Road Municipal Landfill, Harris Co., Texas, Geology, active faulting
BFI Stratton Ridge Injection Well, Brazoria Co., Texas, Geology, fracture potential
CECOS Livingston Hazardous Waste Landfill, Livingston Parish, Louisiana, Geology
BFI Galveston County Landfill, Galveston Co., Texas , Resistivity study, baseline data
City of Houston, Crystal Chemical Injection Well, Harris Co., Texas, Active faulting, geology of reservoir
Rice Center for Community Design and Research, Chambers County Natural Factors Study, Chambers Co., Texas, Geology components
Texas Coast Project, Two County Tier, Texas, Geology components
Metropolitan Transit Authority Project, Harris Co., Texas, Composite fault map metropolitan area
Citizens, Willis, Montgomery Co., Texas, Municipal Landfill, Geology and groundwater
Citizens and County, Matagorda Co., Texas , Phillips 66 Landfarms, Landfills, Contaminated Water Ponds, Geology, groundwater, systems design
Fayette County Resource Watch, Fayette Co., Texas, Cummins Creek Lignite Mine Geology, geophysics and groundwater
Citizens, Katy, Texas, CMI Municipal Landfill, Cypress Creek, Geology, faulting
Citizens, East Houston, Texas, Municipal Landfill—Negev, now Bluebonnet, Geology, faulting
Citizens, North Houston, Texas Municipal Landfill—Atascocita, Geology, geophysics
Citizens and Power Systems Equipment, Chappel Hill, Washington Co., Texas Municipal Landfill, Geology, geophysics, groundwater
CASE, Beaumont-Port Arthur, Jefferson County, Texas, CWMI Injection Well
Campbell, Foss, and Buchannan, Inc. Eureka, Nevada, Mine Exploration
Magnetic measurements and interpretation Norse-Windfall Mines, Eureka, Nevada

Magnetic and seismic refraction measurements and interpretation
Anderson and Frierson, Geologists Central Texas Oil Exploration
Gravity and magnetic measurements and interpretation
U S Army Corps of Engineers, Galveston, Texas Galveston Bay Sand Supply Study
Data compilation and interpretation
U S Air Force, Office of Ballistic Missile Research Micro-blast rapid tunnel excavation. Sunburst Recovery Seismic recording, CSM Experimental Mine, Golden, Colorado
Tenneco Oil, Exploration and Production, Houston, Texas
Magnetic ranging system for detection of well blowout, patent
Allied Chemical, Norfolk, Virginia, Magnetic survey, steel tank construction site
SanJacinto Development Corp., Landslide and groundwater influence, downstream Livingston Dam; San Jacinto Co., Texas
Vinson and Elkins, Attorneys, Houston, Fault study. West Houston
Keplinger Associates, Petroleum Engineers, Houston, Oil Mining Study, Ohio, Geophysical measurements and interpretation Mining Prospect, Alaska, laboratory magnetic measurements and interpretation
Universal Savings Association, Houston
Hazardous waste study—former pipeline terminal and sludge storage pits
Soil borings, monitor well installation; soil, sludge, groundwater
sampling, interpretation of chemical test results
Hazardous waste study—former manufacturing facility
Waste disposal audit, supervision of testing program
Active surface fault study—former manufacturing complex Field surface study and interpretation of surface, photo, and subsurface data
Hazardous waste study—office park and landfill area
Soil borings, monitor well installation; soil, sludge, groundwater sampling, interpretation of chemical test results
ERM Southwest, Houston, Texas, Pesticide Manufacturing Plant, Dallas County, Texas
Seismic refraction interpretation
Testing Unlimited, Houston, Texas, Conroe Jail, Montgomery County, Texas, Seismic study, basement heave
General Dynamics, Fort Worth, Texas Air Force Plant 4, Fort Worth, Texas, Seismic reflection study, groundwater problem
McClelland Engineers, Houston, Texas, Bosque Dam Construction Planning, Seismic refraction study, outlet works
Police Jury, Calcasieu Parish, Louisiana Chemical Waste Management Hazardous Waste Landfill, Lake Charles Facility-Geologic and hydrologic study
Commissioners Court, Matagorda County, Texas -Phillips 66 Landfarm- geohydrologic study of landfarm operation
Citizens of Security, Texas-Montgomery County Contractors Type 1 Landfill, geology and geohydrology—Permit amendment for special wastes
Texas Environmental Coalition, Concerned Citizens of Winona-Land Banned Waste Exemption Petition - WDW 186, Gibraltar Chemical Resources, Winona, Texas
Citizens, Fort Bend County, Texas-Fort Bend County Landfill - proposed expansion
Resolution Trust Corporation-Former Industrial Facility - ground water contamination
Fault study - seismic reflection profile study-splay faults and contaminant transport
City of League City, Texas-Waste oil processor-Hazardous waste and ground water
Calhoun County Resource Watch, Texas-Union Carbide Plant Hazardous Waste Landfill Faulting, geology, and ground water; British Petroleum Plant-Hazardous waste landfill geology and performance
Mitchell Development Corporation-Bald Head Island Beach erosion and relationship to Wilmington Channel Dredging

Allen County [Ohio] Citizens for the Environment Workshop on deep well injection
Louisiana Department of Environmental Quality-Workshop on deep well injection
Law Engineering, Houston, Texas-Workshop on landfills
Citizens, Fort Bend County, Texas-Fort Bend County Landfill - methane migration and groundwater
Citizens, Waco, Texas-City of Waco Landfill Expansion, geological and geophysical analysis
City of Petronila, Nueces County, Texas Texas Ecologists Hazardous Waste Disposal
Analysis of application for two injection wells
Numerous groups in Texas, Louisiana, Ohio: Critical comments on hazardous waste injection wells including: Gibralter Chemical; Chemical Waste Management, Port Arthur and Corpus Christi, Texas; Vickery, Ohio; DSI, Empak, Waste Water Inc, Dupont, Celanese, American Cyanamid, Cecos, Rollins, BP Green Lake, IMC Fertilizer, BP Lima Harris County, Texas-Westbelt Landfill, geological and geophysical analysis; American Envirotech Hazardous Waste Incinerator, geological and geophysical analysis
City of Houston and Harris County-Hunter Industrial Facilities salt dome storage of hazardous waste, geological and geophysical analysis
City of Wilmer, Texas Laidlaw Wilmer Landfill Remand Hearing, geological analysis
Citizens, Lacy-Lakeview (Tirey Trust) Lacy-Lakeview Landfill Expansion, groundwater and geology
CASE-CWMI Port Arthur Landfill-audit of landfill documents-geologic analysis
Citizens, Fairview (COFF), McKinney Landfill Expansion, geological and geophysical analysis
Lower Colorado River Authority-Tricil Landfill, Altair, Texas geological and geophysical analysis
City of Del Rio-CWMI Dryden Landfill, Dryden, Texas
CONTROL [Citizens of Justin, Texas] Sentry Landfill Proposal, Denton, Texas-geological analysis
West Harris County MUDS-Madden Road Landfill geological and geophysical analysis
Sierra Club, Eagle Pass, DOS Republicas Coal Mine, geological and agricultural analysis of alluvial valley floor
Citizens Live Oak County, Texas IEC Injection Wells 156, 159, geological and geophysical analysis
Citizens Winnsboro, Texas East Texas Landfill, geological analysis
Citizens East Fort Worth, Laidlaw Landfill, MSW 2145, geological analysis
City of Lancaster, Texas WMX Skyline [Ferris] Landfill, 42-C, geological analysis
Citizens Walker County, Texas DDI Landfill, geological analysis
Citizens Palo Pinto County and Fawcett XO Ranches-Blue Flats Landfill, geological analysis
MOSES [Mothers Organized to Stop Environmental Sins] Injection Wells 186 and 229, Smith County, Texas-injection well, geological and geophysical analysis
Citizen groups Jefferson County NORM facility, geological and geophysical analysis
CCAP Wharton County-Hazardous waste caverns, injection, geology and geophysics
Baggett, McCall & Burgess, Lake Charles PPG Plant contamination plume
ABLE, Canyon, Texas-BFI Canyon Landfill expansion proposal geological analysis
Frost Family Farms, Liberty County Class I [non-hazardous] injection well proposal, geophysical and geological analysis
Spring Cypress Landfill Coalition, Harris County-Type IV landfill, geology and hydrogeology
Sierra Blanca Legal Defense Fund, Hudspeth County, Texas, Low Level Nuclear Waste Disposal license application, geophysical analysis
Citizens groups, Kinney County, Adobe Landfill proposal, geophysical and geological analysis
Bill Sutton family, Fort Bend County Long Point Dome landfill, geophysical and geological analysis
North Texas Municipal Utility District 121 Landfill design team, geological and geophysical measurements
Raytheon [McBride Ratcliff Engineers], Active fault and BMC Software complex, Houston
Limestone County, Texas-Hansen Aggregates quarry design and hydrogeology analysis
Citizens, Hays County, Texas-Aquasource water treatment and discharge facility, geology and hydrogeology
BFI-Blueridge Landfill expansion, geology and hydrogeology

McFadden Family-Dupont Beaumont no-migration exemption renewals for injection wells, analysis
Frost, FPL Farming Ltd-Amendment to injection well permits WDW316 and 317
Chambers County, TSP Cypress Point Industrial Landfill, geologic issues analysis, industrial rules analysis
Citizens Fort Bend County, Juliff Type IV Landfill application
Individuals, various LPST and drycleaner contamination cases
BVSMA, Grimes County, landfill application
O'Connor Ranches, Victoria, groundwater resources in South Texas and analysis of issues
BFI-McCarty Landfill expansion
BFI-Blueridge Landfill expansion
State of Nevada, Agency for Nuclear Projects, Yucca Mountain, repository geology and geophysics
Sierra Blanca Ranch, Hudspeth County, quarry site reclamation, geologic issues
Lafitte's Cove Nature Society, Galveston, comments on hurricane sever potential related to cut and fill development
Cooke County citizens, Salt Water Disposal well and Barnett Shale operations
Erath County citizens, Salt Water Disposal Well and Barnett Shale operations
Goliad County, geologic hazards and uranium exploration project
TJFA as protestant, Williamson County Landfill Expansion
TJFA as protestant, Comal County Landfill Expansion
Goliad County, UEC uranium mining application opposition
Montgomery County citizens, Type IV Landfill application analysis
Texans For Sound Energy Policy, Victoria nuclear power plant review
Lewisville, Camelot Landfill geology and hydrogeology review
Pescadito Environmental Resource Center, Webb County, Type I landfill application
NoCoal Coalition Matagorda County, White Stallion power plant water well application
Goliad County GCD, UEC uranium mine aquifer exemption discussion
Earthjustice, New York salt cavern storage of LNG and CNG in Watkins Glen brine field FERC
BlackburnCarter, Matagorda County contamination—salt water disposal well[s]
BlackburnCarter, Harris County contamination—gas well/injection well/disposal well
Goliad County citizens—uranium mine aquifer exemption analysis and EPA comments
Quintana LNG Terminal proposal, geologic issues including Stratton Ridge FERC
BlackburnCarter, Bayou Corne, LA, salt cavern collapse and sinkhole

Publications

Keller, M.F., and Clark, H. C. Jr., 1964, Prediction of magnetic anomalies due to four buried spheres, in Computers In the Mineral Industries, Stanford University Press.

Clark, H. C. Jr., 1966, A Study of a Thick Oligocene Sill as a Paleomagnetic Record of Secular Variation, (abs.): Trans. Am. Geophys. Un., V.47, p. 79.

Clark, H.C. Jr., 1967, A Fused Quartz Curie-point Balance in Methods in Paleomagnetism, Developments in Solid Earth Geophysics: Amsterdam, Elsevier Publ. Co., v. 3, pp. 438–439.

Clark, H. C. Jr., 1967, Variation of Remanent Magnetic Properties Related to the Differentiation of the Mary's Peak Sill, Oregon, (abs): Trans. Am. Geophys. Union, v. 48, p. 79.

Lankford, R. R., Clark, H. C. Jr., Warme, J. E., and Rehkemper, L. J. 1969, Galveston Bay Estuarine system - Case study in Case Studies of Estuarine Sedimentation and its Relation to Pollution of the Estuarine Environment: Gulf Universities Research Corporation, Houston, Texas, pp. A-l–A-64.

Gilliland, M. W., Clark H. C. Jr., and Sutler, J. F., 1969, Paleomagnetism of the Buck Hill volcanic series. Big Bend, Texas (abs.): Trans. Am. Geophys. Un.,V. 50, p. 131.

Clark, H. C. Jr., 1959, Remanent Magnetism, Cooling history, and Paleomagnetic Record of the Mary's Peak Sill, Oregon: Journal of Geophysical Research, V. 74, ff. 1, pp. 3143-3160.

Clark, H. C. Jr., Flournoy, L. D., and Haupt, L., 1969, Late Pleistocene to Holocene Secular Variation Observed in Cores from the Gulf of Mexico: Trans. Am. Geophys. Union, V. 50, p. 606.

Clark, H. C. Jr., and Hickcox, A. E., 1970, Remanent magnetic stability and cooling history of the Mary's Peak Sill, Oregon (Abs.): Bull. Geol. Soc. Am., V 2, p. 276.

Clark, H. C. Jr., and Johnson E. A., 1971, Paleomagnetism of Oaxaca State, Mexico (abs), Trans. Am. Geophys. Un., V. 52, p. 190.

Clark, H. C. Jr., and Kennett, J. P., 1972, Confirmation of the reality of the Laschamp Geomagnetic Polarity Event in cores from the Gulf of Mexico (abs.): Trans. Am, Geophys. Un., V. 53, p. 423.

Clark, H. C. Jr., and Kennett, J. P.,1973, Paleomagnetic excursion recorded in Late Pleistocene deep sea sediments. Gulf of Mexico: Earth and Planetary Science Letters, V. 19, pp. 267-274.

Clark, H. C. Jr,, Fryer, G. E, Gasparini, P., Roberti, N., Scandone, R., 1973, II laboratorio de paleomagnetismo dell'osservatorio vesuviano: Prod. Associane Geofixica Italiana.

Kennett, J. P., Huddleston, F., Clark, H. C. Jr., 1973, Paleoclimatology, paleomagnetism, and teprochronology of late Pleistocene sedimentary cores, Gulf of Mexico. In CNRS Symposium Volume: Les Methodes quantitative d'Estudes des variations du climat au cours du Pleistocene. No. 219, p. 239–250.

Clark, H. C. Jr, Remanent magnetism of volcanic rocks, 1974, Physical Volcanology (Gasparini, P. and Civetta, L., Editors), 20 pages, Elsevier. Amsterdam.

Clark, H. C. Jr., and Bradbeer, G. E., 1974, Geology and natural environmental factors. Chambers County. Texas in Environmental Analysis for Development Planning, Chambers County, Texas. Rice Center for Community Design and Research and Southwest Center for Urban Research. 28 Manuscript pages and figures.

Clark, H. C. Jr., 1975, Geology, Map 9 In Texas Gulf Coast Project, Research Report 1, Williams, D. L., and Rowe, P.G., ed., Rice Center Community Design and Research, Houston, 261 pages.

Gevirtz, J. L., Clark, H. C. Jr., Rowe P. G., 1975, Environmental Description for Land-Use planning, Abstracts with Programs, Geological Society of America, Vol. 8, Number l, p. 21.

Clark, H. C. Jr., Georges, D., and Rowe, P. G., 1976, Geologic Hazards and Land Use Planning in the Gulf Coast, Abstracts with Programs, Geological Society of America, Vol. 8, Number 1, p. 14.

Anderson, J, B., Weaver, M.F., Clark, H. C. Jr., 1977, Sediments and Sedimentary Processes on High Latitude Continental Shelves, Offshore Technology Conference, V. 9,2738, 8 pages.

Anderson, J. B., and Clark, H. C. Jr, 1977, Geologic Studies for the Galveston County Shore Erosion Study, U.S. Army Corps of Engineers, Galveston District, 52 pages.

Clark, H. C. Jr., and Gilliland, M. W. 1975, "Paleomagnetism of Early Tertiary Volcanics, Big Bend, Texas." Cenozoic Geology of the Trans Pecos Volcanic Field of Texas; Conference Proceedings, Alpine, May 21–25,1978.

Watson, C.W. and Clark, H.C. Jr, 1978, "Gravity measurements and the Big Bend, Texas, as Part of a Continental Rift." Cenozoic Geology of the Trans Pecos Volcanic Field of Texas; Conference Proceedings, Alpine, May 21–25, 1978.

Clark, H.C. Jr,1978, Geologic Hazards and Houston, Houston Engineer, May-June, 1978, p. 23–24.

Fainstein. R., and Clark, H.C. Jr., 1975. The Crustal Structure beneath the Victoria-Trinidade Ridge, Revista Brasileira De Geosciencias, v. 8, p. 170–283.

Metcalfe, C. W. and Clark, H. C. Jr.,1978, Gravity Analysis of the Big Bend, Texas, as part of a Continental Rift, Abs., Transactions Am. Geoph. Union, V. 59, Number 12, p. 1189.

Gilliland, M. W. and Clark, H. C. Jr., 1979, Paleomagnetism of Early Tertiary Volcanics, Big Bend, Texas, Guidebook 19, Cenozoic Geology of the Trans-Pecos Volcanic Field of Texas, Anthony W. Walton and Christopher D. Henry, Texas Bureau of Economic Geology Guidebook Series.

Metcalfe, C. W., and Clark, H. C. Jr., 1979, Gravity Measurements and the Big Bend, Texas, as part of a Continental Rift," Guidebook 19, Cenozoic Geology of the Trans-Pecos Volcanic Field of Texas, Anthony W. Walton and Christopher D. Henry, eds., Texas Bureau Of Economic Geology, Guidebook Series.

Clark, H.C. Jr, and Metcalfe, C. W., 1979, Ouachita Orogenic Belt Offset, Central Texas, ABSTRACT, Transactions of the American Geophysical Union, V. 60,46.

Clark, H. C. Jr., Greene, L. A. Jr., and Sealy, C. 0., 1979, Ground and Surface Water, Geologic Hazards, and Waste Disposal: Houston, Texas. ABSTRACT, Trans. Am. Geoph. Union, V. 60,46, p. 230.

Clark, H. C. Jr., and Georges, D., 1981, Deep Well Injection of Liquid Waste: Hazards and Planning, Abstract, EOS, Transactions of the American Geophysical Union, V, 62, p. 865.

Clark, H. C., 1982, Ouachita Orogenic Complex, Central Texas - Geophysical Measurements and Basement Offset, Transactions of The Gulf Coast Association of Geological Societies., (M. Malek-Aslani, ed.), 32, p.157–163.

Clark, H C. Jr., Young, Chapman, Barker, Ronald., 1984, "Field Tests of the Stem-Induced Explosive Fracturing Technique, Society of Petroleum Engineers of the AIME, Proceedings of the Unconventional Gas Recovery Symposium, SPE 12840; May 23, 1984, 8 pages.

Young, C., Barker, D., and Clark, H. C., 1986, Field Tests of the Stem Induced Explosive Fracturing Technique, Society of Petroleum Engineers, Journal of Production Engineering, p. 266–273.

Clark, H.C., 1993, Geophysical Measurements and Environmental Problems in the Regulatory Process, Special Session, Third International Congress of the Brazilian Geophysical Society, Rio de Janeiro [Invited Paper].

Clark, H.C., 1995, Geophysical Measurements and the Public Environmental Process [Best of SEG],

American Association of Petroleum Geologists Annual Meeting, p. 17a, Houston.
Clark, H.C., 1996, Overview of Environmental Problems and Non-Invasive Geophysics and Their Role in the Legal/Regulatory Framework, Looking Into the Earth, Geophysical Society of Houston, Environmental Applications Special Interest Group, p. 19–20.

Clark, H.C., 2006, Our Bayou City Farmers' Market; a Public Place, Guide, Urban Harvest, Houston, Winter, 2006, p. 1–2.

Clark, H.C., 2007, Landscape On The Move, Houston Atlas of Biodiversity, Houston Wilderness, p. 2–4, Texas A&M University Press, College Station.

Clark, H.C., 2010, Critical Agricultural Strategies from the Outside--In: Approaching Sustainability Through Doable Farming Centered Enterprise, Gulf Coast Green, Annual Meeting, Houston; also presented at Houston 2040 and Houston Urban Gardeners.

Clark, H.C., 2011, Is It Time To Re-invent Your Farmers' Market?, Growing For Market, v. 20, no. 6, p. 2, Fairplain Publishing, Lawrence, Kansas.

Clark, H.C., 2014, Confession of a Weekend Grass Farmer, The Stockman GrassFarmer, March, 2014, V.14, no. 3, p. 10-14, Mississippi Valley Publishing Co., Ridgeland, MS.

Clark, H.C. and Broussard, M.L., 2014, Houston Rocks, Houston Geological Society Bulletin, v. 59, no.9, p. 35–39, Houston, TX.

Clark, H.C., 2014, Springfield Spring and Groesbeck's Water Supply—a cautionary tale for small towns in Texas, Houston Geological Society Bulletin, v. 57, no.3, p. 17–19, Houston, TX.

Patent: Waters; Robert L. (Austin, TX); Roberts; George F. (Georgetown, TX); Walters; Philip H. (Austin, TX); Clark; Howard C. (Houston, TX); Fitzgerald; Don D. (Houston, TX); Stelly, II; Otis V. (Lafayette, LA), 1988, Downhole Combination Tool, 5,064,006 USPO, 1991.