

COMPRESSED AIR ENERGY STORAGE

NYSEG SENECA LAKE PROJECT

FINAL REPORT

Prepared for

NYSEG

Binghamton, New York

Prepared by



PB ENERGY STORAGE SERVICES, INC.

Houston, TX

Project No. 50756B

December 2011

TABLE OF CONTENTS

SECTION P	AGE
1.0 INTRODUCTION	1
2.0 GEOLOGY ^{A-D}	2
3.0 CAVERN CONCEPTUAL DESIGN ^{E,F}	4
4.0 CAVERN THERMODYNAMIC MODELING ^G	7
5.0 THERMAL AND THERMOMECHANICAL MODELING ^H	8
5.1 Heat Transfer Finite Element Model5.2 Thermomechanical modeling	
6.0 DRILLING AND COMPLETION ^{I-V}	11
6.1 Casing and Tubular Specifications6.2 Wellhead Specifications6.3 Drilling Program	.12
7.0 DEWATERING ^W	12
8.0 MECHANICAL INTEGRITY TESTING ^X	13
9.0 CAVERN CONSTRUCTION EXECUTION ^{Y-AA}	13
10.0 CAVERN CONSTRUCTION COST ^{BB}	13
11.0 SUBMITTALS	14

NYSEG SENECA LAKE CAES PROJECT WATKINS GLEN CAES FACILITY

1.0 INTRODUCTION

NYSEG proposes to develop a compressed air energy storage (CAES) project near Watkins Glen, NY which has a rated generating capacity of 135 - 210 MW. The proposed site is located in the in the town of Reading, NY near the intersection of State Route 14 and State Route 14A (Figure 1).



Figure 1 – NYSEG CAES Site Location

CAES facilities use electricity from the electric grid, at times of low electricity demand, to compress air and store the compressed air in storage chambers for later use. During periods of high electricity demand air is withdrawn from the CAES reservoir, heated, and expanded through a turbine to drive an electric generator. The CAES plant electricity generation cycle uses about 1/3 the amount of fuel that is required to generate the electricity using conventional combined cycle gas turbines.

NYSEG plans to store the compressed air in underground caverns solution mined from the bedded salt deposits of the Syracuse Formation, located approximately 2,400 feet below the NYSEG Site. Water for the solution mining will be provided by the U.S. Salt and the brine

resulting from the salt dissolution will be processed in the U.S. Salt evaporation plant. Salt has been actively mined using solution mining techniques at the Watkins Glen Field since the 1890's.

This report is a synopsis of the individual contract submittals prepared by PB Energy Storage Services in its role as the Cavern Development Consultant. Each subject heading is followed by superscripts that reference contract submittals. The submittals are identified in Section 11.0 of this report.

2.0 GEOLOGY^{A-D}

Western New York lies in the north end of the Appalachian Synclinorium. The geologic setting consists of a series of gently dipping sedimentary formations overlying the basement complex. The sedimentary-rock surface is mantled by glacial deposits which resulted from glaciation of stream valleys. A generalized geologic column for Western New York is given in Figure 2.

Structural deformation of the Watkins Glen area salt deposits and overlying formations probably occurred during the Appalachian Orogeny, a major period having several cycles of major tectonic activity which took place between late Devonian and the end of Permian time. Compressive forces acting in a nearly north-south direction caused a series of parallel folds oriented approximately N 80° E., thrust faults striking in a similar direction, and high angle northsouth strike-slip faults in Silurian and Devonian rocks in the area.

The salt beds underlying the NYSEG site are part of the Salina Group, deposited in the late Silurian time. Overlying the Salina Group is the Akron Dolomite and below the Salina is the Bertie Limestone. The Salina Group is made up of four formations (Figure 3), which are in ascending order:

- Vernon Formation
- Syracuse Formation
- Camillus Formation
- Bertie Formation

MIDDLE POCONO KNAPP CONCINTER AND SANDSTONE SANDSTONE, AND SANDSTONE SANDSTONE, AND SANDSTONE UPPER CONEWANGO SANDSTONE, AND SANDSTONE SANDSTONE, AND SANDSTONE UPPER CONEWANGO SANDSTONE, AND SANDSTONE SANDSTONE, AND SANDSTONE CONNEAUT CHADAKON SANDSTONE SANDSTONE CANADAWAY PERRYSBURG MINOR SANDSTONE VEST FALLS NUNDA SHALE AND SILSTONE SONYEA MINOR SANDSTONE SHALE AND SILSTONE SONYEA MINOR SANDSTONE SHALE AND SILSTONE MIDDLE HAMILTON UNDERSEN SHALE AND SILSTONE MIDDLE HAMILTON UDROWLEE SHALE AND SUBSTONE MIDDLE HAMILTON UDROWLEE SHALE AND SUBSTONE LOWER THISTATES ONISONAGA ULIMESTONE LOWER THISTATES ONISONAGA UMESTONE LOWER THISTATES ONISONAGA UMESTONE LOWER THISTATES ONISONAGA UMESTONE LOWER GENETIC SHALE AND SUBSTONE AND CON	PE	RIOD	GROUP	UNIT		LITHOLOGY
MODE CONEWANGO CONEWANGO SHALE AND SANDSTONE UPPER CONVEAUT CHADAKON SHALE AND SANDSTONE UNDEFERENTIATED SHALE AND SANDSTONE SHALE AND SANDSTONE UNDEFERENTIATED SHALE AND SANDSTONE VEST FALLS JAVA SHALE AND SANDSTONE SONTEA MINOR SANDSTONE MIDDLE TULLY SHALE AND SANDSTONE MINOR SANDSTONE SHALE AND SANDSTONE MINOR SANDETONE AND CONCURENTE MINOR TRISTATES ONISKAW SANDETONE MARCELLUS SHALE AND SANDSTONE MINORICE MARCELUS SANDSTONE LOWER <td>ENN</td> <td></td> <td>POTTSVILLE</td> <td>CLEAN</td> <td>8:00;</td> <td></td>	ENN		POTTSVILLE	CLEAN	8:00;	
MODE CONEWANGO CONEWANGO SHALE AND SANDSTONE UPPER CONVEAUT CHADAKON SHALE AND SANDSTONE UNDEFERENTIATED SHALE AND SANDSTONE SHALE AND SANDSTONE UNDEFERENTIATED SHALE AND SANDSTONE VEST FALLS JAVA SHALE AND SANDSTONE SONTEA MINOR SANDSTONE MIDDLE TULLY SHALE AND SANDSTONE MINOR SANDSTONE SHALE AND SANDSTONE MINOR SANDETONE AND CONCURENTE MINOR TRISTATES ONISKAW SANDETONE MARCELLUS SHALE AND SANDSTONE MINORICE MARCELUS SANDSTONE LOWER <td></td> <td></td> <td></td> <td></td> <td>0.000</td> <td></td>					0.000	
MODE CONEWANGO CONEWANGO SHALE AND SANDSTONE UPPER CONVEAUT CHADAKON SHALE AND SANDSTONE UNDEFERENTIATED SHALE AND SANDSTONE SHALE AND SANDSTONE UNDEFERENTIATED SHALE AND SANDSTONE VEST FALLS JAVA SHALE AND SANDSTONE SONTEA MINOR SANDSTONE MIDDLE TULLY SHALE AND SANDSTONE MINOR SANDSTONE SHALE AND SANDSTONE MINOR SANDETONE AND CONCURENTE MINOR TRISTATES ONISKAW SANDETONE MARCELLUS SHALE AND SANDSTONE MINORICE MARCELUS SANDSTONE LOWER <td>AISS</td> <td></td> <td>POCONO</td> <td>KNAPP</td> <td>0.0</td> <td></td>	AISS		POCONO	KNAPP	0.0	
CONEWANGO Id SCATTERE CONSIGNATES CONREAUT CHADAKON SCATTERED CONSIGNATIONSTONE UNDERENTIATED SCATTERED CONSIGNATIONSTONE SCATTERED CONSIGNATIONSTONE CANADAWAY PERRISUBIES SHALE AND SILISTONE WEST FALLS NUNDA SHALE AND SILISTONE SONYEA MIDDLEER SHALE AND SILISTONE MIDDLE TULLY SHALE AND SILISTONE MIDDLE MOSCOW AND CONSUMERTIES MIDDLE MOSCOW AND CONSUMERTIES ILOWER HELDERNERG MANUUN ILOWER BERTIE SH						
CONNEAUT CHADAKON SHALE AND SAMDSTONE UPPER CANADAWAY PERRYSBURG SHALE AND SILTSTONE UNDER JAVA SHALE AND SILTSTONE SHALE AND SILTSTONE WEST FALLS NUNDA SHALE AND SILTSTONE SONYEA MINOR SANDSTONE ARGUARZEOUS LIMISTONE SONYEA MINOR SANDSTONE ARGUARZEOUS LIMISTONE SONYEA MINOR SILTSTONE ARGUARZEOUS LIMISTONE SONYEA MINOR SILTSTONE ARGUARZEOUS LIMISTONE SONYEA MINOR SILTSTONE ARGUARZEOUS LIMISTONE GENESLE TULLY AND LONGUMERATE MIDDLE HAMILTON SANALE AND SILTSTONE MIDDLE HAMILTON SANALE AND SILTSTONE MIDDLE HAMILTON SANALE AND SILTSTONE MINDLE TRISTATES ORISKAWY SANALE AND SILTSTONE MINDLE TRISTATES ORISKAWY SANESTONE LIDWER TRISTATES ORISKAWY SANESTONE LIDWER TRISTATES ORISKAWY SANESTONE LIDWER TRISTATES <td></td> <td></td> <td>CONEWANGO</td> <td></td> <td></td> <td></td>			CONEWANGO			
UDDFFER UNDFFERENTIATED SHALE AND SILESTONE UDDFER JAVA PERPSSURG MINOR SANDSTONE WEST FALLS NUNDA SHALE AND SILESTONE SONYEA MIDDLE AMINOR SANDSTONE SONYEA MIDDLESEX SHALE AND SILESTONE SONYEA MIDDLESEX SHALE AND SILESTONE MIDDLE TULLY SHALE AND SILESTONE MIDDLE TULINOW/ILLE AND CONGLOREATE UDNOWNILLE SHALE AND SILESTONE AND CONGLOREATE UDNORG SHALE AND SILESTONE AND CONGLOSTONE ILOWER TRISTATES ORIGINARY SANDSTONE ILOWER HELDERBERG MANUUS UMESTONE UPPER GC GAMUUS						
UPPER CANADAWAY UNDIFFERENTIATED SHALE AND SILESTONE UPPER JAVA SHALE AND SILESTONE MINOR SANDSTONE VEST FALLS NUNDA SHALE AND SILESTONE Additude Sandstone SONYEA MIDDLE SHALE AND SILESTONE Additude Sandstone GENESEE SHALE AND SILESTONE Additude Sandstone MIDDLE TULLY SHALE AND SILESTONE MIDDLE HAMILTON SUMALE AND SILESTONE MIDDLE TULLY SHALE AND SILESTONE MIDDLE HAMILTON SUMALE AND SILESTONE MIDDLE TULLY SHALE AND SILESTONE MIDDLE TULLY SHALE AND SILESTONE MIDDLE TULLY SHALE AND SILESTONE MIDDLE TULY SHALE AND SILESTONE MARCELLUS SHALE AND SILESTONE AND CONGLOMERATE NOWER THISTATES ORIGONAGA UMESTONE LOWER HELDERBERG MANUUS UMESTONE VERNON CAMILUS UMESTONE AND DOLOSTONE UPPER GAMILIS GAM		1	CONNEAUT	CHADAKON	-0-0-	
UPPER CANADAWAY PERRYSBURG MINOR SANDSTONE IUPPER JAVA SHALE AND SILESTONE MINOR SANDSTONE SONYEA MUDDA SHALE AND SILESTONE ARGILLACEOUS LIMESTONE SONYEA MIDDLESER SHALE AND SILESTONE ARGILLACEOUS LIMESTONE GENESEE TULLY SHALE AND SILESTONE AND LIMESTONE MIDDLE TULLY LIMESTONE WITH MINOR SILESTONE AND LIMESTONE MIDDLE HAMILTON SUSTONE SHALE WITH MINOR SILESTONE MIDDLE HAMILTON SUSTONE SHALE WITH MINOR SILESTONE MIDDLE HAMILTON SUSTONE SHALE AND SILESTONE MIDDLE HAMILTON SUSTONE SHALE AND SILESTONE MIDDLE HAMILTON SUSTONE SHALE AND SILESTONE MIDDLE TITISTATES ORIGRAWY SANDSTONE AND CONSCIMENTE LIOWER TITISTATES ORIGRAWY SANDSTONE AND CONSCIMENTE LIOWER TITISTATES ORIGRAWY SANDSTONE AND CONSCIMENTE UPPER GENTE SA				UNDIFFERENTIATED		
UPPER IAVA MINOR SANDSTORE VEST FALLS NUNDA SHALE AND SILESTONE SONYEA MIDDLESEX SHALE AND SILESTONE SONYEA MIDDLESEX SHALE AND SILESTONE ORNESCE SHALE AND SILESTONE ARGUALSTONE MIDDLE TULLY LIMESTONE WITH MINOR SILESTONE MIDDLE HAMILTON SILATE AND SILESTONE MIDDLE HAMILTON SILATE AND SILESTONE MIDDLE HAMILTON SILATE AND SILESTONE MIDDLE HAMILTON SILATE WITH MINOR SILESTONE MIDDLE HAMILTON SILATE WITH MINOR SILESTONE MARCELLIS SHALE AND SILESTONE AND CONSILOMERATE ILOWER THISTATES ORISKANY SANDETONE ILOWER HELDERBERG MANULS LIMESTONE AND DOLOSTONE ILOWER HELDERBERG MANULS LIMESTONE AND DOLOSTONE ILOWER HELDERBERG MANULS LIMESTONE AND DOLOSTONE ILOWER GEMRIL SANDETONE SANDETONE ILOWER CLOCKPORT LIMESTONE </td <td></td> <td rowspan="2">UPPER</td> <td>CANADAWAY</td> <td></td> <td></td> <td>SHALE AND SILTSTONE</td>		UPPER	CANADAWAY			SHALE AND SILTSTONE
MURDA MURDA ARGILLACEOUS LIMESTONE SONYEA MIDDLESEX SHALE AND SUISTONE GENESEE SHALE AND SUISTONE SHALE AND SUISTONE MIDDLE TULLY LIMESTONE WITH MINOR SUISTONE MIDDLE MOSCDW AND SANDSTONE MIDDLE MOSCDW SHALE WITH MINOR SUISTONE MIDDLE MOSCDW SHALE AND SUISTONE MIDDLE MOSCDW SHALE AND SUISTONE LOWER TRISTATES ORISKANY SHALE AND SUISTONE LOWER HELDERBERG MANUUS LIMESTONE UPPER SYACUSE ANNOT DOLOSTONE LOWER LOCKPORT LOCKPORT LOCKPORT LOCKPORT LOWER CLINTON SANDSTONE AND SANDSTONE SANDSTONE				PERRYSBURG		MINOR SANDSTONE
MUNDA ARGILLACE/OUS LIMESTONE SONYEA MIDDLESER SHALE AND SUISTONE GENESEE SHALE AND SUISTONE AND LIMESTONE MIDDLE TULLY LIMESTONE WITH MINOR SUISTONE MIDDLE TULLY SHALE WITH MINOR SANDSTONE MIDDLE TULLY SHALE WITH MINOR SANDSTONE MIDDLE HAMILTON SKANEATELES MIDDLE HAMILTON SKANEATELES ONTONGAG LIMESTONE LOWER TRISTATES ORISKANY HELDERBERG RUNDOUT LIMESTONE LOWER TRISTATES ORISKANY UPPER CAMILLIS SANDSTONE ARRON LIMESTONE AND CONSCIONE LOWER TRISTATES ORISKANY UPPER CAMILLIS SANDSTONE CONTORAGA LIMESTONE AND CONSCIONE LOWER TRISTATES ORISKANY LOWER DOLOSTONE SANDSTONE LOWER DOLOSTONE SANDSTONE LOWER DOLOSTONE SANDSTO						SHALE AND SUITSTONE
SONVEA MINDULESK SHALE AND SUBSTONE GENESEE TULLY SHALE WITH MINDRSUISTONE AND SANDSTONE MIDDLE TULLY LIMESTONE WITH MINDRSUISTONE AND SANDSTONE MIDDLE HAMILTON SUBSTONE MIDDLE MOSCIDW SHALE WITH MINDRSUISTONE AND SANDSTONE MIDDLE HAMILTON SUBSTONE MIDDLE MOSCIDW SHALE WITH MINDRS SUBSTONE NARCELLUS AND CONSUMERATE MARCELLUS AND CONSUMERATE LOWER HELDERBERG HELDERBERG MANUUS LOWER HELDERBERG UPPER CAMILLUS STRATES ORISKANY STRATES ORISKANY LOWER HELDERBERG UPPER CAMILLUS STRATES CAMILLUS LOCKPORT LOCKFORT LOCKPORT LOCKFORT LOCKFORT LOCKFORT LOWER MEDINA GEINSTON SANDSTONE UPPER CLINTON ROOLSTONE SANDSTONE AN			WEST FALLS	NUNDA		SHALL AND SILISTONE
MIDDLE TULY LIMESTONE AND SANDSTONE MIDDLE HAMILTON SKANEATELES SHAIE WITH MINOR SANDSTONE LUDURUNULLE SKANEATELES AND CONDORA LUMESTONE LUDWER TRISTATES ORISKANY SANDSTONE LUWER TRISTATES ORISKANY SANDSTONE LUWER TRISTATES ORISKANY SANDSTONE LUWER TRISTATES ORISKANY SANDSTONE UPPER TRISTATES ORISKANY SANDSTONE UPPER CAMILLIS LIMESTONE ANH CONSTONE UPPER STRACUSE TRISTATES ORISKANY LOCKPORT LOCKPORT LIMESTONE ANHYDRITE AND HALITE LOCKPORT LOCKPORT LIMESTONE AN DOLOSTONE NHYDRITE AND SANDSTONE LOWER CLINTON SODUS THOROLO SANDSTONE LOWER MEDINA GRIMSBY SANDSTONE AND SANDSTONE LOWER MEDINA GRIMSBY SANDSTONE UPPER MEDINA TRENTON LIMESTONE AND SIN	z	1			-1-1-1-	
MIDDLE TULY LIMESTONE AND SANDSTONE MIDDLE HAMILTON SKANEATELES SHAIE WITH MINOR SANDSTONE LUDURUNULLE SKANEATELES AND CONDORA LUMESTONE LUDWER TRISTATES ORISKANY SANDSTONE LUWER TRISTATES ORISKANY SANDSTONE LUWER TRISTATES ORISKANY SANDSTONE LUWER TRISTATES ORISKANY SANDSTONE UPPER TRISTATES ORISKANY SANDSTONE UPPER CAMILLIS LIMESTONE ANH CONSTONE UPPER STRACUSE TRISTATES ORISKANY LOCKPORT LOCKPORT LIMESTONE ANHYDRITE AND HALITE LOCKPORT LOCKPORT LIMESTONE AN DOLOSTONE NHYDRITE AND SANDSTONE LOWER CLINTON SODUS THOROLO SANDSTONE LOWER MEDINA GRIMSBY SANDSTONE AND SANDSTONE LOWER MEDINA GRIMSBY SANDSTONE UPPER MEDINA TRENTON LIMESTONE AND SIN	MIA		SONYEA	MIDDLESEX		
MIDDLE TULY LIMESTONE AND SANDSTONE MIDDLE HAMILTON SKANEATELES SHAIE WITH MINOR SANDSTONE LUDURUNULLE SKANEATELES AND CONDORA LUMESTONE LUDWER TRISTATES ORISKANY SANDSTONE LUWER TRISTATES ORISKANY SANDSTONE LUWER TRISTATES ORISKANY SANDSTONE LUWER TRISTATES ORISKANY SANDSTONE UPPER TRISTATES ORISKANY SANDSTONE UPPER CAMILLIS LIMESTONE ANH CONSTONE UPPER STRACUSE TRISTATES ORISKANY LOCKPORT LOCKPORT LIMESTONE ANHYDRITE AND HALITE LOCKPORT LOCKPORT LIMESTONE AN DOLOSTONE NHYDRITE AND SANDSTONE LOWER CLINTON SODUS THOROLO SANDSTONE LOWER MEDINA GRIMSBY SANDSTONE AND SANDSTONE LOWER MEDINA GRIMSBY SANDSTONE UPPER MEDINA TRENTON LIMESTONE AND SIN	õ		GENESEE			
MIDDLE HAMILTON LUNCOUNT AND SANDSTONE HAMILTON LUDGOWILLE SKANEARLES S AND STONE AND CONGLOMERATE AND CONGLOMERATES AND CONGLOMERATES AND CONGLOMERATES AND CONCENT AND CONC	B				T	
MIDDLE HAMILTON MOSCOW LUNDOW/LLE 20 SHAIE WITH MINOR SANDSTONE INDOLE AND CONGLOMERATE MARCELLUS AND CONGLOMERATE AND CONGLOMERATE AND CONGLOMERATE IOWER TRISTATES ORISMAY SANDSTONE AND CONGLOMERATE IOWER TRISTATES ORISMAY SANDSTONE AND CONGLOMERATE IOWER TRISTATES ORISMAY SANDSTONE AND CONGLOMERATE IOWER HELDERBERG MANUUS IUMESTONE AND CONGLOMERATE IOWER ARRON IUMESTONE AND CONSTONE IOWER BERTIE SHALE, SILTSTONE ANHYDRITE AND HALITE IONOCEQUOIT LOCKPORT LOCKPORT IUMESTONE AND CONSTONE IOWER CLINTON SODUS IUMESTONE AND SANDSTONE IOWER MEDINA GRIMBBY SANDSTONE AND SANDSTONE IUPPER MEDINA GRIMBBY SANDSTONE AND SINDER IUPPER OSWEGO SHALE AND SILTSTONE UIMESTONE IUPPER IDRATINE IIMESTONE IIMESTONE IUPPER				TULLY	T	
MIDDLE HAMILTON LUDIOWVILLE SKANEATELES SHALE WITH MINOR SANDSTONE AND CONGLOMERATE LOWER TRISTATES ORIONOAGA LIMESTONE AND CONGLOMERATE LOWER TRISTATES ORIONOAGA LIMESTONE AND CONGLOMERATE UPPER TRISTATES ORIONOAGA LIMESTONE AND CONGLOMERATE UPPER TRISTATES ORIONOAGA LIMESTONE AND CONSTONE UPPER TRISTATES ORIONOAGA LIMESTONE AND DOLOSTONE UPPER DERTIE STRACUSE STRACUSE UPPER CAMILLIS ANHYDRITE AND HALITE VERNON STRACUSE LIMESTONE AN DOLOSTONE UPPER CLOCKPORT LOCKPORT LIMESTONE AND DOLOSTONE LOWER CLINTON SODUS LIMESTONE AND SANDSTONE LOWER GRIMBBY SANDSTONE AND SANDSTONE LIMESTONE AND SANDSTONE UPPER GRIMBBY SANDSTONE AND SANDSTONE LIMESTONE AND SANDSTONE UPPER GRIMBBY SANDSTONE AND SANDSTONE LIMESTONE AND MINIT DOLOSTONE UPPER BECKMANTOWN <td></td> <td></td> <td></td> <td>MORGONI</td> <td>- 1 - 1 Marc</td> <td>AND SANDS LONE</td>				MORGONI	- 1 - 1 Marc	AND SANDS LONE
AMILTON SKANEATELES AND CONGLOMERATE MARCELLUS AND CONGLOMERATE INVER TRISTATES ORISKAW SANDSTONE LOWER HELDERBERG RUNDOUT UPPER SC CAMILLIS LOCKPORT DOLOSTONE LOCKPORT LOCKPORT LIMESTONE AND HALTE RUNDOUT SHALE, SUITSTONE LOCKPORT LOCKPORT LIMESTONE AND CONSTONE RECEMBRIAN CHUCK RIVER LOWER MEDINA WHIRLOOL UPPER CLINTON BLACK RIVER LOWER RECEMBRIAN CHUCK RIVER LOWER CLINTON BLACK RIVER LOWER CLINTON BLACK RIVER LOWER CLINTON BLACK RIVER LOWER CLINTON BLACK RIVER LOWER CLINTON CLICKRORT LIMESTONE AND SANDSTONE UPPER CLINTON CLICKRORT LIMESTONE AND SANDSTONE LOWER CLINTON SODUS CLINTON SODUS CLINTON SODUS CLINTON CLICKRORT LIMESTONE AND SANDSTONE CLINTON SODUS CLINTON SODUS CLINTON CLICKRORT LIMESTONE AND SANDSTONE CLINTON SODUS CLINTON CLICKRORT LIMESTONE AND SOLOSTONE CLINTON SODUS CLINTON CLICKRORT LIMESTONE AND SOLOSTONE CLINTON CLICKRORT LIMESTONE AND SOLOSTONE CLINTON CLICKRORT LIMESTONE AND SOLOSTONE CLINTON CLICKRORT LIMESTONE AND SOLOSTONE CLINTON CLICKRORT LIMESTONE AND SOLOSTONE CLICKRORT LIMESTONE AND SOLOSTONE CLINTON CLICKRORT LIMESTONE AND SOLOSTONE CLICKRORT CLICKRORT LIMESTONE AND SOLOSTONE CLICKRORT CLICKRORT LIMESTONE AND SOLOSTONE CLICKRORT CLICKRORT LIMESTONE AND SOLOSTONE CLICKRORT CLICKRORT CLICKRO		MIDDLE			-0	SHALF WITH MINOR SANDSTONE
AND CONGLOMERATE AND CONCOMPANY INSTATES ORISINAN IDDUE INSTATES INSTATES ORISINAN IDDUE INSTATES ORISINAN IDDUE INSTATES ORISINAN IDDUE INSTATES ORISINAN IDDUE INSTATES INSTATES ORISINAN IDDUE INSTATES INTER INSTATES INSTATE			HAMILTON		5	
NOME TRISTATES ONONOAGA LIMESTONE LOWER HELDERBERG MANUUS LIMESTONE AND DOLOSTONE UPPER AKRON DOLOSTONE DOLOSTONE UPPER SHALE SUITSION SHALE SUITSIONE LOCKPORT LOCKPORT LIMESTONE AND DOLOSTONE LOCKPORT LOCKPORT LIMESTONE AND HALTE LOCKPORT LOCKPORT LIMESTONE AND DOLOSTONE LOCKPORT LOCKPORT LIMESTONE AND DOLOSTONE LOWER CLINTON SPACUSE MINDEQUOIT ROUHESTER SHALE SUITSTONE AND DOLOSTONE SHALE AND SANDSTONE LOWER CLINTON SODUS LIMESTONE AND DOLOSTONE LOWER MEDINA GRIMBBY SANDSTONE AND SANDSTONE UPPER OSUEGO SHALE AND SUITSTONE UPPER DECKMANTOWN LIMESTONE AND MINDE DOLOSTONE LOWER BECKMANTOWN LIMESTONE AND MINDE DOLOSTONE LOWER BECKMANTOWN LIMESTONE AND MINDE DOLOSTONE LOWER BECKMANTOWN LITTLE FALLS QUARTZ SANDSTONEAND						AND CONGLOMERATE
LOWER TRISTATES ORISKANY SANDSTONE LOWER HELDERBERG MANUUS LIMESTONE AND DOLOSTONE UPPER AKRON DOLOSTONE DOLOSTONE UPPER SHALE, SILTSTONE SHALE, SILTSTONE LOCKPORT LOCKPORT LIMESTONE AND DOLOSTONE LOCKPORT LOCKPORT LIMESTONE AND DOLOSTONE LOWER ROUTENTER SHALE, SILTSTONE LOWER CLINTON SODUS ANHYDRITE AND HALITE LOWER CLINTON SODUS SANDSTONE AND CLOSTONE LOWER CLINTON SODUS LIMESTONE AND CLOSTONE LOWER CLINTON SODUS LIMESTONE AND SANDSTONE LOWER MEDINA WITHONOE GRIMSBY UPPER MEDINA TRENTON BLACK TRENTON UPPER BLACK RIVER LIMESTONE AND MINICR DOLOSTONE LOWER BEEKMANTOWN TRENTON LIMESTONE AND MINICR DOLOSTONE UPPER BLACK RIVER LIMESTONE AND MINICR DOLOSTONE SANDSTONE UPPER BEEKMANTOWN					L	LIMESTONE
LOWER HELDERBERG MANUUS RONDOUT LIMESTONE AND DOLOSTONE UPPER AKRON DOLOSTONE UPPER S CAMILLIS SYRACUSE SHALE, SILTSTONE LOCKPORT LOCKPORT LIMESTONE AND DALOSTONE LOCKPORT LOCKPORT LIMESTONE AND HALITE LOCKPORT LOCKPORT LIMESTONE AND CROSTONE LOWER CLINTON SODUS SHALE, SILTSTONE LOWER CLINTON SODUS LIMESTONE AND CROSTONE LOWER CLINTON SODUS LIMESTONE AND SANDSTONE LOWER MEDINA GRIMBBY SANDSTONE AND SANDSTONE UPPER OSWEGO SHALE, AND SUITSTONE SHALE, AND SUITSTONE UPPER CUPENTON SHALE, AND SUITSTONE UIMESTONE UPPER TRENTON - BLACK TRENTON LIMESTONE AND MINOR DOLOSTONE LOWER TRENTON - BLACK TRENTON LIMESTONE LOWER BEEKMANTOWN CHUCTANUNDA LIMESTONE LOWER BEEKMANTOWN CHUCTANUNDA LIMESTONE LOWER<			TRISTATES			SANDSTONE
NOMOUT DOLOSTORE AKRON DERTIE SHALE, SUITSTONE UPPER GAMILLUS ANHYDRITE AND HALITE VERNON VERNON ANHYDRITE AND HALITE LOCKPORT LOCKPORT LIMESTONE AN DOLOSTONE ROLHESTER SHALE, SUITSTONE ROLHESTER SHALE, SUITSTONE LOWER CLINTON SODUS LOWER GRIMBY SANDSTONE AND SANDGTONE LOWER MEDINA GRIMBY UPPER GRIMBY SANDSTONE AND SUBSTONE UPPER BEEKMANTOWN UNESTONE AND MINOR DOLOSTONE UPPER GALWAY (HERESA) UNESTONE AND MINOR DOLOSTONE UPPER GALWAY (HERESA) DOLOSTONE VURTEL FALLS UNDESANDTONEAND DOLOSTONE SANDSTONE GNUCTANUNDA T T		LOWER		MANUUS	1 1 the	UNITED IS AND DOLOGYOUR
MUPPER DERTIFE SHALE, SUITSTONE UPPER CAMILLUS ANHYDRITE AND HALITE SYRACUSE UMESTONE AN DOLOSTONE LOCKPORT LOCKPORT LIMESTONE AN DOLOSTONE ROLHESTER SHALE, SUITSTONE ROLHESTER SHALE, SUITSTONE LOCKPORT LIMESTONE AN DOLOSTONE CUINTON SODUS REVINES LIMESTONE AND DOLOSTONE LOWER GRIMBY ANDSTONE AND SUBSTONE UPPER GRIMBY UPPER UNCAR UPPER TRIBES HILL UPPER GALWAY (HERESA) UPPER GALWAY (HERESA) OUSTONE SANDSTONE OUSTONE SANDSTONE OUSTONE GALWAY (HERESA) AND SANDY DOLOSTONE CONGONERATE BASE <td></td> <td></td> <td>HELDERBERG</td> <td>RONDOUT</td> <td>1 7471</td> <td>LIMESTONE AND DOLOSTONE</td>			HELDERBERG	RONDOUT	1 7471	LIMESTONE AND DOLOSTONE
UPPER STRACUSE STRACUSE ANHYDRITE AND HALITE UPPER LOCKPORT LOCKPORT LIMISTONE AN DRUGTONE LOCKPORT LOCKPORT LIMISTONE AND SANDSTONE ROUHESTER ROUHESTER SHALF AND SANDSTONE LOWER CLINTON SODUS LIMISTONE AND DRUGTONE LOWER CLINTON SODUS LIMISTONE AND SANDSTONE LOWER MEDINA GRIMBY SANDSTONE AND SUBSTONE UPPER OSWEGO SHALF AND SUBSTONE UITCA UNESTONE AND MINER DOLOSTONE UIMESTONE AND MINER DOLOSTONE UNCER TRIBES HILL TITUE TITUE LOWER BEEKMANTOWN LIMESTONE LIMESTONE UPPER GALWAY (HERESA) TITUE SANDSTONE VUPPER GALWAY (HERESA) SANDSTONE CONGONERATE BASE RECAMBRIAN <td></td> <td></td> <td></td> <td>AKRÓN</td> <td>1111</td> <td>DOLOSTONE</td>				AKRÓN	1111	DOLOSTONE
UPPER STRACUSE STRACUSE ANHYDRITE AND HALITE UPPER LOCKPORT LOCKPORT LIMISTONE AN DRUGTONE LOCKPORT LOCKPORT LIMISTONE AND SANDSTONE ROUHESTER ROUHESTER SHALF AND SANDSTONE LOWER CLINTON SODUS LIMISTONE AND DRUGTONE LOWER CLINTON SODUS LIMISTONE AND SANDSTONE LOWER MEDINA GRIMBY SANDSTONE AND SUBSTONE UPPER OSWEGO SHALF AND SUBSTONE UITCA UNESTONE AND MINER DOLOSTONE UIMESTONE AND MINER DOLOSTONE UNCER TRIBES HILL TITUE TITUE LOWER BEEKMANTOWN LIMESTONE LIMESTONE UPPER GALWAY (HERESA) TITUE SANDSTONE VUPPER GALWAY (HERESA) SANDSTONE CONGONERATE BASE RECAMBRIAN <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>						
LOCKNON SYRACUSE JUNITION LOCKPORT LOCKPORT LOCKPORT LIMESTONE AN DOLOSTONE LOWER ROCHESTER SHALE AND SANDSTONE SANDSTONE AND DOLOSTONE LOWER CLINTON SODUS ILMESTONE AND DOLOSTONE LOWER MEDINA GRIMSBY SANDSTONE AND DOLOSTONE UPPER MEDINA GRIMSBY SANDSTONE AND SUNSTONE UPPER MEDINA WITH MINOR SANDSTONE UNTH MINOR SANDSTONE UPPER OSWEGO SHALE AND SULTSTONE UITCA MIDDLE TRENTON - BLACK TRENTON - BLACK RIVER LIMESTONE AND MINOR DOLOSTONE LOWER BEEKMANTOWN TRENTON - BLACK RIVER LIMESTONE AND MINOR DOLOSTONE LOWER BEEKMANTOWN TRENTON - BLACK RIVER LIMESTONE AND MINOR DOLOSTONE UPPER GALWAY (IHERESA) TRESHILL TRENTON - CHUCTANUNDA UPPER GALWAY (IHERESA) SANDSTONE AND SONDEMONE GNEISS, MARBLE, NAD SULSTONE CONGLOMERATE BASE RECAMBRIAN GINESS, MARBLE, NAD SULS ROCKS			₫	BERTIE		SHALE, SILTSTONE
LOCKNON SYRACUSE JUNITION LOCKPORT LOCKPORT LOCKPORT LIMESTONE AN DOLOSTONE LOWER ROCHESTER SHALE AND SANDSTONE SANDSTONE AND DOLOSTONE LOWER CLINTON SODUS ILMESTONE AND DOLOSTONE LOWER MEDINA GRIMSBY SANDSTONE AND DOLOSTONE UPPER MEDINA GRIMSBY SANDSTONE AND SUNSTONE UPPER MEDINA WITH MINOR SANDSTONE UNTH MINOR SANDSTONE UPPER OSWEGO SHALE AND SULTSTONE UITCA MIDDLE TRENTON - BLACK TRENTON - BLACK RIVER LIMESTONE AND MINOR DOLOSTONE LOWER BEEKMANTOWN TRENTON - BLACK RIVER LIMESTONE AND MINOR DOLOSTONE LOWER BEEKMANTOWN TRENTON - BLACK RIVER LIMESTONE AND MINOR DOLOSTONE UPPER GALWAY (IHERESA) TRESHILL TRENTON - CHUCTANUNDA UPPER GALWAY (IHERESA) SANDSTONE AND SONDEMONE GNEISS, MARBLE, NAD SULSTONE CONGLOMERATE BASE RECAMBRIAN GINESS, MARBLE, NAD SULS ROCKS			L L	CAMILLIS		
VERNON VERNON LOCKPORT LUMESTONE AN DOLOSTONE ROUNE REVINALS LOWER CLINTON CUINTON SODUS LOWER THOROLO MEDINA CHINTON GRIMBY SANDSTONE AND DOLOSTONE UPPER GRIMBY UPPER CUINTON BECKMANTOWN CUINTON UPPER CUINTON UPPER CUINTON CUINTON SANDSTONE UPPER CUINTON CUINTON SANDSTONE UPPER CUINTON CUINTON SANDSTONE UPPER CUINTON CUINTON SANDSTONE UPPER CUINTON CHUCTANUNDA LIMESTONE AND MINDR DOLOSTONE UNTER BECKMANTOWN CHUCTANUNDA LIMESTONE UPPER GALWAY (HERESA) CHUCTANUNDA CHUCTANUNDA CHUCTANUNDA CHUCTANUNDA CHUCTANUNDA CHUCTANUNDA CHUCTANUNDA		UPPER	S.		BRIANTIANTIA	ANHYDRITE AND HALITE
LOCKPORT LOCKPORT LIMESTONE AN DOLOSTONE ROUMER ROUMERTER SHALF AND SANDSTONE LOWER CLINTON SODUS SANDSTONE AND DOLOSTONE LOWER MEDINA GRIMSBY SANDSTONE AND DOLOSTONE UPPER MEDINA GRIMSBY SANDSTONE AND SOLOSTONE UPPER MEDINA WHIRLBOOL QUARTZ SANDSTONE AND SILTSTONE UPPER OSWEGO SHALF AND SILTSTONE UIPPER CIUEENSTON SHALF AND SILTSTONE UIPPER UIRENTON WITH MINOR SANDSTONE UIPPER TRENTON - BLACK TRENTON - BLACK RIVER LIMESTONE AND MINOR DOLOSTONE LOWER BEEKMANTOWN TRENTON - BLACK RIVER LIMESTONE LOWER BEEKMANTOWN TRENTON - CHUCTANUNDA LIMESTONE UPPER GALWAY (IHERESA) DOLOSTONE SANDSTONE UPPER GREISS, MARBLE, NL, LITTLE FALLS QUARTZ SANDSTONEAND AND SANDY DOLOSTONE RECAMBRIAN GINESS, MARBLE, NL, LITTLE FALLS CONGLOMERATE BASE CONGLOMERATE BASE	z				*****	
INDIVIDUAL INDIVIDUAL INDIVIDUAL SOUS REVIALES LIMESTONE AND DOLOSTONE LOWER MEDINA MEDINA GRIMBBY UPPER OSWEGO UPPER OSWEGO MIDDLE TRENTON - BLACK RIVER TRIBES HILL LOWER BECKMANTOWN LOWER CHUCTANUNDA UPPER GALWAY (IHERESA) UPPER GALWAY (IHERESA) LOWER GALWAY (IHERESA) LONDER GALWAY (IHERESA) CHUCTANUNDA CHUCTANUNDA CHUCTARUNDA CHUCTANUNDA CHUCTARUNDA CHUCTARUNDA CHUCTARUNCA CHUCTARUNCA CHUCTARUNCA <td>RIA</td> <td></td> <td>LOCKPORT</td> <td></td> <td>111</td> <td>LIMESTONE AN DOLOSTONE</td>	RIA		LOCKPORT		111	LIMESTONE AN DOLOSTONE
INDIVIDUAL INDIVIDUAL INDIVIDUAL SOUS REVIALES LIMESTONE AND DOLOSTONE LOWER MEDINA MEDINA GRIMBBY UPPER OSWEGO UPPER OSWEGO MIDDLE TRENTON - BLACK RIVER TRIBES HILL LOWER BECKMANTOWN LOWER CHUCTANUNDA UPPER GALWAY (IHERESA) UPPER GALWAY (IHERESA) LOWER GALWAY (IHERESA) LONDER GALWAY (IHERESA) CHUCTANUNDA CHUCTANUNDA CHUCTARUNDA CHUCTANUNDA CHUCTARUNDA CHUCTARUNDA CHUCTARUNCA CHUCTARUNCA CHUCTARUNCA <td></td> <td></td> <td></td> <td>ROCHESTER</td> <td></td> <td>SHALE AND CANDGTONE</td>				ROCHESTER		SHALE AND CANDGTONE
LOWER REVINES THOROLD LIMESTONE AND DOLOSTONE MEDINA GRIMBBY SANDSTONE AND SUTSTONE UPPER CULERISTON MIDDLE TRENTON	, i					SHALL AND SAND TONE
LOWER THOROLD MEDINA GRIMBBY QUARTZ SANDSTONE AND STONE UPPER QUEENTON UPPER QUEENTON UNDELE TRENTON - BLACK RIVER TRENTON - BLACK RIVER TRENTON - BLACK RIVER TRENTON - BLACK LOWER BLACK RIVER LOWER BEEKMANTOWN CHUCTANUNDA LIMESTONE LOWER BEEKMANTOWN CHUCTANUNDA LIMESTONE LOWER BEEKMANTOWN CHUCTANUNDA LIMESTONE UPPER GALWAY (IHERESA) POTSDAM CONGLOMERATE BASE QUARTZITE, ETC LIMETAMORPHIC AND IGNEOUS ROCKS			CLINTON		717	
MEDINA GRIMBBY WHIREGOL SANDSTONE AND SILTSTONE UPPER CUEENSTON OSWEGO LORAINE SHALE AND SILTSTONE MIDDLE TRENTON - BLACK RIVER TRENTON BLACK RIVER WITH MINOR SANDSTONE MIDDLE TRENTON - BLACK RIVER TRENTON BLACK RIVER LIMESTONE AND MINOR SANDSTONE LOWER BEEKMANTOWN LIMESTONE LIMESTONE LOWER BEEKMANTOWN LIMESTONE LOWER BEEKMANTOWN LIMESTONE LOWER BEEKMANTOWN LIMESTONE LITTLE FALLS QUARTZ SANDSTONE SANDSTONE DOI OSTORE SANDSTONE UPPER GALWAY (HERESA) SANDSTONE AND SANDY DOLOSTONE CONGLOMERATE BASE RECAMBRIAN GNEISS, MABBLE, CUARTZITE, ETC LIX					1, 1, 1	LIMESTONE AND DOLOSTONE
MEDINA WHIRLOOL QUARTZ SANDSTONE QUPPER QUEENTON SHALE AND SILTSTONE UPPER OSWEGO UTICA MIDDLE TRENTON - BLACK TRENTON - BLACK RIVER ILOWER BECKMANTOWN ILMESTONE AND MINUR DOLOSTONE LOWER BECKMANTOWN ILMESTONE UPPER GALWAY (IHERESA) ILMESTONE UPPER GALWAY (IHERESA) DOLOSTONE SANDSTONE ND SANDSTONE		LOWER			- I Top	
UPPER QUEENSTON OSWEGO UPPER SHALE AND SILTSTONE UTCA MIDDLE TRENTON - BLACK RIVER TRENTON BLACK RIVER UTTA IMIDDLE TRENTON - BLACK RIVER TRENTON BLACK RIVER UMESTONE AND MINOR DOLOSTONE UMESTONE LOWER BEEKMANTOWN IMESTONE LOWER BEEKMANTOWN IMESTONE UPPER GALWAY (IHERESA) IMESTONE SANDSTONE UPPER GALWAY (IHERESA) IMESSIONE SANDSTONE POTSDAM ON SANDY DOLOSTONE CONGLOMERATE BASE RECAMBRIAN GREISS, MABRIE, QUARTZITE, ETC I + + + +			MEDINA			
UPPER OSWEGO LORRANE MIDDLE TRENTON - BLACK RIVER BLACK RIVER LOWER BEEKMANTOWN LOWER BEEKMANTOWN UPPER GALWAY (IHERESA) GALWAY (IHERESA) CHUCTANUNDA UTTLE FALLS GALWAY (IHERESA) CHUCTANUNDA CHUCTANUNA						QUARTZ SANDSTONE
UPPER LORRAINE WITH MINOR SANDSTONE MIDDLE TRENTON - BLACK RIVER TRENTON - BLACK RIVER TRENTON - LIMESTONE AND MINOR DOLOSTONE LOWER BEEKMANTOWN TRIBES HILL LIMESTONE LOWER BEEKMANTOWN CHUCTANUNDA LIMESTONE UPPER GALWAY (IHERESA) DOLOSTONE SANDSTONE CNUCTANUNDA AND SANDSTONE UPPER GALWAY (IHERESA) CNUCTANUNDA RECAMBRIAN GINEISS, MARBLE, QUARTZITE, ETC METAMORPHIC AND IGNEOUS ROCKS		UPPER				SHALE AND SILTSTONE
MIDDLE TRENTON - BLACK RIVER TRENTON BLACK RIVER UITICA UITICA MIDDLE TRENTON - BLACK RIVER TRENTON BLACK RIVER UIMESTONE AND MINOR DOLOSTONE LOWER BEEKMANTOWN TRIBES HILL L LOWER BEEKMANTOWN CHUCTANUNDA L UPPER GALWAY (HERESA) DOI OSTONE SANDSTONE VPPER GREISS, MABBLE, CULARTZITE, ETC L						
MIDDLE TRENTON - BLACK RIVER BLACK RIVER LIMESTONE AND MINITE DOLOSTONE LOWER BECKMANTOWN UPPER GALWAY (IHERESA) GALWAY (IHERESA) CHUCTANUNDA UPPER GALWAY (IHERESA) CHUCTANUNDA CHUCTANUNA CHUCTA					7.0.7.7	WITH MINOR SANDSTONE
LOWER BECKMANTOWN CHUCTANUNDA CHUCTANUNDA LITTLE FALLS UPPER GALWAY (IHERESA) FOTSDAM GINEISS, MARBLE, GALWAY (IHERESA) KRECAMBRIAN GINEISS, MARBLE, GINEIS, MARBLE, GINEISS, MARBLE, GINEISS, MA	z		TOPUTOL		I J	
LOWER BECKMANTOWN CHUCTANUNDA CHUCTANUNDA LITTLE FALLS UPPER GALWAY (IHERESA) FOTSDAM GINEISS, MARBLE, CHUCTANUNCAND GINEISS, MARBLE, CHUCTANUNCAND CONGLOMERATE BASE CONGLOMERATE CONGL	G	MIDDLE		TRENTON	T	LIMESTONE AND MINOR DOLOSTONE
LOWER BECKMANTOWN CHUCTANUNDA CHUCTANUNDA LITTLE FALLS UPPER GALWAY (IHERESA) FOTSDAM GINEISS, MARBLE, CHUCTANUNCAND GINEISS, MARBLE, CHUCTANUNCAND CONGLOMERATE BASE CONGLOMERATE CONGL	8		RIVER	BLACK RIVER	7 7	
LOWER BECKMANTOWN CHUCTANUNDA CHUCTANUNDA LITTLE FALLS UPPER GALWAY (IHERESA) FOTSDAM GINEISS, MARBLE, CHUCTANUNCAND GINEISS, MARBLE, CHUCTANUNCAND CONGLOMERATE BASE CONGLOMERATE CONGL	B I				1 1 1	
CHUCTANUNDA UPPER GALWAY (IHERESA) POTSDAM GNEISS, MARBLE, 112 41 CHUCTANUNDA UPPER GALWAY (IHERESA) POTSDAM GNEISS, MARBLE, 112 42 41 METAMORPHIC AND IGNEOUS ROCKS	0	LOWER	BECKMANTOWN	TRIBES HILL	1-1-1-	
UPPER GALWAY (IHERESA) POTSDAM GNESS, MABBLE, CUARTZ SANDSTONEAND DOI OSTONE SANDSTONE AND SANDY DOLOSTONE CONGLOMERATE BASE CUARTZITE, ETC + + + + + METAMORPHIC AND IGNEOUS ROCKS					<u></u>	LIMESTONE
UPPER GALWAY (IHERESA) POTSDAM GNEISS, MARBLE, GUARTZ SANDSTONE CONGLOMERATE BASE GNEISS, MARBLE, QUARTZ SANDSTONE SANDSTONE CONGLOMERATE BASE CONGLOMERATE BASE CONGLOMERATE BASE				CHUCTANUNDA		
CONSIGNERATE BASE GALWAY (IHERESA) DOI OSTONE SANOSTONE SANOSTONE POTSDAM OFF BASE CONSIGNERATE BASE GREISS, MARBIE, 113 123 12 METAMORPHIC AND IGNEOUS ROCKS QUARTZITE, ETC +++++				CITES PROTON	T	
CONSIGNERATE BASE GALWAY (IHERESA) DOI OSTONE SANOSTONE SANOSTONE POTSDAM OFF BASE CONSIGNERATE BASE GREISS, MARBIE, 113 123 12 METAMORPHIC AND IGNEOUS ROCKS QUARTZITE, ETC +++++	-	UPPER		LITTLE CALLS	11/17	OUADTZ CANDSTONEAND
POTSDAM CONGLOMERATE BASE GNELSS, MARBLE, 1,1,4,2,1,2 QUARTZITE, ETC 4-1+1+1+1 METAMORPHIC AND IGNEOUS ROCKS	CAMBRIAN			LITTLE FALLS	1,1,1	
POTSDAM CONGLOMERATE BASE GNELSS, MARBLE, 1,1,4,2,1,2 QUARTZITE, ETC 4-1+1+1+1 METAMORPHIC AND IGNEOUS ROCKS				GALWAY (THERESA)	2, 1, 1	
POTSDAM CONGLOMERATE BASE GNELSS, MARBLE, 1,1,4,2,1,2 QUARTZITE, ETC 4-1+1+1+1 METAMORPHIC AND IGNEOUS ROCKS				sector (menes)d		
RECAMBRIAN GNEISS, MARBLE, 13, 42, 52 QUARTZITE, ETC 4+1+1+1+ METAMORPHIC AND IGNEOUS ROCKS				POTSDAM	1.1.1	
	_				.0. 0. 0.	CONGLOMERATE BASE
	RECAN	IBRIAN			14444	METAMORPHIC AND IGNEOUS ROCKS
εχριανατιόν				QUARIZITE, ETC	4 + + + +	
EXPLANATION						
				EXPLANATION		

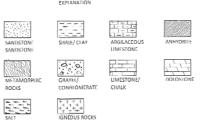


Figure 2 - Generalized Geologic Column for Western New York (From Van Tyne et al - 1983)

The Syracuse Formation consists of layers of salt separated by layers of insoluble rock. The major non-salt beds are generally continuous across the field, although the thickness and composition of the beds change. Many of the thinner units cannot be traced between adjacent wells. Geologic interpretation of available well log data near the proposed NYSEG Site implies that the top of the F salt unit is at approximately 2,352 feet below ground level and it will be 475 to 480 feet thick.

3.0 CAVERN CONCEPTUAL DESIGN^{E,F}

Preliminary cavern design was based upon the anticipated geology at the NYSEG Site, the average brine flow rate that can be accommodated by U.S. Salt (350 gpm), the time allocated for solution mining by NYSEG (730 days), the need to maintain a salt roof for the cavern, and the desire to minimize the maximum cavern diameter.

The cavern will be mined in the F unit of the Salina formation. Figure 4 is a conceptual diagram of the F unit at the proposed location. The F unit extends from about 2,352 feet to about 2,827 feet below ground level and is about 475 feet thick at the NYSEG Site. Of the 475 foot F Unit thickness, about 334 feet is salt. For the conceptual design, 50 feet of salt will be left to form the roof of the cavern.

Cavern solution mining simulation modeling was performed to determine the maximum cavern volume that could be developed. All solution mining modeling was performed using SANSMIC. SANSMIC is a cavern simulation model designed to project the development of caverns from a single well. SANSMIC, a widely used cavern modeling program, was developed by Sandia National Laboratories. The model is a two-dimensional numerical simulation code, which approximates the dissolution of salt by water.

Table 1 shows the results of the SANSMIC modeling of caverns developed in three different intervals within the Syracuse Formation. As can be seen in the table, higher vertical percentages of salt in the cavern interval result in larger open cavern volumes. The difference in volume between the last two intervals in the table is very small; however, the increase in cavern diameter from the second to the third interval is significant. Based upon these modeling results a cavern interval from 2,402 feet to 2,632 feet was selected for cavern development.

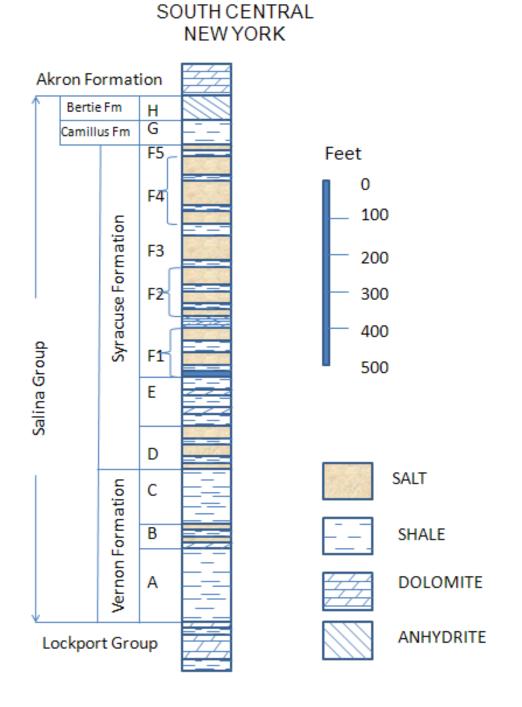


Figure 3 - Generalized Section of the Salina Group in South Central NY (From Johnson)

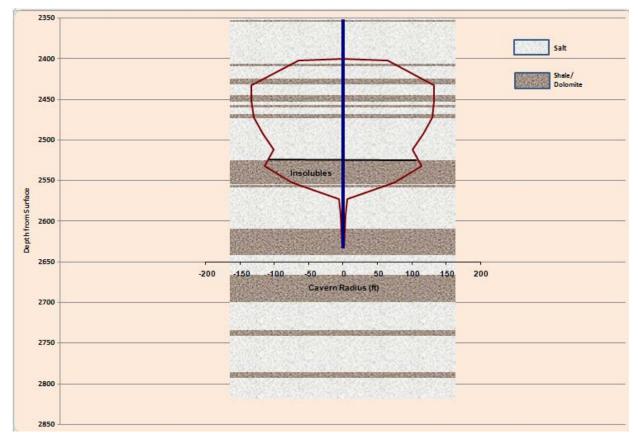


Figure 4 - Cavern Location in Expected Stratigraphy of F Salt at CAES Site

SANSMIC modeling for the interval between 2,402 feet and 2,632 feet indicates that a cavern with an open volume of 970,000 barrels can be solution mined in 710 days. The solution mining will require an intermediate workover after the completion of the first reverse leaching stage to re-position leaching strings. Results from the leaching simulation runs are provided in Table 2 and the predicted final cavern shape, and position within the Salina Salt is shown in Figure 4.

Modeled DepthOpenRangeVolume		Floor Depth	Maximum Diameter	Vertical Thickness of Salt	
Feet	Barrels	Feet	Feet	Percent	
2,402 - 2,832	933,000	2,567	258	66	
2,402 - 2,632	970,000	2,527	266	71	
2,402 - 2,532	974,000	2,508	284	79	

Table 1 Comparison of Caverns Developed at Three Depth Ranges

Mining Step	Step Time at 350 gpm	Total Mining Time	Open Mined Volume	Gross Cavern Volume	Brine Saturation
	Days	Days	Barrels	Barrels	Percent
Sump/Chimney	130	130	67,000	105,000	52.1
Reverse	150	280	272,000	324,000	84.8
Reverse	150	430	506,000	575,000	88.6
Reverse	150	580	752,000	840,000	90.8
Reverse	130	710	970,000	1,073,000	90.8

Table 2 – Results of Final Leaching Simulation Model Runs

4.0 CAVERN THERMODYNAMIC MODELING^G

Site specific geology, preliminary CAES duty cycle, and cavern conceptual design data were used to perform thermodynamic modeling of cavern operations. Modeling was performed by RESPEC Inc. using the Salt Cavern Thermal Simulator (SCTS).¹ The SCTS Model was developed by PB Energy Storage Services and RESPEC Inc. to simulate the thermodynamic performance and heat transfer resulting from storage operations of a natural gas storage cavern developed in salt. The version of SCTS used by RESPEC Inc. was modified from the original to include the thermodynamic properties of hydrogen and air.

Thermodynamic modeling of a storage cavern with an open volume of 970,000 bbl, using the NYSEG duty cycle and operating at pressures between 800 psi and 1500 psi, indicated that large swings in temperature could occur. Temperature swings during cavern operation of more than 85°F were predicted by SCTS.² When air is withdrawn from a cavern the air will decompress, causing a decrease in the air temperature that results in the development of thermal stresses in the salt. If the pressure drop is too great, the resultant pressure drop creates a stress state in the salt surrounding the cavern that eventually becomes tensile and the salt fails in tension.

Preliminary geomechanical analyses were performed to assess the impact of the temperature swings on cavern stability. These analyses indicated that tensile stress would develop in the cavern wall due to thermodynamically induced stress when wellhead pressures fall below 1,150

¹ Nieland, J. D. . *Salt Cavern Thermal Simulator Version 2.0 User's Manual*. RSI-1760. RESPEC, Inc. 2004

² Ratigan, Joe L. Presentation to NYSEG. Cavern Volume Review – Seneca Lake CAES Project. August 3, 2011.

psi. Since salt has a very low tensile strength, caverns are designed to avoid tensile stress development. The preliminary modeling results indicated that three 970,000 bbl caverns, operated at pressures between 1,150 psi and 1,500 psi, would be required to eliminate the development of tensile stresses during CAES operations.

Based upon these modeling modeling results, the cavern design basis was revised. The revised cavern preliminary design requirements are three storage caverns, each with an open volume of 970,000 barrels, operating between 1,150 psi and 1,500 psi.

Thermodynamic modeling of the revised cavern design was performed by RESPEC, using SCTS, to estimate the temperature boundary condition for the heat transfer numerical modeling and to establish the required diameters for the casing liners. The results of the thermodynamic modeling indicated that:

- The first cavern would require a 20 inch diameter casing liner to compress air at the design rate of 639 lbs per second and withdraw air at 617 lbs per second for 2.3 hours of electrical power generation.
- The second and third caverns require a 16 inch diameter casing to flow air at a combined rate of 639 lbs per second and to withdraw air at 617 lbs per second for 4.9 hours of electrical power generation.
- All three caverns combined are required to generate electricity in accordance with the preliminary NYSEG duty cycle.
- The wellhead temperature will vary from 71° F to 101° F during CAES operations.
- The Salt temperature will cycle between 85° F and 126° F during CAES operations.
- Wellhead Pressures will cycle between 1,150 psi and 1,500 psi at the wellhead during CAES operations.

5.0 THERMAL AND THERMOMECHANICAL MODELING^H

Numerical modeling of a single 970,000 barrel CAES cavern, operating at pressures between 1,150 psi and 1,500 psi, was performed by RESPEC. The modeling was performed to evaluate cavern stability, determine cavern closure due to creep, and to estimate well casing strains during CAES operation. The modeling was composed of two separate models; the heat transfer finite element model and the thermomechanical model.

Cavern stability is a function of the stress state in the salt surrounding the opening, which in turn is a function of the cavern shape, the air pressure inside the cavern, the insitu stress, cavern creep and the thermally induced stresses in the salt. The thermally induced stresses, due to

pressure cycling of the cavern during operation, have a significant impact on the stress state in the salt surrounding the cavern.

5.1 HEAT TRANSFER FINITE ELEMENT MODEL

SPECTROM-41³ was used to simulate the heat transfer between the cavern wall and the surrounding salt. SPECTROM-41 is a finite element heat transfer program developed by RESPEC, Inc. to model heat transfer in geologic formations.

Heat transfer modeling was performed to simulate a thirty year time period, during which the cavern was cycled between minimum and maximum operating pressure in accordance with the preliminary NYSEG CAES duty cycle. Temperature fluctuations in the salt surrounding the cavern, due to cavern operations, ranged from 25°F at the cavern wall to 0° F five feet beyond the wall of the cavern. Predicted temperatures at the salt walls of the cavern are shown in Figure 5.

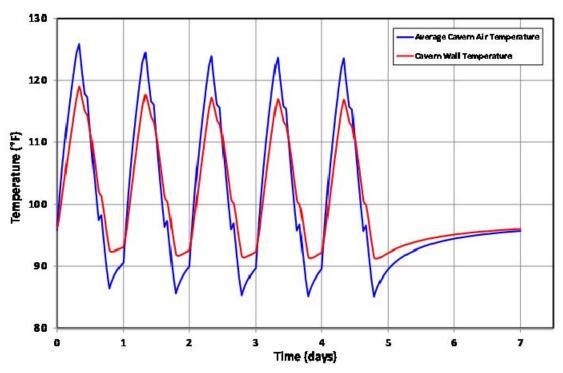


Figure 5 – Salt Wall Predicted Temperatures After 5 Years of Operation

³ Svalstad, D. K. *Documentation of SPECTROM-41: A Finite Element Heat Transfer Analysis Program.* RE/SPEC Inc. 1989.

The preliminary geomechanical modeling results, discussed in Section 4.0, implied that tensile stress would not develop in the cavern walls for the temperature swing of 25°F. The results from the heat transfer modeling were used in the thermomechanical modeling to assess cavern stability.

5.2 THERMOMECHANICAL MODELING

Cavern salt temperature modeling results, predicted cavern pressures during operations, insitu stress, rock material properties, and rock thermal properties were used to model the thermomechanical behavior of the cavern over a 30 year operating period. The numerical modeling code SPECTROM-32⁴ was used for the thermomechanical modeling. SPECTROM 32 was developed by RESPEC for simulation of underground openings in both brittle rock and in rock which behaves viscoplastically like salt.

Thermomechanical modeling for a period of 5 years of cavern operations was performed to evaluate the potential for salt dilation and hydraulic fracture. A 30 year thermomechanical model, at minimum cavern pressure, was used to estimate cavern creep closure, shear failure of non-salt geologic units, and strain in the well casing.

Modeling results from the cavern operation model were evaluated by calculating factors of safety in the salt and non salt units relative to dilation (for salt) and shear failure in nonsalt units. Modeling results indicate that minimal salt dilation is predicted to occur in the upper corner of the cavern and the floor of the cavern during the first two weeks of operation. While the dilation may result in sloughing of the salt it is not expected to affect cavern stability. No shear failure of the nonsalt units above the cavern was predicted during cavern operations. Fracturing of thin nonsalt units intersecting the cavern are not expected to result in instability or loss of cavern integrity. Stresses surrounding the cavern remained compressive for the five year cavern operation modeling period, implying that no thermally induced fractures are predicted perpendicular to the cavern walls.

Cavern closure and strain in the cemented casing were evaluated during a simulated 30 year period of operation at minimum cavern pressure (1,150 psi). A creep closure of 0.48% was predicted over the 30 year simulation period. This magnitude of creep closure is very small relative to other salt storage caverns. This closure rate will result in strain rates in the cemented

⁴ Callahan, G. D., A. F. Fossum, and D. K. Svalstad. *Documentation of SPECTROM-32: A Finite Element Thermomechanical Stress Analysis Program*, RE/SPEC Inc., 1989.

casing of less than 7 mircostrain and is not expected to result in casing failure during the life of the cavern.

6.0 DRILLING AND COMPLETION^{I-V}

The drilling and completion programs for the proposed NYSEG CAES wells are premised on the NYSEG requirements that:

- All three caverns must flow in parallel at the design rate for the NYSEG specified duty cycle.
- The first cavern must flow at the design flow rate.
- Any two caverns must flow in parallel at the design flow rate

6.1 CASING AND TUBULAR SPECIFICATIONS

Based upon these requirements the well casing, casing liner, and tubulars for solution mining and dewatering were selected. All casing performance was assessed in accordance with American Petroleum Institute (API 5C3).

Casing for the first well will be a 42" surface conductor casing set and cemented to approximately 175 feet below ground surface, a 30" diameter surface casing set and cemented to a depth of approximately 850 feet below ground surface, a 24" final cemented casing set and cemented to a depth of approximately 2,360 feet below ground surface, and a 20" suspended stainless steel production liner set at a depth of 2,407 feet below ground surface.

Casing for Wells 2 & 3 will be a 42" surface conductor casing set and cemented to approximately 175 feet below ground surface, a 26" diameter surface casing set and cemented to a depth of approximately 850 feet below ground surface, a 20" final cemented casing set and cemented to a depth of approximately 2,360 feet below ground surface, and a 16" suspended stainless steel production liner set at a depth of 2,407 feet below ground surface.

Leaching tubulars are sized for a brine flow rate of 350 gpm, subject to the requirement to be able to pass a 4" conventional sonar survey tool. The casing depths are specified in the leaching plan. Setting depths, at the start of solution mining, are 2,530 feet below ground level for the outer 8-5/8" casing and 2,630 feet below ground level for the inner 5-1/2" tubing.

6.2 WELLHEAD SPECIFICATIONS

Wellheads were specified in accordance with API 6A. The leaching wellhead was selected to suspend tubulars for solution mining. Upon completion of solution mining, the leaching wellhead sections above the bradenhead flange will be replaced with corrosion resistant wellhead sections. Following dewatering, the dewatering string will be snubbed out of the cavern, the master valve shut, and corrosion resistant wellhead components installed to prepare the cavern for CAES operations.

6.3 DRILLING PROGRAM

Final drilling procedures will be developed after selecting a drilling contractor and final casing setting depths will be established after wellbore logging. The drilling program developed for NYSEG consists of:

- Drilling, running, and cementing the conductor pipe.
- Mobilizing drilling rig to the wellpad.
- Drilling the surface hole, running the surface casing, and cementing it in place.
- Drilling the production hole, running the production casing, and cementing it in place.
- Drilling the hole through the cavern interval to the total depth. Coring will be performed during the drilling of Well No. 2 only.
- Running the leaching strings and installing the surface wellhead.
- Demobilizing drilling rig from wellpad.

7.0 DEWATERING^w

Upon completion of solution mining the cavern will undergo preliminary mechanical integrity testing, followed by a conversion workover to ready the cavern for dewatering. The workover consists of removing the leaching tubulars and leaching wellhead components, running and welding the stainless steel cemented casing liner, installing the dewatering sections of the wellhead, and running a dewatering string to a depth near the floor of the cavern.

Due to the low rate of brine acceptance by U.S. Salt it will be necessary to dewater the cavern using temporary compressors. Injection of air will take place down both the annulus between the dewatering string and the liner and between the liner and the final cemented casing to prevent casing collapse. The dewatering will take approximately 78 days. After the air / brine interface reaches the roof of the cavern the wellhead pressures will not increase significantly during

dewatering. A maximum air pressure of 1,300 psi and a maximum flow rate of 3,750 scfm are anticipated during dewatering.

8.0 MECHANICAL INTEGRITY TESTING^x

Each NYSEG cavern will undergo preliminary mechanical integrity testing prior to the start of the conversion workover. This test will assess the integrity of the cavern prior to running and welding the stainless steel liner. The nitrogen interface will be set between the casing shoe and the cavern roof by removing a portion of the nitrogen which makes up the roof blanket. Once the nitrogen interface is set, the wellbore integrity will be evaluated using nitrogen mechanical integrity testing techniques.

The final MIT for the NYSEG caverns will take place after running the stainless steel liner, and installing the dewatering casing and wellheads. This test is designed to test the cavern wellbore, dewatering wellhead components, and dewatering string for gross leakage prior to the start of dewatering.

9.0 CAVERN CONSTRUCTION EXECUTION^{Y-AA}

Cavern construction execution is composed of the overall project schedule, combined, with a proposed methodology of contracting wellpad construction, drilling, solution mining, workovers, and final conversion. A cavern development construction manager who is thoroughly familiar with drilling large diameter cavern storage wells, cavern well workover, and the management of solution mining of storage caverns is critical to the success of the project.

The responsibilities of the cavern development construction manager include specification development, specialized procurement, management and contracting of drilling and workover operations required, management of solution mining operations, and engineering support required to successfully develop storage caverns.

10.0 CAVERN CONSTRUCTION COST^{BB}

A final revised cavern construction cost estimate of \$36.6 million (2011 dollars) was developed by PB ESS based upon actual historical costs experienced along the Gulf Coast and in New York. This cost does not include land acquisition cost, access road cost, or costs associated with the permitting of a CAES facility in New York.

11.0 SUBMITTALS

- A. Eyermann, Thomas. *Overview of Geology of the Area Around the US Salt Watkins Glen Refinery*. PB Energy Storage Services Inc. September 2011.
- B. PB ESS Inc. Letter Report: Location of TEPPCO Watkins Glen Propane Storage Facility. October 20, 2011.
- C. PB ESS Inc. Letter Report: *Constituents and Quality of Formation's Salts*. October 24, 2011.
- D. PB ESS Inc. Letter Report: *Update of Earthquake Data 1998 2011*. November 30, 2011.
- E. Eyermann, Thomas. *Initial Cavern Design Watkins Glen CAES*. PB Energy Storage Services Inc. October 2011.
- F. PB ESS Inc. Drawing: *Storage Well Site Plan*. November 2011.
- G. Nieland, Joel. Letter Report. Nieland to McHenry. Subject: Thermodynamic Evaluation of Proposed New York State Electric & Gas Corporation Compressed Air Energy Storage Cavern Design. RESPEC Inc. October 4, 2011.
- H. RESPEC Inc. Geomechanical Evaluation of the New York State Electric & Gas Corporation Compressed Air Energy Storage Cavern Design. Topical Report RSI – 2240. November 2011.
- I. PB ESS Inc. *Well Casing and Tubulars Watkins Glen CAES*. November 2011.
- J. PB ESS Inc. NYSEG Seneca Lake CAES Proposed New Leaching Wellhead Cavern No. 1. November 2011.
- K. PB ESS Inc. NYSEG Seneca Lake CAES Proposed New Leaching Wellhead Cavern No. 2 & 3. November 2011.
- L. PB ESS Inc. NYSEG Seneca Lake CAES Proposed New Dewatering Wellhead Cavern No. 1. October 2011.
- M. PB ESS Inc. NYSEG Seneca Lake CAES Proposed New Dewatering Wellhead Cavern No. 2 & 3. October 2011.
- N. PB ESS Inc. NYSEG Seneca Lake CAES Proposed New Production Wellhead Cavern No. 1. October 2011.
- O. PB ESS Inc. NYSEG Seneca Lake CAES Proposed New Production Wellhead Cavern No. 2 & 3. October 2011.
- P. PB ESS Inc. *NYSEG Watkins Glen Proposed CAES Well No. 1 Drilling Program.* September 2011.
- Q. PB ESS Inc. NYSEG Watkins Glen Proposed CAES Well No. 2 Drilling Program. November 2011.

- R. PB ESS Inc. NYSEG Watkins Glen Proposed CAES Well No. 3 Drilling Program. November 2011.
- S. PB ESS Inc. *Intermediate Workover Program Well No. 1, 2, & 3*. November 17, 2011.
- T. PB ESS Inc. *Conversion Workover Program Well No. 1, 2, & 3*. November 17, 2011.
- U. PB ESS Inc. Snubbing Program Well No. 1, 2, & 3. November 17, 2011.
- V. PB ESS Inc. NYSEG Watkins Glen Open Hole Logging Plan. November 2011.
- W. PB ESS Inc. Letter Report: *Dewatering Program for NYSEG CAES Caverns*. McHenry to Rettberg. December 13, 2011.
- X. PB ESS Inc. *Cavern Testing Program CAES Storage Cavern*. November 2011.
- Y. PB ESS Inc. *Construction Execution Plan CAES Storage Cavern*. November 2011.
- Z. PB ESS Inc. Drawing: NYSEG Seneca Lake Wellpad Sections and Details. November 2011.
- AA. PB ESS Inc. NYSEG CAES Project Schedule. Delivered in Microsoft Project 2007 Format. October 2011.
- BB. PB ESS Inc. Individual Cost Estimates.
 - a. Cavern Construction Cost Estimate. October 31, 2011.
 - b. Wellpad Cost Estimate. December 7, 2011.
 - c. MIT Cost Estimate Cavern No. 1. October 2, 2011.
 - d. MIT Cost Estimate Cavern No. 2 & 3. October 2, 2011.
 - e. Drilling Cost Estimate Well No. 1. October 2011.
 - f. Drilling Cost Estimate Well No. 2. October 2011.
 - g. Drilling Cost Estimate Well No. 3. October 2011.
 - h. Intermediate Workover Cost Estimate. October 31, 2011.
 - i. Conversion Workover Cost Estimate Well No. 1. October 15, 2011.
 - j. Conversion Workover Cost Estimate Well No. 2 & 3. October 15, 2011.
 - k. Final Wellhead Installation Cost Estimate Well No. 1. October 31, 2011.
 - 1. Final Wellhead Installation Cost Estimate Well No. 2 & 3. October 10, 2011.
 - m. Set Nitrogen Blanket Cost Estimate Well No. 1. October 2, 2011.
 - n. Set Nitrogen Blanket Cost Estimate Well No. 2 & 3. October 2, 2011.
 - o. Snubbing Cost Estimate. October 31, 2011.
 - p. Sonar Survey Cost Estimate. October 11, 2011.
 - q. Wellpad Piping Cost Estimate. October 10, 2011.
- CC. PB ESS Inc. Letter Report: Preliminary Cavern Criteria. August 11, 2011.

DD. PB ESS Inc. Letter Report: Environmental Report Questionnaire Input. December 15, 2011.

