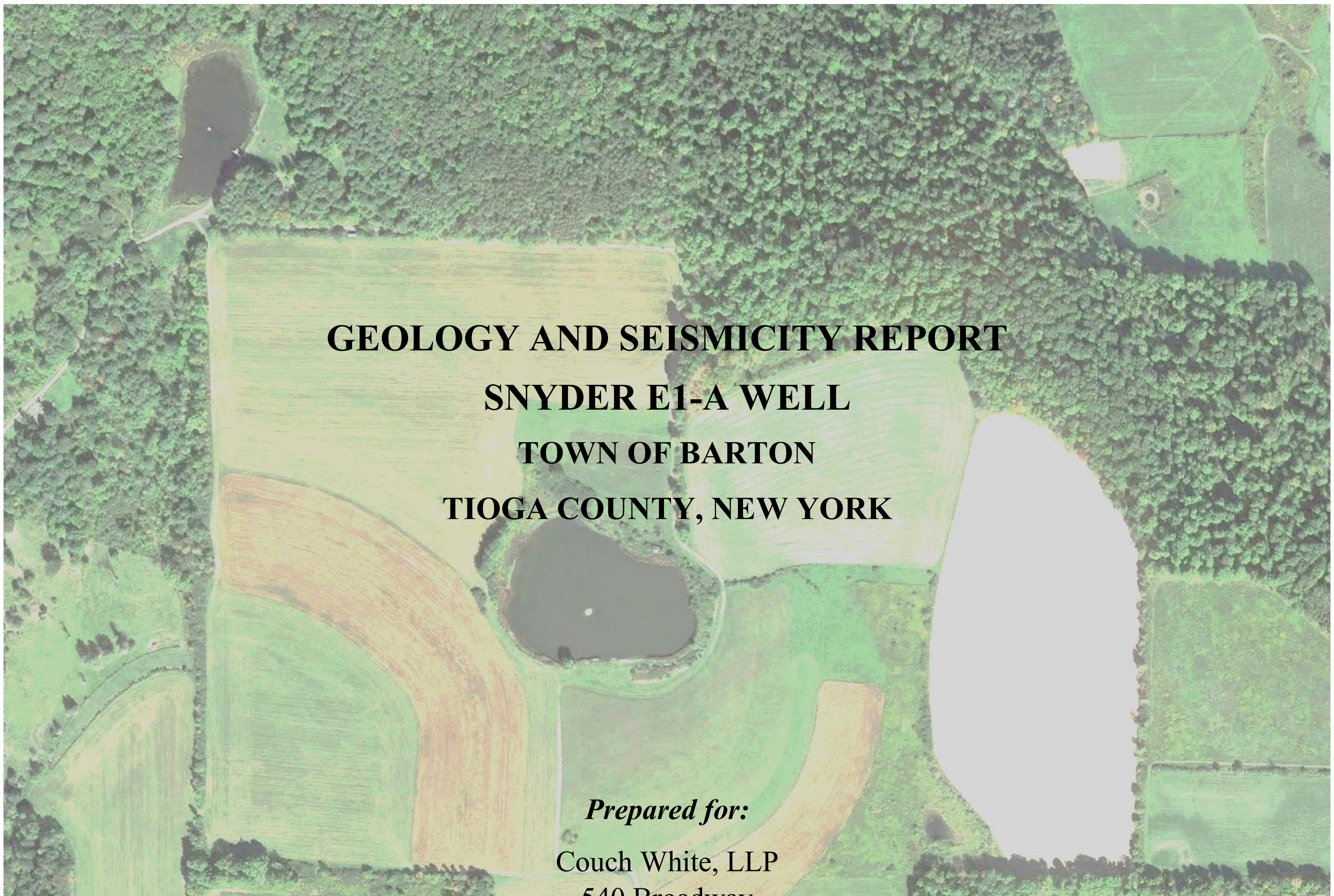

GEOLOGY AND SEISMICITY REPORT

SNYDER E1-A WELL

TOWN OF BARTON

TIOGA COUNTY, NEW YORK

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July 25, 2017

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1.0 EXECUTIVE SUMMARY

This analytical report regarding regional and site-specific geology, seismicity (including the potential for induced seismicity) and the porosity and permeability of the geologic structure surrounding and overlying the proposed Snyder E1-A horizontal well has been prepared by Continental Placer Inc. at the request of Couch White, LLP on behalf of Tioga Energy Partners, LLC.

Geologic faulting and seismicity are relevant issues for assessing the potential risks associated with well completion activities (e.g bedrock fracturing with gelled propane, referred to in this report as "well stimulation") in the Snyder E1-A Well. However, some of the concepts addressed herein, such as the relationship between faulting and seismicity, cannot be understood, nor meaningfully discussed, in isolation. Basic geologic concepts, such as how and why faults are formed and exist, must be understood before being able to understand the significance or non-significance of the geologic features surrounding the Snyder E1-A Well, and how the stimulation of the wellbore will interact with those geologic features. It is only with this understanding that the context of the risk assessment presented herein can be understood.

Based upon the detailed information and analysis contained in the body of this report, the following observations, conclusions and recommendations can be made:

1. The geology surrounding the Snyder well is unremarkable, and typical of this part of New York's Southern Tier;
2. There are no known seismically active faults within 100 miles of the proposed well;
3. The closest fault to the well is more than a mile to the west of the western edge of the well spacing unit (known as a Wrench Fault), which is a significant separation distance;
4. The induced fractures created during well completion will not extend beyond the edge of the well spacing unit;
5. Faults within Tioga County are not believed to extend to basement bedrock, rendering their potential to be geologically active exceedingly small;
6. There is 2,800 feet of cap rock above the top of the fracture zone and below the fresh groundwater zone;
7. The porosity and permeability of the cap rock prevents the upward migration of gases and fluids. Additionally, there will be no persistent, long-term driving pressure gradients (head) created after well completion activities are complete;
8. The localized induced seismicity from completion activities will be below human detection limits, and is not associated with a geologic event;
9. Completion activities will be focused on a singular borehole, and will not use high volume water development;
10. In an abundance of caution and to address any concerns regarding induced seismicity, seismic monitoring in the area of the Snyder well is recommended before, during and after completion activities. Enforceable permit conditions should include a requirement that the operator evaluate and consult with the agency regarding any seismic activity above 1.5, but below 2.5 (Richter Scale); and an immediate cessation of drilling or completion activities if seismic activity exceeds 2.5. (See Section 6.1 for the complete recommendation).

2.0 INTRODUCTION

This study reviews the geologic structure, including faulting and seismic activity in the area surrounding the proposed Snyder E1-A Well (the "Project"). The Project is proposed to be located in the Town of Barton, Tioga County, New York. To prepare this study, Continental Placer, Inc. completed an exhaustive review of publicly available well log data, published academic studies and articles, GIS data, the 1992 Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program, the Final Supplemental Generic Environmental Impact Statement on the Oil and Gas and Solution Mining Regulatory Program (May 2015) prepared by the New York State Department of Environmental Conservation (hereinafter "2015 FSGEIS") and other information.

Geologic structure often includes faults in various layers of the rock underlying the earth's surface. Generally speaking, geologic faults are fractures along which rocks on opposing sides have been displaced (moved) relative to each other after the lithologic process (rock formation process) is complete. The amount of displacement may be small (centimeters) or large (feet to miles). Geologic faults are prevalent throughout the United States. Faults are most often associated with specific tectonic or orogenic (mountain building) events. Since rock formations are durable and persist through geologic time, faults from long-ago events may still be observed today, although the specific feature is no longer active. That is to say that the stress field that allowed the fault to form has long since been satisfied and there is no energy available to create motion along the fault.

Identification of potential linearities (linear features associated with fault movement that express themselves on the earth's surface) or faults in and of themselves is an admirable academic exercise to further our understanding of Geology. However, simply identifying a potential fault does not automatically lead to a conclusion that the fault is active or that it will be active at some point in the future.

The term "seismic event" or "earthquake" is used to describe any event that is the result of a sudden release of energy in the earth's crust that generates seismic waves. Most earthquakes are too minor to be detected without sensitive equipment. Large earthquakes result in ground shaking and sometimes displacement of the ground surface. Earthquakes are caused mainly by movement along geological faults. Among many others, current seismically active areas include the Himalayan Mountains, portions of the countries of Turkey and Iran, and the western United States.

Induced seismicity (e.g. seismic events) refers to induced ground vibrations triggered by human activity such as mine blasts, nuclear experiments, and fluid injection, including traditional, water-based borehole fracturing and fluid injection (disposal) wells.

The following sections of this report discuss each of these topics, their relationship and interaction with each other, and evaluates their significance relative to development of the Snyder E1-A Well.

2.1 Depositional Sequences and General Stratigraphic Sequence

To analyze the relevance of the lithologies, formation tops, geologic structure and the presence of faulting in the area surrounding the proposed Snyder Well, one must first understand the general geology of the Southern Tier of New York and Northern Pennsylvania. Figure 1 – Site Location Map, illustrates the proposed project location and surrounding areas.

The area of interest of the Paleozoic stratigraphy of the northeastern edge of the Appalachian Basin in New York includes portions of the northern Appalachian Plateau, Onondaga-Helderberg escarpment and Mohawk Valley physiographic province. In this region, Cambrian through Devonian strata are exposed in approximately east-west trending outcrop belts, and units dip gently to the south- southwest at ~1 degree.

Natural bedrock exposures are found in stream valleys or along valley walls in steep, and glacially-carved terrain. Wisconsin-age glacial deposits are thickest in major valleys and mantle many upland areas. The prominent east-west trending Onondaga-Helderberg escarpment provides the best natural exposures. Road cuts are numerous along major highways including US Route 20 and Interstate Route 90 (although access is limited).

Bedrock structural features are relatively uncomplicated in the western portion of the area of interest. In the central and eastern Mohawk Valley, approximately north-south trending normal faults are evident and bound horsts that were active during Ordovician and early Silurian time (which predate the deposition of the Marcellus Shale), and acted to control sedimentation patterns during the evolution of the Taconic foreland basin. Associated syndepositional and early post-depositional folding and faulting are common in interbedded limestone-shale facies. In the eastern Mohawk Valley and adjacent northern Catskill Mountains, subhorizontal thrust structures are present as decollement surfaces within ductile dark shale units in the Ordovician and Devonian section.

The Ordovician-aged Utica Shale and the Devonian-aged Marcellus Shale are of particular interest because of recent estimates of natural gas resources and because these units extend throughout the Appalachian Basin from New York to Tennessee. The lithologies and structural features of the Southern Tier of New York, specifically in Tioga County, are detailed below. The following sections describe the Marcellus Shales and surrounding formations in south-central New York.

The Appalachian Basin, of which bedrock in New York's Southern Tier was deposited, was a tropical inland sea that extended from New York to Alabama, as shown in the following inset pictures. The tropical climate of the ancient Appalachian Basin provided favorable conditions for generating organic matter needed to form bedrock hydrocarbons. In addition, erosion of the mountains and highlands bordering the basin to the east provided clastic material (i.e. sediment from weathered bedrock) for deposition. The sedimentary rocks that fill the basin include shales, siltstones, sandstones, evaporites, and limestones that were deposited as distinct layers that represent several sequences of sea level rise and fall, subduction and continued deposition. A General Stratigraphic Cross Section of south-central New York is provided as Figure 2.

Black shales, such as the Marcellus Shale, are fine-grained sedimentary rocks that contain high levels of organic carbon. The fine-grained material and organic matter accumulate in deep, warm, quiescent marine basins, as well as in forebasin shallows. In Middle Devonian New York, the Marcellus deposited in shallower waters west of the main Catskill Delta that formed from the erosion of the Acadian Mountains of eastern New York and Western New England.

The warm climate at the time favored the proliferation of plant and animal life. The deep basins allowed for an upper aerobic (oxygenated) zone that supports life and a deeper anaerobic (oxygen-depleted) zone that inhibits decay of accumulated organic matter. The organic matter is incorporated into the accumulating sediments and is buried. Pressure and temperature increase and the organic matter is transformed by slow chemical reactions into liquid and gaseous petroleum compounds as the sediments are buried deeper. The degree to which the organic matter is converted is dependent on the maximum temperature, pressure, and burial depth.

The stratigraphic column for southcentral/southwestern New York State is shown in Figure 3 Stratigraphic Column - Central New York, and includes oil and gas producing horizons (based on depositional environment and shows of gas during drilling). Specific geologic formations and members are discussed in the following subsections, which is taken in large part from a Colgate University field guide of southcentral New York.

2.1.1 Upper Devonian Lithologies

In the area south of the central Mohawk Valley, in south central New York, dark marine shales, siltstones and sandstones of the Genesee Group overlie sandy upper Hamilton Group facies. The basal Tully Formation consists of calcareous sandstone deposited in a near-shore, tide-dominated shelf system. The uppermost Genesee Group consists of non-marine fluvial deposits of the Oneonta Formation. The succeeding West Falls Group is dominated by marine shelf to basin shale, siltstone and sandstone deposited by mixed storm and turbidite processes (downslope erosion and deposition).

2.1.2 Marcellus-Hamilton

Basal Marcellus Formation organic-rich mud accumulated as high productivity, density stratified surface waters that rained organic matter onto oxygen-deficient substrates that received very limited terrigenous clastic input. The Union Springs Member contains the highest organic content. The Cherry Valley Limestone Member represents resumption of carbonate accumulation during an episode of oxygenation of bottom waters. The succeeding Chittenango (=Oatka Creek), Bridgewater-Otsego and Solsville Members of the Marcellus comprise a sequence of dark gray to gray shales. The succeeding formations in the Hamilton Group (Skaneateles, Ludlowville, Moscow) are not clearly separable in the area south of the central Mohawk Valley, but generally consist of gray shale, siltstone and fine sandstone with a normal marine fauna. This is the target formation for the Snyder E1-A Well.

2.1.3 Tristates-Onondaga

Clastic units of the Tristates Group are limited to the central and eastern Mohawk Valley and eastern Catskill regions, southward into the southern tier. Shelf-to-basin shaley limestone, calcareous shale, siltstone and sandstone of the Schoharie, Esopus and Carlisle Formations record uplift and erosion of early Acadian orogenic source regions (Phase I Acadian Orogeny). The Onondaga Formation carbonates accumulated as terrigenous clastic input diminished in the early middle Devonian, although widespread volcanic ash input continued.

2.1.4 Helderberg

Renewed collisional tectonism in Early Devonian time prompted foreland subsidence that accommodated the deposition of platform carbonates of the Helderberg Group. Abundant volcanic ash beds in the Helderberg document eruptive volcanic activity. Helderberg strata are absent west of the eastern Finger Lakes region, and are thickest in the eastern Catskills, thinning to the west through Tioga County.

2.1.5 Oneida-Clinton-Salina

In the Mohawk Valley and to the south into the southern tier, latest Ordovician units (Pulaski, Oswego) are absent, and Silurian strata rest unconformably on eroded Frankfort Formation. The Oneida Conglomerate, Sauquoit Formation, Willowvale Shale, Herkimer Sandstone, and Ilion Shale are thinned proximal equivalents to thicker basinal sequences found to the west of the Mohawk Valley region. The Oneida and Herkimer are shoreline facies with local thickness variations that are related to syndepositional faulting. The Upper Silurian Salina Group, hosting thick evaporate deposits in the Finger Lakes region, is represented in the Mohawk Valley by thin peritidal carbonates and dolomitic shale (Cobleskill and Chrysler Formations) in the Mohawk Valley and areas to the south.

2.1.6 Black River-Trenton-Utica-Frankfort

Limestone strata of the Black River Group are present throughout the Mohawk Valley and represent resumption of carbonate deposition in peritidal and shallow subtidal platform environments during the earliest phases of foreland basin subsidence associated with the onset of the Taconic Orogeny. Volcanic ash beds are widespread in the Black River Group and document eruption of andesitic to rhyolitic stratovolcanoes along the maturing Taconic arc system. The succeeding Trenton Group carbonates accumulated as the Taconic arc margin began to collapse westward onto the Laurentian margin of present-day western Vermont, Massachusetts and Connecticut. Early Paleozoic sediments of the old Laurentian shelf and slope were driven westward onto the passive margin platform. Trenton carbonates consist of platform, ramp and foreland basin facies that interfinger with, and are progressively replaced east to west by basinal mud of the Utica Formation. Late Ordovician Frankfort Formation mud, silt and sand represent rapid filling of the Taconic foreland basin. By the end of Ordovician, shallow marine deltaic facies of the Pulaski and Oswego Formations built westward to complete the Taconic tectophase.

2.1.7 Potsdam-Beekmantown

The basal Paleozoic strata in the region consist of subarkosic arenite and quartz arenite of the Potsdam Formation, which rests in profound non-conformity on 1100 ma rocks of the Adirondack Grenville Province. These basal clastics are succeeded by dolomitic limestone and dolostone of the Galway, Little Falls and Tribes Hill Formations. The middle Cambrian to lower Ordovician units, comprising the Beekmantown Group, form a relatively thin (150-600 feet) passive margin sequence. Inliers of Beekmantown units are found within normal-fault bounded valleys of the southern and central Adirondack Mountain, suggesting that the Adirondack uplift was covered by marine waters during Beekmantown Group deposition. Beekmantown strata thicken to the south-southwest of the Mohawk Valley region. Early middle Ordovician Chazy Group strata, present in the northern Champlain Valley and Ottawa-St. Lawrence Lowlands, are absent from the Mohawk Valley. Post-Beekmantown uplift of the region resulted in subaerial erosion and meteoric alteration of the early Ordovician passive margin. This “pre-Black River” or “Knox” unconformity is attributed to progressive east to west regional uplift related to forebulge development during the onset of the 450 ma Taconic Orogeny.

3.0 GEOLOGIC FORMATIONS – DETAILED DESCRIPTION OF TARGET ZONE

Following the general description of Southern Tier lithologies above, the descriptions below focus on Tioga County lithologies that will be encountered in and around the Snyder E1-A Well, and specifically the target zone for well development, the Marcellus Shale. Again, this information is taken from Colgate University field guide book information.

Upper Marcellus Formation - Pecksport Shale Member

The Pecksport Member consists of moderately fissile gray to dark gray silty shale and siltstone with a low diversity brachiopod/gastropod fauna. The irregular bedding and lack of lamination suggest that the muddy sediment was intensely bioturbated prior to burial and consolidation.

Bridgewater, Solsville, and Pecksport Members

These shale, siltstone and fine sandstone units thicken rapidly to the east, with the combined Bridgewater-Solsville interval exceeding 500 feet thick in the area south of Cherry Valley, NY. The Bridgewater Member consists of gray, shaley siltstone. The contact with the overlying Solsville Member is gradational, with subtle but regular increases in grain size and bedding thickness up section. Vertical burrows and larger brachiopods (*Spinocyrtia*) are characteristic of the calcareous siltstone and fine sandstone of the Solsville. An interval of hummocky cross-stratified fine sandstone with leached shell coquinite occurs 8-10 feet below the summit of the Solsville. The uppermost beds contain rare tabulate corals. The upward shallowing and coarsening of the Solsville is terminated by an abrupt transition to fissile silty gray shale of the basal Pecksport Member.

Union Springs, Cherry Valley and Chittenango Members, Marcellus Formation

The Union Springs Shale, Cherry Valley Limestone and overlying Chittenango Shale Members of the Marcellus Formation are subjacent to the Bridgewater. The Union Springs Member is approximately 25 feet thick.

The Cherry Valley Limestone consists of dark, bituminous limestone and nodular limestone in black shale. The limestone beds contain an abundant but poorly-preserved cephalopod fauna. Some beds consist of styliolinid wackestone; rare brachiopods and auloporid corals indicate that bottom waters were, at times, oxygenated during Cherry Valley deposition. The overlying Chittenango Member consists of dark silty shale.

Photograph 1: Cherry Valley Limestone Member overlain by Chittenango (Oatka Creek) Shale Member

Chittenango Member (Oatka Creek Member)

The dark to light gray silty shales of the middle portion of the Chittenango Member of the Marcellus contain numerous thin (2-5 in) beds of ripple laminated calcareous siltstones, probably of storm origin. Fossils are exceedingly rare, and limited to a sparse brachiopod fauna and occasional orthoconic cephalopods.

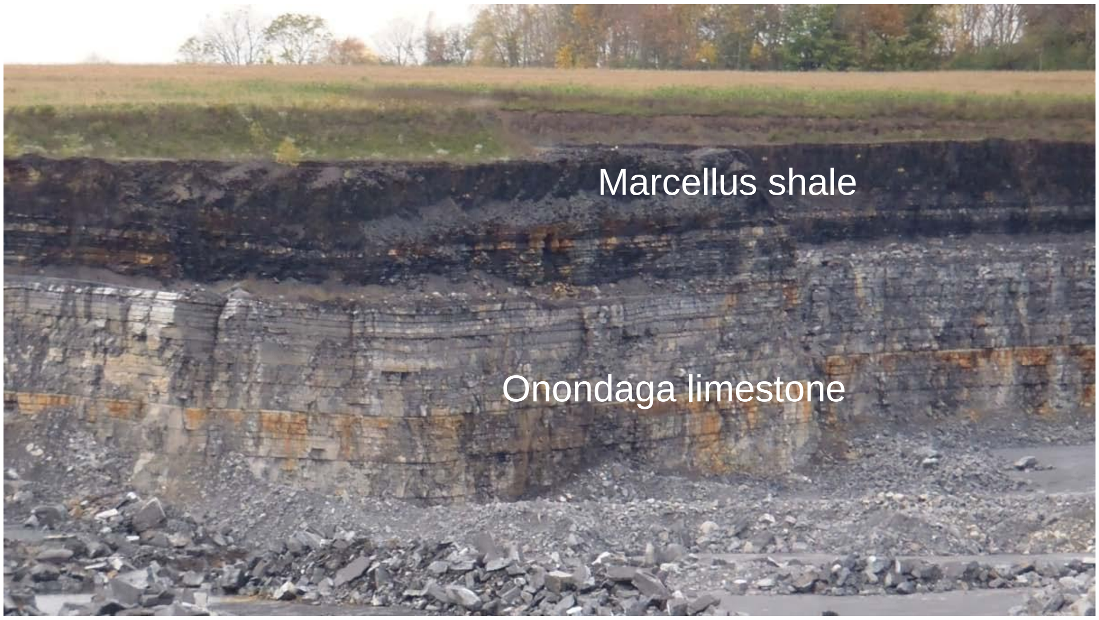
Carlisle Siltstone Formation and Onondaga Formation (Edgecliff, Nedrow, Moorehouse and Seneca Members)

The Carlisle consists of bioturbated ("*Taonurus*") calcareous and glauconitic siltstone; its upper contact with the basal Edgecliff Member of the Onondaga is disconformable, and is marked by accumulation of phosphate nodules and glauconitic sand. The Oriskany Sandstone interval lies within the Carlisle-Edgecliff contact. The Oriskany is sporadically present in outcrops in the Mohawk Valley area, and thickens to the south in the subsurface, where it is present throughout Tioga County.

The Edgecliff Member of the Onondaga Formation consists of coarse, bioclastic grainstones and packstones with bluish gray to white chert nodules. Chert nodules are often rimmed by dolomitized limestone. Silica for chert in the Onondaga Formation was provided by opaline silica from sponge spicules. Surface waters during Onondaga deposition may have been enriched in silica from widespread deposition of volcanic ash.

The Nedrow Member of the Onondaga is a shaley bioclastic packstone-wackestone- mudstone with a limited brachiopod-dominated fauna. The Moorehouse Member consists of medium bedded packstones and wackestones with thin shale interbeds common. Moorehouse Member chert nodules are dark in color and are rimmed by dolomite.

The Seneca Member of the Onondaga is a bioclastic wackestone-mudstone. Chonetid brachiopods in the Seneca are often hematite-stained, suggesting possible subaerial exposure of the Onondaga platform prior to deposition of the Union Springs Member of the Marcellus Formation. Alternatively, the hematite staining may be due to later burial diagenetic processes. The total thickness of the Onondaga Formation is approximately 100 to 120 feet.



Lower Devonian Esopus Shale

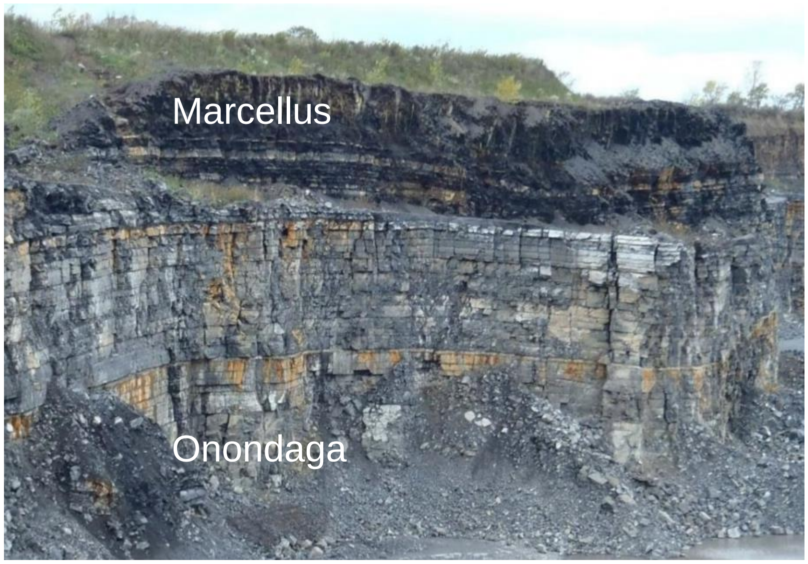
In Tioga County, the Esopus Shale and Carlisle Siltstone Formations total approximately 40 feet in thickness. These marine clastic units are correlative to the thicker Schoharie Formation of the eastern Catskill/Hudson Valley region, and are derived from the initial uplift of source areas to the east during Ettensohn's (1985) Acadian Tectophase I. The Esopus Shale exposure on NY Route 166 consists of fissile, splintery gray shale with a very limited fauna.

Helderberg Group, Oriskany Sandstone Formation, Onondaga Limestone Formation, Marcellus Shale Formation

The Oriskany Falls Quarry at the intersection of NYS Route 26 and Green-Vedder Road exposes the Lower Devonian Helderberg Group (Manlius, Coeymans and Kalkberg Formations), the Oriskany Sandstone (type section; approximately 12 feet in thickness), the entire Onondaga Formation (Edgecliff, Nedrow, Moorehouse and Seneca Members) and the basal Marcellus Formation (Union Springs and Cherry Valley Members; exposures depend on state of working at this active quarry). It is understood that this quarry is well north of Tioga County, but this quarry gives a window on the lithologies present at depth near the Snyder Well.

The working face of the quarry consists of Helderberg and Onondaga carbonates separated by the prominent tan-white band of Oriskany Formation. Esopus and Carlisle Formations are absent here. The Oriskany disconformably overlies Helderberg Group carbonates, demonstrated by erosional and solution truncation of bedding at the top of the Kalkberg Formation, and phosphate and glauconite clasts in the basal Oriskany. The Helderberg carbonate sequence thins rapidly to the west from this location. The Onondaga Formation is likewise in disconformable contact with the underlying Oriskany Formation, with the basal Edgecliff Member bearing clasts of phosphatic sandstone.

The upper quarry level exposes the contact between bioclastic, slightly shaley mudstones of the upper Seneca Member of the Onondaga Formation and black to brownish black shales of the basal Union Springs Member of the Marcellus Formation. Depending on the current state of stripping of overburden, the contact can be directly observed, and the overlying Cherry Valley Member may also be exposed.



Salina Group (Syracuse, Lockport, Rochester Formations)

The exposures near Chittenango Falls State Park consist of upper Silurian dolostone, dolomitic shale and dolomitic limestone of the Syracuse Formation overlain by Helderberg Group (Manlius and Coeymans Formation) carbonates and the basal Edgecliff Member. The Syracuse Formation thickens rapidly to the west and south, and includes the evaporite deposits that characterize the Salina Group of central and western New York.

3.1 Project Area Well Logs, Cross Sections and Fence Diagram

Continental Placer analyzed existing well logs and other available data to review the geology near this project that has been logged in prior oil and gas well drilling efforts. With this information, a more detailed site specific geologic cross section can be prepared. Well data detailing the formations described above were compiled in July, 2016 through the use of the New York State Museum's ESOGIS (Empire State Organized Geologic Information System) website, which is found at: (https://esogis.nysm.nysed.gov/index.cfm). Through this website, one selects a geographic area in New York State and retrieves American Petroleum Institute (API) well numbers for all known, registered wells within the desired area. Once the appropriate API numbers have been compiled, the New York State Museum's Core, Cuttings and Well Log Collection can be researched for available well data (stratigraphic sequences, well logs, gamma logs, etc.).

In addition to the data discussed above, the New York State Department of Environmental Conservation (NYSDEC) has a searchable database for an oil and gas well data, which is found at: (http://www.dec.ny.gov/cfmx/extapps/GasOil/search/wells/index.cfm). Through this website, one can query well data by API well number, County, Town, etc. to review information made available by NYSDEC. Data for queried wells can then be exported to a Microsoft Excel file or Google Earth file. From here the data can be displayed in geologic mapping programs such as Carlson.

With the two data sets described above, one can map available well data and model subsurface conditions based on northing, easting, elevation and stratigraphic information associated with each well. Oil and gas wells of record within two miles[1] of the Snyder E1-A Well are illustrated on Sheet 1 – NYSDEC Oil & Gas Wells in Project Area. Field reconnaissance has shown that there are no known abandoned or orphaned wells within the Snyder E1-A Well spacing unit.

Wells in the vicinity of the project area were reviewed for available stratigraphic information. Wells with available stratigraphic information were selected and data was formatted for importation into Carlson Mining Software. Using elevation information (Drill rig Kelley Bearing elevation in most cases) obtained from the ESOGIS system and geological formation tops from the NYSDEC searchable database, a geologic model was created. It should be noted that some wells did not have published elevation data. In this case, elevations were obtained from Google Earth. Well data and modeled subsurface geology are included on Sheets 2 through 5 (Cross Section – Plan View, Cross Section A-A’, Cross Sections B-B’ & C-C’, and 3D Fence Diagram).

As can be seen from the attached sheets, the Marcellus Shale occurs at a depth below grade that ranges from 2,820 feet to 4,165 feet. Given that the dataset of wells reviewed to create Sheets 2 through 5 spans several miles, it is appropriate to say that the Marcellus Shale is generally flat-lying in the subsurface, with a regional dip of roughly 50 feet to the south for each mile of distance, and that the Marcellus is laterally expansive in the vicinity of the Snyder E1-A Well, extending at least 100 miles or more in all cardinal directions.

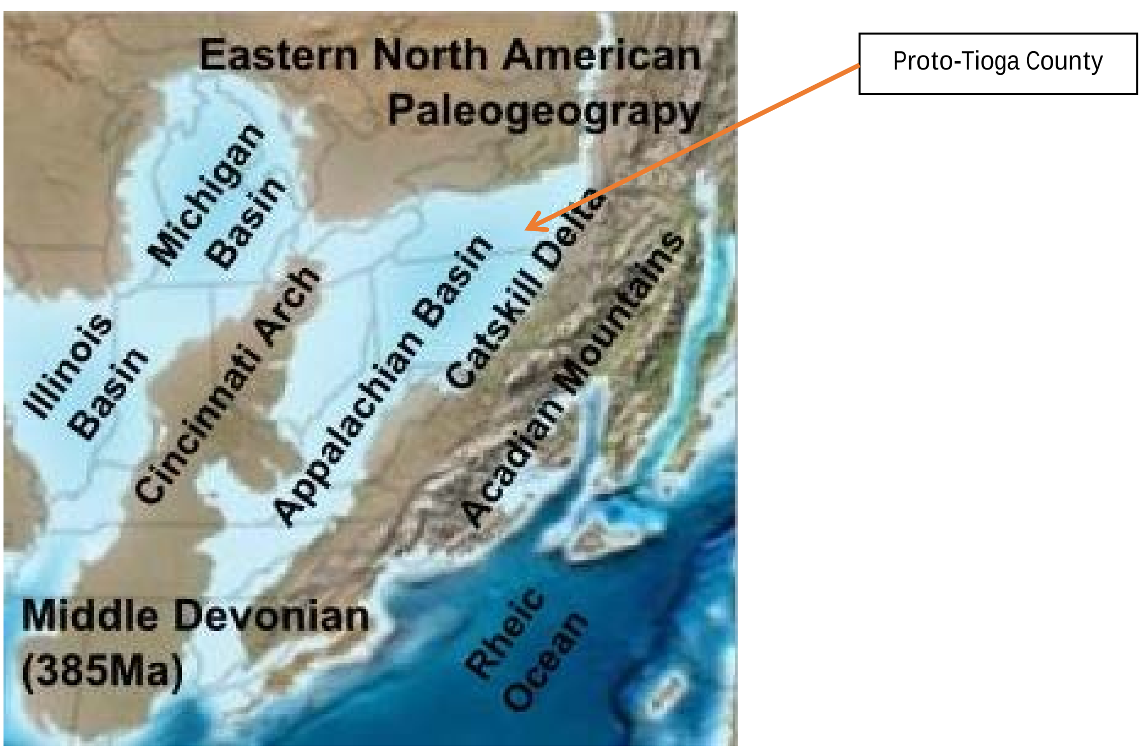
Cross Sections A-A', B-B', & C-C' Marcellus Depths	
Cross Section A-A'	
API Well Number	**Marcellus Depth (ft)**
31-107-22934-00-00	-
31-107-09848-00-00	4,020
31-107-23996-00-00	3,782
31-107-23855-01-00	-
31-107-00257-00-00	2,820
Cross Section B-B'	
API Well Number	**Marcellus Depth (ft)**
31-107-23988-00-00	3,607
31-107-23996-00-00	3,782
31-107-09557-00-00	4,165
Cross Section C-C'	
API Well Number	**Marcellus Depth (ft)**
31-107-23185-00-00	3,788
31-107-23855-01-00	-
31-107-23945-00-00	3,710

[1] It is noted that the 2015 FSGEIS recommended reviewing Department records for nearby wells within a one-mile radius. This study doubles the recommended distance.

4.0 OROGENIC EVENTS AND THE APPALACHIAN BASIN

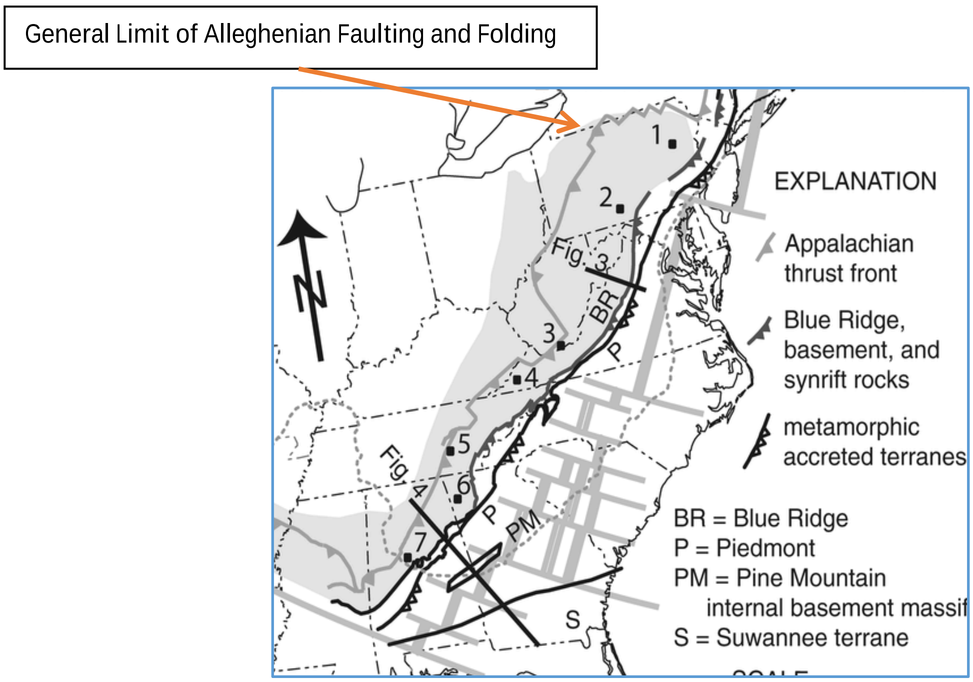
The following discussion is taken primarily from Jacobi (2002) in his paper entitled, "Basement Faults and Seismicity in the Appalachian Basin of New York State". As background, it should be understood that the two main orogenic events (mountain building events) that affected the southern tier of New York State were the older Taconic Orogeny, and the younger Acadian Orogeny. The Taconic Orogeny occurred during the Late Ordovician, ending approximately 440 million years ago. This orogenic event ended approximately 50 million years before the start of the deposition of the Marcellus Shale. As a result, any structure (faults, etc.) associated with the Taconic Orogeny has little import in a discussion of Marcellus structure and seismicity as they are associated with basement bedrock laid down millions of years before Devonian sedimentation and compaction.

The second orogeny, the Acadian Orogeny, was active for approximately 50 million years, spanning from the Middle to Late Devonian, beginning approximately 385 million years ago. Marcellus Formation deposition occurs in the Middle Devonian, dating to approximately 390 million years ago. It is the rise of the Acadian Mountains that supplies the material for Appalachian Basin deposition, as shown in the following depiction of the Appalachian Basin from roughly 385 million years ago. The Marcellus was in a state of active sediment deposition during the Acadian Orogeny and not a solidified, comprehensive lithographic sequence subject to Acadian orogenic tectonics. See Figure 3 - Generalized Stratigraphic Column for a correlation between Geologic Time Periods and New York State stratigraphy.



A third orogenic event was the Alleghenian Orogeny that occurred almost entirely within the Permian Period (299 million to 251 million years ago), and created the Appalachian Mountains. The Alleghenian orogeny resulted from the collision of the central and southern Appalachian continental margin of North America with that of North Africa in late Paleozoic time. It is most pronounced in the central and southern Appalachians and produced the compressional folding and faulting of the Ridge and Valley Province; the westward thrusting of the Blue Ridge over Ridge and Valley rocks; and folding, minor metamorphism, and igneous intrusion in the Piedmont Province of the eastern United States. Evidence of the Alleghenian orogeny is less prominent in the northern Appalachians and southern New York, but late Paleozoic folding and igneous intrusions are present along both the east coast of New England in the United States and parts of the eastern Maritime Provinces of Canada. The limit of tectonic activity was realized in what is now the Southern Tier of New York State. The Wrench or Tear Fault discussed by Murphy (1981) in central Tioga County is most likely associated with the Alleghenian Orogeny.

The following figure shows the general areas across the eastern United States affected by the Alleghenian Orogeny. Notice the termination of the Appalachian thrust front in northern Pennsylvania/southern New York. This indicates that the Alleghenian did not impart significant impact to geologic structure in southern New York and that Alleghenian-aged structure is not pervasive in Tioga County.



4.1 Structure - Central New York

The 2015 FSGEIS recommends that "it is prudent for an applicant for a drilling permit to evaluate and identify known, significant, mapped faults within the area of effect of hydraulic fracturing and to present such information in the drilling permit application…" 2015 FSGEIS at 6-331. While the Snyder E1-A Well does not involve high-volume, water-based hydraulic fracturing, Continental Placer has extensively reviewed academic literature, mapping, and other data to identify any known or suspected faults in the vicinity of the Project. The location and nature of the faults identified is discussed in this section.

Rock masses displaced and moved during orogenic events often move along an array of different geologic faults depending on the stress applied to the rock mass. As a general description, geologic faults are fractures along which rocks on opposing sides have been displaced (moved) relative to each other after the lithologic process is complete. The amount of displacement may be small (centimeters) or large (feet to miles). Geologic faults are prevalent and typically are active along tectonic plate boundaries in basement lithologies where there is an active stress field caused by opposing rock masses. One of the most well-known plate boundary faults is the San Andreas fault zone in California. Faults also occur across the rest of the U.S., including mid-continent and non-plate boundary areas, such as the New Madrid fault zone in the Mississippi Valley, or the Clarendon-Linden fault system in western New York. Faults are most often associated with specific tectonic or orogenic (mountain building) events. Since rock formations are durable and persist through geologic time, faults from long-ago events may still be observed today, although the specific feature is "no longer active." That is to say that the stress field that allowed the fault to form has long since been satisfied.

The following discussion of geologic structure (faults, joints, lineaments, etc.) is focused on the idea that there are several faults across New York that have not previously been widely identified. While this may be true, the correlative idea that is not developed in a lot of the literature focused on water-based hydraulic fracturing is the fact that faults and structure are developed in a stress field. A stress field is created where two adjacent earth crust masses move laterally relative to one another, under one another, etc., and the friction that exists between the two masses prevents or slows that motion. In this scenario, stress and strain build up in a stress field until a critical point is reached and the stress is released and the rock masses move along a fault line. Faults are only "active" when there is an active stress field surrounding the fault. In absence of a stress field, a fault is simply an (non-active) interesting geologic feature.

Of the three main stress field-inducing events that have affected proto-New York, the Taconic, Acadian, and Alleghenian Orogenies all ended at least 290 million years ago. The stress fields associated with those events have long since been relieved. Put plainly, faults in the Southern Tier of New York do not participate in active stress fields and are essentially "dormant".

With the understanding above, the following is from Jacobi (2002 – excerpted and simplified for greater reader understanding).

"The Appalachian Basin of New York State (NYS) has been regarded as generally structurally featureless except for a few well acknowledged faults. For example, the NYS Geological Map (Rickard and Fisher, 1970) displayed only two sets of faults in the Appalachian Basin over a 450-km distance between Albany and Buffalo: (1) N-trending faults in the Mohawk Valley region that were believed to be Ordovician in age (e.g., Bradley and Kidd, 1991) and (2) several E- and N-striking short faults in the Finger Lakes region (central NYS). Other faults recognized in NYS include (from west to east,): (1) the Bass Island Trend (e.g., Van Tyne and Foster, 1979; Beinkafner, 1983), (2) the Clarendon– Linden Fault System (CLF; e.g., Chadwick, 1920; Van Tyne, 1975; Fakundiny et al., 1978; Jacobi and Fountain, 1993, 1996, 2002), (3) an Ordovician-aged, N-striking, normal fault east of the CLF (Rickard, 1973), (4) NNE-striking normal faults at Keuka Lake (Murphy, 1981), (5) Alleghanian folds, thrusts/normal faults, and tear faults in the Southern Tier of NYS (Bradley et al., 1941; Murphy, 1981), and (5) three Ordovician-aged horsts and graben with assumed N- strikes in central NYS (Rickard, 1973). Thus, less than 10 fault systems had been identified across a 450-km swath in the Appalachian Basin of NYS, and only one of these, the CLF, was regularly acknowledged. There were indications that this low number of faults might not be a true representation, based on the lineaments recognized by Isachsen and McKendree (1977), but the standard belief was that essentially little faulting characterized the Appalachian Basin of NYS. Nevertheless, the northern tier of the Appalachian Basin in NYS did exhibit sporadic seismicity. The question then becomes: are these seismic events associated with faults that have not been recognized, or are the seismic events essentially spatially random, with no predictive structural control?

In the late 1980s and early 1990s, several studies in nearby regions of assumed flat-lying units began to demonstrate that basement faults did exist in much greater numbers than previously suspected, and that these faults had been repeatedly reactivated. For example, in the Illinois Basin and bordering areas, faults that penetrate the Precambrian basement appeared to have been active for much of the geological record that can be observed (e.g., Kolata and Nelson, 1991; Nelson and Marshak, 1996). In eastern Ohio, the NW-striking Highlandtown Fault experienced episodic motion from Cambrian to Pennsylvanian (Root, 1992; Riley et al., 1993; Root and Onasch, 1999), and may follow a Precambrian fault (Root and Onasch, 1999)."

Perhaps the single most important study that advanced the recognition of faults in NYS was the identification of lineaments in 1997 by Earth Satellite Corporation (EARTHSAT) on Landsat Thematic

Map-per (TM) images (''E97 lineaments''). EARTHSAT (1997) identified tonal and stereoscopic (topographic) lineaments on the enhanced images by ''eye''.

Fundamental to establishing a relationship between seismicity and faults is to first identify which lineaments indicate faults, and then to determine to what extent a spatial relationship exists between the faults and earthquake epicenters. Evidence utilized for recognition of faults in NYS included the integration of FIDs, E97 lineaments, topographic lineaments, gradients in gravity and magnetic data, seismic reflection profiles, and well logs. Through these studies several potential fault complexes were identified that were previously unknown.

This topic will be discussed in subsequent sections of this report.

4.2 Central New York Fault Systems

4.2.1 N- and NNE-striking faults

Refer to Figures 4 and 5 and Sheet 6 – Preliminary Brittle Structures of New York, for the following discussion. Again, from Jacobi (2002), "A number of NNE-striking faults in central NYS have been identified based on well log analyses, Landsat lineament studies and recent integration of outcrop structure, soil gas, and topographic data. Rickard (1973) proposed an Ordovician, N-striking horst (called the Canandaigua Lake faults) along the east side of Canandaigua Lake on the basis of anomalous formation elevations in one well log. The southern part of the proposed horst coincides with a N-striking magnetic high, suggesting Precambrian basement involvement.

Approximately N-striking faults were also hypothesized for the north end of Keuka Lake (here named the Keuka Lake Fault) on the basis of good log and field data (Bergin, 1964; Murphy, 1981; respectively). From structure contours Murphy (1981) inferred that Alleghenian (?) slip on the fault was down-on-the-west and dextral. These faults are probably associated with faults in the Precambrian basement because the Keuka Lake Fault coincides with a prominent gravity gradient and a less prominent magnetic anomaly. The fault is also coincident with E97 lineaments.

North-striking faults also have been recognized along Seneca Lake (here named the Seneca Lake N-Striking Fault System). On the southeast side of Seneca Lake, N-striking Landsat lineaments identified by Isachsen and McKendree (1977) correspond to N-striking FIDs in outcrop (Lugert et al., 2001, 2002; Jacobi et al., 2002b) and stratigraphic displacements among widely spaced outcrops (Bradley et al., 1941). On the west side of Seneca Lake, NNW-striking lineaments correspond to a NNW-striking fault (Fig. 5) that was proposed on the basis of well log data and brine field fracture flow considerations (Jacoby and Dell wig, 1974; Murphy, 1981). Because the Seneca Lake N- Striking Fault System is not parallel to the primary gravity and magnetic gradients, the faults may not significantly affect Precambrian basement; rather, they may be primarily lateral ramps/tear faults related to Alleghenian thrusts. However, if the gravity low at the south end of Seneca Lake is not a function of incomplete gravity corrections, then the faults may affect more than the section above the Silurian salt.

In the Cayuga Lake region, the N-striking, right-lateral Cayuga Lake Fault was inferred from well logs (Murphy, 1981). In southernmost NYS, the fault is coincident with a prominent topographic lineament (Murphy, 1981) and an E97 lineament. The lack of coincident major gravity or magnetic anomalies suggests that the fault is primarily an Alleghenian tear fault with little basement control."

Jacobi goes on to describe evidence for East-Northeast striking faults, and faults at other dominant orientations throughout New York State. Specific to Tioga County, Jacobi has mapped several potential faults, see Figure 5 and Sheet 7. Regarding Tioga County, Jacobi states, "To the east, the Tioga County

Fault is suspected on the basis of long, NNW-striking E97 lineaments. These lineaments are parallel the southern part of the Cayuga Lake Fault of Murphy (1981). The lack of coincident geophysical anomalies is consistent with Murphy's (1981) suggestion that the Cayuga Lake Fault is an Alleghenian tear fault that ***does not extend below the Silurian salt section***" (emphasis added). The significance of this is that the features identified by Murphy and Jacobi are shallow, not extending below the Silurian-aged bedrock (e.g. faults do not extend to basement bedrock) and are believed to have very low potential to be geologically active, which corresponds to the assignment of this portion of the State being Seismic Risk Zone I (Low Seismic Risk). From basic geology dictionary descriptions, basement bedrock is defined as the thick foundation of ancient, and oldest metamorphic and igneous rock that forms the crust of continents, often in the form of granite. Basement rock is contrasted to overlying sedimentary rocks, which are laid down on top of the basement rocks after the continent was formed, such as sandstone, limestone, and shale. Faults in these ancient bedrock foundations are typically not associated with the overlying sandstones, limestone and shales as these rocks were formed well after basement rock faulting occurred.

Murphy (1981) was also cited in a 1984 NYSERDA study report (81-18), in which the Tear Fault, or Wrench Fault in Tioga County is referenced.

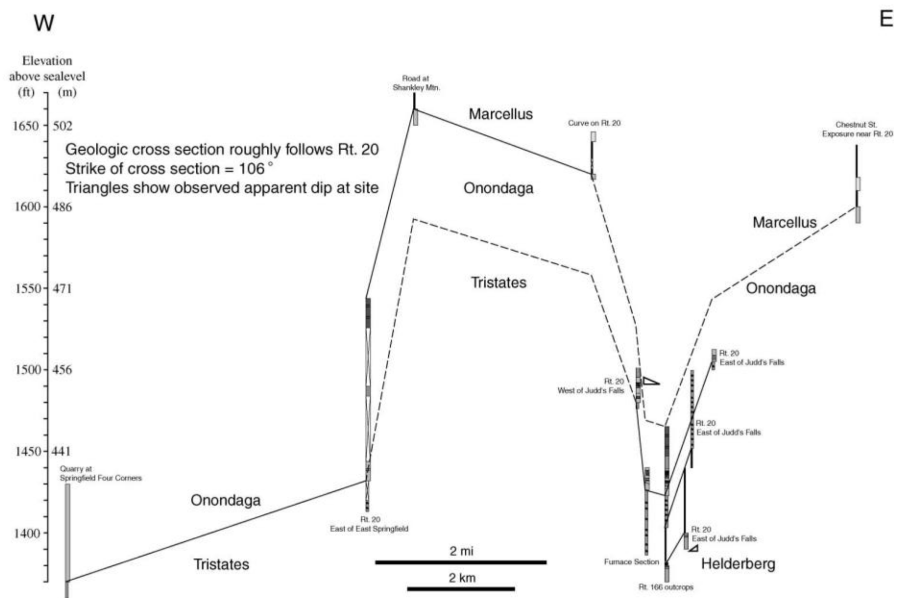
As discussed above, the identification of these suspected faults as Alleghenian Tear or Wrench faults that do not extend below the Silurian-aged rocks is a very important point, meaning essentially that the fault does not extend to the basement bedrock in the area (see the Stratigraphic Column shown in Figure 3). According to a U.S. Environmental Protection Agency Report (2014), entitled, *Minimizing and Managing Potential Impacts of Injection-Induced Seismicity from Class II Disposal Wells*, it is stated that recorded events of induced seismicity from disposal well injection projects are a result of injection into or near a fault with an active stress field associated with Basement rock formations, as follows: "Nearly all early cases of suspected injection-induced seismicity felt by humans have involved communication between disposal zones and basement faults." Specifically, the report goes on to state:

> In almost all historic cases, felt injection-induced seismicity was the result of direct injection into basement rocks or injection into overlying formations with permeable avenues of communication with basement rocks. Therefore, the vertical distance between an injection formation and basement rock, as well as the nature of confining strata below the injection zone, are key components of any assessment of injection-induced seismicity. In areas of complex structural history, strata beneath the injection zone may have compromised vertical confining capability due to natural fracturing. Also, faulting in basement rock can extend into overlying sedimentary strata, thus providing direct communication between the disposal zone and the basement rock.

The takeaway from this discussion is that the identified potential fault(s) are at or above the Silurian-aged rock formations and do not extend to the subjacent basement bedrock. In this situation, the presence of a fault is of significantly less concern as it does not extend to the basement rock, and is therefore much less likely to respond to short duration hydrofracturing events, or respond/react to geologic changes within the subjacent basement bedrock. Additionally, based on available literature, with the fault(s) not extending to the subjacent basement rock there is no opportunity for fracturing media to communicate with basement bedrock, which is the concern cited in the EPA paper regarding injection disposal and induced seismicity, which is discussed later in this report. Well stimulation activities in the Snyder E1-A Well will be short in duration, limited to five or six single-day events.

Identification of potential linearities or faults in and of itself is an admirable academic exercise to further our understanding of Geology. The identification of potential faults, however, does not lead to the conclusion that the faults are currently active or that they will be active at some point in the future. That is to say, as discussed above, that if there is not an active stress field associated with the fault, then the identification of a fault adds to our understanding of the Earth's past, yet does not imply an imminent threat or concern. Seismicity, or the movement of the shallow Earth's crust on seismic plates, will be the topic of the following section.

In an effort to identify New York faults, Jacobi uses the figure below to provide evidence for the presence of a fault. The figure is a plot of various wells and shows the change in elevation of the Tristates, Onondaga and Marcellus contacts, which in some cases is on the order of 150 feet elevation difference. From the significant elevation difference, Jacobi infers that a fault is present to account for the variability in bedrock contact elevation.



Review of the lithologies identified in the New York State gas well database and shown on Sheet 3 and 4 (Cross Section A-A', Cross Section B-B' and C-C') of this report do not show any such offset or elevation variability in bedrock formation contact elevation(s) in and around the Snyder E1-A Well. To the contrary, the lithologies appear to be fairly flat and uniform in thickness. As such, even though Jacobi identifies suspected faults in the vicinity of the Town of Barton and in Tioga County as a whole, a comprehensive review of site specific information does not indicate the presence of a fault in the immediate vicinity of the Snyder Well.

Additionally, the planned orientation of the lateral to be drilled will not approach Jacobi's suspected faults. Specific to the Snyder E1-A Well site, Jacobi's suspected Tioga County faults are plotted in relationship to the Snyder Well. As can be seen on Sheet 7 Mapped Faults – Tioga County, the closest expression of Jacobi's suspected fault is 1.07 miles to the west of the Snyder E1-A well spacing unit. This spatial difference is significant in that the proposed orientation of the to-be-drilled horizontal lateral is in a northerly direction; essentially getting no closer to the suspected fault than 1.07 miles at any point within the spacing unit. With this suspected feature(s) more than a mile away, well stimulation activities in the Snyder E1-A Well do not present a risk of intersecting or impacting suspected faults in the area, if present at all.

5.0 SEISMICITY

It is not the charge of this report to reevaluate the 2015 FSGEIS, but more to update the understanding provided by the 2015 FSGEIS with a specific look at the presence and occurrence of suspected faults in Tioga County. To this end, several components of the 2015 FSGEIS will be restated for clarity in the current response, with required details added as needed.

The discussion provided herein is modified from several texts, including the 2015 FSGEIS, authored by the State of New York in evaluation of High Volume Hydraulic Fracturing of Marcellus Shales in New York. Specific citations from the 2015 FSGEIS are noted. The most significant update in this text to the 2015 FSGEIS is that the mapping discussed is specific to Tioga County and suspected faults plotted in and around the Town of Barton and Tioga County as a whole.

5.1 Background

The term "seismic event" or "earthquake" is used to describe any event that is the result of a sudden release of energy in the earth's crust that generates seismic waves. Many earthquakes are too minor to be detected without sensitive equipment. Large earthquakes result in ground shaking and sometimes displacement of the ground surface. Earthquakes are caused mainly by movement along geological faults. Sheet 7 – Tioga Mapped Faults, shows the locations of lineaments and other structures that may indicate the presence of buried faults in New York State, the sheet illustrates the plot and orientation of faults offered by Murphy (1981) and Jacobi (2002). Sheet 6 – New York State Brittle Structures Map shows a reproduction of the Brittle Structures Map produced by New York State (Isachsen, 1977). From these maps, one can see there is a concentration of structures in eastern New York along the Taconic Mountains and the Champlain Valley that resulted from the intense thrusting and continental collisions during the Taconic and Acadian orogenies that occurred 350 to 500 million years ago. There is also a concentration of faults along the Hudson River Valley. The later Alleghenian Orogeny (250 to 300 million years ago) had limited impact on the geology of the Southern Tier of New York, as can be seen in the work of Murphy (1981).

5.2 Seismic Risk Zones

The United States Geological Survey (USGS) Earthquake Hazard Program produced the National Hazard Maps showing the distribution of earthquake ground movement/impact levels that have a certain probability of occurring in the United States at any given time. The maps were created by incorporating geologic, geodetic and historic seismic data, and information on earthquake rates and associated ground shaking potential. These maps are used by others to develop and update building codes and to establish construction requirements for public safety. Figure 4 shows seismic risk zones for New York State. Tioga County's seismic risk zone is I, the lowest zone mapped for New York State, indicating very low potential for damage from earthquakes.

New York State is not associated with a major fault along a tectonic boundary like the San Andreas, but seismic events (albeit at levels that are generally unnoticeable) are relatively common in New York. Again, Figure 4 shows the seismic hazard map for New York State. The map shows levels of horizontal shaking, in terms of percent of the gravitational acceleration constant (%g) that is associated with a 2 in 100 (2%) probability of occurring during a 50-year period. Much of the Marcellus and Utica Shales underlie portions of the state with the lowest seismic hazard class rating in New York (2% probability of exceeding 4 to 8 %g in a 50-year period), 2015 FSGEIS at 4-24. The Town of Barton and the proposed Snyder Well are also in this low seismic risk area.

5.3 Seismic Events

Table 4.2 of the 2015 FSGEIS summarizes the recorded seismic events in New York State by county between December 1970 and July 2009. Taken from the 2015 FSGEIS, "…earthquakes have been recorded since Europeans settled New York in the 1600s. The largest earthquake ever measured and recorded in New York State was a magnitude 5.8 event that occurred on September 5, 1944, near Massena, New York. "There were a total of 813 seismic events recorded in New York State during that period (1970 to 2009)[2]. The magnitudes of 24 of the 813 events were equal to or greater than 3.0. Magnitude 3 or lower earthquakes are mostly imperceptible and are usually detectable only with sensitive equipment. The largest seismic event during the period 1970 through 2009 is a 5.3 magnitude earthquake that occurred on April 20, 2002, near Plattsburgh, Clinton County."

Figure 5 of this report shows the distribution of recorded seismic events in New York State, taken from Jacobi, 2002. The majority of the recorded events occur in the Adirondack Mountains and along the New York-Quebec border. A total of 180 of the 813 seismic events shown on Table 4.2 (of the 2015 FSGEIS) for a period of 39 years (1970–2009) occurred in the area of New York that is underlain by the Marcellus and/or the Utica Shales. The magnitude of 171 of the 180 events was less than 3.0. As a seismic event of 3.0 is typically only detectible with the most sensitive equipment, nearly all seismic activity in New York was not felt on the ground surface, 2015 FSGEIS at 4-28. The distribution of seismic events on Figure 5 is consistent with the distribution of fault structures discussed in Jacobi (2002), and the seismic hazard risk map Figure 4. These conclusions are the same as those cited in the 2015 FSGEIS. And, in general, the vast majority of events occur outside of Tioga County. Both Figures 4 and 5 show that there are no mapped earthquake epicenters in Tioga County. This is most likely because the mapped faults are associated with the long dormant Alleghenian Orogeny, with faults and structure that do not extend to basement bedrock.

5.4 Induced Seismicity

Induced seismicity (e.g. seismic events) refers to induced ground vibrations triggered by human activity such as mine blasts, nuclear experiments, and fluid injection, including traditional, water-based hydraulic fracturing and fluid injection (disposal) wells. Specific to fracturing of bedrock formations, the 2015 FSGEIS states that,

> "Hydraulic fracturing releases energy during the fracturing process at a level substantially below that of small, naturally occurring, earthquakes. However, some of the seismic events shown on Figure 4.15 (of the 2015 FSGEIS) are known or suspected to be triggered by other types of human activity. The 3.5 magnitude event recorded on March 12, 1994, in Livingston County is suspected to be the result of the collapse associated with the Retsof salt mine failure in Cuylerville, New York. The 3.2 magnitude event recorded on February 3, 2001, was coincident with, and is suspected to have been triggered by, test injections for brine disposal at the New Avoca Natural Gas Storage (NANGS) facility in Steuben County. The cause of the event likely was the result of an extended period of fluid injection near an existing fault for the purposes of siting a deep injection well. The injection for the NANGS project occurred numerous times with injection periods lasting 6 to 28 days and is

[2] As an update to the information above, there have been 227 recorded earthquakes from 2009 to January, 2017 in New York State. Three earthquakes of the 227 were recorded at 3.0 or higher on the Richter Scale. Of the 227 recorded earthquakes there were no epicenters in Tioga County.

substantially different than the short-duration, controlled injection used for hydraulic fracturing."

5.5 Bedrock Fracturing - Background

The 2015 FSGEIS provides a reasonable summary of water-based hydraulic fracturing, as follows: "Bedrock fracturing entails injecting a frac media into a wellbore at a pressure sufficient to fracture the rock within a designed distance from the wellbore. Other processes where fluid is injected into the subsurface include deep well fluid disposal, fracturing for enhanced geothermal wells, solution mining and hydraulic fracturing to improve the yield of a water supply well. The similar aspect of these methods is that fluid is injected into the ground to fracture the rock; however, each method also has distinct and important differences.

There are past and ongoing studies that have investigated small, felt, seismic events that may have been induced by injection of fluids in deep disposal wells. These small seismic events ***are not*** (emphasis added) the same as the microseismic events triggered by bedrock fracturing that can only be detected with the most sensitive monitoring equipment. The processes that induce seismicity in both cases are very different."Well stimulation is a process that involves injecting fluid or other frac media under higher pressure for shorter periods than the pressure level and duration of time maintained in a fluid disposal well. In a fluid injection/disposal well the goal is to inject and dispose of potentially millions of gallons of wastewater. In these wells, the wastewater is injected at the highest fluid flow rate deemed safe and sustainable for the receiving deep bedrock formation. Activities in injection wells can last for weeks or months at a time, or until the volume of wastewater is injected.

Wellbore stimulation is different than deep well wastewater injection/disposal. A horizontal well is fractured in stages so that the pressure needed to fracture the rock is repeatedly increased and released over a short period of time, with the goal of producing fractures in relatively close proximity to the borehole. The subsurface pressures for hydraulic fracturing are sustained typically for one to five days to stimulate a single well. The seismic activity induced by wellbore stimulation is only detectable at the surface by very sensitive equipment. The Snyder E1-A Well stimulation process will not employ large volumes of water. Further differentiating the Snyder E1-A Well from fluid injection wells is that wellbore stimulation activities at the Snyder E1-A Well will last for a period of five days and occur only during daylight hours.

Avoiding pre-existing fault zones minimizes the possibility of triggering movement along a fault through well stimulation activities. It is important to avoid injecting frac media into known, significant, mapped faults when fracturing subsurface bedrock. Generally, operators will avoid faults because they disrupt the pressure and stress field and make the fracturing process more difficult. The presence of faults also potentially reduces the optimal recovery of gas and the economic viability of a well or wells as the formation may have degassed millennia ago owing to the presence of the fault (if it is laterally and vertically expansive). In the case of the Snyder E1-A Well, the frac media will not be injected into or adjacent to any mapped faults as the closest mapped fault is 1.07 miles away from the Snyder E1-A Well spacing unit.

6.0 FRACTURE – INDUCED SEISMICITY

The 2015 FSGEIS provides a lengthy discussion of seismicity, and specifically fracture-induced seismicity. In short, the 2015 FSGEIS states that "the release of energy during hydraulic fracturing produces seismic pressure waves in the subsurface." The 2015 FSGEIS goes on to state that, "Seismic events that occur as a result of injecting fluids…are termed "induced." There are two types of induced seismic events that may be triggered as a result of hydraulic fracturing. The first is energy released by the physical process of fracturing the rock which creates microseismic events that are detectable only with very sensitive monitoring equipment." This type of microseismic event is a normal part of the well stimulation process used in the development of both horizontal and vertical oil and gas wells, and by the water well industry. A microseismic event does not create ground movement that is expressed and observed at the surface of the earth. Instrumentation is required to detect microseismic events. A "felt" seismic event is when earth movement associated with the event causes displacement and motion that is discernable by humans at the ground surface without the aid of instrumentation.

With respect to gas well development and potential induced seismic events, the 2015 FSGEIS evaluates substantial data evidencing the very low probability of seismic events. Specifically, the 2015 FSGEIS examines data from the more than 12,500 wells drilled in the Barnett Shale, a similar rock formation geologically speaking, as well as New York's prior drilling data, which includes horizontal wells. 2015 FSGEIS at 6-326 to 6-328FSGEIS.

And, "based on the similarity of conditions" between the Barnett shale play and the shales in New York, the 2015 FSGEIS predicted that for New York "the microseismic events would be unfelt at the surface and no damage would result from the induced microseisms." 2015 FSGEIS at 6-329. The 2015 FSGEIS also finds that due to the small number of fault zones in the Marcellus and Utica bearing regions, and the undesirability of drilling near them due to potentially reduced gas recovery, "the possibility of fluids injected during hydraulic fracturing the Marcellus or Utica shales reaching a nearby fault and triggering a seismic event are remote." 2015 FSGEIS at 6-330.

The second type of induced seismicity can result from fluid injection of any kind, including hydraulic fracturing, which can trigger seismic events ranging from imperceptible microseismic, to small- scale, "felt" events, if the injected fluid reaches an existing geologic fault and changes to the stress regime. Different injection processes, such as waste disposal injection or long-term injection for enhanced geothermal, may induce events that can be "felt", as discussed in the following section. Induced seismic events can be reduced by engineering design and by avoiding existing fault zones.

Similar to the conclusions of the 2015 FSGEIS, The Association of American State Geologists published a summary article in which the relationship between hydraulic fracturing and induced seismicity was addressed. The article concludes the following:

> In recent years, earthquake activity has increased noticeably in several areas of active oil and gas production across the United States. Much public attention has been drawn to hydraulic fracturing (or "fracking"), which involves use of water, sand (or similar material), and chemical additives, under high pressure, to fracture rocks in the subsurface to allow additional oil and gas production. By definition, hydraulic fracturing causes seismic events, and measurement of these micro-seismic events in the subsurface is one method for determining where fractures in the rock have been created. Except in a few cases, however, seismic events related to hydraulic fracturing are too small to be felt at the surface, and thus to cause structural damage.

6.1 Summary of Potential Seismicity Impacts

The issues associated with seismicity related to wellbore stimulation addressed herein include seismic events generated from the physical fracturing of the rock, and possible seismic events produced when frac media are injected near/into existing faults and change the stress regime.

The 2015 FSGEIS concludes that, "The possibility of frac media injected during hydraulic fracturing the Marcellus Shale reaching a nearby fault and triggering a seismic event are remote for several reasons. The locations of major faults in New York have been mapped and few major or seismically active faults exist within the fairways for the Marcellus and Utica Shales. Similarly, the paucity of historic seismic events and the low seismic risk level in the fairways for these shales indicates that geologic conditions generally are stable in these areas. By definition, faults are planes or zones of broken or fractured rock in the subsurface. The geologic conditions associated with a fault generally are unfavorable for hydraulic fracturing and economical production of natural gas. As a result, operators typically endeavor to avoid faults for both practical and economic considerations."

As an extension to this discussion, this response is charged with researching and identifying potential, area-specific geologic structures and faults in the vicinity of the Snyder Well that may have a negative impact on potential well performance and potential environmental impacts. Specific to the Snyder E1-A Well site, Jacobi's suspected Tioga County faults are plotted in relationship to the Snyder E1-A Well. As can be seen on Sheet 7 – Mapped Jacobi Faults, the closest expression of a suspected fault is 1.07 miles to the west of the Snyder E1-A Well spacing unit. This spatial difference is significant in that the proposed orientation of the to-be-drilled horizontal lateral is in a northerly direction; getting no closer to the suspected fault than 1.07 miles cited. Additionally, the features identified by Murphy and Jacobi are shallow, not extending below the Silurian-aged bedrock (e.g. not a fault extending to basement bedrock) and are believed to have very low potential to be geologically active, which corresponds to the assignment of this portion of the State being Seismic Risk Zone I. The location of the Snyder E1-A Well conforms with recommendations of the 2015 FSGEIS that existing or suspected faults be avoided when developing a fractured black shale well in the Marcellus. Even though Jacobi identifies suspected faults in the vicinity of the Town of Barton and in Tioga County as a whole, site specific information does not indicate the presence of a fault in the immediate vicinity of the Snyder Well, nor is the planned orientation of the lateral to be drilled getting any closer to the suspected faults than the well bore itself.

Additionally, as re-stated from above, the identified potential fault(s) are at or above the Silurian-aged rock formations and do not extend to the subjacent basement bedrock. In this situation, the presence of a fault is of significantly less concern as it does not extend to the basement rock, and is therefore much less likely to respond to short duration hydrofracturing events, or respond/react to geologic changes within the subjacent basement bedrock. Additionally, with the fault(s) not extending to the subjacent basement rock there is essentially no opportunity for well stimulation media to communicate with basement bedrock, which is the concern cited in the EPA paper regarding injection disposal.

The 2015 FSGEIS further provides that "additional evaluation or monitoring may be necessary" in a situation where "hydraulic fracturing fluids might reach a known, significant, mapped fault such as the Clarendon-Linden fault system." 2015 FSGEIS at 6-331. As described above, there are no such "known, significant, mapped faults" near the Snyder E1-A Well. In such a situation, the 2015 SGFEIS finds that "monitoring beyond that which is typical for hydraulic fracturing does not appear to be warranted, based on the negligible risk posed by the process and very low seismic magnitude." 2015 FSGEIS at 6-331. Notwithstanding the high unlikelihood of fault activity, TEP is willing to implement, at the Department's request, a monitoring system including a calibrated control or "traffic light" system to ensure that any unanticipated seismic events are monitored and appropriate responses taken. An example of such a program, based upon the recommendations made by the Ohio Department of Natural Resources, is as follows:

Example Traffic Light Seismic Monitoring Program (after Ohio DNR):

A "traffic light" seismic monitoring system would include a minimum of four (4) monitoring stations within each Spacing Unit (four individual ground-coupled or buried seismographs). The seismograph monitors will be capable of Narrow Band monitoring. The monitoring duration/frequency will be continuous for 60-days pre-completion (fracturing event), to establish a baseline, and 30-days post-completion. During monitoring, the following thresholds will be observed/reported:

1. For a magnitude < 1.5 event either Agency or the operator will notify the other party that seismicity has been detected in the vicinity of a well pad undergoing completion activity. No further action is required.
2. For a detected event with a magnitude > 1.5 but < 2.0 discussions are initiated with the parties that intensity is increasing and modifications to the completion design may be warranted. Information is provided as to the well(s) and specific stages involved at the detection time. Additional Agency staff and management will be notified of the activity. No further action is required.
3. For a detected event with a magnitude > 2.0 but < 2.5, the operator is required to stop completion activities on the well(s) being stimulated at the detection time. Direct voice communication between the operator and Agency staff will evaluate the event, the location, and the time. The operator will be encouraged to modify the job design by stopping zipper tracing (if being used), skip stages, reduce frac pressure, rates, volumes and pro pant. If satisfied with actions taken, Agency may verbally allow completion activity to continue.
4. For a detection event with a magnitude 2.5 or greater, the operator must immediately stop completion activity on the well or wells in question. Completion activity on the specific well or wells will not be permitted until a thorough review of the event has been completed by Agency and the operator.

6.2 Additional Considerations

The question of the presence and location of geologic structure in the vicinity of the Snyder Well leads to a consideration of the potential for fluids and gases to migrate or move either laterally or vertically as a result of wellbore stimulation and potential interaction with geologic structure(s) (e.g. faults may be conduits for gas and fluid migration). Volumes have been written on the science of induced fracturing around vertical and horizontal boreholes, which is not the main topic of this report. The general conclusion of induced fracture literature is that induced fracture density and propagation can be controlled and the effects limited to the immediate environs of the borehole itself by careful design and execution. In all cases, the induced fractures are quite small and short in relation to the thickness of overburden bedrock above the target formation (Marcellus in this case) and overlying stratigraphy. However, in light of this, some researchers have suggested that induced fractures may propagate into formations above the target Marcellus in select cases. Whether this is the case or not, the question of fluid and gas migration is whether or not there is a driving mechanism to invite deep fluids and/or gases to move either laterally or vertically through literally thousands of feet of shale, limestone, dolostone and sandstone during or after a wellbore stimulation event; and/or if there are retarding layers/formations that frustrate fluid and liquid migration (low permeability layers that limit migration)? Asked another way, is there an upward driving head or upward pressure gradient in the vicinity of the Snyder Well that would cause fluids and gases to move vertically through literally thousands of feet of overlying bedrock with varying vertical and lateral permeabilities? Similarly, are there retarding layers above the Marcellus to limit upward gas migration (again, low permeability)? And, lastly, does fracturing a bedrock formation at depth overcome the physics of fluid/gas migration through overlying geologic media with varying porosity and permeability characteristics?

The very simple answers to these questions can be found in the current condition of the fresh water groundwater table in the Town of Barton today. In other words, Marcellus connate waters (salty water trapped in the formation from the time of deposition) and trapped hydrocarbons have been in the subsurface for millions of years; yet, has the presence of this very old groundwater and expansive gas reserve impacted the near-surface environment in and around the Town of Barton and Tioga County as a whole prior to the current discussion of gas reserve development? History shows that when there is a connection between gas reserves at depth and near-surface bedrock and groundwater resources, the evidence of the connection is very evident. From the book, *Geology of New York* (1991), as far back as 1669, American Indians showed French explorers a gas vent near the city of Canandaigua, Ontario County. And, in 1821, William Hart drilled the first natural gas well in the United States outside the Town of Fredonia, NY, which was located next to a spring that had natural gas bubbling in it. No such expression of natural gas at or near the land surface has been reported for Tioga county.

As a reminder to the reader for the following discussion, porosity of a substance, such as bedrock, is the ratio, expressed as a percentage of the volume of the internal pore space of a substance, compared to the total volume of the mass of the substance. Permeability is the capability or capacity of a porous rock or sediment to permit the flow of fluids through its pore spaces (porosity). Fracturing bedrock enhances the permeability of the formation by increasing the connection and connectivity of the pore spaces, and natural joints and fractures.

Following the questions asked above, Tioga County is a rural county with a preponderance of residential and commercial properties served by individual, private water wells. For the vast majority of properties, groundwater resources accessed by individual residential and commercial wells intercept and develop a fresh, potable water resource, with no impacts from gas, salt, brine, or connate water. That is to say that shallow groundwater resources in Tioga County, and specifically in the vicinity of the Town of Barton and the Snyder Well, are generally potable and of good quality, indicating that shallow groundwater resources do not communicate with the Marcellus Formation ±3,000 to 4,000 feet below the existing ground surface.

To expand on this observation, as seen on Sheets 3 and 4, the top of the Marcellus Formation occurs from roughly 2,800 feet below grade to approximately 4,165 feet below grade in the vicinity of the Snyder Well. In the vicinity of the Snyder Well spacing unit the top of the Marcellus occurs roughly 3,500 to 3,800 feet below grade. Above the Marcellus is the Tully Formation and other undifferentiated shales and sandstones of the Hamilton and Genesee Group Formations. Subjacent to and below the Marcellus is the Onondaga, the Helderberg Group and Salt-bearing formations of the Salina. The presence of these formations is highlighted because the Marcellus is proven to be a viable gas reservoir and the Salina contains abundant salt deposits and brines (brine is a salt/groundwater mixture). Given the millennia that have passed since the deposition of the Marcellus, it is entirely reasonable that if Genesee and Hamilton rock formations experienced an upward pressure gradient then the groundwater resources in the County would be salty, gas riddled and generally unusable. Further to this point there are no readily available studies showing that the occurrence of natural gas in shallow groundwater wells (if present) has isotopic signatures of thermogenically (deep burial) produced gas.

In fact, given the topography of the area surrounding the Snyder Well, it is presumed that there is a slightly downward gradient in the formations beneath the Snyder Well site with no natural mechanism for upward gradients. Even with vast salt, brine and gas reserves at depth, the near subsurface in Tioga County enjoys abundant fresh groundwater supplies, with flora and fauna unimpacted by copious volumes of escaping gas reserves from the Marcellus Shale or subjacent Salina salts. The effective hydraulic isolation of these formations by up to 3,000 feet of overburden bedrock is clearly demonstrated by the fact that fluids and gas have been present and trapped at depth for tens to hundreds of millions of years, and do not currently impact the shallow groundwater resources of the County. Again, this indicates that there are no natural upward gradients awaiting to mobilize fluid or gas upon the inducement of a fracture in the immediate vicinity of a borehole (vertical or horizontal).

One can argue that even in the absence of natural upward gradients that may affect fluid migration, gas can migrate upward in the stratigraphic column without an upward hydraulic gradient-owing to its own buoyancy forces. While this may be true in more permeable settings, the bedrock of the overlying Genesee Group members has very low vertical permeability and significantly retards the upward migration of gases. Similarly, interstitial pore spaces in the overlying bedrock are often fluid or gas filled from the time of diagenesis of the individual rock units. Vertically migrating gas or fluid from depth, if driven by some mechanism to do so (including buoyancy), would have to displace the existing fluid/gas in the overlying formations and force in-place material to move either vertically upward or laterally. The force/mechanism to do so has not be offered or explained by those who offer that this may happen. And, if this force were to exist, the low permeability nature of the Genesee Group rock formations limits the connectivity of the fluid/gas in the pore spaces, limiting the upward migration of gas. Again, the lack of buoyancy-induced gas migration is evidenced by the lack of shallow gas in near-surface bedrock and shallow groundwater throughout Tioga County, and in the fact that a sizable gas reserve remains at depth.

Similarly, gas production following a fracture stimulation event creates a low-pressure zone in and around the borehole that will draw fluids and gases downward toward the borehole rather than upward. Additionally, the 2015 FSGEIS and its Appendix 11 found that seepage velocity created by a fracture stimulation event is not likely to create fluid migration. Fluid migration only occurs for the limited time (i.e. typically one day to several days) that fracturing occurs. The 2015 FSGEIS, Appendix 11 concluded that "hydraulic fracturing does not present a reasonably foreseeable risk of significant adverse environmental impacts to potential freshwater aquifers." It also estimated that the likelihood of groundwater contamination resulting from fracturing operations and fluid migration is less than one in fifty million wells, 2015 FSGEIS at 6-54. Overall, there are no significant upward fluxes of brine, well stimulation media, or natural gas either before, during, or after a stimulation event for the following reasons:

- Wellbore stimulation activities are short-lived (one day or so);
- Fractures developed within the borehole of the well remain entirely within Spacing Unit of the well;
- Induced fractures will not interact with geologic faults as there are no mapped faults in the Spacing Unit. The closest mapped fault is over one (1) mile west of the Spacing Unit.

Flewelling and Sharma (2013), in a general report not associated with the Snyder Well application, entitled *Constraints on Upward Migration of Hydraulic Fracturing Fluid and Brine*, support these conclusions as detailed below. In this article, Flewelling and Sharma discuss the physical constraints on upward fluid migration from black shales to shallow aquifers, taking into account the potential changes to the subsurface brought about by fracturing. Their literature review indicates that fracturing affects a very limited portion of the entire thickness of the overlying bedrock and, therefore, is unable to create direct hydraulic communication between black shales and shallow aquifers via induced fractures. As a result, upward migration of fluid and brine is controlled by preexisting hydraulic gradients and bedrock permeability. Some conclusions of Flewelling and Sharma are extended to the Snyder Well by the authors of this report.

From Flewelling and Sharma: the characteristics of sedimentary basins in which black shales are located (including the Marcellus) do not allow for rapid upward migration of fluid or brine over short or long timescales for the following reasons:

- Hydraulic fracturing affects a much smaller thickness of rock than that of the overburden bedrock (tens of feet vs 3,000 feet). As a result, regarding the Snyder Well, there will be no interaction with mapped geologic features in the area of the well;

- Building off of conclusions regarding the lateral extent of bedrock formations it follows that the Snyder Well is located far enough east in the physiographic province such that there is limited potential for fluid and gas to move laterally beyond an overlying confining layer(s) of the Genesee Group. That is to say that the overlying sandstones and shales are laterally expansive beyond the location of the Snyder Well;

- Vertical permeabilities are dominated by the least permeable layer in the stratigraphy above black shales (Marcellus), which is typically dominated by shales, siltstones, and mudstones, and many of these layers have inherently low permeability, which is further reduced by high effective stress at depth, cementation, and partial saturation. These layers are the main inhibitors of vertical gas migration. Relative to the Snyder Well, the confining layers are found in the Genesee Group;

- Similarly, the elevated pressure associated with bedrock fracturing is both short-lived and produces a localized fracture network. Therefore, upward migration of fluid or brine would be controlled by natural vertical head gradients and would have to traverse a thick interval of low permeability bedrock in order to reach shallow groundwater with no apparent driving mechanism to do so (as they do not currently exist in the vicinity of the Snyder Well);

- Induced fractures are contained at depth (i.e., no direct hydraulic connection to shallow groundwater; Fisher and Warpinski, 2011) and the fracture pressure pulse is too short in duration (a day or so for the Snyder Well) to affect natural hydraulic gradients. As stated above, regarding the Snyder Well, the effective hydraulic isolation of these formations is clearly demonstrated by the fact that fluids have been trapped at depth for tens to hundreds of millions of years.

- Unlike wastewater disposal wells where injection occurs for an extended period of time, wellbore stimulation is a short-term event designed to create permeable avenues in lower permeability hydrocarbon-bearing formations. Wellbore stimulation activity is followed by the extraction of reservoir fluids and a decrease in pressure within the formation. Therefore, the "pressure footprint" of a well that has been fractured is typically limited to the fracture growth or fracture propagation area (Gidley et al., 1990). In comparison, the "pressure footprint" of an injection well is related to the injection rate, duration of the injection period and transmissibility of the reservoir (Lee et al., 2003). Class II disposal wells typically inject for months or years and generate large "pressure footprints" with no offset production of fluids. In this way injection wells are not corollaries to stimulated/fractured gas wells, and the potential for induced seismicity in a fractured gas well borehole is significantly different than the long-term injection of wastewater.

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