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Waste Isolation Pilot Plant

Geotechnical Analysis Report for July 2020 – June 2021

U.S. Department of Energy
Carlsbad Field Office

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U.S. Department of Energy
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October 2022

Approved by: Michael Gerle Digitally signed by Michael Gerle Date: 2022.10.18 15:50:53 -06'00'

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FOREWORD AND ACKNOWLEDGMENTS

This report contains the most recent assessment of the geotechnical status of the Waste Isolation Pilot Plant (WIPP). During the excavation of the WIPP principal underground access and experimental areas, the status was reported quarterly. Since 1987, when the initial construction phase was completed, reports have been published annually. This report presents and analyzes data collected from July 1, 2020, to June 30, 2021.

This Geotechnical Analysis Report (GAR) was written to meet the needs of several regulatory requirements. It satisfies requirements contained in the WIPP Hazardous Waste Facility Permit[1] (HWFP) Part 4 Section 4.6.1.2, Reporting Requirements, and Attachment A2, Section A2-5b(2), Geomechanical Monitoring, and the Certification of Compliance[2] with Subparts B and C, Title 40 *Code of Federal Regulations* (CFR) Part 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes." Part 191 defines the waste containment requirements. One of these requirements, stipulated in Part 191.14(b), is “Disposal systems shall be monitored after disposal to detect substantial and detrimental deviations from expected performance.” Part 194.42 describes the minimum post-disposal system parameters to be analyzed. This report focuses on the geotechnical performance of the various components of the WIPP underground facility, including shaft stations, access drifts, and waste disposal areas. The results of investigations of excavation effects and other geotechnical studies are also included.

This report compares the geotechnical performance of the repository to the design criteria, outlined in Table 9-1. It describes the techniques that were used to acquire the data. The depth and breadth of the evaluation of the different components of the underground facility vary according to the types and quantities of data available, and the complexity of the recorded geotechnical responses. Graphic documentation of data and tabular documentation of instrument history can be provided upon request.

This GAR was prepared by Nuclear Waste Partnership LLC for the U.S. Department of Energy (DOE), Carlsbad Field Office, in Carlsbad, New Mexico. Work was supported by the DOE under Contract No. DE-EM0001971.

[1] New Mexico Environment Department (NMED), 2022, Waste Isolation Pilot Plant Hazardous Waste Facility Permit, NM4890139088-TSDF, Santa Fe, NM

[2] U.S. Environmental Protection Agency, 1998, "Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the Disposal Regulations: Certification Decision," *Federal Register*, Vol. 63, No. 95, pp. 27354, May 18, 1998, Washington, DC

CHANGE HISTORY SUMMARY

Revision Number	Date Issued	Description of Changes
0	Oct. 18, 2022	• Initial issue.

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ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
AIS	Air Intake Shaft
bp	before present
bsc	below shaft collar
CFR	Code of Federal Regulations
CH	contact-handled
cm	centimeter(s)
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ft	foot (feet)
GAR	Geotechnical Analysis Report
GIS	geomechanical instrumentation system
HWFP	Hazardous Waste Facility Permit
in	inch(es)
km	kilometer(s)
kVA	kilovolt ampere(s)
m	meter(s)
Ma	million years
MB	marker bed
NMED	New Mexico Environment Department
OMB	orange marker bed
psi	pound(s) per square inch
RCRA	Resource Conservation and Recovery Act
RH	remote-handled
SDI	Salt Disposal Investigation
SDDI	Salt Defense Disposal Investigation
SNL	Sandia National Labs
SPDV	Site and Preliminary Design Validation
TRU	Transuranic
WIPP	Waste Isolation Pilot Plant

1.0 INTRODUCTION

This Geotechnical Analysis Report (GAR) presents and interprets geotechnical data from the underground excavations at the Waste Isolation Pilot Plant (WIPP). The data, which are obtained as part of a regular monitoring program, are used to characterize conditions, to compare actual performance to the design criteria, and to evaluate and forecast the performance of the underground excavations.

WIPP GARs have been available to the public since 1983. During operation of the Site and Preliminary Design Validation (SPDV) Program, the architect/engineer for the project produced these reports quarterly to document the geomechanical performance during and immediately after early excavations of the underground facility. Since completion of the construction phase of the project in 1987, the management and operating contractor for the facility has prepared these reports annually. This report describes the performance and condition of selected areas of the WIPP for the period July 1, 2020, to June 30, 2021.

This report is divided into 10 sections. Section 1 provides background information on the WIPP, its mission, and the purpose and scope of the geomechanical monitoring program. Section 2 describes the local and regional geology of the WIPP Site. Sections 3 and 4 describe the geomechanical instrumentation in the shafts and shaft stations, present the data collected by that instrumentation, and provide interpretation of these data. Sections 5 and 6 present the results of geomechanical monitoring in the two main portions of the WIPP underground (the access drifts and the waste disposal area). Section 7 introduces the Salt Disposal Investigation (SDI) and Salt Defense Disposal Investigation (SDDI) areas. Section 8 discusses the results of the Geoscience Program, which include fracture mapping and observation borehole information. Section 9 summarizes the results of geomechanical monitoring and compares the current excavation performance to the design requirements. Section 10 lists references.

1.1 Location and Description

The WIPP facility is located in southeastern New Mexico, 26 miles east of Carlsbad (Figure 1-1). The surface facilities were built on flat to gently rolling terrain that is characteristic of the Los Medaños area. The underground facility is being excavated approximately 2,150 feet (ft) beneath the surface in the Salado Formation. Figure 1-2 shows a plan view of the underground configuration of the WIPP as of June 30, 2021.

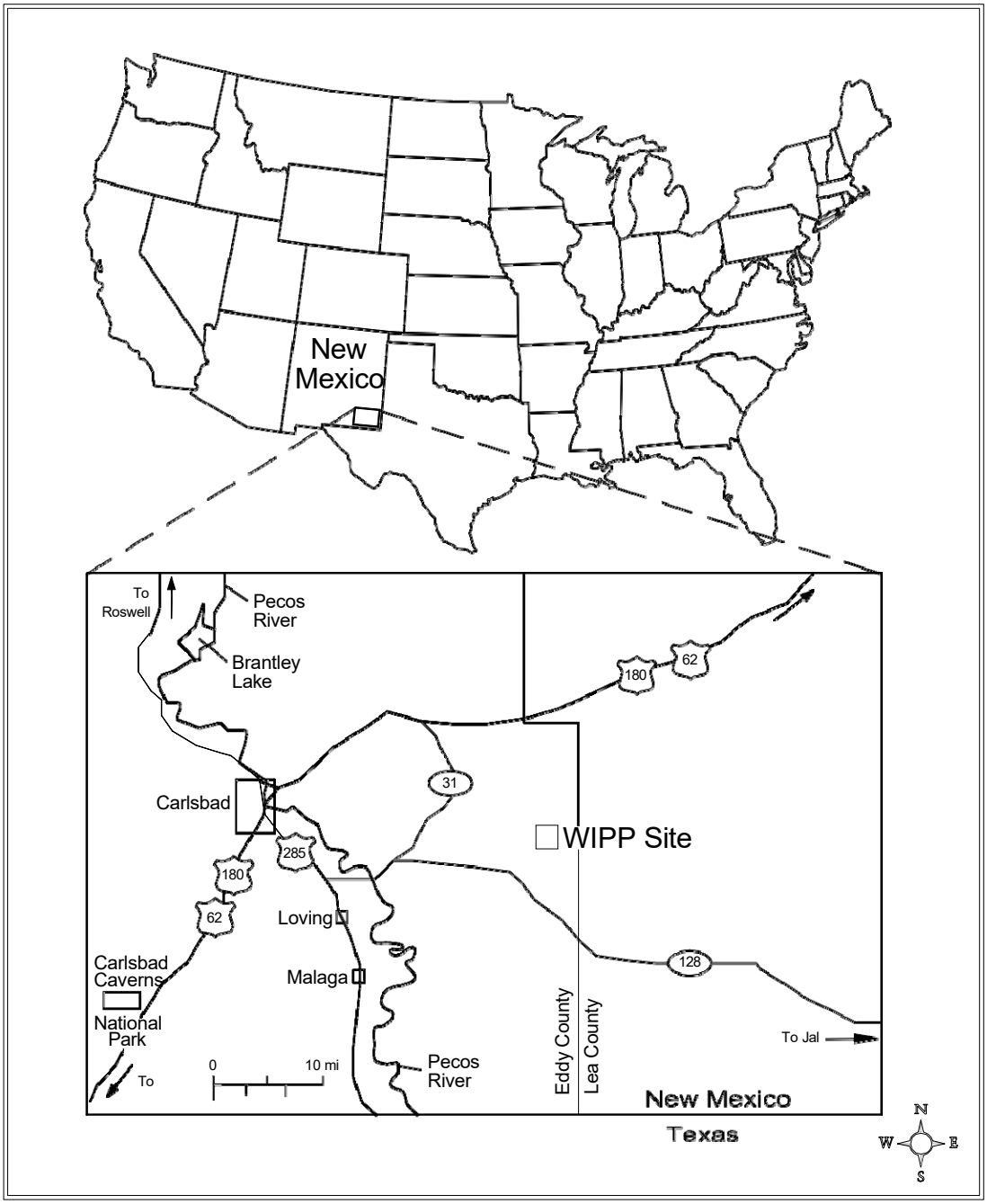

Figure 1-1 WIPP Location

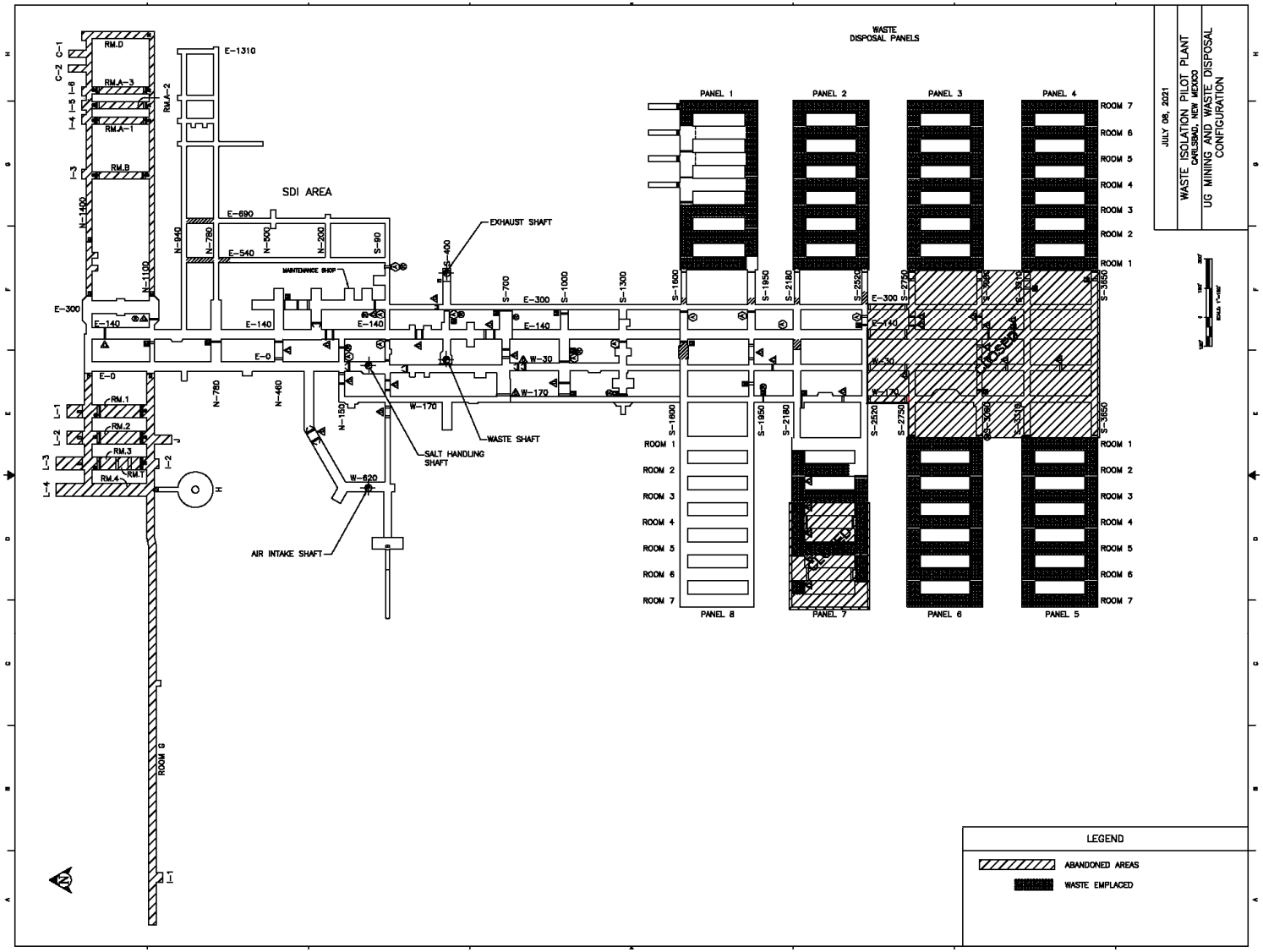

Figure 1-2 Underground Mining and Waste Disposal Configuration as of June 30, 2021

1.2 Mission

In 1979 Congress authorized the WIPP (Public Law 96-164, Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980) to provide,"… a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission." To fulfill this mission, the U. S. Department of Energy (DOE) constructed a full-scale facility to demonstrate both technical and operational principles of the permanent disposal of transuranic (TRU) and TRU mixed wastes. Technical aspects are those concerned with the design, construction, and performance of the subsurface excavations. Operational aspects refer to the receiving, handling, and emplacement of TRU wastes in the facility. The facility was first used for *in situ* studies and experiments without the use of radioactive waste. The WIPP now receives, handles, and permanently disposes of TRU waste and TRU mixed waste.

1.3 Development Status

To fulfill its mission, the DOE developed the WIPP in a phased manner. The goal of the SPDV phase, begun in 1980, was to characterize the site and obtain *in situ* geotechnical data from underground excavations to determine whether Site characteristics and *in situ* conditions were suitable for permanent waste disposal. During this phase, the Salt Shaft, a ventilation shaft, a drift to the southernmost extent of the proposed waste disposal area, a four-room experimental panel, and access drifts were excavated. Surface-based geological and hydrological investigations were also conducted. The data obtained from the SPDV investigations were reported in the Summary of the Results of the Evaluation of the WIPP Site and Preliminary Design Validation Program (DOE, 1983).

Based upon the favorable results of the SPDV investigations, additional activities were initiated in 1983. These included the construction of surface structures, conversion of the ventilation shaft for use as the Waste Shaft, excavation of the Exhaust Shaft, development of additional access drifts to the waste disposal area and excavation of additional experimental rooms to support research and development. Geotechnical data acquired during this phase were used to evaluate the performance of the excavations in the context of established design criteria (DOE, 1984). Results of these evaluations were reported in geotechnical field data reports (DOE, 1985; DOE, 1986a), and were summarized in the *WIPP Design Validation Final Report* (DOE, 1986b).

The *WIPP Design Validation Final Report* concluded that the facility, including waste disposal areas, could be developed and operated to fulfill the long-term mission of the WIPP (DOE, 1986b). All available information validated the design of underground openings to safely accommodate the permanent disposal of waste under routine operating conditions.

The Air Intake Shaft was constructed between March 1988 and November 1989. Panel 1 mining began in 1986 and was completed in 1988. Panel 1 was intended to receive waste for an initial operations demonstration and pilot plant phase that was scheduled to start in October 1988; however, the demonstration and pilot plant phase was not put into effect because waste could not be emplaced until permits were acquired.

In October 1996, the DOE submitted to the U.S. Environmental Protection Agency (EPA) a compliance certification application in accordance with Title 40 *Code of Federal Regulations* (CFR) Parts 191 and 194, which addressed the long-term (10,000-year) performance criteria for the disposal system. On May 18, 1998, the EPA published the final certification that allowed for the receipt of TRU waste at the WIPP. Immediately before this certification, the DOE Carlsbad Area Office completed an Operational Readiness Review, which is required by the DOE before the start-up or a process change of any nuclear facility. As a result of the review, the DOE Carlsbad Area Office notified the Energy Secretary on April 1, 1998, that the WIPP was operationally ready to receive waste. On March 26, 1999, the first shipment of TRU waste was received from Los Alamos National Laboratory. By the end of June 2013, many additional waste generator sites had shipped waste to the WIPP. The cleanup of several small-quantity waste generator sites, as well as one large-quantity site (Rocky Flats Environmental Technology Site), is now complete.

New Mexico has primary responsibility for permitting, implementation, and enforcement of most aspects of the Resource Conservation and Recovery Act (RCRA). In 1999, the New Mexico Environment Department (NMED) granted the WIPP Hazardous Waste Facility Permit (HWFP) to the DOE. The WIPP HWFP was renewed for a ten-year period in 2010. In March 2020, the HWFP was submitted to the NMED for renewal and modification. The review was ongoing during this reporting period.

Waste disposal in Panels 1, 2, 3, 4, 5, and 6 is complete. Panels 1, 2, and 3 contain only contact-handled (CH) waste. The first remote-handled (RH) waste shipment arrived January 24, 2007. Panel 4 was the first to receive both CH and RH waste. CH and RH waste emplacement had commenced in Panel 7, but was halted initially by a truck fire in the underground, which was quickly followed by a radioactive release in Panel 7. CH waste emplacement resumed in January 2017, and RH waste emplacement was resumed in Panel 7 in February 2019 using shielded containers only, no additional borehole emplacement occurred during this reporting period. Panel 8 is scheduled to begin receiving waste in 2022, upon the completion of waste disposal in Panel 7.

1.4 Purpose and Scope of Geomechanical Monitoring Program

As specified in the WIPP HWFP Part 4 Section 4.6.1.2, Reporting Requirements, and Attachment A2, Section A2-5b(2), Geomechanical Monitoring (New Mexico Environment Department [NMED], 2016), the purpose of the geomechanical monitoring program is to obtain *in situ* data to support the continuous assessment of the design for underground facilities.

Specifically, the program provides for:

- Early detection of conditions that could affect operational safety.
- Evaluation of disposal room closure that ensures adequate access.
- Guidance for design modifications and remedial actions.
- Data for interpreting the behavior of underground openings, in comparison with the established design criteria.

Data taken by, or input into the geomechanical instrumentation system (GIS), are evaluated and reported in this GAR. This annual report fulfills the requirements set forth in Part 4.6.1.2., Attachment A2, Section A2-5b (2) of the WIPP HWFP (NMED, 2022), and 40 CFR §191.14, "Assurance Requirements," implemented through the certification criteria, 40 CFR Part 194.

The Geomechanical Monitoring Program generates the data for four of the compliance monitoring parameters:

- Creep closure and stresses
- Extent of deformation
- Initiation of brittle deformation
- Displacement of deformation features

The instrumentation system for geomechanical monitoring provides data for routine evaluations of safety, stability, and performance of underground openings. *In situ* data are also used to model long-term disposal system performance. Changes resulting from excavations are monitored by routine inspections of selected observation borehole arrays and fracture mapping to detect and quantify occurrences of discontinuities such as fractures and bed separations. Analysis of data indicating areas of potential instability allows timely corrective action before the areas become unsafe. Other geoscience activities include geologic mapping and sampling, and seismic monitoring.

The GIS provides data that are collected, processed, and stored for analysis. The following subsections briefly describe the major components of the GIS.

1.4.1 Instrumentation

Instrumentation installed for measuring the geomechanical response of the shafts, drifts, and other underground openings includes convergence points, convergence meters, extensometers, rock bolt load cells, pressure cells, strain gauges, piezometers, and joint meters. Table 1-1 lists a summary of the specifications for geomechanical instrumentation.

Instrument Type	Measures	Range[2]	Resolution[2]
Convergence point (tape extensometer)	Cumulative deformation	2 - 66 ft	0.001 in
Wire convergence meter	Cumulative deformation	0 – 40 in	0.005 in
Embedded strain gauge	Cumulative strain	0 – 3000 microstrain	1 microstrain
Spot-welded strain gauge	Cumulative strain	0 – 2500 microstrain	1 microstrain
Rock bolt load cell	Load	0 – 50 tons	40 pounds
Earth pressure cell	Pressure	0 – 1000 psi	1 psi
Piezometer	Fluid pressure	0 – 500 psi	0.5 psi
Joint meter	Cumulative deformation	0 – 4 in	0.001 in
Wire extensometer	Cumulative deformation	0 – 25 in	0.005 in

Table 1-1 Geomechanical Instrumentation Data Acquisition

Geomechanical instruments are read either manually, using portable devices, or remotely, by electronically polling the stations from the surface, in accordance with approved operating procedures. Remotely read instruments are connected to one of the underground data loggers, and readings are collected by initiating the appropriate polling routine. Upon completion of a verification process, data are transferred to a computer database. Manual readout devices are taken to instrument locations in the underground. Data are recorded on data sheets and later entered into an electronic database.

The underground data acquisition system consists of instruments, polling devices, and a communications network. Instruments are connected to polling devices that are installed in electrical enclosures near the instrument locations. Polling devices are connected by a data link to a surface computer.

[2] Manual readout boxes for the instruments were manufactured to render measurements in U.S. customary units. Range and resolution measurement units have not been converted to metric units. PSI denotes, pounds per square inch.

Whether acquired manually or remotely, geomechanical data are entered into the database files of the GIS data processing system. The data processing system consists of computer programs that are used to enter, reduce, and transfer the data to permanent storage files. Additional routines allow access to the permanent storage files for numerical analysis, tabular reporting, and graphical plotting. Copies of the report are available upon request[3].

1.4.2 Data Evaluation

Rounding and significant digits are used in the data tables of this document. The reference document is American Society for Testing and Materials (ASTM) document ASTM D 6026-06, "Standard Practice for Using Significant Digits in Geotechnical Data."

Closure measurements are acquired manually from convergence point anchors and remotely from convergence meters. Data are presented in plots of closure versus time. Closure rate data are calculated and presented as part of the data analysis. Extensometers provide displacement data from instrumented rods or wires anchored at various depths. Plots show displacement versus time for individual anchors.

Displacement rate data from the hole (collar) to the deepest anchor are presented in the data analysis.

The annual closure rate is calculated as follows:

$$RRRRRRRR\ \left(\frac{iiiiiihRRee}{yyRRRRyy}\right) = \left(\frac{yyRRRRrriiiirr2 - yyRRRRrriiiirr1}{rrRRRRRR2 - rrRRRRRR1}\right) * 365.25\ \frac{rrRRyyee}{yyRRRRyy}$$

reading = the change from the initial reading (inches)

reading1 = reading closest to the beginning of the reporting period

reading2 = reading closest to the end of the reporting period

Comparisons between closure rates of the previous and current reporting periods are presented as percent changes in rate and are calculated as follows:

$$percent\ change\ in\ rate = (Rate_{Current\ Period} - Rate_{Previous\ Period}) / (Rate_{Previous\ Period}) \times 100\%$$

Rock bolt load cells are used to determine bolt support performance. Plots show load versus time for each instrumented bolt.

[3] Instrumentation data and data plots are presented in "Geotechnical Analysis Report for July 2018 - June 2019 Supporting Data" (DOE/WIPP-20-3610 Volume 2). The document is available upon request from the National Technical Information Service. See page ii for details and addresses.

Earth pressure cells and strain gauges are used to determine the stresses and deformation in and around the shaft liners. Data are depicted in time-based plots. Piezometers are used to measure the gauge pressure of groundwater and are installed in the shafts at varying elevations to monitor the hydraulic head acting on the shaft liners. Data are plotted as pressure versus time.

Joint meters, installed perpendicular to a fracture, monitor the dilation of the fracture with time. Data are presented as displacement versus time.

1.4.3 Data Errors

GIS data are processed through a comprehensive database management system. Whether acquired manually or remotely, GIS data are processed and permanently stored according to approved procedures. On occasion, erroneous readings can occur. There are several possible explanations for erroneous readings, including the following:

- The measuring device was misread.
- The reading was recorded incorrectly.
- The measuring device was not functioning within specifications.

When a reading is believed to be erroneous, the suspect reading is evaluated, and, if necessary, a second reading is collected. If the second reading falls in line with the instrument trend, the first reading is discarded and the second reading is entered in the database. If the second reading and subsequent readings remain out of the instrument trend, the ground conditions in the vicinity of the instrument are assessed to determine the reason for the discrepancy. In addition, the reading frequency may be increased.

2.0 GEOLOGY

This section provides a stratigraphic summary of the WIPP region and the Site. Readers desiring further geologic information may consult the *Geological Characterization Report, WIPP Site, Southeastern New Mexico* (Powers et al., 1978). This report was developed as a source document on the geology of the WIPP Site for individuals, groups, or agencies seeking basic information on geologic history, hydrology, geochemistry, or detailed information, such as physical and chemical properties of repository rocks. A more recent survey of WIPP stratigraphy is included in the *Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant* (Holt and Powers, 1990).

2.1 Regional Stratigraphy

The stratigraphy in the vicinity of the WIPP Site includes rocks of Permian (295 to 250 million years [Ma] before present [bp]), Triassic (250 to 203 Ma), and Quaternary (1.75 Ma to present) ages. The descriptions of formations provided in this section are given in order of deposition (oldest to youngest), beginning with the Castile Formation (Figure 2-1).

2.1.1 Permian

The Permian system in southwestern North America is divided into four series. The last of these, the Ochoan Series, contains the host rock in which the WIPP repository is located.

The Ochoan Series is of mostly marine origin and consists of four formations: three evaporite formations (the Castile, the Salado, and the Rustler) and one redbeds formation (the Dewey Lake). The Ochoan evaporites overlie marine limestones and sandstones of the Guadalupian Series (Delaware Mountain Group). The younger redbeds represent a transition from the lower evaporite deposition to fluvial deposition on a broad, low-relief, fluvial plain. The Permian rocks are overlain by fluvial deposits of the Triassic and Quaternary periods.

2.1.1.1 Castile Formation

The Castile Formation, lowermost of the four Ochoan formations, is approximately 1,250 ft thick in the WIPP vicinity. Lithologically, the Castile is the least complex of the evaporite formations and is composed chiefly of interbedded anhydrite and halite, with limestone present in minor amounts.

2.1.1.2 Salado Formation

The Salado Formation comprises nearly 2,000 ft of evaporites, primarily halite. The formation is subdivided into three informal members: the unnamed lower member, the McNutt potash zone, and the unnamed upper member. Each member contains similar amounts of halite, anhydrite, and polyhalite, and is differentiated on the basis of soluble potassium- and magnesium-bearing minerals. The WIPP disposal horizon is located within the unnamed lower member, 2,150 ft below the surface.

2.1.1.3 Rustler Formation

The Rustler Formation is subdivided into five members, starting from its base: the Los Medaños Member, the Culebra Dolomite Member, the Tamarisk Member, the Magenta Dolomite Member, and the Forty-niner Member.

In the vicinity of the WIPP Site, the Rustler is approximately 310 ft thick and thickens to the east. The lower portion (Los Medaños Member) contains primarily fine sandstone to mudstone with lesser amounts of anhydrite, polyhalite, and halite. Bedded and burrowed siliciclastic sedimentary rocks with cross-bedding and fossil remains signify the transition from the strongly evaporitic environments of the Salado to the brackish lagoonal environments of the Rustler (Holt and Powers, 1990).

The upper portion of the Rustler contains interbeds of anhydrite, dolomite, and mudstone. The Culebra Dolomite Member is generally brown, finely crystalline, and locally argillaceous. The Culebra contains rare to abundant vugs with variable gypsum and anhydrite filling, and is the most transmissive hydrologic unit within the Rustler. The Tamarisk Member consists of lower and upper sulfate units separated by a unit that varies laterally from mudstone to mainly halite. The Magenta Dolomite Member is a gypsiferous dolomite with abundant primary sedimentary structures and well-developed algal features. The Forty-niner Member consists of lower and upper sulfate units separated by a mudstone that displays sedimentary features and bedding. East of the Site area, halite correlates with the mudstone. The Culebra and Magenta Dolomite members are persistent and serve as important marker units.

2.1.1.4 Dewey Lake Redbeds

The Dewey Lake Redbeds is the uppermost of the Ochoan Series formations. Within the series, the Dewey Lake represents a transition from the lower marine evaporite deposition to fluvial deposition on a broad, low-relief, fluvial plain. The redbeds, approximately 475 ft thick, consist of predominantly reddish-brown interbedded fine-grained sandstone, siltstone, and claystone. This formation is differentiated from others by its lithology and distinctive color (both of which are remarkably uniform), and by sedimentary structures, including horizontal- and cross-laminae and ripple marks. The redbeds also contain locally abundant greenish-gray reduction spots and gypsum filled fractures. The formation thickens from west to east due to eastward dips and erosion to the west.

2.1.2 Triassic

The only Triassic rocks present in the WIPP region belong to the Dockum Group.

2.1.2.1 Dockum Group

The Dockum Group consists of fine-grained floodplain sediments and coarse alluvial debris of Triassic age. From a pinch-out near the center of the WIPP Site it thickens eastward, forming an erosional wedge. Local subdivisions of the Dockum Group are the Santa Rosa Sandstone and the Chinle Formation; however, only the Santa Rosa occurs in the vicinity of the Site. It consists primarily of poorly sorted sandstone with conglomerate lenses and thin mudstone partings, and contains impressions and remnants of fossils. These rocks have more variegated hues than the underlying uniformly colored Dewey Lake.

2.1.3 Quaternary

Quaternary Period deposits include the Gatuña Formation, Mescalero Caliche, and surficial sediments.

2.1.3.1 Gatuña Formation, Mescalero Caliche, and Surficial Sediments

The Gatuña Formation (ranging in age from approximately 1.3 million to 600,000 years bp) (Powers and Holt, 1993) is a stream-laid deposit overlying the Dockum Group in the WIPP vicinity. At the Site center, the formation consists of poorly consolidated sand, gravel, and silty clay at a thickness of approximately 13 ft. The Gatuña Formation is light red and mottled with dark stains. The unit contains abundant calcium carbonate, but is poorly cemented. Sedimentary structures are abundant (Powers and Holt, 1993, 1995).

The Mescalero Caliche (approximately 500,000 years bp) is approximately 4 ft thick in the WIPP vicinity. The Mescalero is a hard, resistant soil horizon that lies beneath a cover of wind-blown sand. The horizon is petrocalcic (i.e., very strongly cemented with calcium carbonate). Petrocalcic horizons form slowly beneath a stable landscape at the average depth of infiltration of soil moisture, and indicate stability and integrity of the land surface. Many of the surface buildings at the WIPP are founded on top of the Mescalero Caliche.

Surficial sediments include sandy soils developed from eolian material and active dune areas. The Berino Series (a soil type) covers about 50 percent of the Site and consists of deep sandy soils that developed from wind-worked material of mixed origin. Based on sample analyses, the Berino soil from the WIPP Site formed 330,000 ± 75,000 years bp.

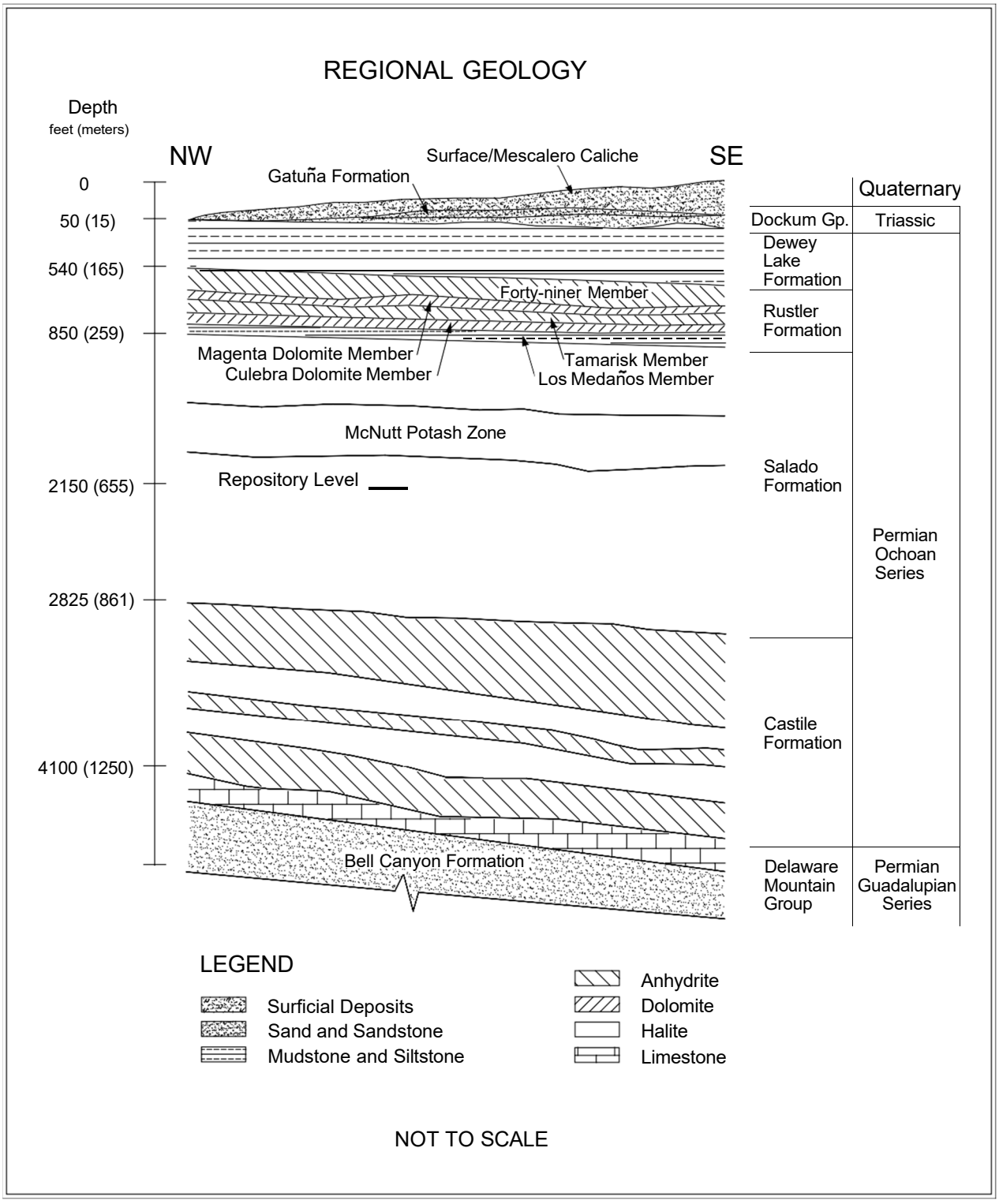

Figure 2-1 Regional Geology

2.2 Underground Facility Stratigraphy

The WIPP disposal horizon lies near the midpoint of the Salado Formation. The Salado was deposited in a shallow saline lagoon environment, which progressed through numerous inundation and desiccation cycles that are reflected in the formation. An "ideal" cycle progresses upward as follows: a basal layer consisting predominantly of claystone, followed by a layer of sulfate, which is in turn followed by a layer of halite. The entire sequence is capped by a bed of argillaceous (clay-rich) halite accumulated during a period of mainly subaerial exposure.

A regional system used for numbering the more significant sulfate beds within the Salado designates these beds as marker beds (MBs), counted from MB100 near the top of the formation to MB144 near the base. The repository is located between MB138 and MB139 within a sequence of laterally continuous depositional cycles as described above. Within this sequence, layers of clay and anhydrite that are locally designated (as shown) can have a significant impact on the geomechanical performance of the excavations. Clay layers provide surfaces along which slip and separation can occur, whereas anhydrites form brittle layers that do not deform plastically.

In the vicinity of the WIPP, the stratigraphy is fairly continuous and uniform. Beds generally dip toward the south-southeast at a slope of approximately 3 percent.

2.2.1 Disposal Horizon Stratigraphy of Panels 1, 2, and 7

This disposal horizon contains Panels 1, 2, and 7, all the shaft areas, the shop areas, the SPDV areas (which are now closed), and all the access drifts north of S-2520. Farther south, the four main entries rise in a ramp that starts at S-2520 and ends at S2750. Panel 7 excavation was completed in January 2013. Most underground excavations are located within this disposal horizon (Figure 2-2). In it, the Orange Marker Bed (OMB) lies near the middle of the rib (i.e., the excavation wall). The OMB is a laterally consistent unit of moderate to light reddish-orange translucent halite, about 6 inches (in) thick that is used as a point of reference during excavation.

MB139 lies approximately 11.5 ft below the OMB. MB139 is a 20 to 32-in -thick layer of polyhalitic anhydrite. The top of the anhydrite undulates up to 15 in, while the bottom is sub-horizontal and is underlain by Clay E.

Above MB139, a unit of halite terminates at the base of the OMB. Within this unit, polyhalite is locally abundant and decreases upward, while argillaceous material increases upward.

Above the OMB, a thin band of argillaceous halite gives way to a thick sequence of clear halite that becomes increasingly argillaceous upward and is capped by Clay F. This constitutes a thin layer occasionally interrupted by partings and breaks and is readily visible in the upper ribs. Above Clay F, another sequence of halite begins that, as in lower sequences, becomes increasingly argillaceous upward. This sequence terminates at the Clay G/Anhydrite "b" interface, approximately 6.5 ft above the roof of most disposal horizon excavations, forming a roof beam that typically acts as a structural unit.

The roof of some disposal horizon excavations (e.g., the E-140 drift between S-1000 and S-1950) has been excavated to the upper contact of Anhydrite "b." In this case, a roof beam is formed by the next depositional sequence beginning with Anhydrite "b" and progressing upward to the Clay H/Anhydrite ’a’ interface, approximately 6.5 ft above the upper contact of Anhydrite "b."

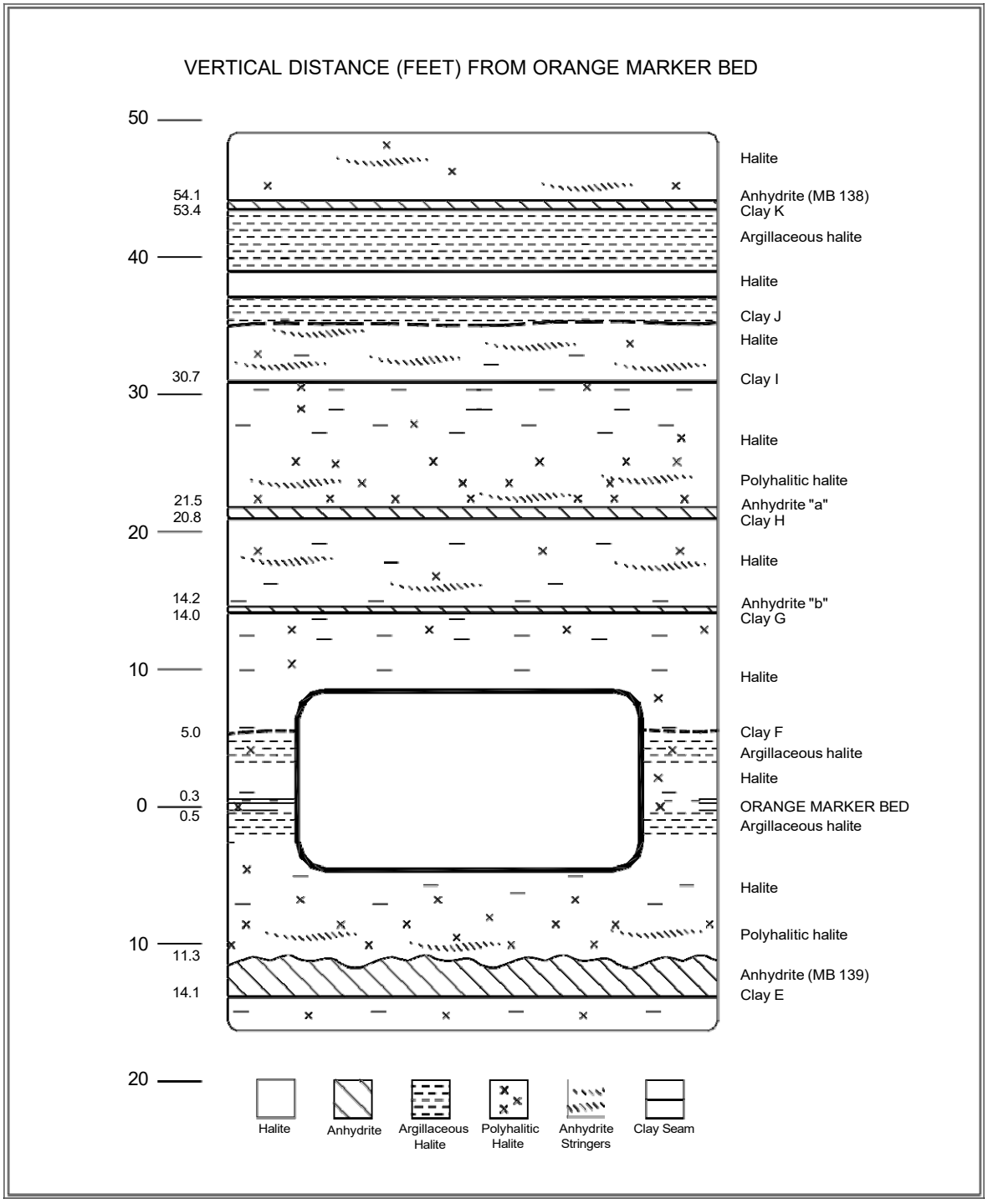

Figure 2-2 Repository Level Stratigraphy of Panels 1, 2, and 7

2.2.2 Disposal Horizon Stratigraphy of Panels 3, 4, 5, and 6

Field observations and computer modeling indicated that moving the disposal horizon stratigraphically upward (so that the roof was located at Clay G) would improve long-term ground conditions and provide a more stable roof configuration without significantly impacting repository performance. In 2000, the decision was made to implement this change by moving the mining horizon up approximately 6 ft. Subsequently, in 2000 and 2001, ramps were mined in the W-170, W-30, E-140, and E-300 drifts between S-2520 and S-2750 (Figure 1-2). As a result, the disposal horizon for Panels 3, 4, 5, and 6, and the associated connecting drifts, lies above the horizon for the other panels (Figure 2-3).

In this horizon, the OMB lies at or below the floor. MB139 lies about 12 ft below the floor. The roof lies at or slightly above Anhydrite "b." Clay G/Anhydrite "b" is used as the mining reference during excavation of this disposal horizon. Locally continuous anhydrite stringers are found within this horizon that extend to Clay H at Anhydrite “a,” generally concentrated in the lower portion toward Anhydrite "b." These effectively divide the roof beam itself into a series of thinner, independent beams, thereby weakening the overall beam strength.

2.2.3 Disposal Horizon Stratigraphy of Panel 8

Panel 8 was originally mined on the lower horizon, but due to the interruption in mining, which resulted in significant low angle shear and separation in the immediate back; it is now being mined to the upper horizon. Ramps are in place both in the intake and exhaust drifts (S1600 and S1950) west of W170.

Due to this change, Panel 8 has become a hybrid of the upper and lower horizon panels. The floor of Panel 8 lies two feet below the OMB to reduce floor heave and movement, while the back of the mine has been mined up to Clay G/Anhydrite “b” to increase the back stability.

2.2.4 Northeast Area Stratigraphy

The Northeast Area, formerly an experimental area, is now deactivated and closed for access. These excavations lie at a higher stratigraphic level than the disposal excavations. Floors are at Anhydrite "b." As in the lower units, the halite intervals between the clay seams/anhydrite beds contain relatively pure halite that becomes increasingly argillaceous upward. Above Clay I, two more halite intervals complete the underground facility stratigraphy. Clay J, at the top of the first of these intervals, may consist of a distinct seam or merely an argillaceous zone. Clay K tops the second interval and is overlain by MB138.

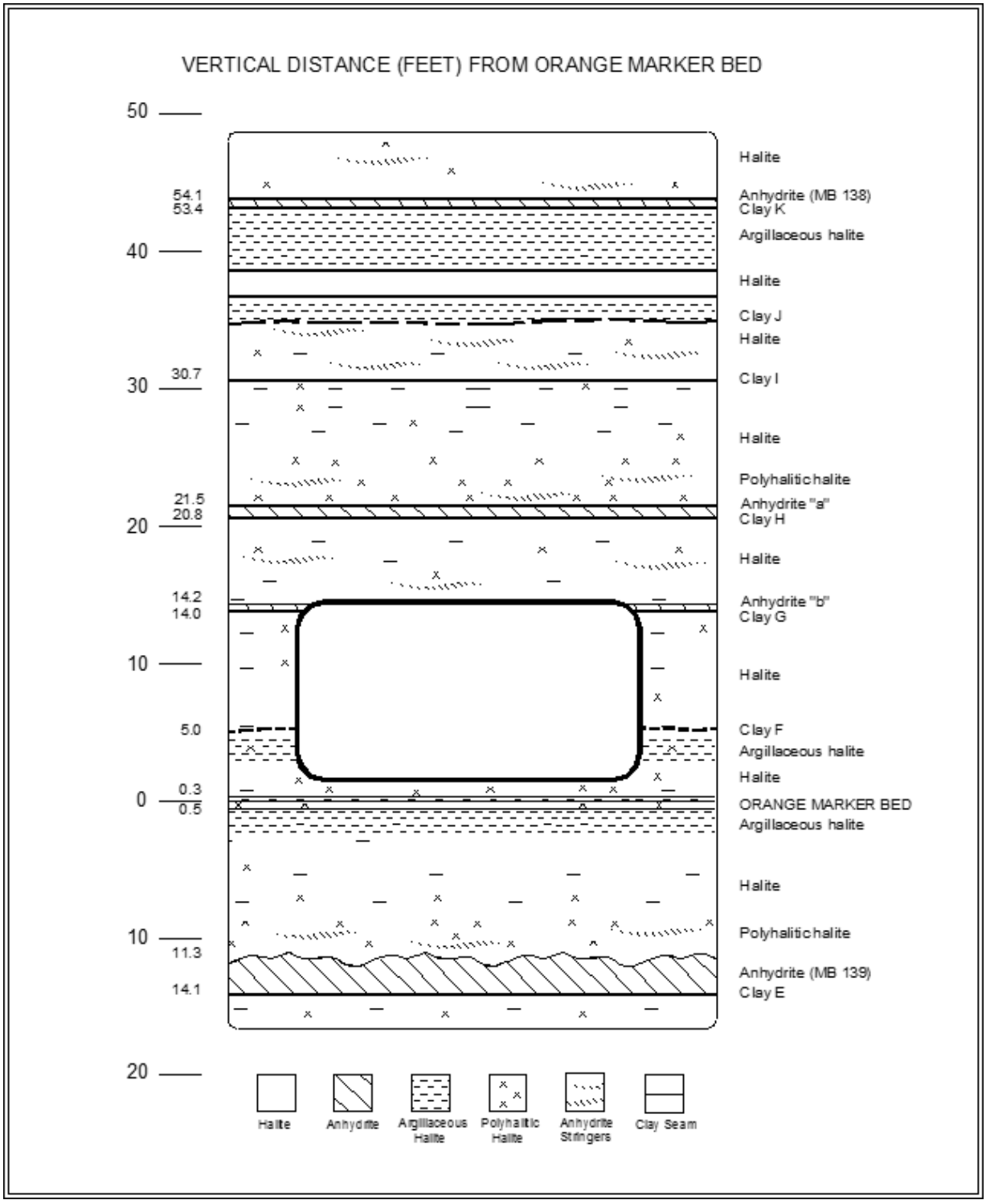

Figure 2-3 Repository Level Stratigraphy of Panels 3, 4, 5, and 6

3.0 PERFORMANCE OF SHAFTS AND KEYS

Four shafts connect the surface with the underground at the WIPP. They are the Salt Shaft, which is used primarily for removing excavated salt from the underground and for transporting personnel and materials; the Waste Shaft, which is used primarily for transporting TRU waste to the underground and for transporting personnel and materials; the Exhaust Shaft, which is used to exhaust the ventilation air from the underground; and the Air Intake Shaft, which is the primary source of fresh air ventilation to the underground. This section describes the geomechanical performance of these shafts.

Although much of the instrumentation installed in the shafts has failed through the years, there are no plans to replace it. The project has a good understanding of the expected movements in the shafts. Monitoring results up to the point of instrument failure did not indicate unusual shaft movements or displacements. Continued periodic visual inspections confirm the expected shaft performance and provide necessary observations to evaluate shaft performance. Replacement of failed instrumentation will not provide significant additional information.

3.1 Salt Shaft

The first construction activity undertaken by the SPDV Program was the excavation of the Exploratory Shaft. This shaft was subsequently referred to as the Construction and Salt Shaft, and is currently designated the Salt Shaft (see Figure 1-2). The shaft was drilled from July 4, to October 24, 1981, and geologically mapped in the spring of 1982 (DOE, 1983). Figure 3-1 presents the stratigraphy in the shaft.

The Salt Shaft is lined from the surface to 846 ft with steel casing having an inside diameter of 10 ft. The thickness of the steel liner (including external stiffener rings) increases from 0.62 in at the top to 1.5 in at the key. Cement grout was placed between the liner and the rock face. The 10-ft -diameter steel liner extends through the concrete shaft key to 880 ft. The shaft key is a 37.5-ft -long, reinforced concrete structure that begins 3.5 ft above the bottom of the steel liner. From the key to the bottom at 2,298 ft), the shaft has a nominal diameter of 12 ft.

Wire mesh anchored by rock bolts is installed in sections of the lower shaft as a safety screen to contain rock fragments that may become detached. The shaft extends approximately 140 ft below the repository horizon in order to accommodate the skip loading equipment and a sump.

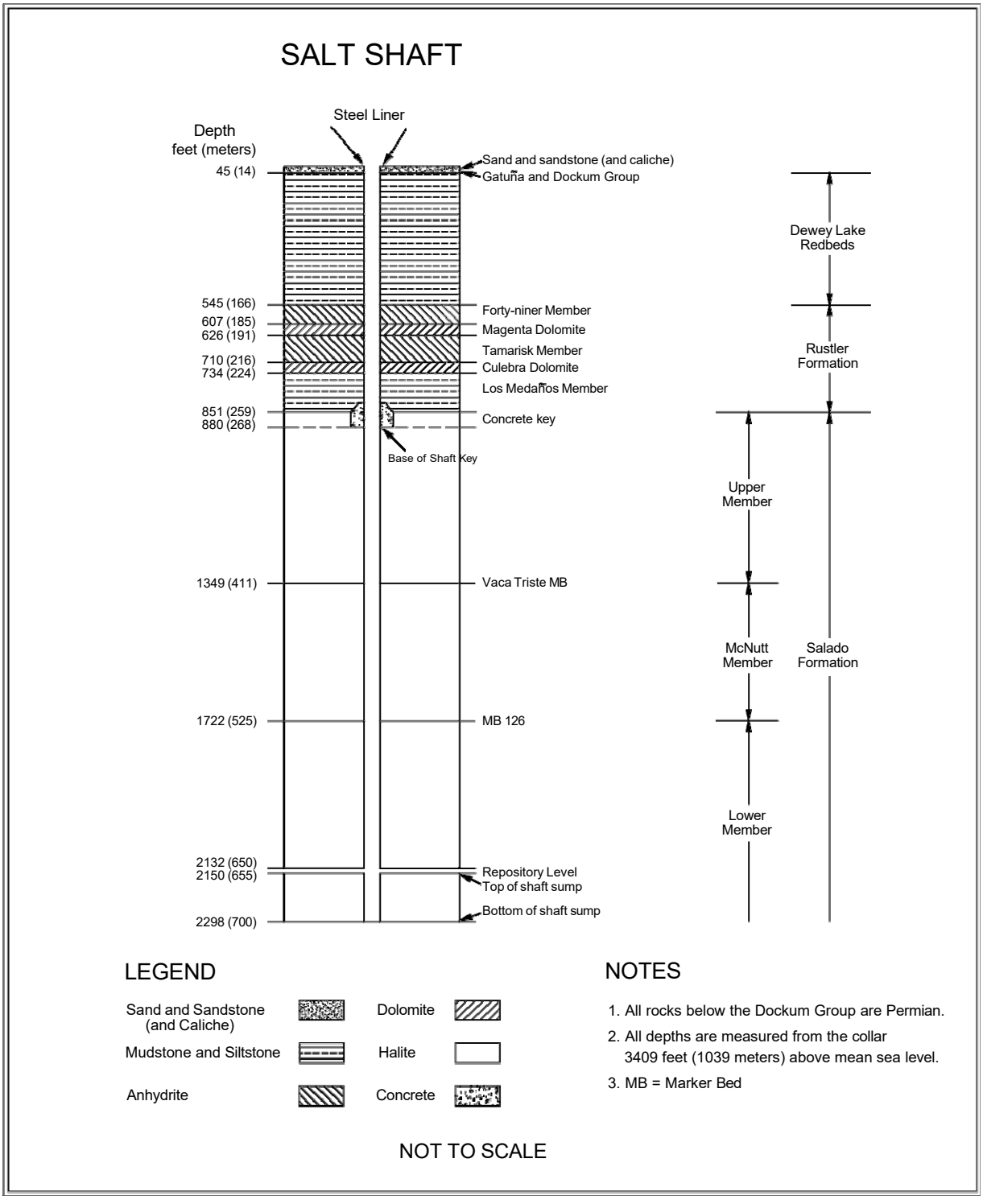

Figure 3-1 Salt Shaft Stratigraphy

3.1.1 Shaft Observations

Underground operations personnel conduct weekly visual inspections. These inspections are performed principally to assess the condition of the hoisting and mechanical systems, but they also include examining the shaft walls for water seepage, loose rock, or sloughing. Visual inspections during this reporting period found that the shaft remains in satisfactory condition. Only routine ground control activities were required.

3.1.2 Instrumentation

Geomechanical instruments (radial convergence points, extensometers, and piezometers) were installed at various levels in the shaft from April through July 1982 (Figures 3-2 and 3-3). Instruments in the shaft key included strain gauges, pressure cells, and piezometers. Radial convergence points were installed prior to outfitting. Upon completion of shaft outfitting, no more readings were taken.

Six piezometers continue to provide data. There were no readings for the previous reporting period due to a defective data logger. The data logger has been repaired and readings resumed 03/2021. Due to age related instrumentation degradation and unreliability in provided data, the array of piezometers in the salt shaft is considered a legacy system.

Four Earth pressure cells were installed in the key section during concrete emplacement at the 860-ft level. These instruments measure the normal stress between the concrete key and the Salado Formation as salt creep loads up the key structure. After readings resumed in 03/2021, one Earth pressure cell continues to provide data. This instrument indicates essentially no contact pressure since installation this is most likely due to improper installation.

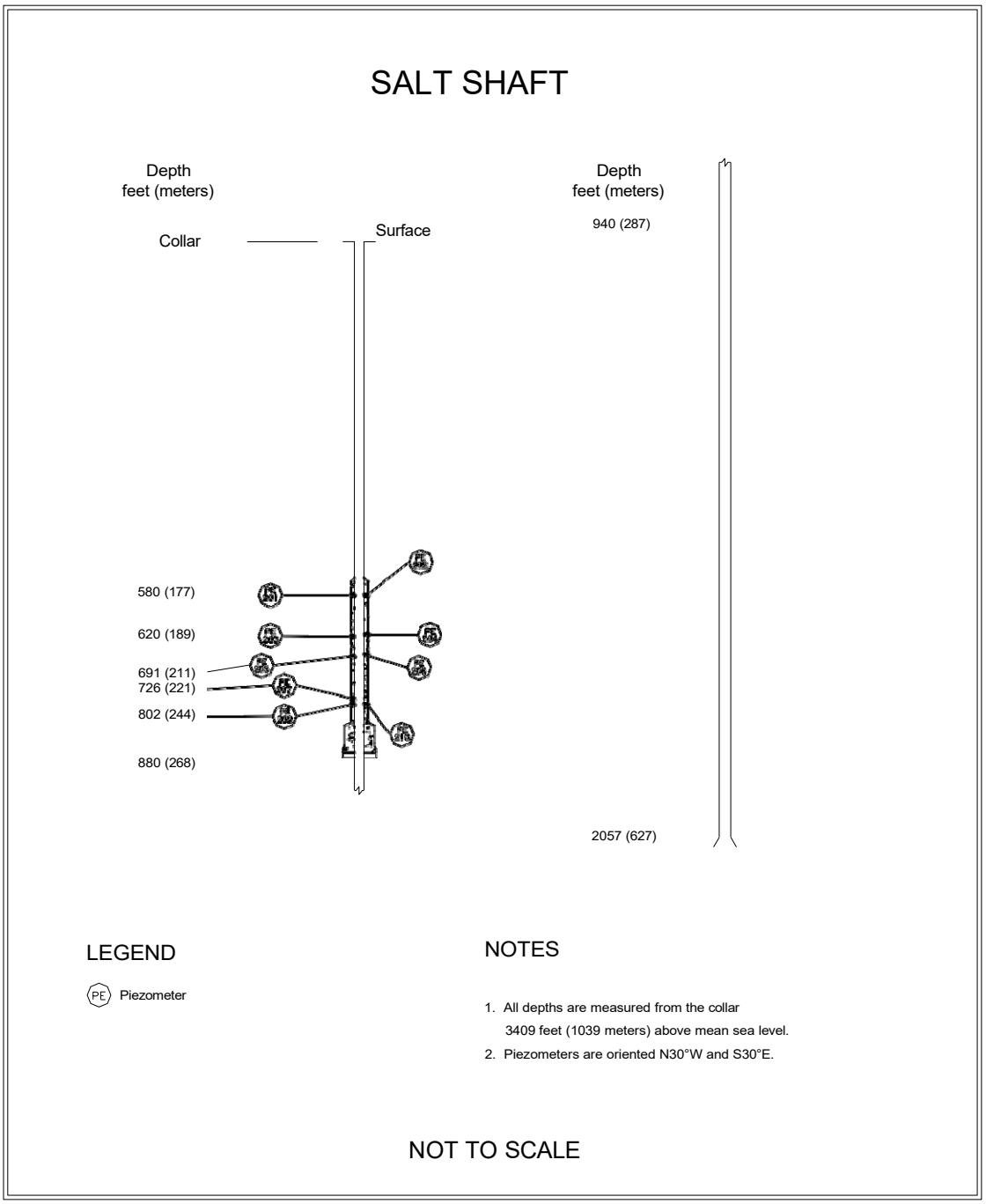

Figure 3-2 Salt Shaft Instrumentation

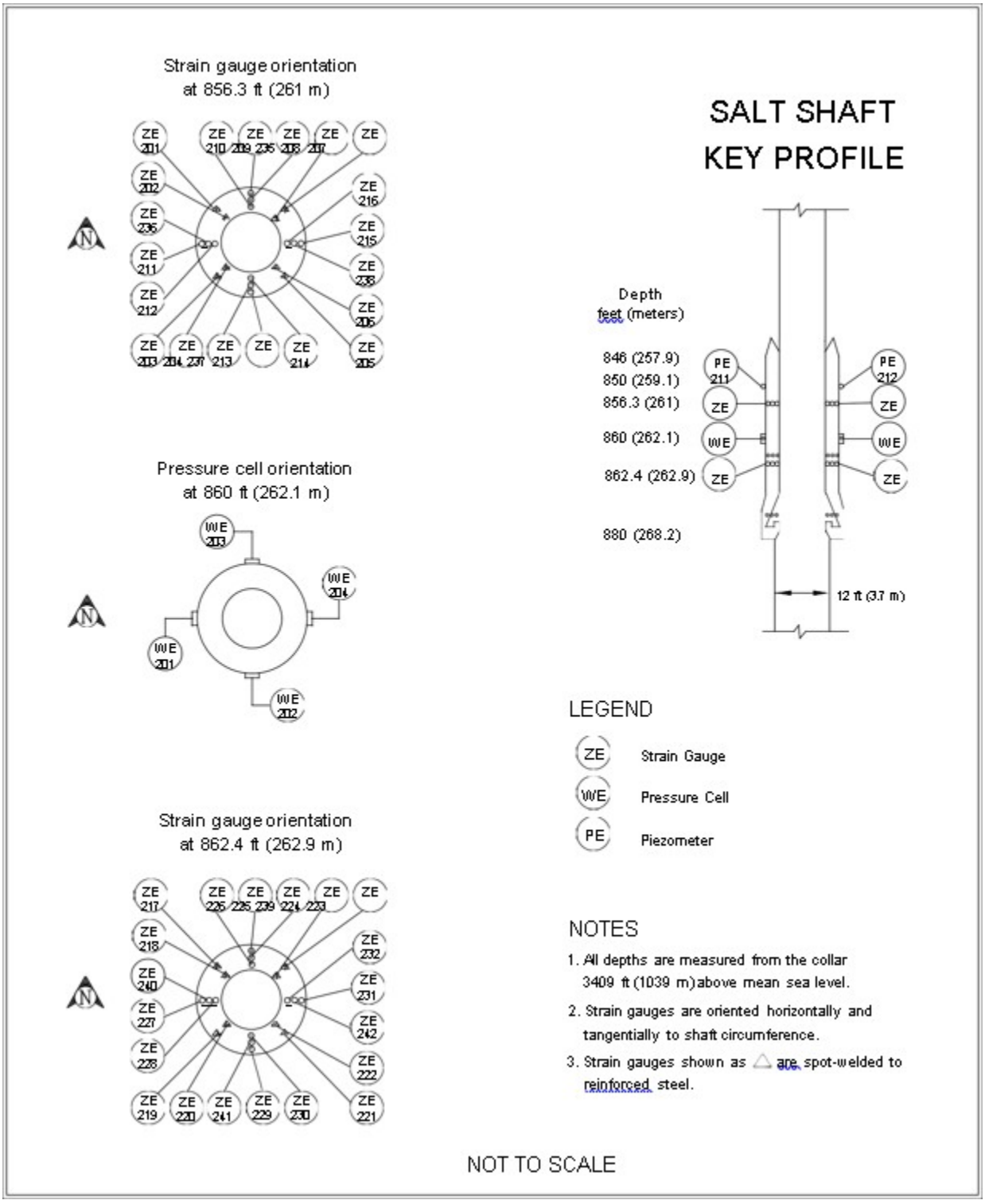

Figure 3-3 Salt Shaft Key Instrumentation

Sixteen spot-welded and 24 embedment strain gauges were installed on and in the shaft key concrete at both the 856.3-ft (261-m) level and at the 862.4-ft (263-m) level. One spot-welded strain gauge is still functioning at the 856.3-ft (261-m) level. The maximum strain this period is 663 microstrain and the maximum for the 2018-2019 reporting period was 677 microstrain.

Seventeen embedment strain gauges are still functioning. The strains at the 856.3-ft (261-m) level ranged from -637 to 953 microstrain. The strains from the 6 embedment strain gauges at the 862.4-ft (263-m) level were 41 to 908 microstrain. The strain recorded by the spot-welded strain gauge and the embedment strain gauges during this reporting period are similar to the strains recorded by these instruments at the end of the previous reporting period.

3.2 Waste Shaft

As part of the SPDV Program, a 6-ft (2-m)-diameter ventilation shaft, now referred to as the Waste Shaft, was excavated from December 1981 through February 1982 (see Figure 1-2). This shaft and the Salt Shaft created a two-shaft underground air circulation system. From October 11, 1983, to June 11, 1984, the shaft was enlarged to a diameter of 20 to 23 ft and lined above the key. Stratigraphic mapping (Figure 3-4) was conducted during shaft enlargement from December 9, 1983, to June 5, 1984 (Holt and Powers, 1984).

The Waste Shaft is lined with non-reinforced concrete having a 19-ft inside diameter from the surface to the top of the key at 837 ft. Liner thickness increases from 10 in at the surface to 20 in at the key. The key is 63 ft long and 4.25 ft thick, and is constructed of reinforced concrete. The bottom of the key is 900 ft key and increases to 23 ft just above the shaft station. The shaft below the key is lined with wire mesh anchored by rock bolts. The diameter of 23 ft extends to a depth of approximately 2,286 ft), with the shaft sump comprising the lower 119 ft of that interval.

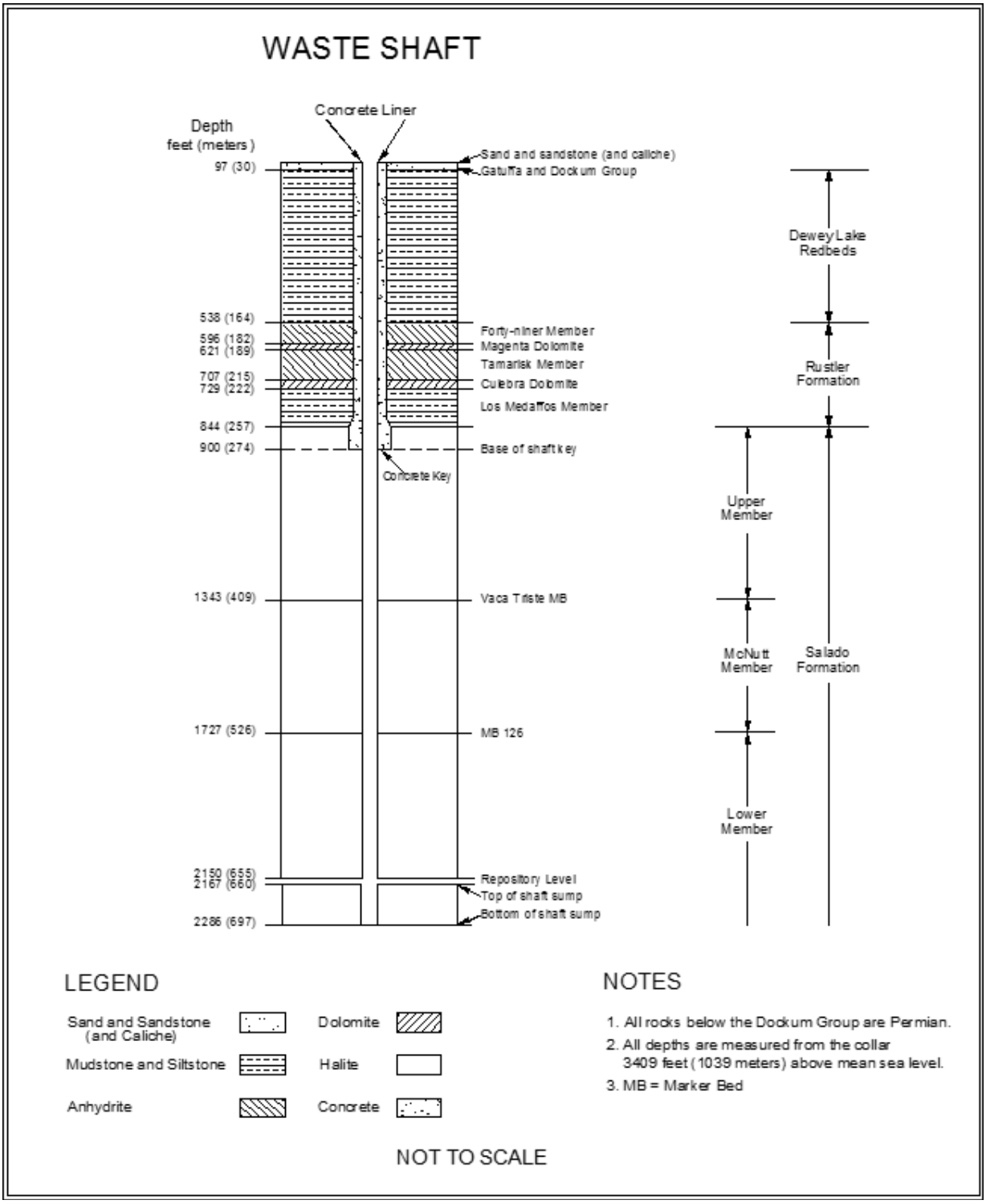

Figure 3-4 Waste Shaft Stratigraphy

3.2.1 Shaft Observations

Underground operations personnel conduct weekly visual inspections, principally to assess the condition of the hoisting and mechanical systems, but also to examine the shaft walls for water seepage, loose rock, or sloughing. The visual inspections found that the shaft was in satisfactory condition. No ground control activities other than routine maintenance were required.

3.2.2 Instrumentation

Radial convergence points, extensometers, piezometers, and earth pressure cells were installed in the Waste Shaft between August 27, and September 10, 1984. Radial convergence points were installed prior to the outfitting. Upon completion of shaft outfitting, no more radial convergence readings were taken. Figure 3-5 and Figure 3-6 show the instrument locations.

Nine multi-position extensometers were installed in arrays 1,071 ft, 1,566 ft, and 2,059 ft) below the surface, as shown in Figure 3-5. Each array consists of three extensometers. No extensometer data have been collected in recent years due to the malfunction of the data acquisition equipment. Since the extensometer type installed in the shaft over 30 years ago is no longer manufactured, remote data acquisition equipment for these extensometers is also unavailable.

Twelve piezometers were installed in the lined section of the Waste Shaft on September 7 and 8, 1984, to monitor fluid pressure behind the shaft liner and the key section. As of this reporting period, data is no longer being received from any of the piezometers.

Four earth pressure cells were installed in the key section of the Waste Shaft during concrete emplacement, which occurred between March 23, and April 3, 1984. Earth pressure cells measure the normal stress between the concrete key and the Salado Formation as salt creep loads the key structure. As of this reporting period, data is no longer being received from any of the Earth pressure cells.

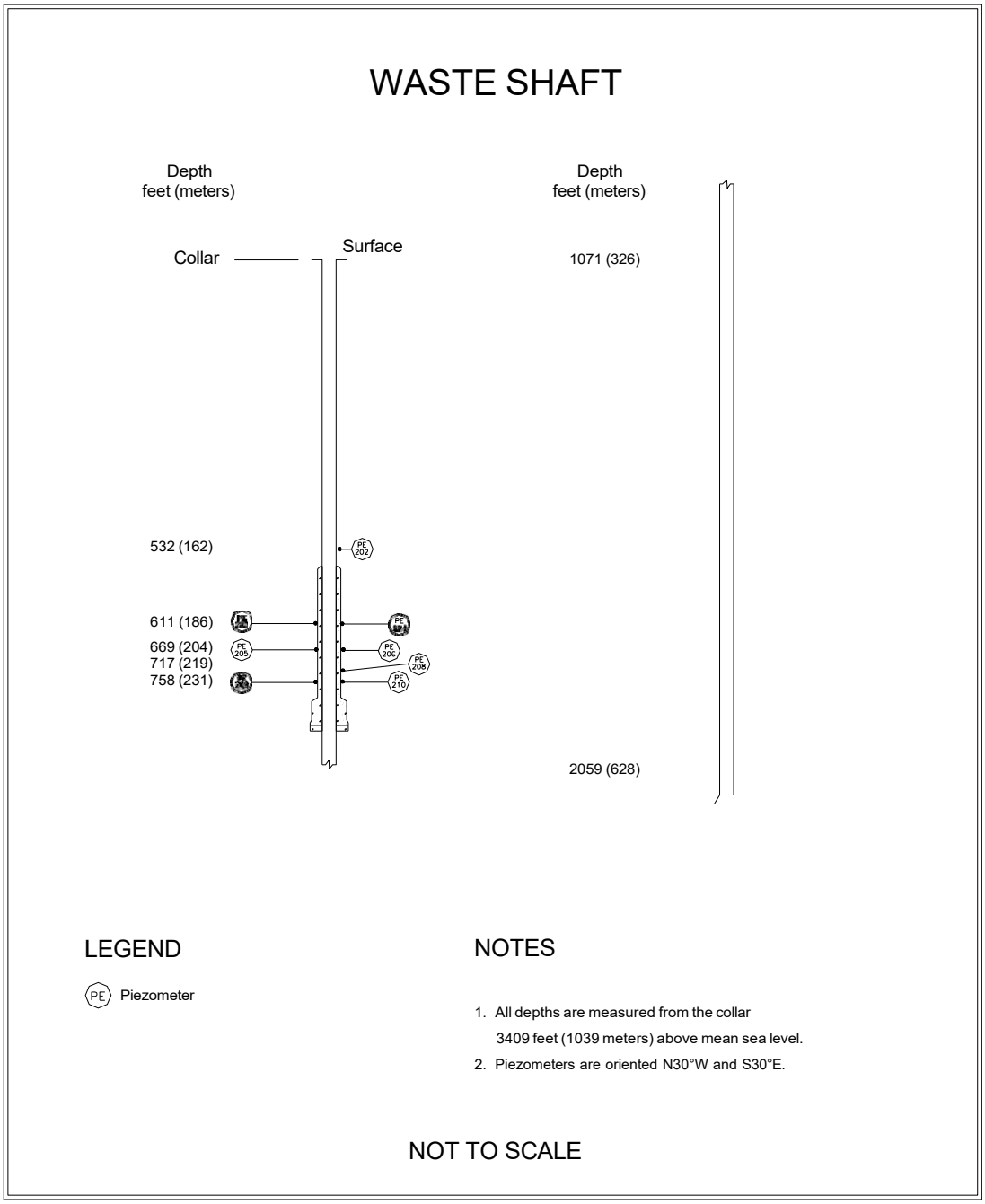

Figure 3-5 Waste Shaft Instrumentation

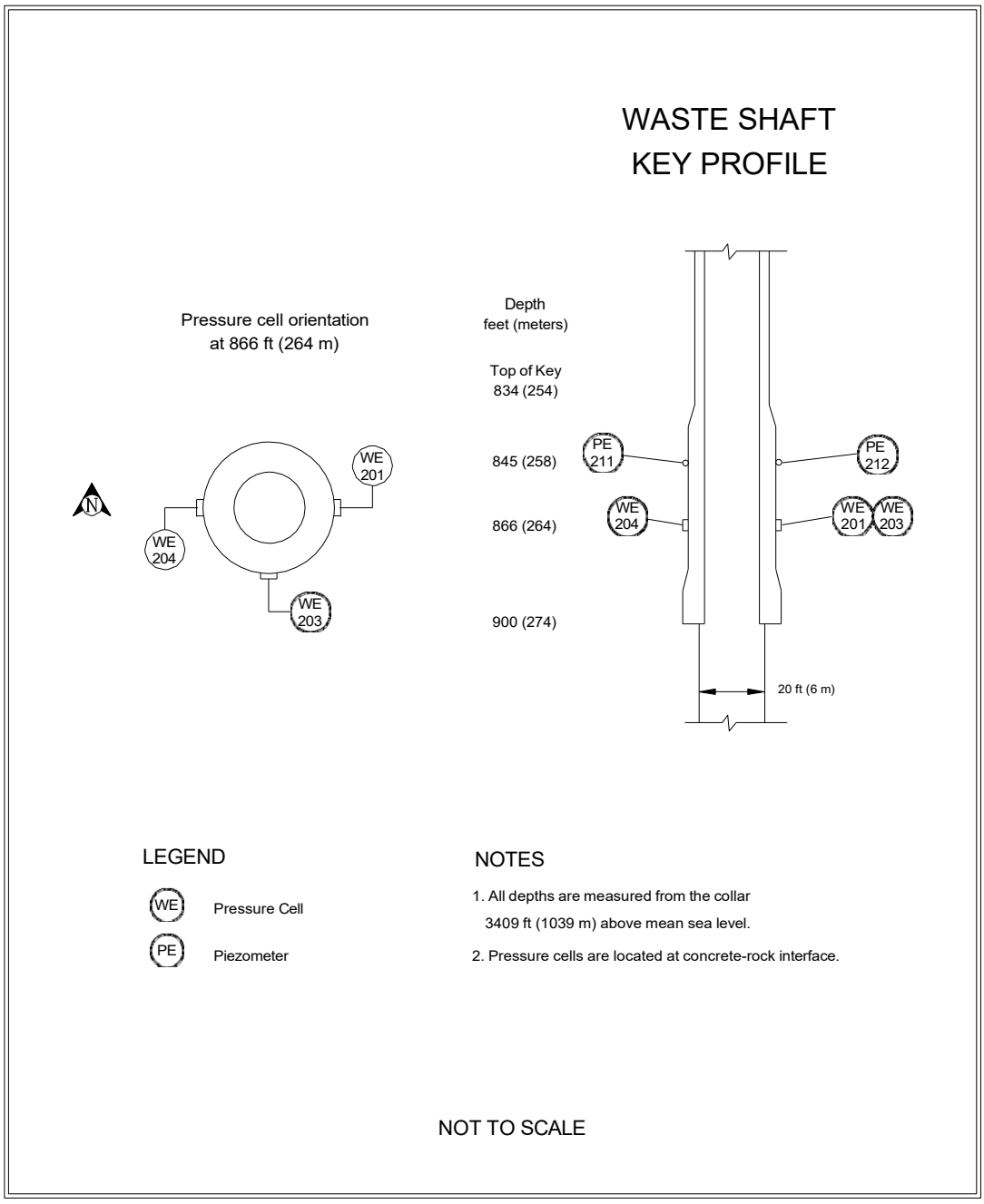

Figure 3-6 Waste Shaft Key Instrumentation

3.3 Exhaust Shaft

The Exhaust Shaft was drilled from September 22, 1983, to November 29, 1984, to establish a route from the underground to the surface for exhaust air (Figure 1-2). Stratigraphic mapping was conducted from July 16, 1984, to January 18, 1985 (DOE, 1986). Figure 3-7 illustrates the shaft stratigraphy.

The Exhaust Shaft is lined with non-reinforced concrete from the surface to the top of the shaft key at 844 ft. The liner thickness increases from 10 to 16 in over that interval. The key is 63 ft) long and 3.5 ft thick. The shaft diameter below the key is 15 ft, and the interval below the key is lined with wire mesh anchored by rock bolts. The shaft terminates at the facility horizon, approximately 2,150 ft deep. This shaft has no sump.

3.3.1 Quarterly Exhaust Shaft Inspection

Quarterly video inspections of the Exhaust Shaft are conducted according to approved WIPP procedures. Inspections are performed to evaluate the condition and to verify the integrity of the shaft. The shaft is examined for cracks, corrosion, salt buildup, seeps, and debris. In addition, inspections examine the condition of anchors, brackets, and down-hole equipment. Exhaust Shaft video inspections were performed this reporting period in September 2020, October 2020, March 2021, and May 2021.

3.3.1.1 Video Camera

Video inspections use a custom-designed, vertical-drop color camera in an aerodynamic housing, with pan, tilt, and zoom capability. The camera is suspended by a dual-armored cable. The cable contains five copper conductors and two multi-mode optical fibers. It is reeled out by a winch mounted in a control trailer. Inspections are recorded electronically.

3.3.1.2 Shaft Inspection Observations

Quarterly video inspection observations concentrate on four major areas: air-monitoring components, shaft liner, shaft walls, and equipment support and cabling. The air-monitoring components consist of one tube that provides a conduit for air-velocity measurements, and three tubes for monitoring possible radionuclides within the exhaust air stream, as shown in Figure 3-8. The video inspection includes examination of each device, including the transport assembly, guide tubes, the sample intake, and the support brackets that extend from Station "A" above the shaft to the shaft collar. Air-monitoring components extend from the collar 21 ft into the shaft. Video inspections indicate that the air-sampling components can accumulate salt buildup of up to several inches thick.

The Exhaust Shaft liner is examined for cracks, seepage, and general shaft stability. Currently, there are three principal zones of seepage in the shaft. The first is about 50 to 55 ft below the shaft collar (bsc), the second is about 60 to 65 ft bsc, and the third is about 80 to 85 ft bsc, as shown in Figure 3-9. Monitoring of seepage horizons started before 1995. Water entering the shaft through these cracks is believed to originate from a perched-shallow-water-bearing horizon at the base of the Santa Rosa Formation. The fluid level in the Santa Rosa near the shaft is about 48 to 49 ft below the surface. Based on examination of inspection videos, the flow rate into the shaft has been estimated to be about 1 to 1½ gallons per minute. Seepage cracks are confined primarily to the eastern side of the shaft wall. It has been observed that flow of seepage varies seasonally.

When fluid was detected seeping into the shaft, a catch basin was designed and installed at the base of the Exhaust Shaft to intercept water and prevent it from draining into the Waste Shaft sump. Fluid was removed from the catch basin from March 1996 through October 2005, as needed. The catch basin was damaged in 2004 by fallen debris, either salt or instrumentation cables or both. A new catch basin was fabricated and installed in December 2004. This basin was damaged in August 2005, most likely the result of fallen debris. An interception well system was installed between November 2005 and March 2006 to replace the catch basin. Interception wells were drilled down gradient in S-400 between E-140 and E-300 (Figure 3-10). The interception well system initially consisted of four 30-ft-deep 9-7/8-in-diameter fluid collection holes with a submersible pump and pressure transducer in each. Fluid was pumped from each hole to a series of storage containers in S-550. A data-acquisition system monitors the fluid level in each hole, turning the pump on and off between set limits, as needed.

Between February 2, and 6, 2008, two additional fluid collection holes, OH631 and OH632, were drilled in S-400 to improve the total volume of fluid recovered by the interception well system. They replaced OH613 and OH614, which generated little fluid. As with the previous four holes, the additional holes were drilled at 9-7/8-in diameter to a total depth of 30 ft. Pumps were pulled from OH613 and OH614 and installed in OH631 and OH632. Figure 3-10 shows the location of the interception well system.

The catch basin and the interception well system collected fluid from July 1997 through June 2006 and from July 2006 through June 2016, respectively. The largest reported volumes are typically associated with periods of reduced ventilation and increased humidity. For a discussion of the factors affecting the quantity of fluid produced in the Exhaust Shaft, refer to DOE/WIPP-00-2000, *Brine Generation Study* (DOE, 2000).

No fluid has been collected by the system since June 2016. The reason for this is the S550 location, which was the location of the three water interception 500-gallon storage tanks and associated equipment was deemed a safe-haven location, that is, two safe-havens were to be located in S550 alcove. Work commenced in August 2016 to dismantle the water interception equipment in S550 and install the equipment in the smaller S300 alcove. Due to space constraints, the three 500-gallon tanks were replace with two 250-gallon tanks. This work continued until November 2016. The Mining and

Geotechnical Engineering (M&GE) section were the designers, installers and technical overseers of the water-interception system from the inception. In November 2016, with almost all of the reinstallation complete, all work on the reinstallation and startup of the relocated system was suspended due to serious, and somewhat prolonged ground control issues in Panel 7. Since August 2022 a restart of the system is being worked. A work order, procurements, and an Engineering Change Notice have been prepared and submitted. Due to additional personnel within the M&GE section, it is anticipated this work can continue essentially uninterrupted with respect to manpower.

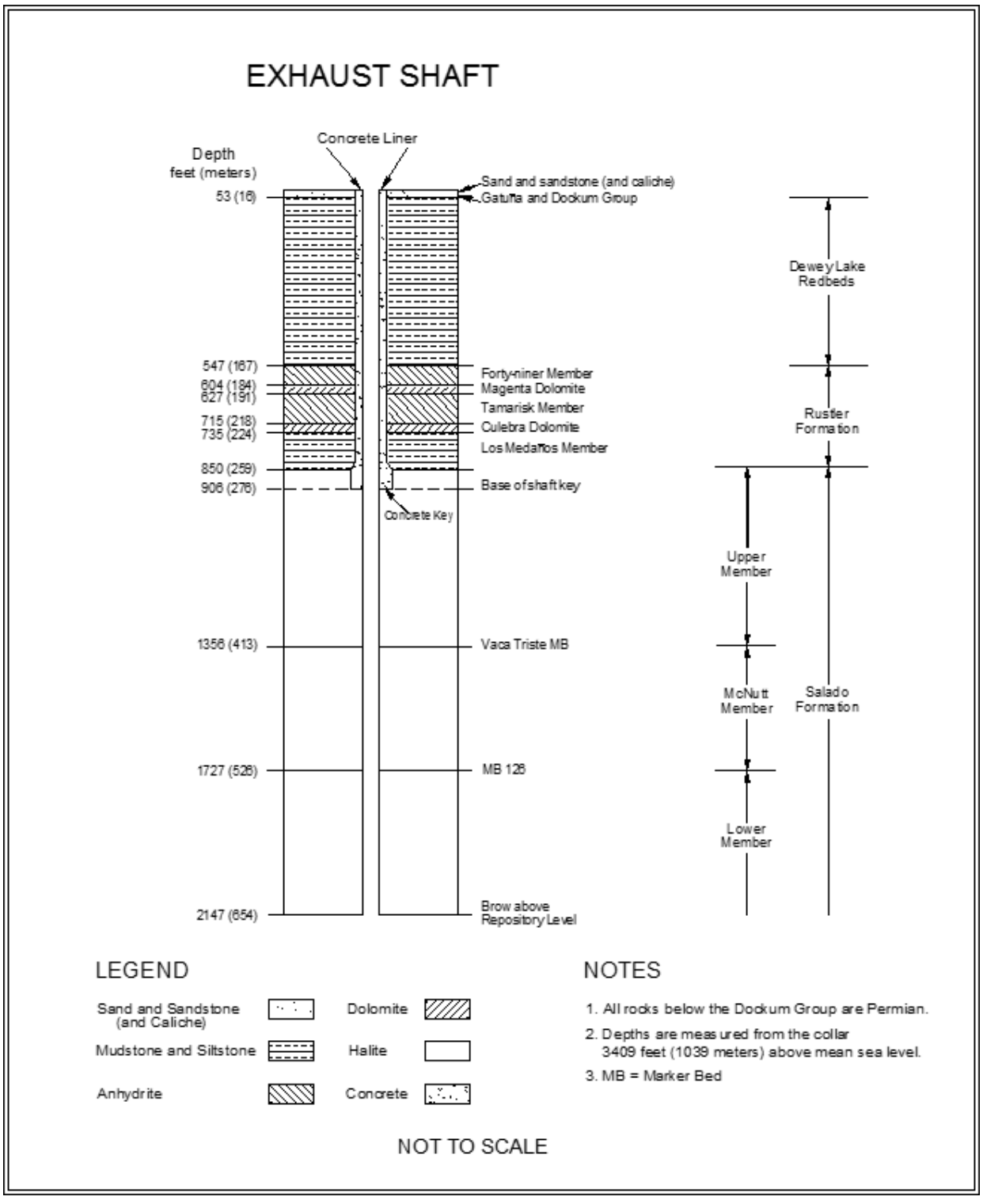

Figure 3-7 Exhaust Shaft Stratigraphy

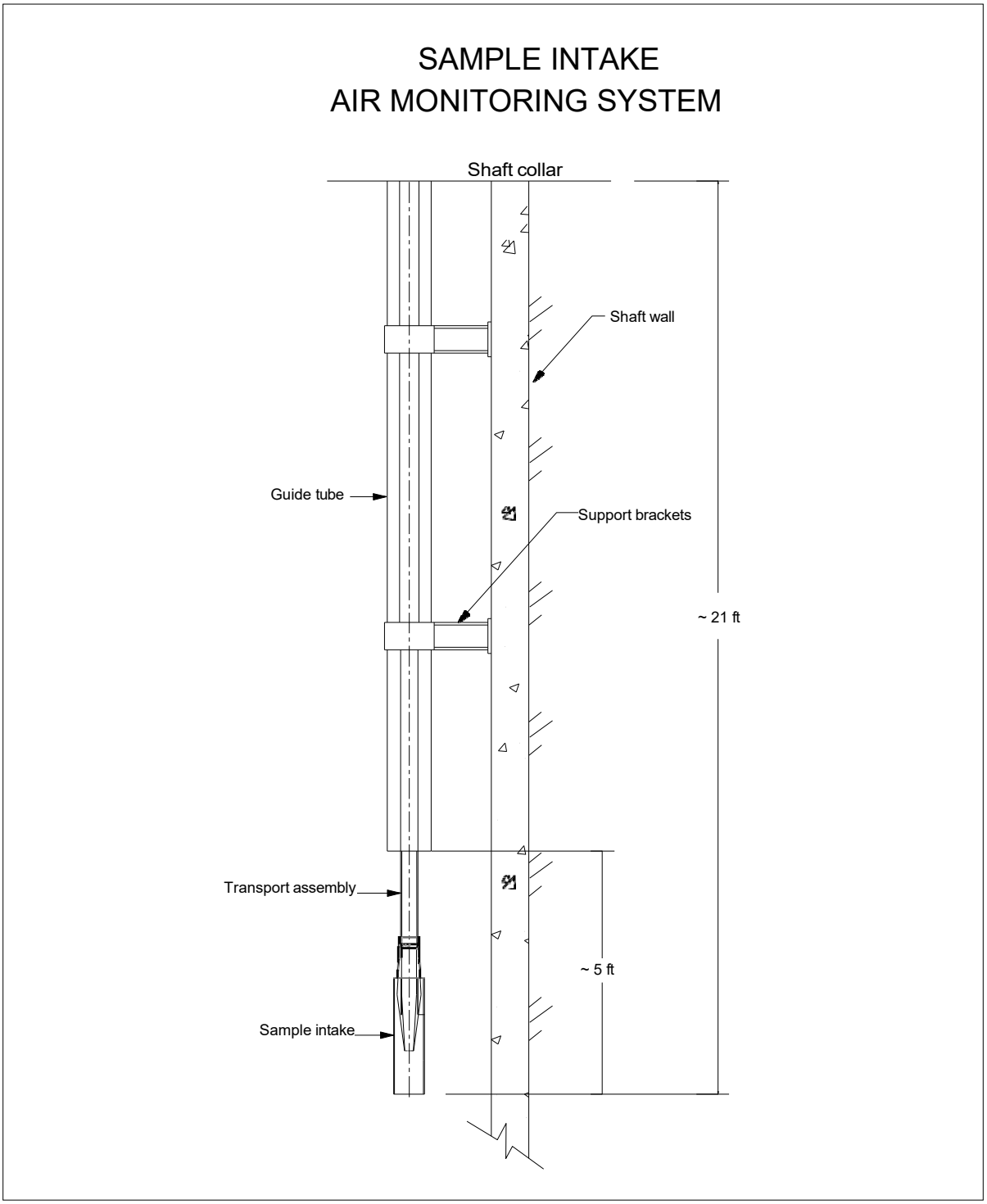

Figure 3-8 Sample Intake of Exhaust Shaft Air Monitoring System

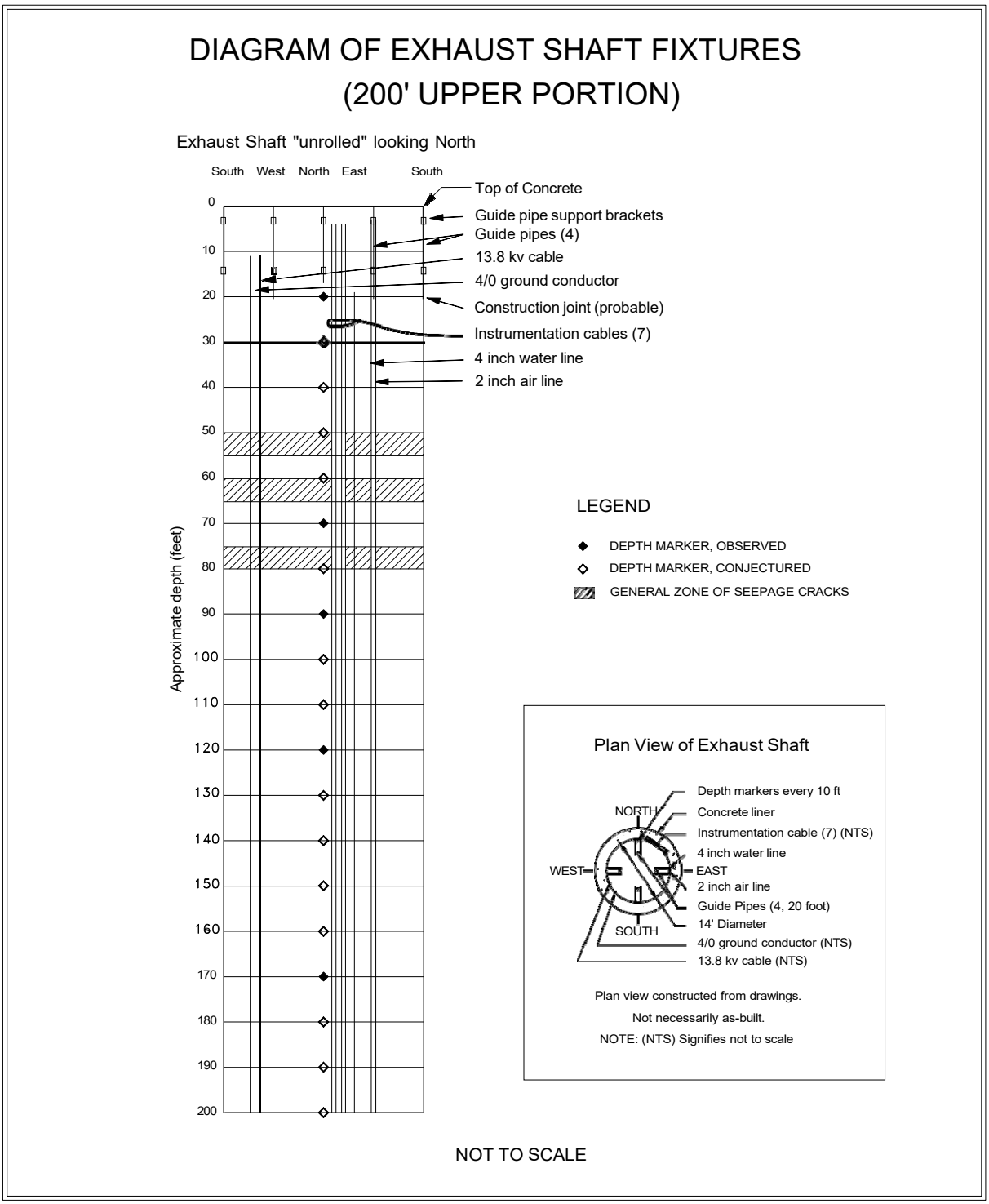

Figure 3-9 Diagram of Exhaust Shaft Fixtures and Seepage Zones (Upper 200 ft)

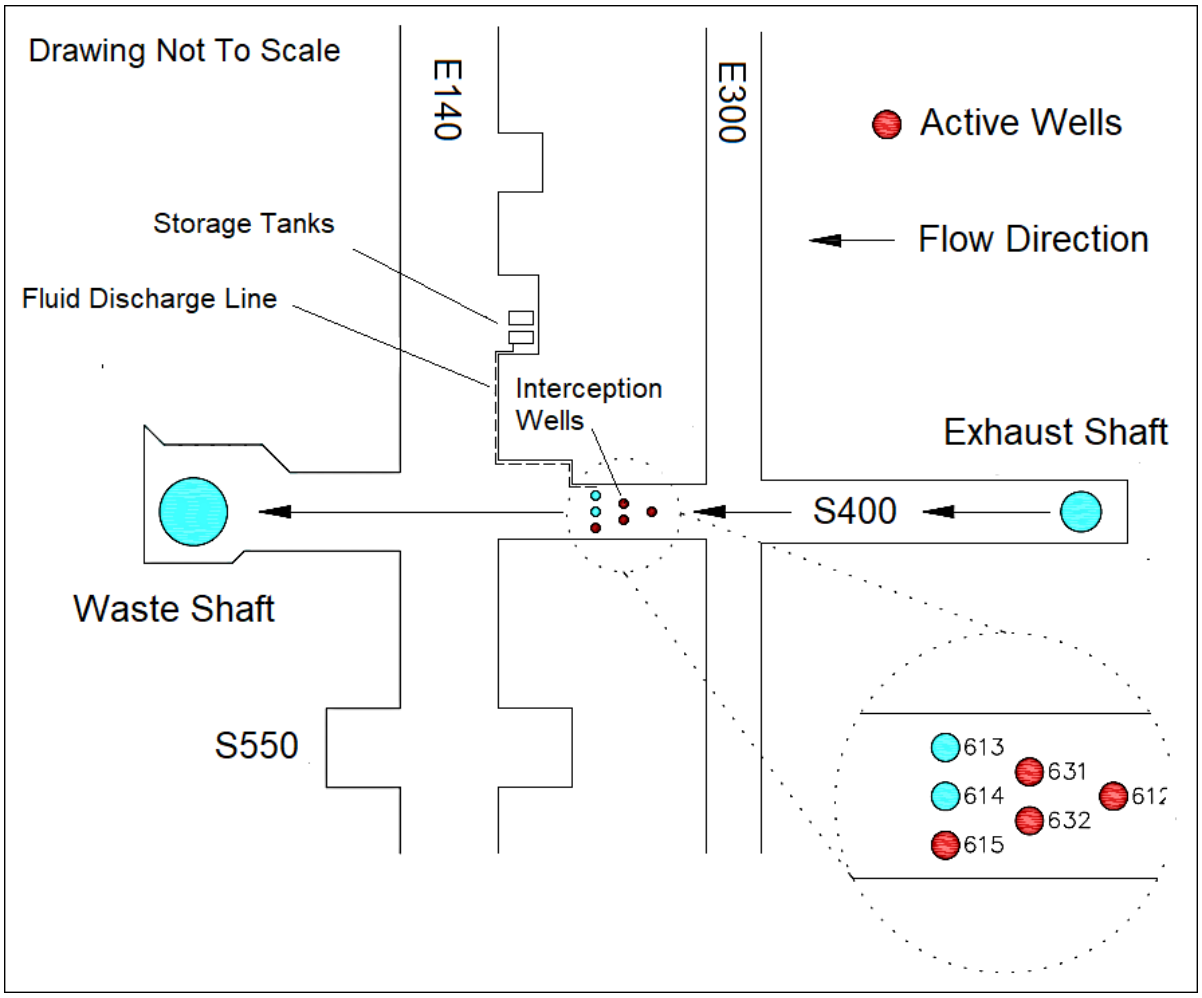

Figure 3-10 Location of Interception Wells and Storage Tanks

The shaft walls were examined for salt buildup, cracks, moisture, and encrustations, with particular attention paid to power cables, instrument cables, air and water lines, and the three water rings occurring at the base of the Magenta and Culebra members of the Rustler Formation and at the bottom of the shaft key. The condition of the shaft wall with respect to salt buildup varies depending on airflow, humidity, temperature, and underground mining activities. The shaft conditions for this reporting period largely mirror the conditions during the previous reporting period. There were no significant changes in the thickness of the salt in the shaft plenum, ranging from zero to several feet thick. The principle seepage in the shaft liner this period was located at about 60-65 ft and 80-85 ft bsc. At the same time, there continues to be an increase in the buildup of salt along the shaft walls in the form of stalactites in the lower portion of the shaft.

Similar to previous inspections, sporadic salt buildup continues on the remaining cables in the shaft. The long-term implication of salt buildup is increased loading on cables and cable hangers, accompanied by intermittent falls of debris. The 4-in compressed air line and the 2-in water line extend from the surface to the bottom of the shaft. At present, neither line is being used. The integrity of the brackets holding the air and

water lines continues to be essentially impossible to assess because of salt buildup. Many instrumentation cables and much of the abandoned 13.8 kilovolt ampere(s) (kVA) power cables have broken off and fallen to the base of the shaft. There are no visible signs of dissolution of the salt below the key.

3.3.2 Instrumentation

The Exhaust Shaft was equipped with geomechanical instrumentation in two stages. Earth pressure cells were installed behind the liner key in November 1984. Piezometers and nine multi-position extensometers were installed during November and December 1985. Figure 3-11 and Figure 3-12 show the instrument locations. None of these instruments currently provide data. Due to inaccessibility to the inside of the shaft, the failed instrumentation and associated cabling cannot be replaced.

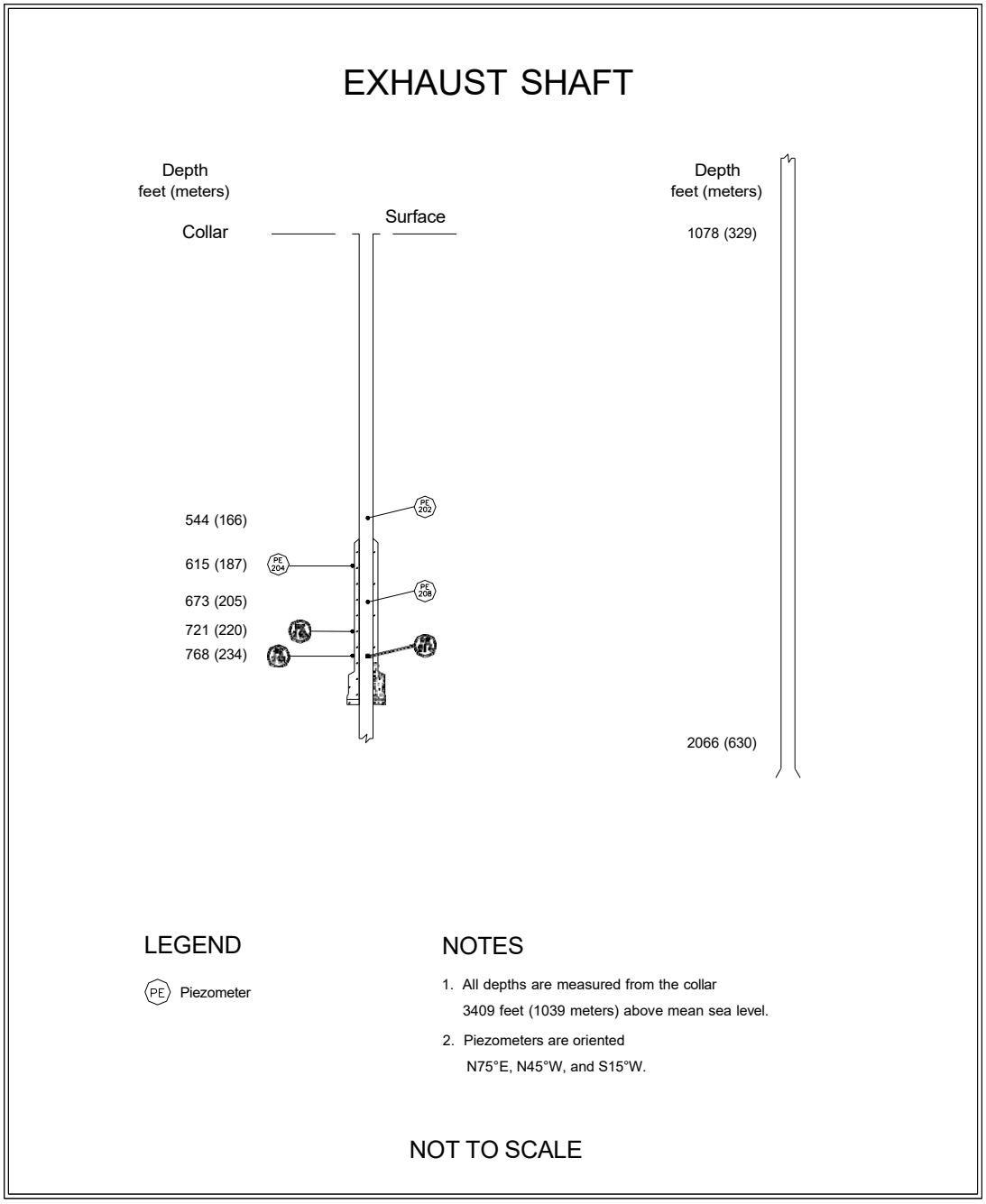

Figure 3-11 Exhaust Shaft Instrumentation

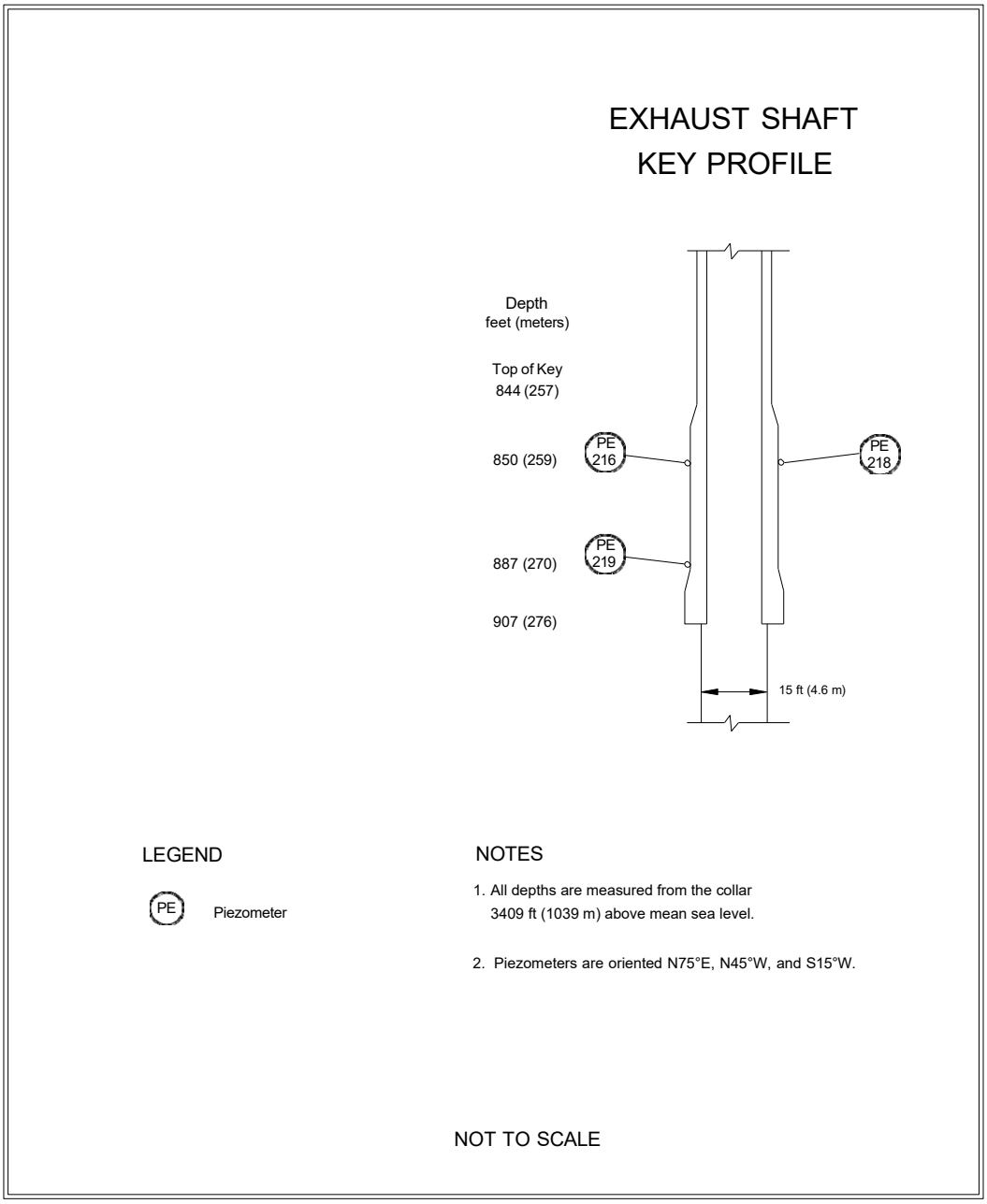

Figure 3-12 Exhaust Shaft Key Instrumentation

3.4 Air Intake Shaft

The Air Intake Shaft was drilled from December 4, 1987, to August 31, 1988, to establish a primary route for surface air to enter the repository (see Figure 1-2). The stratigraphy was mapped from September 14, 1988, to November 14, 1989 (Holt and Powers, 1990). Figure 3-14 summarizes the shaft stratigraphy.

The Air Intake Shaft is lined with non-reinforced concrete from the surface to the bottom of the shaft key at 903 ft. The key is 81ft long with an inside diameter of 16 ft. The shaft diameter below the key is 20 ft, and the shaft below the key is unlined to the facility horizon at 2,150 ft. The shaft walls are bolted and meshed from just below the key all the way down to the shaft station. This shaft has no sump.

3.4.1 Shaft Performance

Weekly visual inspections were performed on the Air Intake Shaft during this reporting period, and the shaft was found to be in satisfactory condition. No ground control activities other than routine maintenance were required during this reporting period.

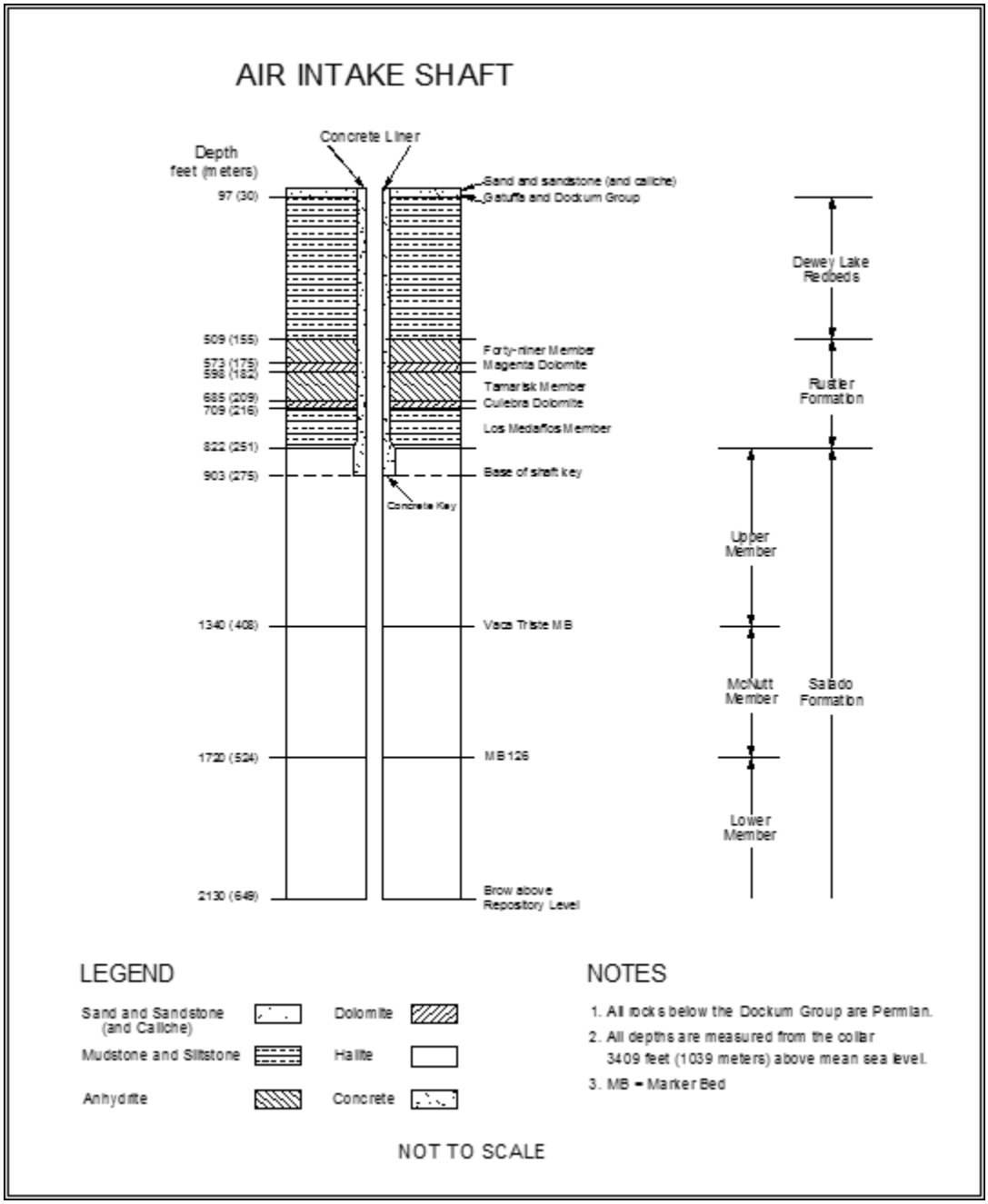

Figure 3-13 Air Intake Shaft Stratigraphy

4.0 PERFORMANCE OF SHAFT STATIONS

This section describes the instrumentation and geomechanical performance of the shaft stations at the base of the Salt Shaft, the Waste Shaft, and the Air Intake Shaft. The Exhaust Shaft does not have an enlarged shaft station; therefore, it is not included in this section.

4.1 Salt Shaft Station

The Salt Shaft Station was excavated by drilling and blasting between May 2, and June 3, 1982. In 1987, the station was enlarged by removing the roof beam up to Anhydrite "b" between S-90 and N-20 using a mechanical scaler. In 1995, the remaining roof beam at the north end of the station was also removed up to Anhydrite "b." The station area south of the shaft is 90 ft long and 32 to 38 ft wide. The height of the station south of the shaft is 18 ft. The station dimensions north of the shaft are approximately 30 ft long, 32 to 35 ft wide, and 18 ft high. The shaft extends approximately 140 ft below the facility horizon to accommodate the skip loading equipment and a sump. Figure 4-1 shows a cross section of the station.

4.1.1 Modifications to Excavation and Ground Control Activities

The Salt Shaft Station was not modified during this reporting period. Ground control activities were limited to routine maintenance.

4.1.2 Instrumentation

Geomechanical instrumentation was installed in the Salt Shaft Station between June 1982 and February 1983, with subsequent re-installation of extensometers and convergence points, as necessary. Figure 4-2 shows the instrument locations after the roof beam was taken down.

Four vertical convergence points are currently monitored. Table 4-1 summarizes the vertical closure rates in the Salt Shaft Station from July 2020 through June 2021. The closure rates for this reporting period are slightly higher than the rates for the previous reporting period.

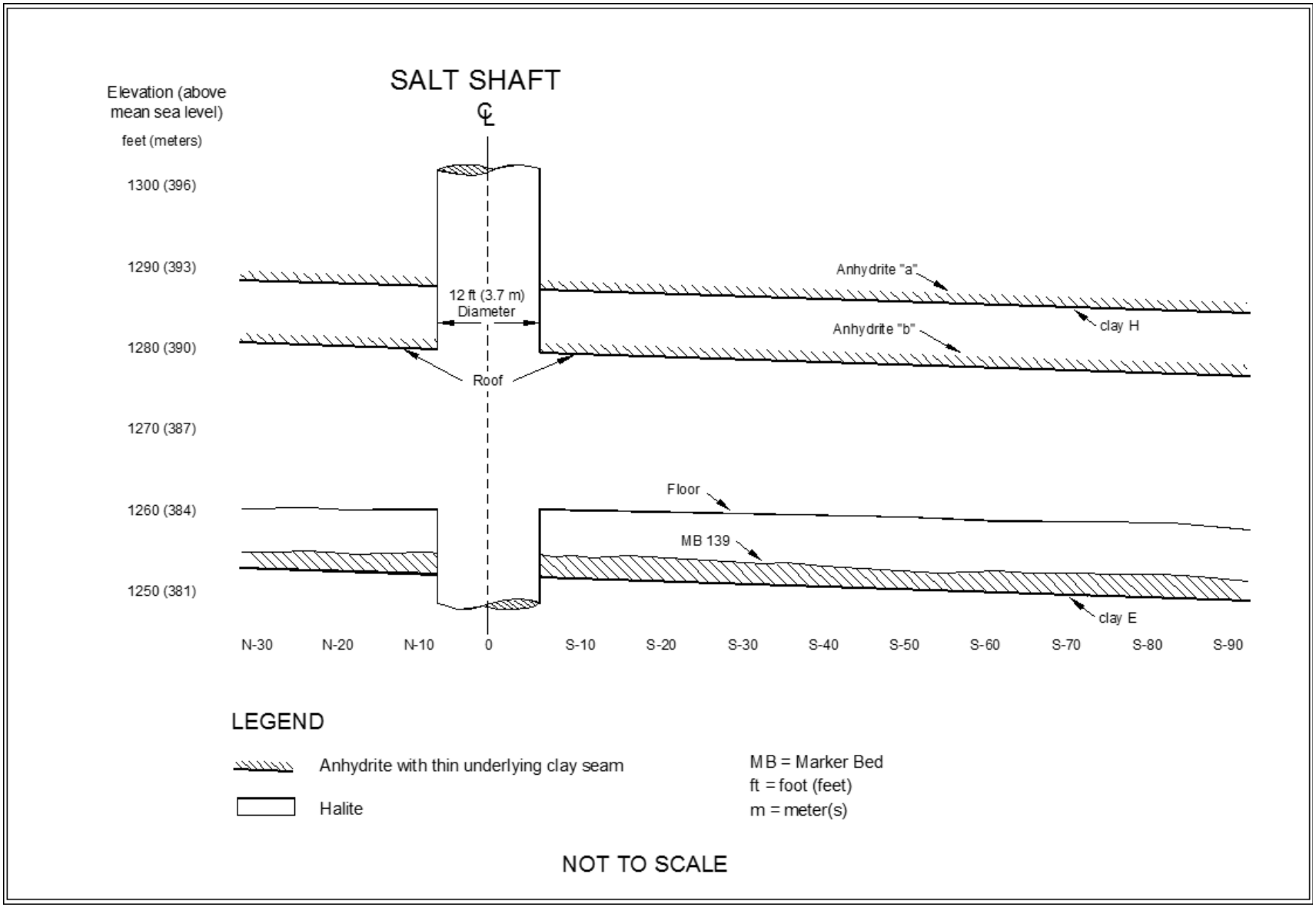

Figure 4-1 Salt Shaft Station Stratigraphy

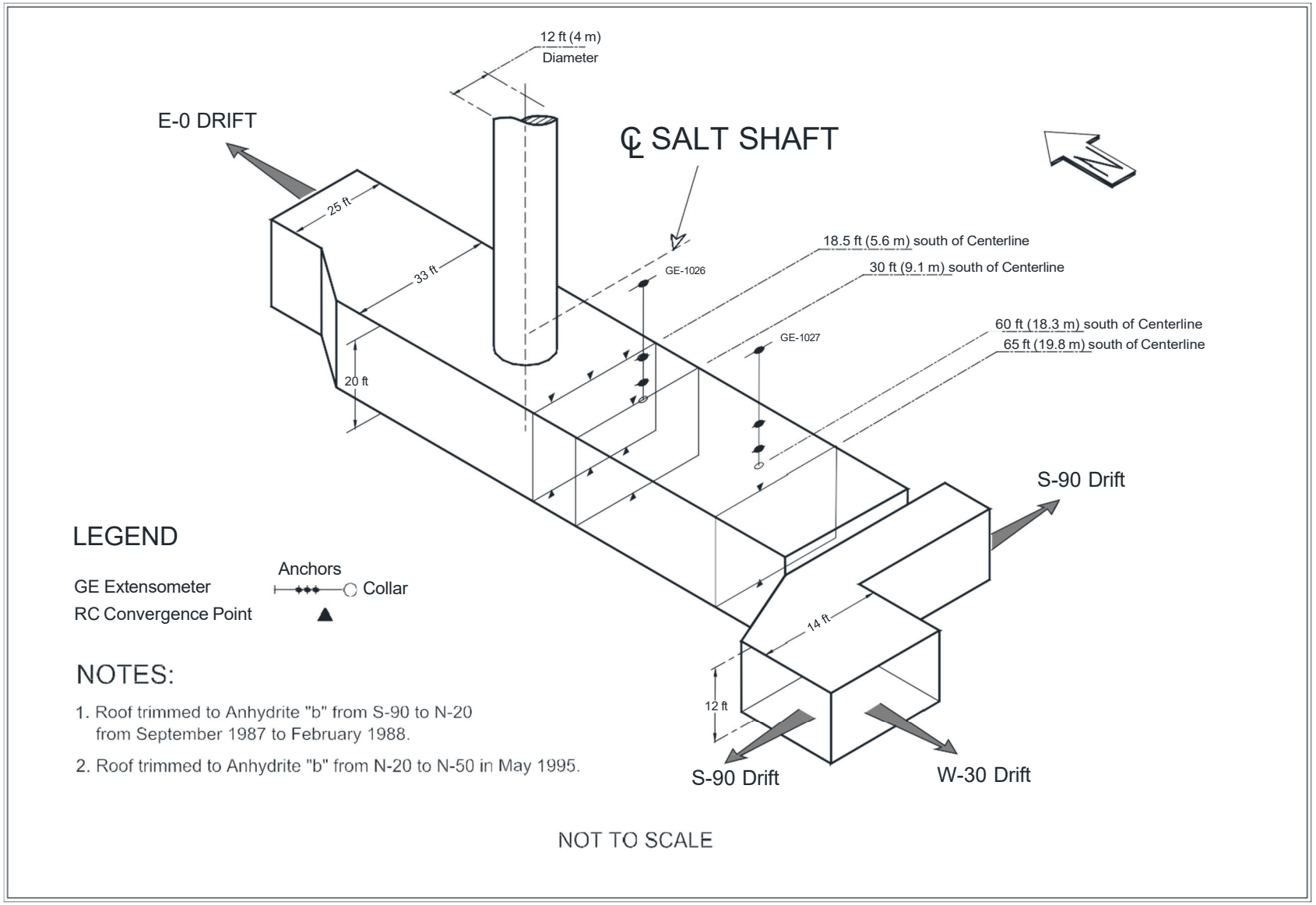

Figure 4-2 Salt Shaft Station Instrumentation After Roof Beam Excavation

Location	Chord[4]	Last Reading	Total Cumulative Displacement (in)	Closure Rate 2020-2021 (in/yr)	Closure Rate 2019-2020 (in/yr))	Rate Change (%)
E0-S18	A-E	06/15/21	54.836	2.2	1.9	16
E0-S18	B-D	06/15/21	40.442	2.6	2.4	8
E0-S18	H-F	10/08/20	24.002	1.4	1.1	27
E0-S30	A-C	06/15/21	38.124	2.1	2.0	5
E0-S65	A-C	06/15/21	26.066	1.4	1.2	17

Table 4-1 Closure Rates in the Salt Shaft Station

4.2 Waste Shaft Station

The Waste Shaft Station was initially excavated with a continuous miner in November 1982 to serve as a ventilation connection to a 6-ft-diameter exhaust shaft. In 1984, the station was enlarged to a height of 15 to 20 ft and a width of 20 to 30 ft. The station is approximately 150 ft long. In 1988, the station walls were trimmed, and concrete was placed on the floor. Since 1988, the Waste Shaft Station has undergone five major floor renovations. A 53-ft long section of the reinforced concrete was removed in February 1991. In 1995, an additional 30-ft section of concrete was removed. In 2000, floor maintenance included trimming of the floor and reinstallation of the rails supported by segmented concrete panels on a crushed rock backfill. The roof of the Waste Shaft Station was mined up to Clay G in December 2008 to assure adequate operational clearance. Chain link fencing and 12-ft resin-anchored roof bolts were installed for ground support. Figure 4-3 shows a cross section of the Waste Shaft Station stratigraphy.

4.2.1 Modifications to Excavation and Ground Control Activities

No modifications to the Waste Shaft Station were made during this reporting period. Ground control activities were limited to routine maintenance.

[4] Chord is defined in Section 5.2 and illustrated in Figure 5-1.

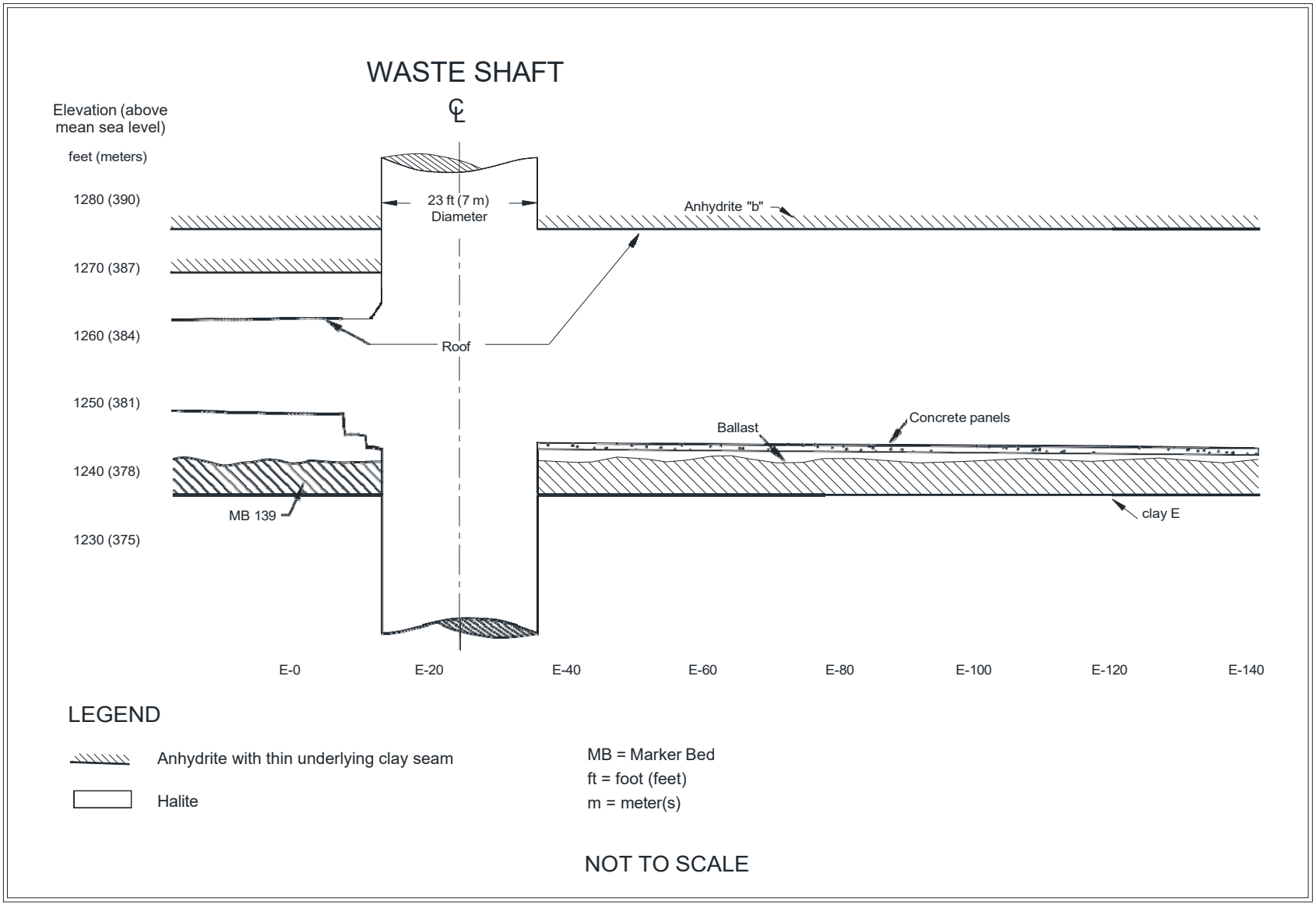

Figure 4-3 Waste Shaft Station Stratigraphy

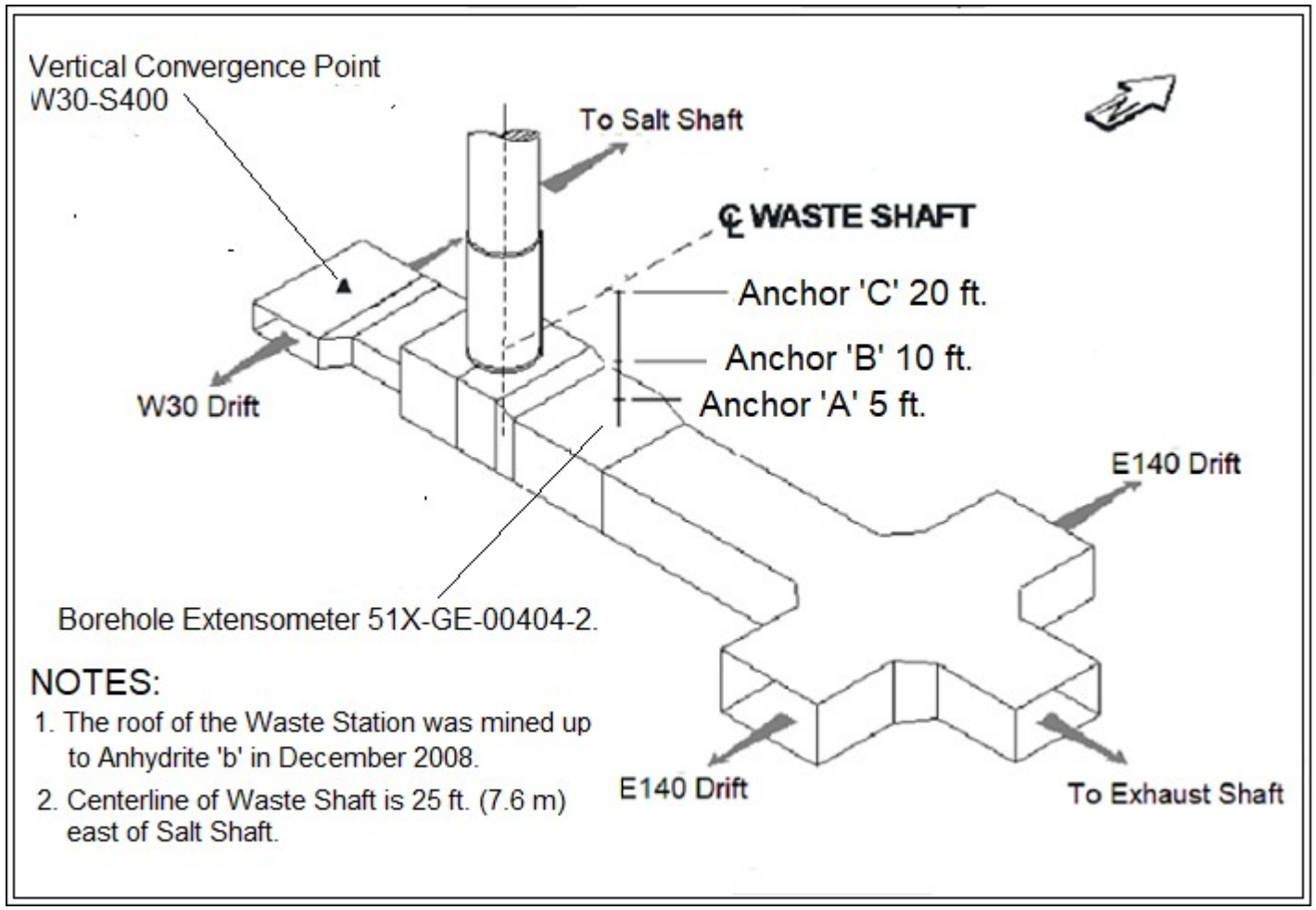

Figure 4-4 Waste Shaft Station Instrumentation

4.2.2 Instrumentation

The Waste Shaft Station geomechanical instrumentation, as depicted in Figure 4-4, consists of a vertical convergence point in W30-S400 and a borehole extensometer east of the Waste Shaft at S400-E35. The convergence rate this reporting period was 1.0 in/yr. The beam expansion rate as measured by the extensometer was 0.3 in/yr. The data are representative of a very stable back.

4.3 Air Intake Shaft Station

The Air Intake Shaft Station was excavated in late 1987 and early 1988, using a continuous miner. The Air Intake Shaft is furnished with a work platform and a small cage that can be raised and lowered to perform routine ground maintenance. The principal purpose of the cage is to provide emergency ingress and egress.

4.3.1 Modifications to Excavation and Ground Control Activities

The Air Intake Shaft Station was not modified during this reporting period. Ground control activities were limited to routine maintenance.

4.3.2 Instrumentation

Radial convergence point and extensometer instrumentation data near the Air Intake Shaft Station are presented in Section 5.0 as part of the discussion on the performance of the access drifts.

5.0 PERFORMANCE OF ACCESS DRIFTS

This section describes the geomechanical performance of the underground access drifts. The Waste Disposal Area is discussed in Section 6.0 and the Salt Disposal Investigation areas are discussed in Section 7.0. Four major north-south drifts in the WIPP underground are intersected by shorter east-west cross-drifts. Drift dimensions range from 13 ft to 21 ft (high, and from14 ft to 33 ft wide.

5.1 Modifications to Excavation and Ground Control Activities

Floor trimming and rock bolting were performed during this reporting period. Table 5-1 summarizes these activities.

Location	Work Activity
E0 Salt Shaft Station	Installed 14 ft. resin anchored roof bolt pattern
E0 drift from N150 to N460	Installed 4 ft. mechanical bolts in ribs
E0 N150-N1400	Replaced broken 14 ft. resin anchored roof bolts
E140 from N150 to N920	Replaced broken 14 ft. resin anchored roof bolts
E140 drift from N920 to N1100	Replaced broken 14 ft. resin anchored roof bolts
E140 drift from N1200 to N1300	Replaced broken 14 ft. resin anchored roof bolts
E140 from S400-S700	Replaced broken 14 ft. resin anchored bolts
E140 drift from S700-S2520	Replaced broken 14 ft. resin anchored roof bolts
E140 S1300-S2520	Installed Cable Slings
N1400 drift between E0 and E300	Installed 14 ft. resin anchored roof bolts
N460 North and East Alcoves	Replaced broken 14 ft. resin anchored roof bolts
S90/Switch Station 1	Installed 14 ft. resin anchored roof bolts
S2520 drift from E140 to W170	Replaced broken 14 ft. resin anchored roof bolts
S400 drift from W30 to Waste Shaft Station	Installed 14 ft. resin anchored roof bolts
S2520 W170	Rib bolting with 4 ft. mechanical bolts
S1600 W30-E140	Replaced broken 14 ft. resin anchored roof bolts
S1600 drift from W30 to W170	Replaced broken 14 ft. resin anchored roof bolts
W30 from S1300 to S1000	Installed 14 ft. resin anchored roof bolts
W30 drift from S1300 to S1950	Replaced broken 14 ft. resin anchored roof bolts
W170 from S1600 to S1950	Replaced broken 14 ft. resin anchored roof bolts
W170 from S1950 to S2180	Replaced broken 14 ft. resin anchored roof bolts
AIS	Installed chain-link mesh and 4 ft. mechanical bolts
AIS (N215 & N300)	Replaced broken 14 ft. resin anchored roof bolts
Maintenance Shop	Rib bolting with 10 ft. and 4 ft. mechanical bolts
Maintenance Shop	Replaced broken 14 ft. resin anchored roof bolts
Mine Wide	Drilled 20 ft. Observation Holes
Panel 7	Replaced broken 14 ft. resin anchored roof bolts
Panel 7	Installed 4 ft. mechanical bolts
Panel 8	Installed chain-link and 4 ft. mechanical bolts
Panel 8	Installed 6 ft. resin anchored roof bolt pattern
Salt Station	Installed 14. ft. resin anchored roof bolts and 10 ft. mechanical bolts
SDI	Installed mechanical bolts on ribs and corners
Waste Station	6 ft. resin anchored roof bolts and 4 ft. mechanical bolts

Table 5-1 Summary of Modifications and Ground Control Activities in the Access

Drifts: July 1, 2020, to June 30, 2021

5.2 Instrumentation

This section discusses instrumentation details in the access drifts.

5.2.1 Extensometers

Sixteen extensometers continue to be monitored at various locations in the access drifts. Where displacement data were available, annual displacement rates were calculated (see Section 1.4.3) for each active installation and compared to the annual displacement rates from the previous reporting period (see Table 4-1 in the 2020-2021 Supporting Data document (Vol 2). Extensometer data are obtained by measuring the displacement from the reference head anchor (collar) to each fixed anchor of the extensometer. These measurements are scheduled to be made at least monthly throughout the WIPP underground. Many of the E-140 extensometers indicate movement in the roof beam that may be attributed to shallow fracturing and the effects of anhydrite stringer separations in the roof. Lateral deformation in the roof beam may influence the extensometer readings, causing an increase in the measured displacement. Although the extensometer data indicate continued deformation and breakup of the lower beam, borehole logging indicates the roof bolt anchorage zone remains competent.

5.2.2 Convergence Points

Convergence point data are obtained by measuring the change in distance between fixed points anchored into the rock across an opening, either from rib to rib or from roof to floor. The measurement end-points constitute a "chord." Figure 5-1 shows typical convergence point array configurations along with typical chord designations.

Convergence points are routinely installed following new mining and in areas where ground maintenance has been performed and previously installed convergence points have been removed. A listing of convergence point installations performed in the access drifts during this reporting period are shown in Table 5-2, Convergence Point Installations in the Access Drifts: July 1, 2020, to June 30, 2021.

Where possible, annual closure rates were calculated from convergence point array data gathered in the access drifts. During this reporting period the active convergence points in the underground were distributed as follows: 187 convergence points in the access drifts, 14 accessible convergence points in Panel 7, and 48 convergence points in the Panel 8. A complete tabulation of the accessible convergence point data and calculated closure rates is presented in the supporting data document for this report (Vol 2).

Locations with increases in annual vertical closure rates of greater than 20 percent are shown in Table 5-3, Vertical Closure Rate Changes in Excess of Twenty Percent in the Access Drifts.

5.3 Analysis of Convergence Point and Extensometer Data

The 187 convergence points for this period had a roof-to-floor closure range of 0.3 to 5.9 in/yr, mean rate of 2.2 in/yr, and a standard deviation of 1.1. Statistically high standard deviation in access drift convergence rates is caused by wide ranging excavation variables such as drift dimension, age, horizon level, etc.

Vertical loading on mine pillars results in lateral stresses on the roof and floor beams. The composition of those beams, in part, determines how these structures will react to the horizontal stresses. In particular, horizontally continuous anhydrite stringers (see Section 2.2.2) divide the beam itself into a series of smaller independent beams.

Lateral strain on the beam imposed by vertical loading on the pillars is accommodated by vertical displacement over the mined opening. This requires that the horizontally oriented beam separate along the most favorable, or weakest, planes.

Where anhydrite stringers interpose the beam, they constitute a plane of weakness, and delamination occurs. The material is confined in the plane above, so that the roof accommodates the lateral strain by bending convex into the mined opening.

Two distinct results develop from this action. First, voids form within the beam as the portions closer to the opening move away from those deeper within the beam. Second, the convex portion of the bended plane is subjected to tensile loading perpendicular to the axis of the drift and superficial tears known as "tensile fractures" develop generally parallel to the axis of the drift.

Where anhydrite stringers are small and discontinuous or absent within the beam, horizontal loading is accommodated along shear planes. These develop at angles of approximately 35 degrees with respect to the horizontal. In some cases, a plane develops preferentially on one side of the drift, and the bulk of material is pushed into the mined opening on that side. This may be thought of as a cantilevered beam.

Whatever mechanism is used, vertical displacement into the mined opening is measured by convergence monitoring. Convergence points consider the displacement between two opposing surfaces: either the roof and floor or the two ribs. Extensometers consider the displacement between one surface (usually the back) and one or more points within the beam. Where a convergence point and an extensometer are adjacent to one another, it is possible to determine the individual displacements of both floor and roof beams.

These data are used to analyze the stability and mechanics of the beam, and to determine what actions may be taken to ensure the safety of personnel and equipment consistent with the safe operation of the facility.

5.4 Excavation Performance

Approximately 281 convergence points were read and assessed regularly throughout the WIPP underground this reporting period. Due to the effect rock temperature has on salt creep, convergence rates vary seasonally, typically increasing during the warmer summer months and decreasing during the cooler and drier winter months. These temperature effects are more pronounced nearer the fresh air intake.

The performance of the access drift excavations during this reporting period was within acceptable criteria. "Acceptable criteria" means that a drift remains accessible, and the ground can be controlled by routine maintenance. Standard remedial ground control in some areas was required to maintain the performance of the excavations. The accessible drifts remain stable and controlled. Of the 187 convergence locations measured in the access drifts, five locations had annual closure rates in excess of 20 percent from the previous year's value. See Table 5-3, Vertical Closure Rate Changes in Excess of Twenty Percent in the Access Drifts.

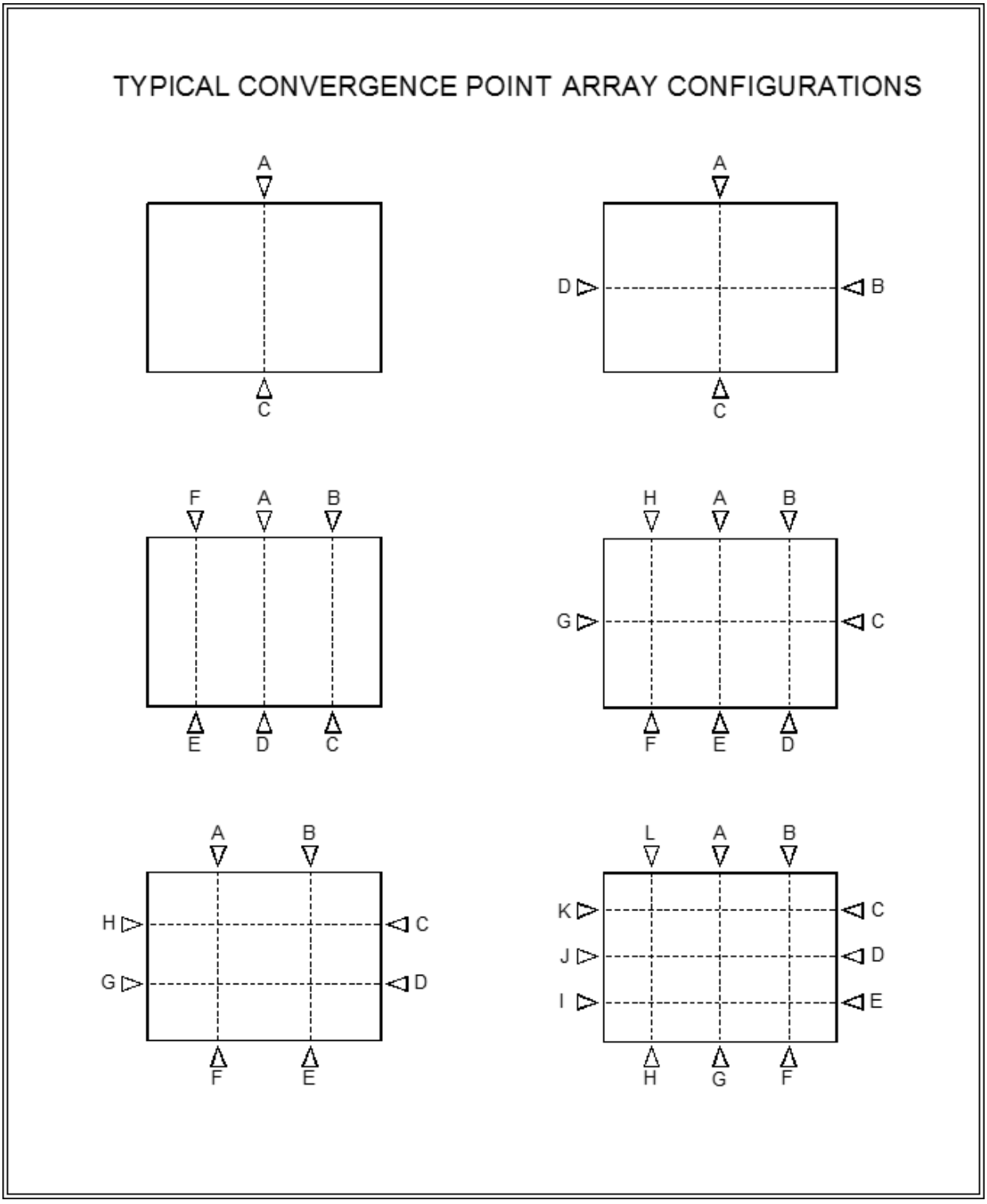

Figure 5-1 Typical Convergence Point Array Configurations Showing Anchor Designations

Location	Installation Date	Type of Installation[5]	Field Tag[6]
S2180-E80	07/20/20	N	51X-CW-01051
S2180-E80	07/31/20	R	51X-CW-01051-2
S2180-E100	08/05/20	N	51X-CW-01052
E300-N490	08/06/20	N	51X-GE-00452
W790-S1862	08/07/20	N	W790-S1862 A-C
S1950-W285	08/12/20	R	S1950-W285-2 A-C
E300-N1262	08/12/20	R	E300-N1262-5 A-C
W30-S2350	08/12/20	R	W30-S2350-5 A-C
S1950-W790	08/24/20	R	S1950-W790-3 A-C
W170-S1600	10/20/20	R	W170-S1600-5 A-C
W170-S1000	10/20/20	R	W170-S1000-4 A-C
W390-S2300	12/15/20	N	51X-GE-00453
W390-S2275	12/15/20	N	51X-GE-00454
E140-S1950	01/21/21	R	E140-S1950-8 A-C
S1950-E160	01/21/21	R	S1950-E160-2 A-C
E140-S1225	01/21/21	R	E140-S1225-7 A-E
S400-E10	02/11/21	N	S400-E10 A-C
S400-W20	02/11/21	N	S400-W20 A-C
W30-S120	02/11/21	R	W30-S120-4 A-C
W30-S90	02/11/21	R	W30-S90-2 A-C
E0-S65	02/18/21	R	E0-S65-6 A-C
E0-S30	02/18/21	R	E0-S30-7 A-C
E0-S18	02/18/21	R	E0-S18-9 A-E
E0-S18	02/18/21	R	E0-S18-6 H-F
E140-S1150	02/23/21	R	E140-S1150-7 A-G
S1950-E113	02/23/21	R	S1950-E113-5 A-C
E140-S1862	02/23/21	R	E140-S1862-5 A-E
E140-S1775	02/23/21	R	E140-S1775-5 A-G
E140-S1600	02/23/21	R	E140-S1600-8 A-C
E140-S1300	02/25/21	R	E140-S1300-7 A-C
S1950-W285	02/25/21	R	S1950-W285-3 A-C
S1950-W390	02/25/21	R	S1950-W390-3 A-C
S1300-W155	03/19/21	N	S1300-W155 A-C
S1600-W520	03/19/21	R	S1600-W520-3 A-C
S1600-W455	03/19/21	R	S1600-W455-3 A-C
S1600-W390	03/19/21	R	S1600-W390-4 A-C
W390-S1700	03/19/21	R	W390-S1700-2 A-C

[5] R - denotes a replacement installation, e.g., roof or floor point(s) could have been mined out, damaged, etc. N – represents a new installation at that location.
[6] Field Tag (aka fieldtag) is a string consisting of 'location' + '- number of times a reinstall was conducted at that location' + ' chord'. Note that new installations do not have a reinstallation number.

W390-S1775	03/19/21	R	W390-S1775-2 A-C
W390-S1850	03/19/21	R	W390-S1850-3 A-C
E140-S2170	04/07/21	N	E140-S2170 A-C
E140-S2190	04/07/21	N	E140-S2190 A-C
S2520-E55	04/07/21	R	S2520-E55-3 A-C
E140-N780	04/29/21	R	E140-N780-5 A-C
S400-W20	04/29/21	N	S400-W20 A-C
S700-E180	04/29/21	R	S700-E180-2 A-C
S700-E205	04/29/21	R	S700-E205-4 A-C
E140-N562	05/05/21	R	E140-N562-4 A-C
N780-E220	05/07/21	R	N780-E220-5 A-C
E140-N460	05/27/21	R	E140-N460-4 A-C
E140-N355	05/27/21	R	E140-N355-3 A-C
E140-N250	05/27/21	R	E140-N250-5 A-C
E140-N150	05/28/21	R	E140-N150-7 A-C
E140-N5	05/28/21	R	E140-N5-8 A-C
E140-S90	05/28/21	R	E140-S90-5 A-C
S1600-W520	06/01/21	R	S1600-W520-4 A-C
S1600-W585	05/25/21	R	S1600-W585-2 A-C
S1600-W725	05/25/21	R	S1600-W725-2 A-C
S1600-W790	05/25/21	R	S1600-W790-2 A-C
S1600-W855	05/25/21	R	S1600-W855-2 A-C
S1600-W920	05/25/21	R	S1600-W920-2 A-C
S1600-W985	05/25/21	R	S1600-W985-2 A-C
S1600-W1050	05/25/21	R	S1600-W1050-2 A-C
S1600-W1190	06/01/21	R	S1600-W1190-2 A-C
W1190-S1687	06/01/21	R	W1190-S1687-2 A-C
W1190-S1775	06/01/21	R	W1190-S1775-2 A-C
W1190-S1862	06/01/21	R	W1190-S1862-2 A-C
S1950-W1120	06/01/21	R	S1950-W1120-2 A-C
S1950-W1190	06/01/21	R	S1950-W1190-2 A-C
W30-S2520	06/09/21	R	W30-S2520-5 A-C
S2520-W100	06/09/21	R	S2520-W100-3 A-C
W170-S2520	06/09/21	R	W170-S2520-3 A-C
S1600-W286	06/08/21	R	S1600-W285-3 A-C
S1600-S660	06/08/21	R	S1600-W660-2 A-C
S1600-W1120	06/08/21	R	S1600-W1120-2 A-C
E140-S460	06/18/21	R	E140-S460-8 A-C
W30-S1600	06/18/21	R	W30-S1600-5 A-C

Table 5-2 Radial Convergence Point Installations in the Access Drifts: July 1, 2020, to June 30, 2021

Location	Chord[7]	Last Reading Date	Closure Rate 2022 to 2021 (in/yr)	Closure Rate 2019 to 2020 (in/yr)	Rate Change (%)
E140-N150	A-C	06/17/21	2.6	1.7	53
E140-N355	A-C	06/17/21	3.1	2.4	29
E140-S90	A-C	06/17/21	2.7	2.1	29
E140-S1524	H-F	01/06/21	5.1	3.4	50
S700-E180	A-C	06/01/21	2.3	1.9	21

Table 5-3 Vertical Closure Rate Changes in Excess of Twenty Percent in the Access Drifts

6.0 PERFORMANCE OF THE WASTE DISPOSAL AREA

The Waste Disposal Area as of June 30, 2021, consisted of Panels 1, 2, 3, 4, 5, 6, 7, and a nearly complete Panel 8. Panels 1, 2, 3, 4, 5, and 6 were closed during previous reporting periods.

6.1 History

Excavation of Panel 1 began in May 1986 with the mining of the access entries. Initially, the disposal rooms and drifts were developed as pilot drifts that were later excavated to nominal operational dimensions of 13 ft high, 33 ft wide, and 300 ft long. Room 1 was completed to these dimensions in August 1986, and pilot drifts for Rooms 2 and 3 were excavated in January and February 1987. Rooms 2 and 3 were completed in February and March 1988, and Rooms 4 through 7 were completed in May 1988. Four short access drifts designed to lead to smaller test alcoves were excavated north off the S-1600 drift and Rooms 4-7 in June 1989. Only the access drifts to the alcoves were completed; the alcoves themselves were not excavated. Panel 1 waste emplacement (in Rooms 1, 2, 3, 7, adjacent areas of S-1600, and all of S-1950) was completed in March 2003, and the panel is closed to all access.

Excavation of Panel 2 began in September 1999 with the mining of access entries. Initially, the disposal rooms and drifts were developed as pilot drifts that were trimmed to finished dimensions. Room 1 was completed in January 2000, and pilot drifts for Rooms 2 and 3 were excavated in February 2000. Pilot drifts were completed for Rooms 4 through 6 in April 2000. The pilot drift for Room 7 was excavated in May 2000. All the rooms were excavated to final dimensions by August 2000. Waste emplacement in Panel 2 was completed during a prior reporting period, and the panel is closed to all access.

[7] Chord is defined in Section 5.2.2 and illustrated in Figure 5-1.

Excavation of Panel 3 began in May 2002 with the mining of access entries. As with Panel 2, the disposal rooms and drifts were initially developed as pilot drifts that were trimmed to finished dimensions. All the rooms were excavated to final dimensions by the end of March 2004. Waste emplacement in Panel 3 was completed in February 2007. Substantial barriers and bulkheads were installed in the exhaust and intake drifts of Panel 3 to prevent access into the panel and to isolate it from the ventilation circuit.

Panel 4 access drift mining began in January 2005. The disposal rooms were initially developed as pilot drifts and were later trimmed to final dimensions. Mining was completed by June 2006. Waste emplacement in Panel 4 was completed in March 2009. Substantial barriers and bulkheads were installed in the exhaust and intake drifts of Panel 4 to prevent access into the panel and to isolate it from the ventilation circuit.

Panel 5 excavation activities began in June 2006. The panel was initially mined to less-than-final dimensions and later trimmed to specification. Mining was complete by February 2008. Waste emplacement was conducted from March 2009 through July 2011. Isolation walls were completed in November 2011

Panel 6 mining began in April 2008. The panel was initially mined to less-than-final dimensions and later trimmed to specification. Mining was complete by April 2010. Waste emplacement began in March 2011 and was completed in January 2014.

Panel 7 mining began in April 2010 and was completed in August 2011. Initial mining placed the floor within 2 ft. of a polyhalitic bed (designated PH-4), which sits atop a thick anhydrite bed designated MB-139. Horizontal stresses caused significant uplift and the floor was then mined down through MB-139 and backfilled with run of mine salt. The remediation of the floor was completed in January 2013. Subsequent geomechanical monitoring indicates stable vertical convergence. RH waste emplacement began in Panel 7 in September 2013 and CH waste emplacement began in January 2014. Waste emplacement and ground control activities were suspended in February 2014 due to a truck fire in the underground followed by a radiation release in Panel 7. Ground control activities resumed in 2015. Waste emplacement resumed in January 2017 at the intersection of Room 6 and S2520.

Panel 8 mining resumed in February 2018. The rough-cut mining with the back at Clay G was completed in January 2020. This was performed due to deformation in the immediate roof beam caused by the lapse in mining and bolting after the events in 2014. The rib-cut mining was completed in October 2020. The floor-cut mining is in progress and is nearing completion.

6.2 Modifications to Excavations and Ground Control Activities

No planned excavation modifications were performed this reporting period in Panel 7. An anticipated roof fall is thought to have occurred in Panel 7, S2180~W985 (a prohibited area closed to personnel access) around July 10, 2021, after the reporting period. The potential for a fall to occur was predicted by increasing room closure rates during the reporting period. The data obtained from the instrument after July 10, 2021, was not indicative of a fully operational instrument, inferring a roof fall had occurred damaging the instrument. A visual confirmation of the roof fall was not possible.

Routine ground control activities were performed in Panel 7 to include scaling and meshing, as needed, and the replacement of broken roof bolts with 14-ft resin anchored bolts in areas that are still accessible.

A very significant modification to Panel 8 (see Section 6.1) is the mining of the back up to the upper horizon at Clay G. Also, the back of Panel 8 is fully bolted with 6-foot resin anchor roof bolts. The bolts were installed as soon as possible after mining to slow the development of separations along anhydrite stringers within the roof beam and subsequent surface tension crack development.

6.3 Instrumentation

Panel 7 instrumentation originally consisted of the following:

- Forty-nine vertical convergence points, distributed as 14 in each of the intake and exhaust drifts and three in each of the rooms; and
- Eleven wire extensometers, distributed as two in each of the intake and exhaust drifts and one in each of the rooms.

A schematic of the geomechanical instrumentation layout found in Panel 7 is shown in Figure 6-1. This figure presents what has been a typical Waste Panel instrumentation layout since emplacement began in Panel 1.

6.4 Analysis of Extensometer and Convergence Point Data

Panel 7 is continuing to experience age-appropriate roof-beam, expansion and floor deformation in areas accessible to ground maintenance. Due to the aforementioned S2180~W985 ground event in July 2021, future remote monitoring capabilities will be limited in Panel 7 to only Room 1.

Absent in this section are Rooms 4, 6, and 7. The rooms are inaccessible due to the following reasons:

- Room 4 experienced an anticipated roof fall over approximately 80% of the room in November 2016.

- Room 6 also experienced an anticipated roof fall over much of the room sometime between December 19, 2018, and January 2, 2019.

- Access to Room 7 was prohibited to general access immediately following the radioactive release in February 2014 and was subsequently sealed following the video investigation of the waste stack.

The Room 3 extensometer measured a roof beam expansion rate this period of 2.5 in/yr, a 56 percent increase from the previous year's reading of 1.6 in/yr. Extensometer readings from Panel 7 Room 2 show a roof beam expansion rate of 1.4 in/yr, a slight reduction from the previous year's reading of 1.5 in/yr.

The Room 1 extensometer measured a roof beam expansion rate this period of 0.9 in/yr, a decrease from the previous year's reading of 1.4 in/yr. The three convergence points in Room 1 measure rates of 4.2, 3.4, and 3.4 in/yr, a slight decrease from the previous reporting period. The indicated decrease in rates can be attributed to ground control efforts to sustain waste emplacement in Room 1.

Extensometer readings from Panel 8 Room 1 show a steady roof beam expansion rate of 1.2 in/yr. Room 1 convergence stations had closure rates of 3.2 and 4.1 in/yr, down from 3.7 and 4.7 in/yr. Convergence monitoring of the newly mined Panel 8 shows closure rates between 0.8 and 9.3 in/yr through 46 convergence stations. Convergence rates are typically higher in freshly mined areas before reaching a steady state, and decrease once sufficient ground support is installed.

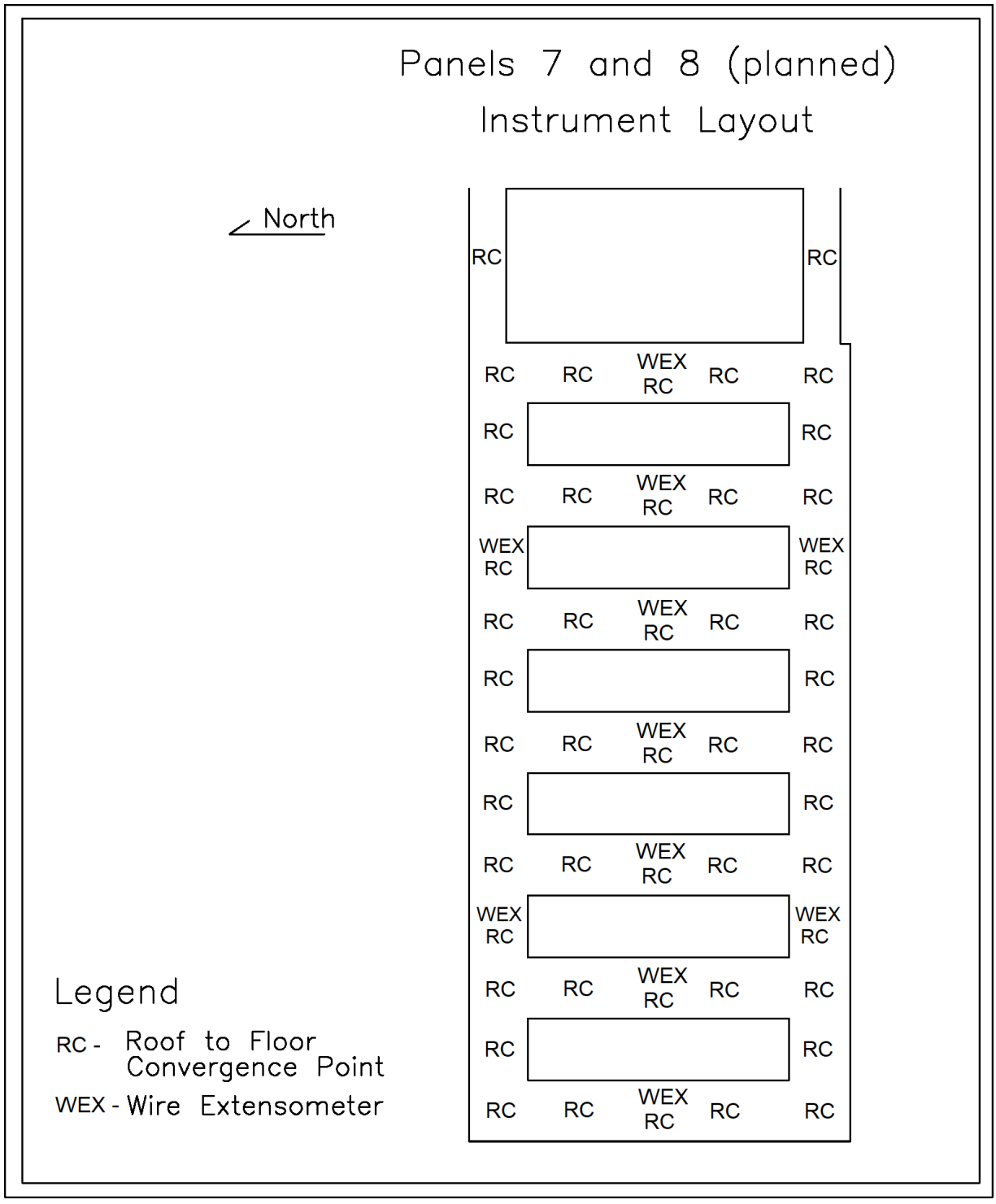

Figure 6-1 Typical Waste Panel Instrument Layout

6.5 Excavation Performance

Panel 7 is performing as expected considering its age and history. The panel should fulfill its intended purpose as long as ground control efforts can continue.

7.0 PERFORMANCE OF THE SALT DISPOSAL INVESTIGATIONS AND SALT DEFENSE DISPOSAL INVESTIGATIONS

This chapter describes the geomechanical performance of the SDI and SDDI areas (hereafter referred to as SDI). Development of the area began in January 2012. When completed, most of the area will have nominal dimensions of 13 ft high and 16 ft wide.

7.1 Ground Control Program

Due to the relatively narrow drifts (nominally 16 ft across) and favorable mining horizon, ground control plans in the SDI area are confined to routine maintenance, such as spot-bolting where localized drummy surface features develop. More substantial engineered ground control systems may be applied in the event that ongoing geomechanical monitoring and analysis of the area identify a need.

7.2 Instrumentation

Fifty-five convergence arrays have been installed in the SDI area. The arrays are read on a periodic basis, when accessible. During this reporting period 32 arrays were accessible.

7.3 Analysis of Convergence Point Data

The 32 convergence points for this period had a roof-to-floor closure range of 0.6 to 2.3 in/yr, mean rate of 1.3 in/yr, with a standard deviation of 0.4. Low rates of closure are expected for this area due to the factors described in the beginning of Section 7.1.

7.4 Excavation Performance

A combination of ground control, and to some extent ventilation challenges, led the Operations Department to restrict access to the SDI area during the previous reporting period so the resources could be channeled to address more significant ground control remediation in other areas. The same operational challenges apply to this reporting period, although, the inaccessibility is primarily limited to 23 convergence stations in the areas in SDI south of the N-780 drift.

8.0 GEOSCIENCE PROGRAM

Borehole observations were the only activities of the geoscience program completed during this reporting period, primarily due to the difficulty in filling a geotechnical engineering position. A description of the various aspects of the geoscience program is presented in the remainder of Section 8.0.

The geoscience program confirms the suitability of the Site through the collection of various geologic data and excavation characteristics from the underground. These include the inspection of open observation holes for fractures (separations) and offsets (lateral displacements) in roof beams, and the mapping of fracture development on roof surfaces. Data collected through these activities support the design and evaluation of ground support systems.

Normally, the following activities are performed:

- Observation hole inspections
- Fracture mapping
- Stratigraphic mapping
- Drilling and Geologic Core Descriptions

Fracture development in the roof is primarily caused by the concentration of compressive stresses in the roof beam and is influenced by the size and shape of the excavation and the stratigraphy in the immediate vicinity of the opening. In a thick roof beam, pillar deformations induce lateral compressive stresses into the immediate roof and floor. With time, the buildup of stress causes differential movement along stratigraphic boundaries. This differential movement is identified as offsets in observation holes and by the bends in failed rock bolts. Large strains associated with lateral movements can induce fracturing in the roof, which is frequently seen near the ribs. However, this process may take years to develop.

At the upper repository horizon, clay or anhydrite stringers exert significant influence over the effective thickness of the roof beam. The presence of these stringers causes the roof beam to behave as a series of thin independent beams. Little or no tensile support is provided across the stringer interface. As horizontal end-loading continues, each beam can deflect downward causing a tensile fracture to develop along the bottom of the beam. These tensile fractures can develop in relatively new excavations soon after separation occurs along the stringer interface.

8.1 Observation Hole Inspections

Geotechnical observation holes are drilled at various locations throughout the underground facility. A location may contain one or more holes arranged in an array. These holes are drilled to depths that allow the monitoring of fracture development and offsetting and are inspected for the development of those features. Roof observation holes usually extend up past Clays G and H (Figure 8-1 and Figure 8-2).

The clay seams nearest the excavation surfaces define the immediate roof beam. The roof beam is bounded by Clay G in most of the access drifts and Panels 1, 2, and 7. Some areas, such as the Salt Shaft Station, portions of the E-0 and E-140 drifts, the south mains south of S-2620, and Panels 3, 4, 5, 6, and 8 are excavated to Clay G and have roof beams bounded by Clay H.

The offset in an observation hole is determined by visually estimating the degree of occlusion. The direction of offset along clay seams is observed as the movement of the strata nearer to the observer relative to the strata farther away. Typically, the nearer strata move toward the center of the excavation (Figure 8-3 and Figure 8-4). Based on previous observations in the underground, the magnitude of offset is usually greater in holes located near ribs than in those located along excavation centerlines. Offsetting along the clay layers is observable until total offset is reached or visibility is obstructed by intervening offsets at other clay seams or fractures.

Observation holes are inspected for fractures using an aluminum rod with a flattened steel wire probe attached to one end perpendicular to the rod (referred to as a "scratch rod"). Fractures and clay seams are located by moving the probe along the inside of the hole until it is snagged in one of these features. Depth to each feature is recorded, as is the magnitude of separations encountered. Although not available this reporting period, a fiber scope camera will be available next reporting period for use in addition to the scratch rod to visually inspect features of interest in a hole. Over this reporting period 22 observation holes (Vol. 2 Table 7-1) were scratched and recorded.

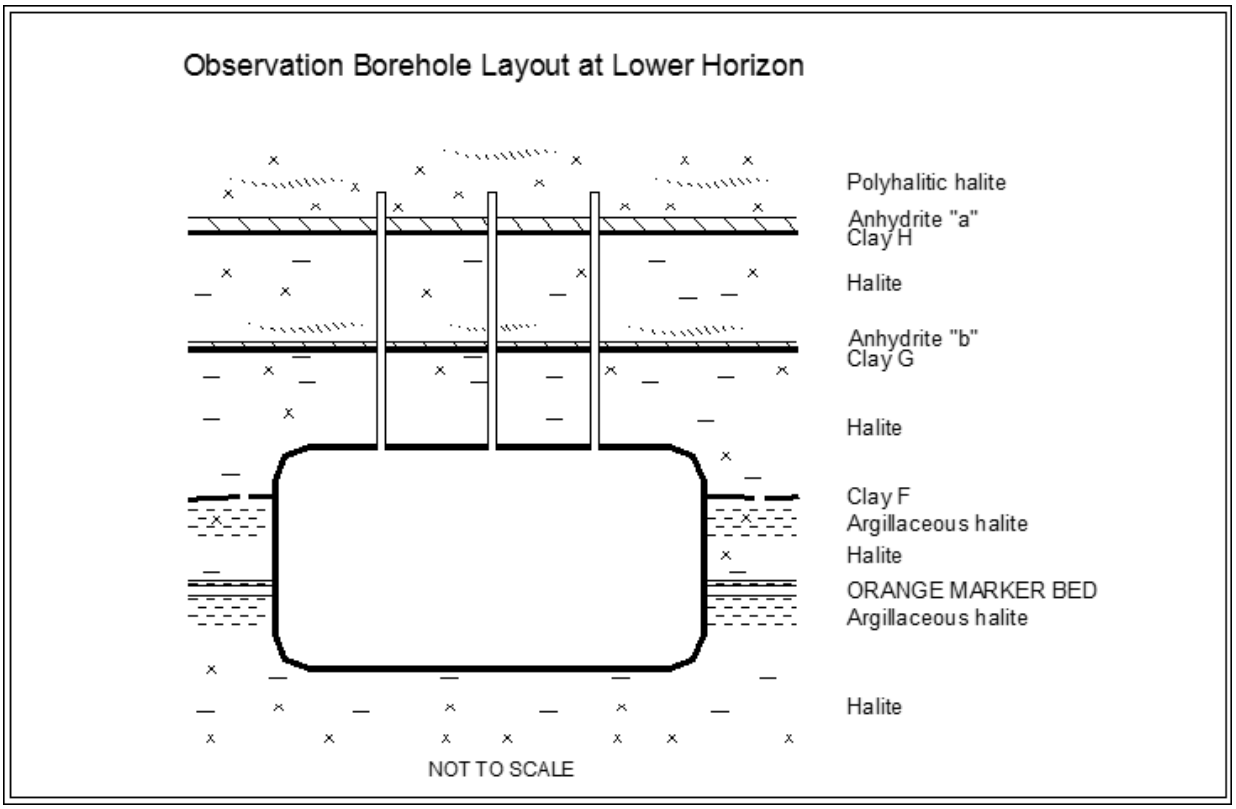

Figure 8-1 Example of Observation Hole Layout at Lower Horizon

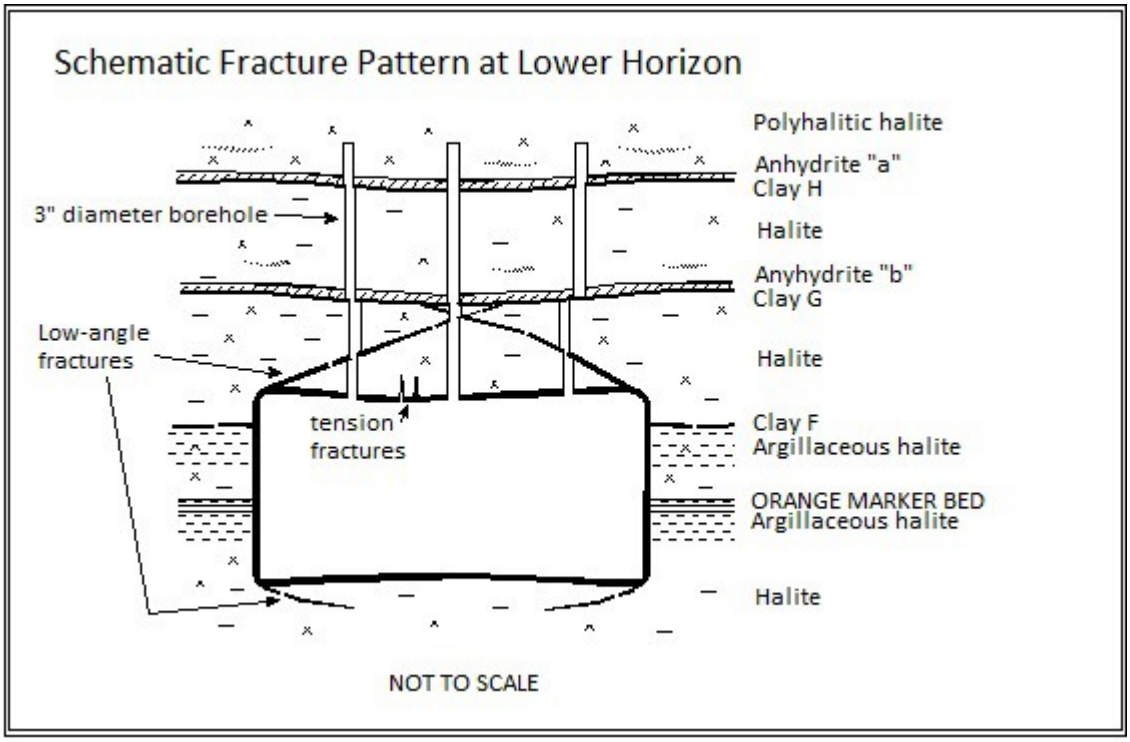

Figure 8-2 Typical Fracture Pattern at Lower Horizon

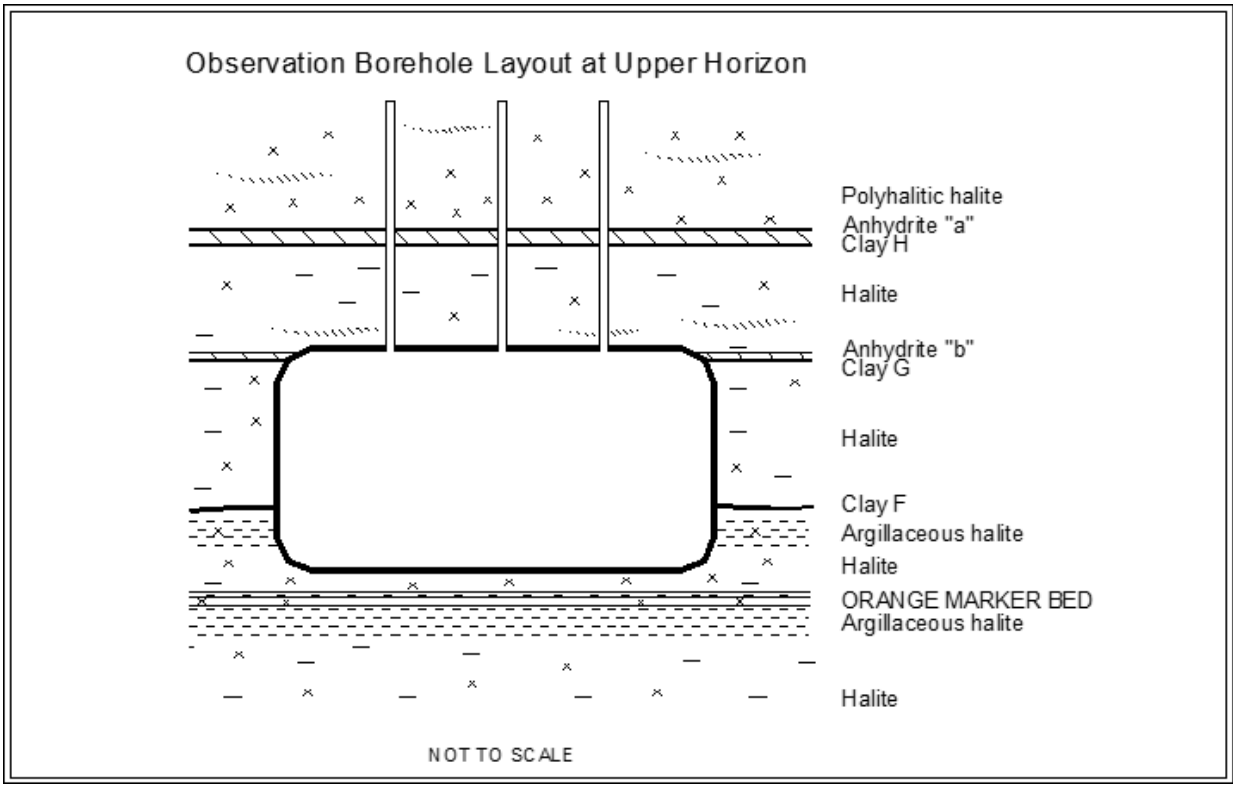

Figure 8-3 Example Observation Hole Layout at Upper Horizon

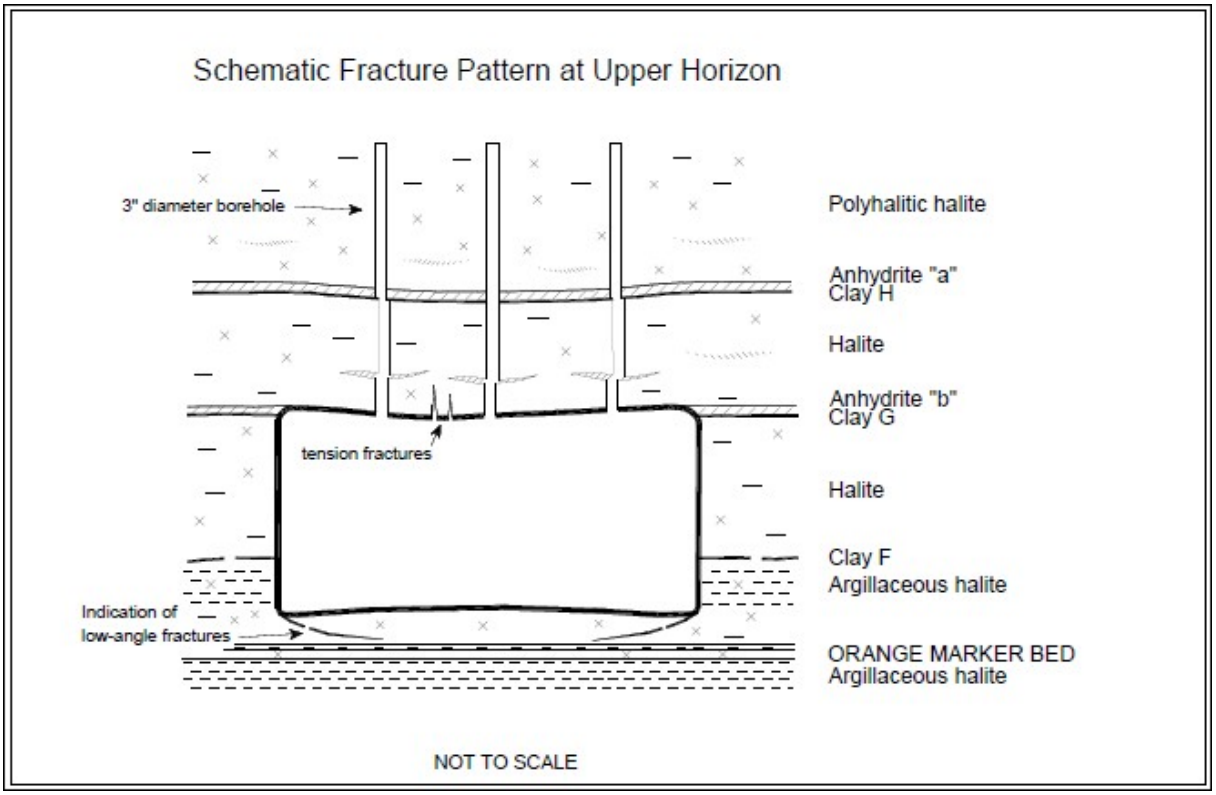

Figure 8-4 Typical Fracture Patterns at Upper Horizon

8.2 Fracture Mapping

Routine mapping documents the progression of fractures in the roof exposed on the excavation surfaces of the drifts and rooms in the underground repository. The fracture surveys are generally performed on an annual basis, and the fracture maps are updated. The fracture maps facilitate the analysis of strain in the immediate roof-beam because they document the development and propagation of fractures through time.

8.3 Stratigraphic Mapping

Stratigraphic mapping is the identification and partitioning of the sequence of rock strata based on their form, distribution, and lithological composition. It is used to verify that there are no nonconformities in the geology within the waste disposal horizon at the WIPP.

8.4 Drilling and Geologic Core Descriptions

As new panels and new experimental areas are excavated, holes are typically drilled and cored vertically into the back and into the floor to depths of 50 ft to identify and describe the stratigraphic units present.

9.0 SUMMARY

At the inception of the WIPP, criteria were developed that addressed the design requirements (DOE, 1984). They pertained to all aspects of the mined facility and its operation as a pilot plant for the demonstration of technical and operational methods for permanent disposal of CH and RH TRU waste. In 1994, as the WIPP focus moved toward the permanent disposal of TRU waste, these design requirements were reassessed and replaced by a new set of requirements called system design descriptions. Table 9-1 shows the comparison of these design requirements with conditions actually observed in the underground from July 2020 through June 2021.

An anticipated roof fall is thought to have occurred in Panel 7, S2180~W985 (a prohibited area closed to personnel access) around July 10, 2021, after the reporting period. The potential for a fall to occur was predicted by increasing room closure rates during the reporting period. The data obtained from the instrument after July 10, 2021, was not indicative of a fully operational instrument, inferring a roof fall had occurred damaging the instrument. Due to waste emplacement in the entries leading to Room 6, a visual confirmation of the roof fall was not possible.

The performances of the accessible and bolted excavations continue to satisfy the appropriate design criteria. Although improvements to ground control maintenance activities in accessible areas in the underground have been made, additional efforts are still needed. Future changes to the planned life of some of the openings may require a change to the geometry of the access drifts by removing unstable roof beam or rib spalls, milling the floor for added clearance, and installing roof bolts with mesh or straps.

In addition to underground instrumentation, qualitative assessments of fracture development are documented through mapping the underground repository and inspecting the observation holes. As indicated in Section 8.0, 20 new observation boreholes were drilled and a total of 22 holes were inspected. Additionally, the accumulation of many years of collected information acquired from these programs contributes to the understanding of the dynamic geomechanical processes in the WIPP underground. This aids in the design of effective ground control and support systems.

Requirement	Comments
"The lining shall be designed for a hydrostatic pressure. ..... "	Water pressure observed on piezometers located behind the shaft liners remains below design levels.
"The key shall be designed to resist the lateral pressure generated by salt creep."	Visual inspections of all shaft keys do not indicate any deterioration due to creep loading.
"The key shall be designed to retain the rock formation and will be provided with chemical seal rings and a water collection ring with drains to prevent water from flowing down the unlined shaft from the lining above."	Shaft inspection observations show no indication of instability due to salt dissolution. No water has been observed flowing along the rock-liner interface.
"The underground waste disposal facilities shall be designed to provide space and adequate access for the underground equipment and temporary storage space to support underground operations."	Geomechanical instrument data and visual observations indicate that the current design provides adequate access and storage and disposal space. Ground control maintenance is performed as necessary to maintain access. If ground control activities cannot be performed in a timely manner and the geomechanical data suggest potential instability, access to the drift is to be restricted or even prohibited until ground remediation can occur.
"Entries and subentries to the underground disposal area and the experimental areas shall be provided and sized for personnel safety, adequate air flow, and space for equipment."	Deformation of excavation remains within the required limits. Normal periodic maintenance consisting of rock bolting, wire meshing, trimming, and scaling continue throughout accessible areas of the repository. Areas such as the waste transport route undergo periodic floor trims in order to maintain adequate operating height.
"Geomechanical instrumentation shall be provided to measure the cumulative deformation of the rock mass surrounding mined drifts ....."	Geomechanical instrumentation is operated and maintained to meet this requirement. This annual report provides a summary and analysis of the geomechanical data.

Table 9-1 Comparison of Excavation Performance to System Design Requirements[8]

[8] U.S Department of Energy (DOE), 1986, *Waste Isolation Pilot Plant Design Validation Final Report*, DOE-WIPP-86-010, Bechtel National, Inc.,San Francisco, California.

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DOE/WIPP- 22-3610
Volume 2

Waste Isolation Pilot Plant

Geotechnical Analysis Report for July 2020 – June 2021

Supporting Data

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Waste Isolation Pilot Plant

Geotechnical Analysis Report For July 2020 – June 2021

Supporting Data

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October 2022

Approved by: Michael Gerle Digitally signed by Michael Gerle Date: 2022.10.18 15:31:31 -06'00'

Michael D. Gerle
Director, Environmental Regulatory Compliance
Division Carlsbad Field Office

Date

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FOREWORD AND ACKNOWLEDGMENTS

This report contains an assessment of the geotechnical status of the Waste Isolation Pilot Plant (WIPP). During the excavation of the WIPP principal underground access and experimental areas, the status was reported quarterly. Since 1987, when the initial construction phase was completed, reports have been published annually. This report presents and analyzes data collected from July 1, 2020, to June 30, 2021.

The Geotechnical Analysis Report (GAR) was written to meet the needs of several audiences. It satisfies requirements contained in the WIPP Hazardous Waste Facility Permit[1] and the Certification of Compliance[2] with Subparts B and C, Title 40 *Code of Federal Regulations* Part 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes." The report focuses on the geotechnical performance of the various components of the WIPP underground facility, including the shafts, shaft stations, access drifts, and waste disposal areas. The results of investigations of excavation effects and other geotechnical studies are also included.

The report compares the geotechnical performance of the repository to the design criteria. It describes the techniques that were used to acquire the data. The depth and breadth of the evaluation of the different components of the underground facility according to the types, qualities, and quantities of data available and the complexity of the recorded geotechnical responses. Graphic documentation of data and tabular documentation of instrument history can be provided upon request.

This GAR was prepared by Nuclear Waste Partnership LLC for the U.S. Department of Energy (DOE), Carlsbad Field Office in Carlsbad, New Mexico. Work was supported by the DOE under Contract No. DE-EM0001971.

[1] New Mexico Environment Department (NMED), 2022, Waste Isolation Pilot Plant Hazardous Waste Facility Permit, NM4890139088-TSDF, Santa Fe, NM

[2] U.S. Environmental Protection Agency (EPA), 1998, "Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the Disposal Regulations: Certification Decision," Federal Register, Vol. 63, No. 95, pp. 27354, May 18, 1998, Washington, DC

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INTRODUCTION

This report is the compilation of geotechnical data for each active instrument installed in the underground at the Waste Isolation Pilot Plant (WIPP) mainly from July 2020 through June 30, 2021. A summary of the geotechnical analyses that were performed using the compiled data is provided in the Volume 1 of the Geotechnical Analysis Report (GAR).

1.1 Instrumentation

Geomechanical instrument data included in this report reflect the measurements of the geotechnical response of the underground mine. The instruments consist of convergence points, borehole extensometers, rock bolt load cells, pressure cells, strain gauges, piezometers, and joint meters.

Closure measurements are taken at convergence points. Rock displacement is calculated by measuring the distance between two opposing points. Displacement is monitored over time and is plotted as closure versus time. Annual rates of closure are calculated for the convergence data and are compared with annual closure rates from previous reporting periods.

Borehole extensometers are used to determine the absolute movements of the ground around the openings within the mine. With these instruments, stainless steel cables are installed into a hole and anchored at various depths. The displacement at the extensometer head (located near the excavation face) is measured relative to each of the fixed anchors. These data are used in the extensometer displacement plots presented in this report. Annual rates of displacement are calculated for each extensometer and are compared with the annual displacement rate reported during the previous reporting period.

Rock bolt load cells are used to measure the load exerted by the overburden and the effectiveness of rock bolts. Plots for each instrumented rock bolt are presented as load versus time.

Earth pressure cells and strain gauges are used in and around the shaft liners to determine their loads. The data are depicted in time-based plots. Monitoring of these instruments indicate whether there are stresses building up in the shaft lining systems.

Piezometers are used to measure the gauge pressure of groundwater. They have been installed in the shafts at varying elevations to monitor the hydraulic head acting on the shaft liners. Plots from piezometers are presented as pressure versus time.

Joint meters are installed perpendicular to a crack and monitor changes in separation of the crack which may occur over time.

1.2 Data Plot Explanation

Data are presented in graphical form for ease of interpretation. Time-based plots are used in this report. Each plot generally displays a legend in the upper right-hand corner that gives the array name and specific location of the instrument or point evaluated. The legend ties the graphical cross-sectional representation of the drift or shaft typically presented in the lower right-hand corner to the symbols on the curve in the graph. For extensometers, each anchor is designated with an alpha character "A" closest to the collar and "B," "C," "D," or "E" for the furthest point from the collar (the deepest anchor). For convergence points, the horizontal and vertical sections of the drift are referred to as chords. Breaks in the graph for convergence data and a numeric designator added to the legend typically indicate that the convergence point was lost due to normal mine maintenance activities and later reinstalled.

1.3 Report Organization

Chapter 1.0 provides an introduction to this Supporting Data volume of the GAR. Chapter 2.0 provides instrument data analysis for the Salt Shaft, followed by data plots for the piezometers, earth pressure cells, spot welded strain gauges, and embedment strain gauges installed in the Salt Shaft. Chapter 3.0 provides instrument data analysis for the Salt Shaft Station and data plots for convergence points located within the station. Chapter 4.0 provides instrument data analysis for the access drifts followed by data plots for the extensometers, convergence points, joint meters, and rock bolt load cells. Chapter 5.0 provides instrument data analysis for the Waste Disposal Area followed by data plots for the extensometers and convergence points. Chapter 6.0 provides convergence point instrument data analysis for the Salt Disposal Investigations (SDI) area. Chapter 7.0 provides geologic data collected through the mapping of fractures, stratigraphic mapping, and the observed displacements in vertical boreholes.

2.0 INSTRUMENTATION SUMMARY FOR THE SHAFTS

Geomechanical instrumentation was originally installed in the Salt, Waste, and Exhaust Shafts. Following the construction of the Air Intake Shaft (AIS), the shaft was instrumented under the direction of Sandia National Labs (SNL). SNL also read and maintained the data from the AIS instrumentation up until it left the site.

Instrument readings from the Waste, AIS, and Exhaust Shafts are no longer available due to failed instruments, broken cabling, and/or inoperable/obsolete data acquisition equipment. Although much of the instrumentation installed in the shafts has failed through the years, there are no plans to replace it. The project has a good understanding of the expected movements in the shafts. Instrument readings up to the point of instrument failure did not indicate unusual shaft movements or displacements. Continued periodic visual inspections confirm the expected shaft performance and provide necessary observations to evaluate shaft performance. Replacement of failed instrumentation will not, at this time, provide significant additional information.

Table 2-1 presents data and analysis of the Salt Shaft instrumentation. Plots of the instrument data are presented as Figures 2-1 through 2-11.

Table 2-1 Salt Handling Shaft Data Analysis

Piezometers								
Field Tag	Level feet	Figure Number	Date of 2020-2021 Max. Reading	2020-2021 Maximum Pressure Readings (psi)	Date of 2019-2020 Max. Reading	2019-2020 Maximum Pressure Readings (psi)	Change in Maximum Pressure From Previous Year (psi)	Comments[1]
37X-PE-00201	580	2-1	04/16/2021	70.8	No Reading	N/A	N/A	N/A
37X-PE-00202	580	2-1	04/08/2021	109.3	No Reading	N/A	N/A	N/A
37X-PE-00203	620	2-2	03/31/2021	132.4	No Reading	N/A	N/A	N/A
37X-PE-00204	620	2- 2	05/14/2021	289.5	No Reading	N/A	N/A	N/A
37X-PE-00205	691	2-3	04/16/2021	142.2	No Reading	N/A	N/A	N/A
37X-PE-00206	691	2-3	04/16/2021	137.8	No Reading	N/A	N/A	N/A
37X-PE-00210	802	2-4	03/31/2021	-0.8	No Reading	N/A	N/A	N/A
37X-PE-00211	850	2-5	04/16/2021	40.3	No Reading	N/A	N/A	N/A
37X-PE-00212	850	2-5	03/31/2021	46.6	No Reading	N/A	N/A	N/A
Earth Pressure Cells								
Field Tag	Level feet	Figure Number	Date of 2020-2021 Max. Reading	2020-2021 Maximum Pressure Readings (psi)	Date of 2019-2020 Max. Reading	2019-2020 Maximum Pressure Readings (psi)	Change in Maximum Pressure From Previous Year (psi)	Comments[1]
37X-WE-00201	860	2-6	05/14/2021	-22.1	No Reading	N/A	N/A	N/A
37X-WE-00202	860	2-6	04/16/2021	1.2	No Reading	N/A	N/A	N/A
Spot-Welded Strain Gauges								
Field Tag	Level feet	Figure Number	Date of 2020-2021 Max. Reading	2020-2021 Maximum Strain Readings (με)	Date of 2019-2020 Max. Reading	2019-2020 Maximum Strain Readings (με)	Change in Maximum Strain From Previous Year (με)	Comments[1]
37X-ZE-00206	856.3	2-7	04/16/2021	652	No Reading	N/A	N/A	N/A

Table 2-1 Salt Handling Shaft Data Analysis (continued)

Embedment Strain Gauges								
Field Tag	Level feet	Figure Number	Date of 2020-2021 Max. Reading	2020-2021 Maximum Strain Readings (με)	Date of 2019-2020 Max. Reading	2019-2020 Maximum Strain Readings (με)	Change in Maximum Strain From Previous Year (με)	Comments[1]
37X-ZE-00209	857	2-8	04/16/2021	-497	No Reading	N/A	N/A	N/A
37X-ZE-00210	856.3	2-8	05/14/2021	953	No Reading	N/A	N/A	N/A
37X-ZE-00211	856.3	2-8	04/16/2021	340	No Reading	N/A	N/A	N/A
37X-ZE-00212	856.3	2-8	04/16/2021	-637	No Reading	N/A	N/A	N/A
37X-ZE-00213	856.3	2-8	04/16/2021	435	No Reading	N/A	N/A	N/A
37X-ZE-00214	856.3	2-8	05/14/2021	-14	No Reading	N/A	N/A	N/A
37X-ZE-00215	856.3	2-8	03/31/2021	156	No Reading	N/A	N/A	N/A
37X-ZE-00216	856.3	2-8	04/16/2021	662	No Reading	N/A	N/A	N/A
37X-ZE-00225	862.4	2-9	04/16/2021	312	No Reading	N/A	N/A	N/A
37X-ZE-00226	862.4	2-9	04/16/2021	41	No Reading	N/A	N/A	N/A
37X-ZE-00229	862.4	2-9	04/16/2021	908	No Reading	N/A	N/A	N/A
37X-ZE-00235	856.3	2-10	04/16/2021	-344	No Reading	N/A	N/A	N/A
37X-ZE-00236	857	2-10	04/16/2021	167	No Reading	N/A	N/A	N/A
37X-ZE-00237	856.3	2-10	05/14/2021	-363	No Reading	N/A	N/A	N/A
37X-ZE-00238	857	2-10	04/16/2021	567	No Reading	N/A	N/A	N/A
37X-ZE-00239	862.4	2-11	04/16/2021	416	No Reading	N/A	N/A	N/A
37X-ZE-00242	862.4	2-11	03/31/2021	96	No Reading	N/A	N/A	N/A

1. N/A : Not Applicable or No Comments or None

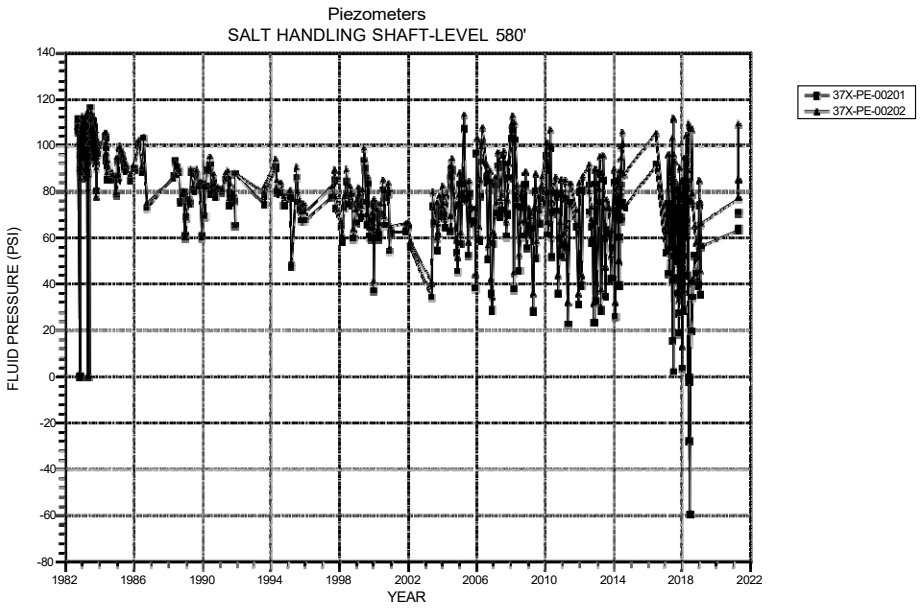


Figure 2-1 Piezometers Salt Handling Shaft – Level 580 at the Forty-niner Member

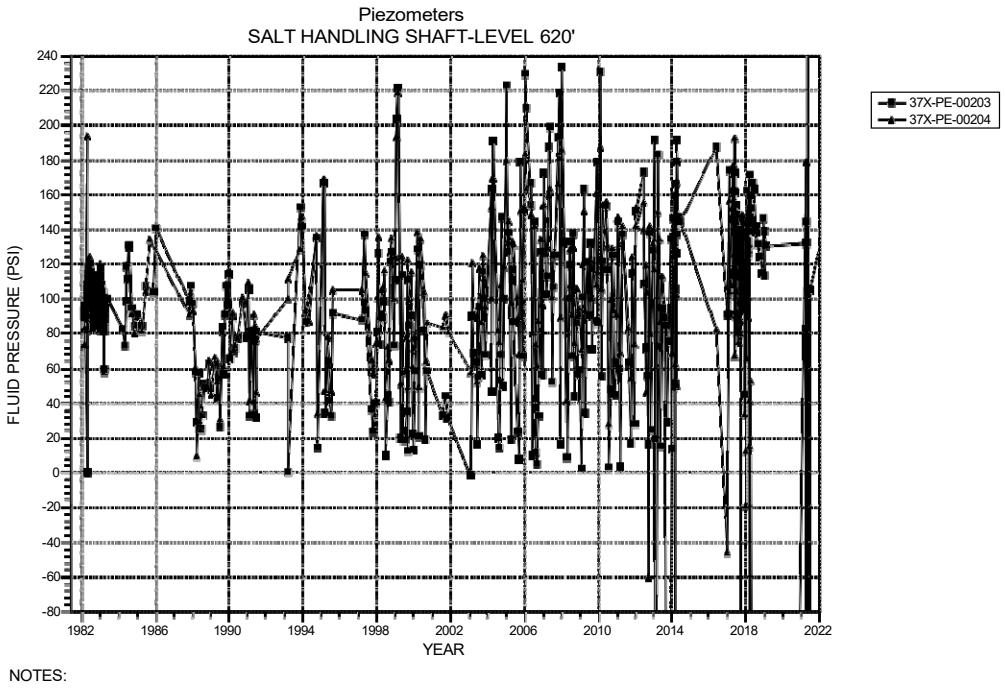


Figure 2-2 Piezometer Salt Handling Shaft – Level 620 at the Magenta Dolomite Member

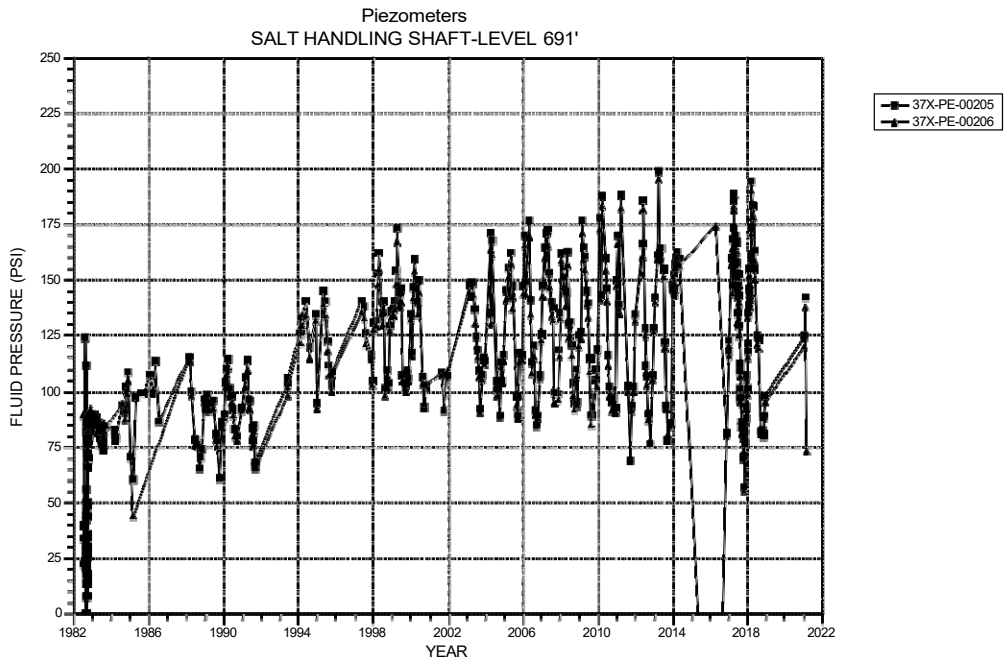


Figure 2-3 Piezometers Salt Handling Shaft – Level 691 at the Tamarisk Member

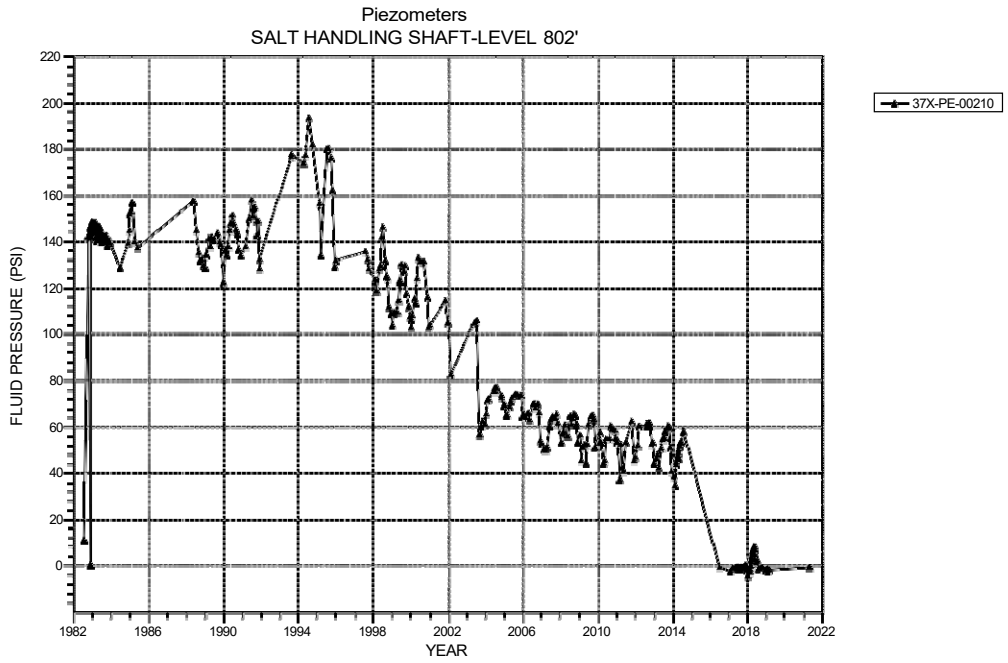


Figure 2-4 Piezometer Salt Handling Shaft – Level 802 at the Los Medaños Member

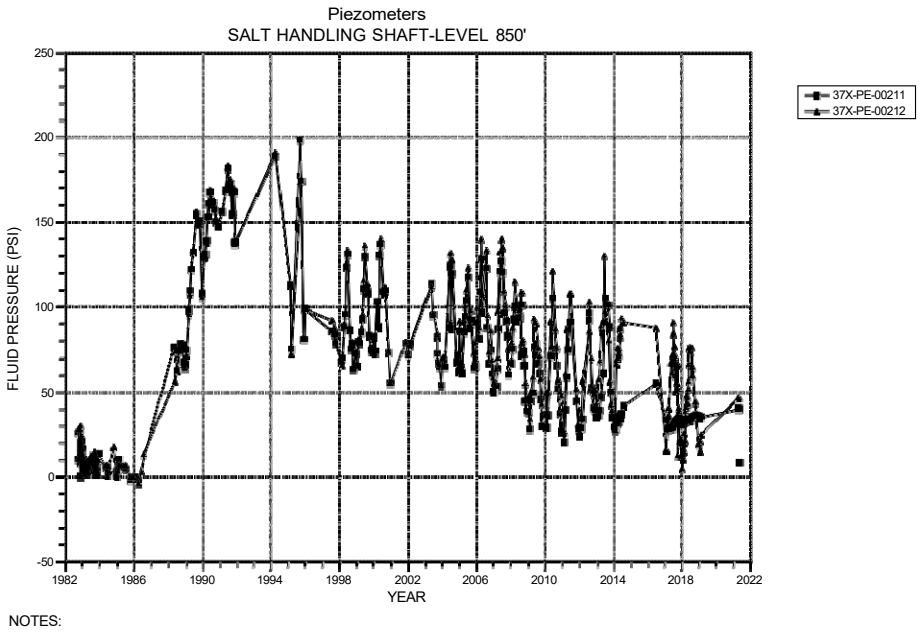


Figure 2-5 Piezometer Salt Handling Shaft – Level 850 at the Rustler-Salado Contact

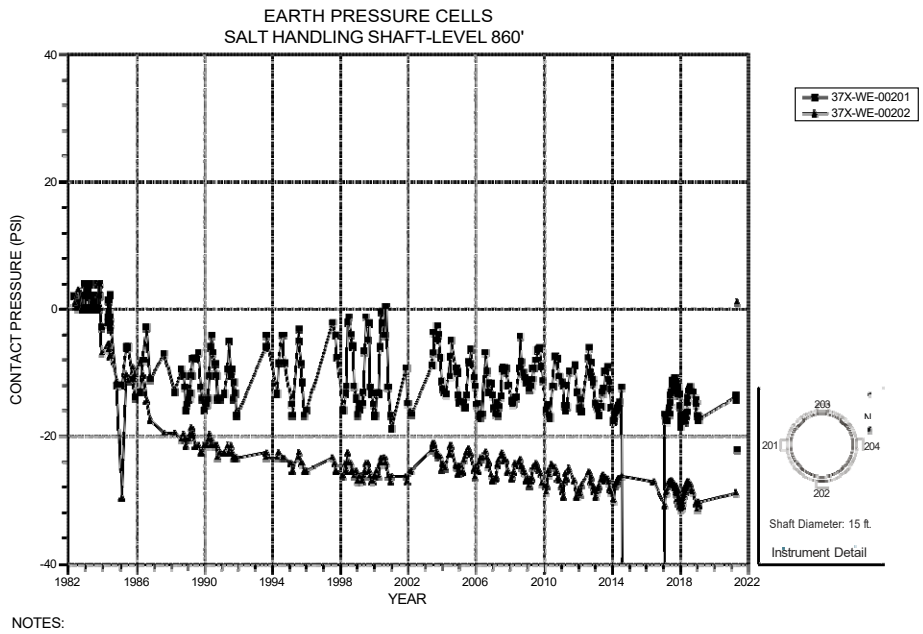


Figure 2-6 Earth Pressure Cells – Salt Handling Shaft Key – Level 860

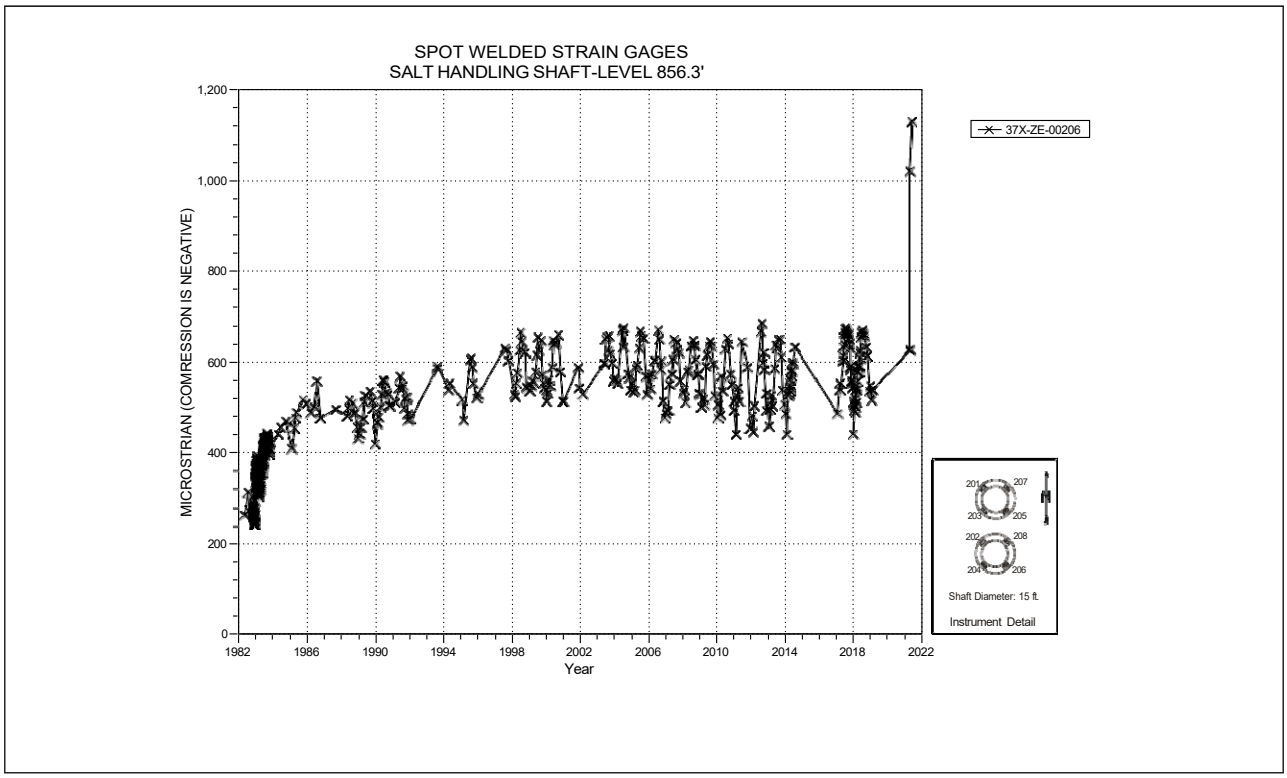


Figure 2-7 Spot Welded Strain Gauge – Salt Handling Shaft Key – Level 856.3

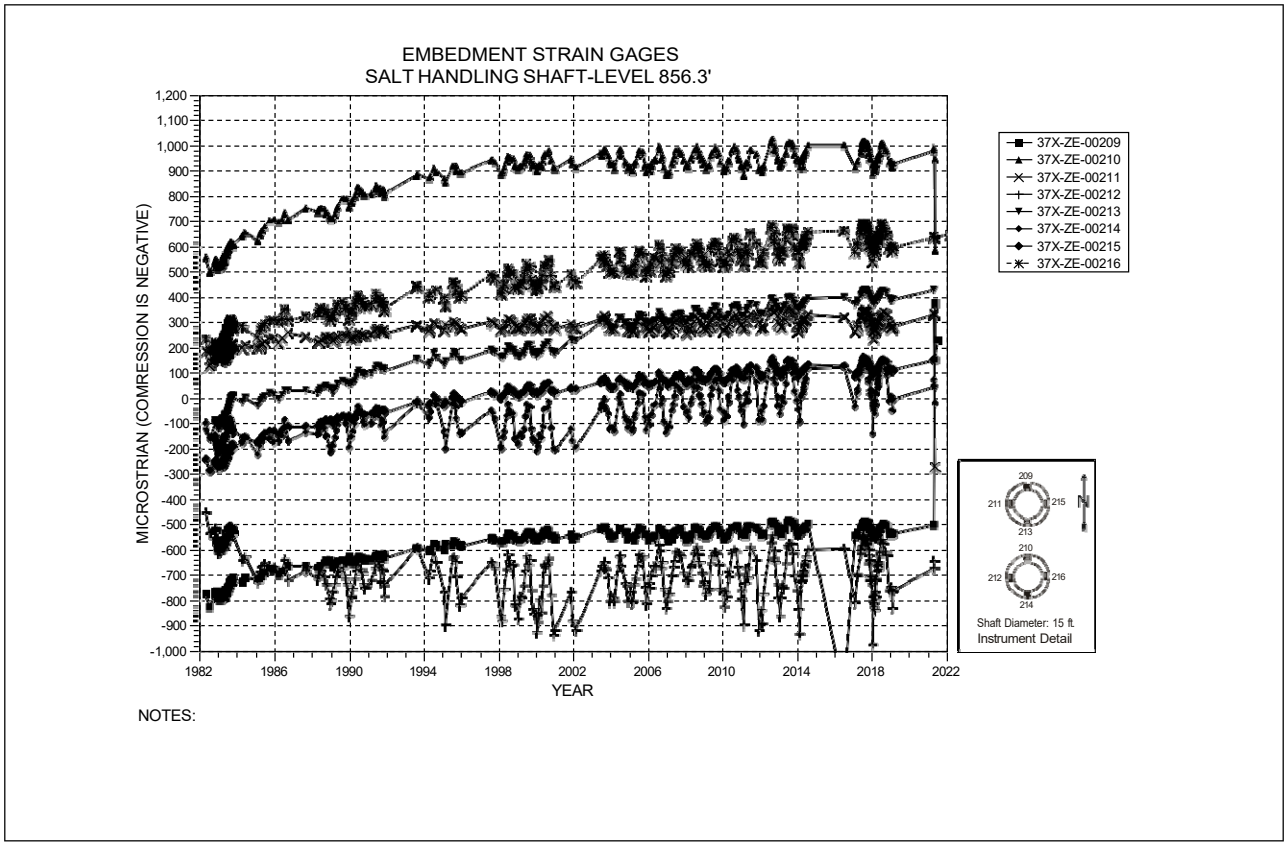


Figure 2-8 Embedment Strain Gauge – Salt Handling Shaft Key – Level 856.3

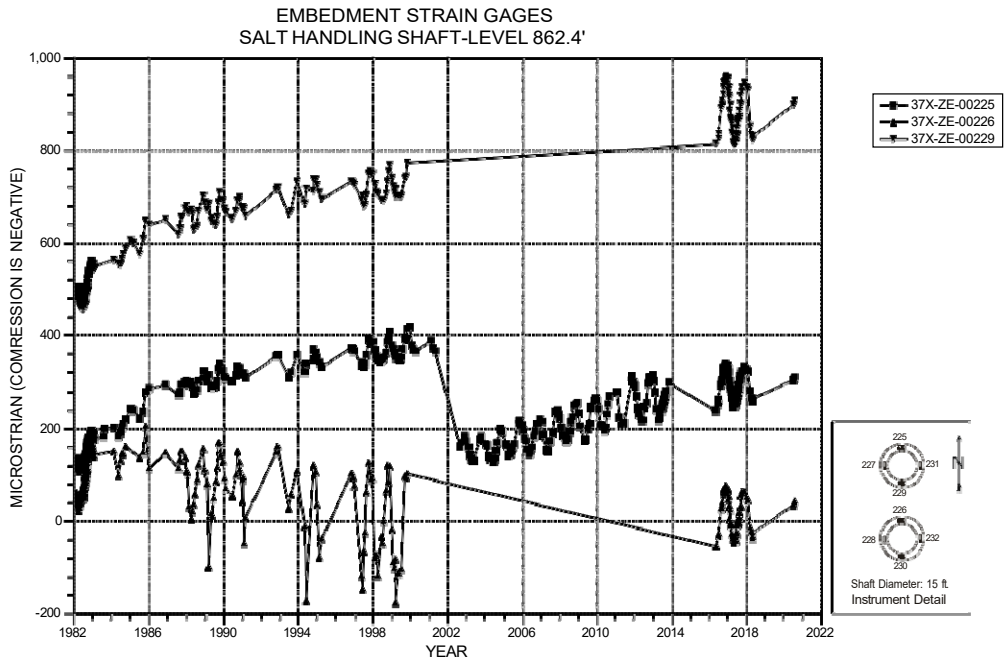


Figure 2-9 Embedment Strain Gauge – Salt Handling Shaft Key – Level 862.4

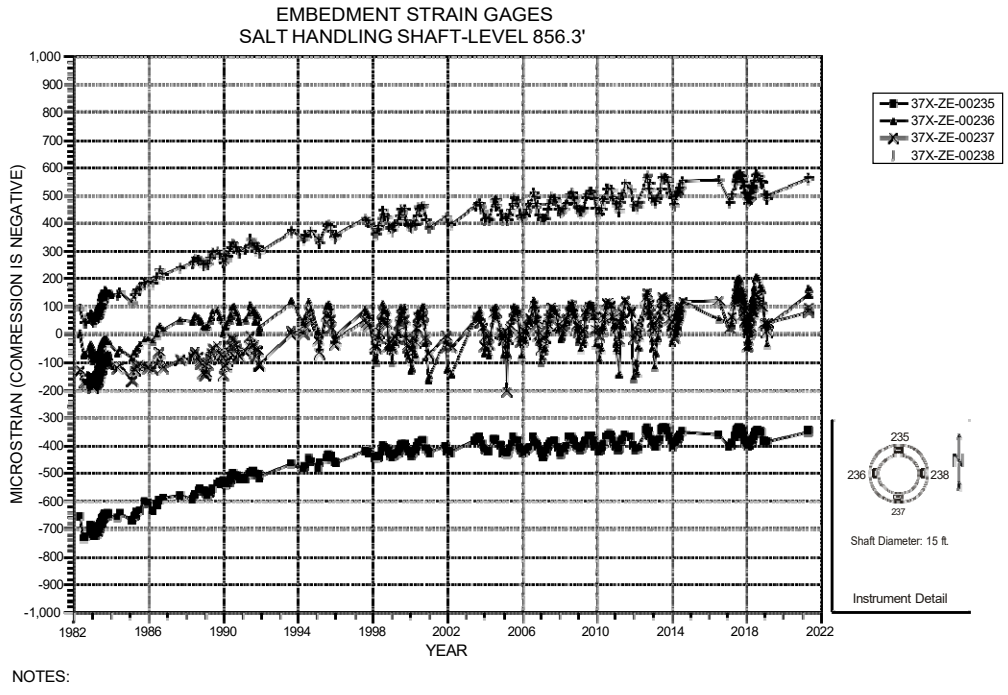


Figure 2-10 Embedment Strain Gauge – Salt Handling Shaft Key – Level 856.3

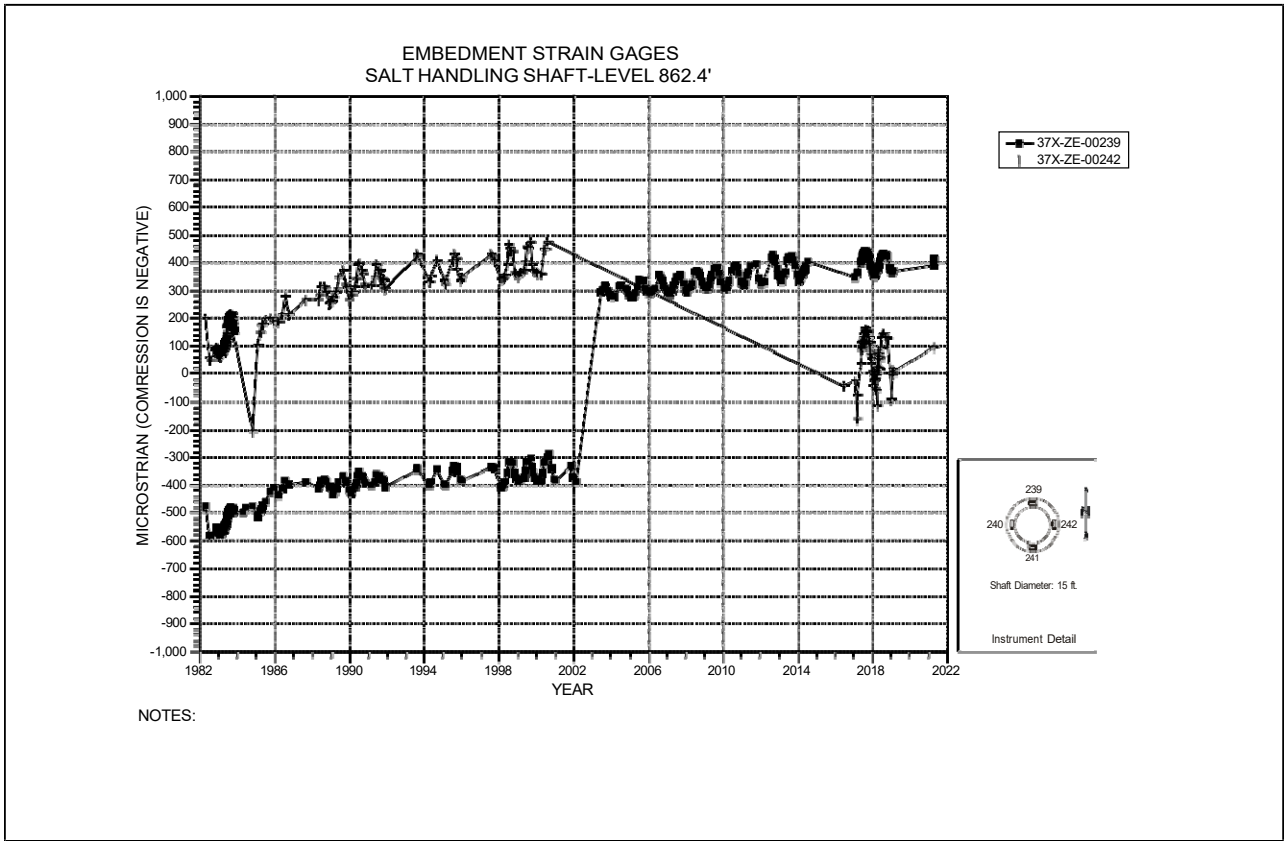


Figure 2-11 Embedment Strain Gauge – Salt Handling Shaft Key – Level 862.4

3.0 INSTRUMENTATION SUMMARY FOR THE SHAFTS STATIONS

The following instrumentation data analysis is for the Salt Handling Shaft Station. Table 3-1 presents data analyses for each of the Salt Handling Shaft Station instruments. Figures 3-1 through 3-4 present plots of the instrumentation data for the Salt Handling Shaft Station.

The Waste Shaft Station and the area around the bottom of the Air Intake Shaft are presented in Section 4.0, Table 4-1, and in the applicable graphs. Please note below the corresponding Instrument Field Tags, Locations, and Figure Number in the report.

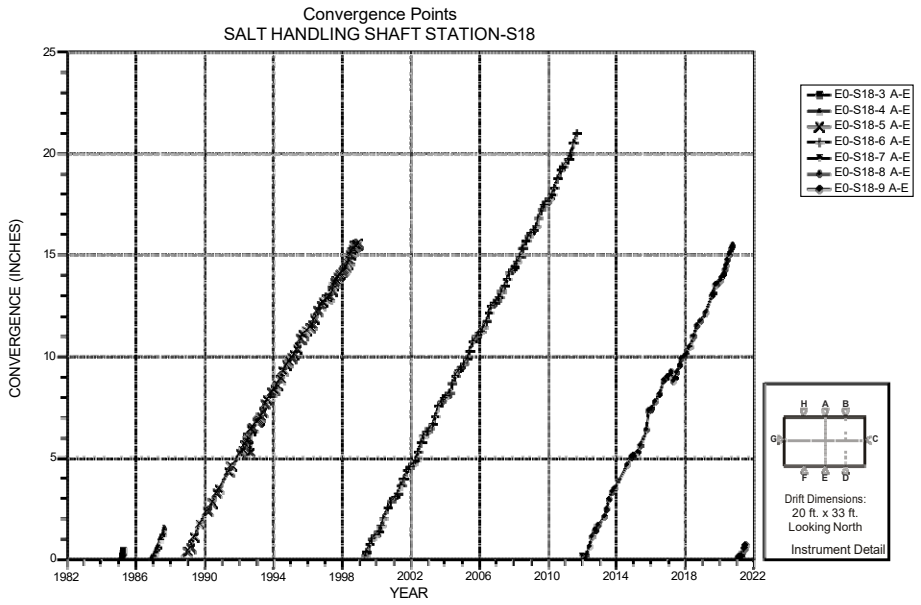
Waste Shaft Station			
Instrument Field Tag	Instrument Type	Location	Table 4-1 Figure Number
51X-GE-00404-2	Extensometer	S400-E35	4-17
W30-S400-2 A-C	Convergence Point	W30-S400	4-194

AIS Shaft Bottom			
Instrument Field Tag	Instrument Type	Location	Table 4-1 Figure Number
51X-GE-00440	Extensometer	AIS North Brow	4-13
51X-GE-00441	Extensometer	AIS South Brow	4-14
51X-GE-00401	Extensometer	W620- N20	4-15
41X-GE-00122	Extensometer	W620- S65	4-16

Table 3-1 Salt Handling Shaft Station Data Analysis

Convergence Points									
Field Tag	Location	Figure Number	Last Reading 2020-2021		Cumulative Displacement (inches)	Closure Rate 2020 to 2021 (in/year)	Closure Rate 2019 to 2020 (in/year)	Rate Change Percent	Comments[1]
			Date	Inches					
E0-S18-9 A-E	E0-S18	3-1	06/15/2021	0.690	54.836	2.2	1.9	16	N/A
E0-S18-7 B-D	E0-S18	3-2	06/15/2021	5.889	40.442	2.6	2.4	8	N/A
E0-S18-5 H-F	E0-S18	3-2	10/08/2020	9.541	24.002	1.4	1.1	27	N/A
E0-S30-7 A-C	E0-S30	3-3	06/15/2021	0.687	38.124	2.1	2.0	5	N/A
E0-S65-6 A-C	E0-S65	3-4	06/15/2021	0.436	26.066	1.4	1.2	17	N/A

1. N/A: Not Applicable or Not Available or No Comments



NOTES:
1. Excavation date: May 1982.

Figure 3-1 Convergence Point Array – Salt Handling Shaft Station at S18 – Roof to Floor

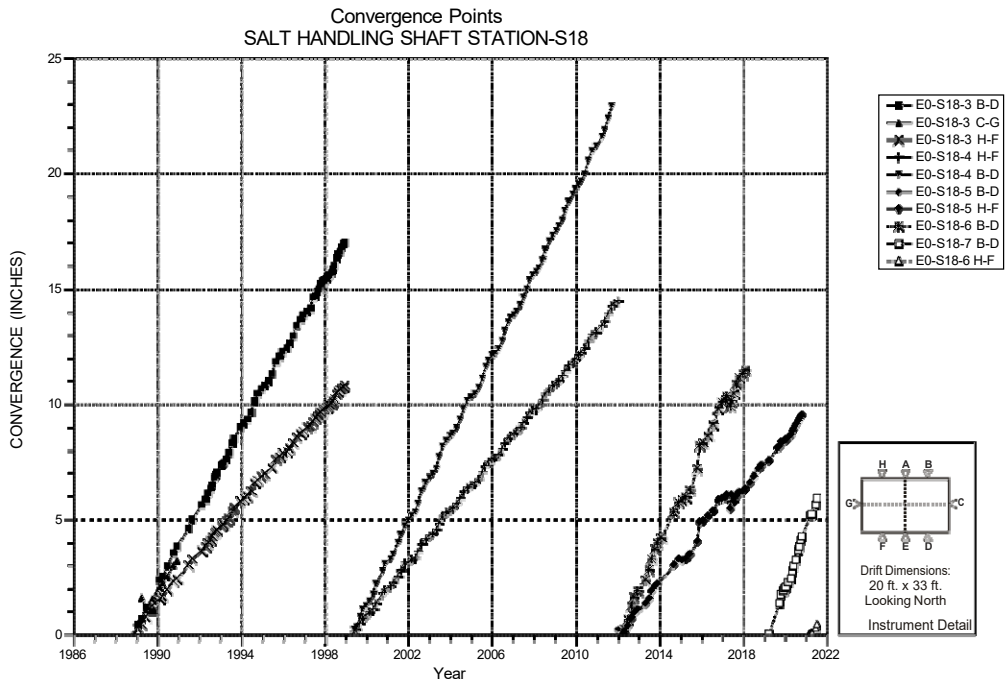
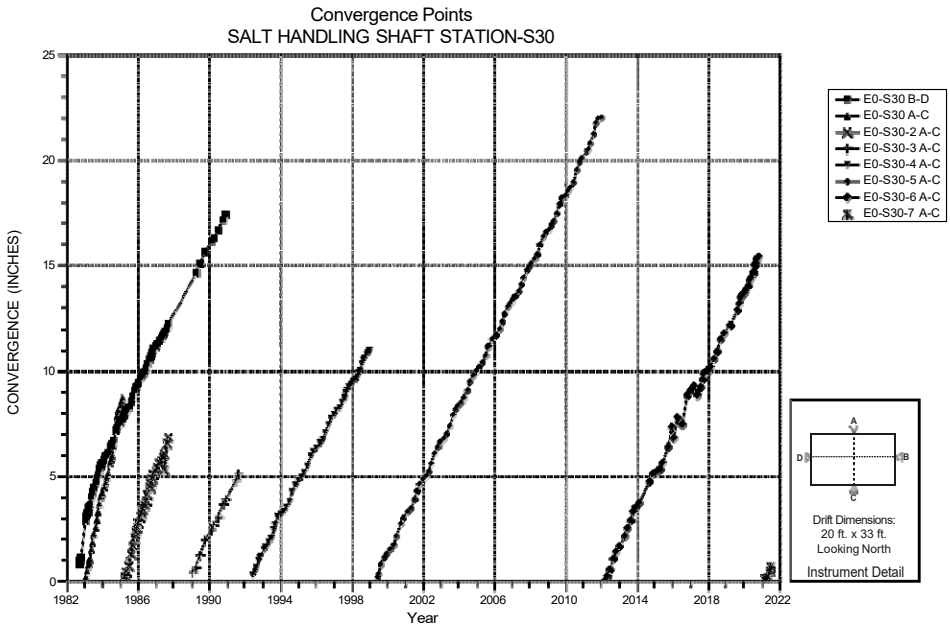
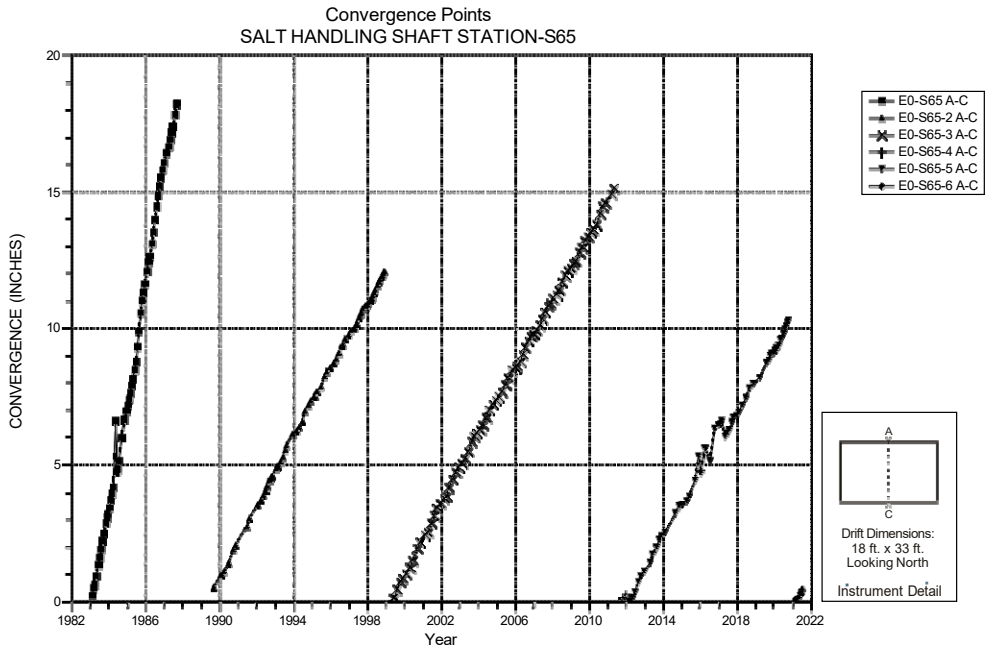


Figure 3-2 Convergence Point Array – Salt Handling Shaft Station at S18 – All Chords



NOTES:
1. Excavation date: May 1982.

Figure 3-3 Convergence Point Array – Salt Handling Shaft Station at S30 – All Chords



NOTES:
1. Excavation date: May 1982.

Figure 3-4 Convergence Point Array – Salt Handling Shaft Station at S65 – Roof to Floor

4.0 INSTRUMENTATION SUMMARY FOR THE ACCESS DRIFTS

This chapter presents the instrumentation data and data analyses for the access drifts throughout the WIPP underground:

- Table 4-1 provides the results of analyses performed on the instrument data including displacement, convergence rates, and rock bolt loading.
- Figures 4-1 through 4-7 present data from convergence meters in the access drifts.
- Figures 4-8 through 4-23 present data from borehole extensometers installed in the access drifts.
- Figures 4-24 through 4-210 present the convergence point data.
- Figures 4-211 through 4-214 present data from joint meters installed at the S1950-E300 overcast and the access drifts.
- Figures 4-215 through 4-224 present the AIS brow support rock bolt load cell data.

Table 4-1 Access Drifts Data Analysis

Wire Convergence Meters								
Field Tag	Location	Figure Number	Date of Last Reading	Displacement (inches)	Displacement Rate 2020 to 2021 (in/year)	Displacement Rate 2019 to 2020 (in/year)	Rate Change Percent[1]	Comments
51X-CW-01037	E140-S2750	4-1	6/02/2021	16.593	4.2	4.2	0	N/A
51X-CW-01052	S2180-E100	4-2	6/29/2021	1.726	1.9	N/A	N/A	New Instrument
51X-CW-01051-2	S2180-E80	4-3	6/29/2021	3.997	4.4	N/A	N/A	New Instrument
51X-PG-00445	S700-E220	4-4	8/3/2020	2.722	1.8	1.8	0	N/A
51X-CW-01039	W170-S2735	4-5	6/02/2021	9.136	2.7	2.3	17	N/A
51X-CW-01038	W30-S2750	4-6	6/02/2021	28.16	6.6	7.1	-8	N/A
51X-PG-00446	N460-E320	4-7	6/18/2021	3.018	1.2	1.2	0	N/A
Extensometers								
Field Tag	Location	Figure Number	Date of Last Reading	Collar Displacement Relative to Deepest Anchor (inches)	Displacement Rate 2020 to 2021 (in/year)	Displacement Rate[1] 2019 to 2020 (in/year)	Rate Change Percent[1]	Comments
51X-GE-00353	E0-N626	4-8	6/25/2021	17.186	1.1	1.1	0	N/A
51X-GE-00352-2	E0-N940	4-9	6/25/2021	2.702	1.2	1.2	0	N/A
51X-GE-00364	E140-N1266	4-10	6/25/2021	13.659	0.9	1.2	-25	N/A
51X-GE-00374	E300-N1186	4-11	6/25/2021	14.994	0.9	1.2	-25	N/A
51X-GE-00388	E300-N1266	4-12	6/25/2021	11.712	0.7	1.2	-42	N/A
51X-GE-00440	AIS North Brow	4-13	6/18/2020	1.194	0.3	0.3	0	N/A
51X-GE-00441	AIS South Brow	4-14	6/18/2020	1.449	0.3	0.4	-25	N/A
51X-GE-00401	W620- N20	4-15	6/25/2021	3.107	0.2	0.2	0	Data from anchor B
41X-GE-00122	W620- S65	4-16	10/1/2020	5.326	0.6	0.3	100	Data from anchor B
51X-GE-00404-2	Waste Shaft Station	4-17	6/25/2021	3.208	0.3	0.3	0	N/A
51X-GE-00448	E140-S1498	4-18	6/18/2021	0.962	0.5	0.5	0	N/A
51X-GE-00449	E140-S1518	4-19	6/18/2021	1.424	0.7	0.8	13	N/A
51X-GE-00450	E140-S1546	4-20	6/18/2021	2.200	1.1	1.1	0	N/A
51X-GE-00445	E140-S1665	4-21	6/18/2021	2.645	1.3	1.4	7	N/A
51X-GE-00446	E140-S1694	4-22	6/18/2021	2.044	1.1	1.0	10	N/A
51X-GE-00447	E140-S1717	4-23	6/18/2021	2.105	1.2	1.0	20	N/A

Table 4-1 Access Drifts Data Analysis, continued

Convergence Points									
Field Tag	Location	Figure Number	Last Reading 2020 - 2021		Cumulative Displacement (inches)	Closure Rate 2020 to 2021 (in/year)	Closure Rate[1] 2019 to 2020 (in/year)	Rate Change Percent[1]	Comments
			Date	Inches					
CORE-W30 A-C	CORE STORAGE W30	4-24	6/08/2021	32.782	32.782	1.0	1.4	-29	N/A
CORE-W73 A-C	CORE STORAGE W73	4-24	6/08/2021	39.924	39.924	1.3	1.3	0	N/A
E0-N75 A-C	E0-N75	4-25	6/15/2021	38.839	38.839	2.1	2.2	-5	N/A
E0-N225-5 A-C	E0-N225	4-26	6/15/2021	3.883	51.698	1.6	1.6	0	N/A
E0-N300-6 A-C	E0-N300	4-27	6/15/2021	19.038	35.375	1.7	1.9	-11	N/A
E0-N460-5 A-C	E0-N460	4-28	6/15/2021	3.334	64.411	2.0	2.5	-8	N/A
E0-N562 A-C	E0-N562	4-29	6/15/2021	39.282	39.282	3.3	2.9	14	N/A
E0-N626-5 A-C	E0-N626	4-30	6/15/2021	14.275	85.671	2.6	2.8	-7	N/A
E0-N686 A-C	E0-N686	4-31	10/08/2020	43.701	43.701	3.2	2.6	23	N/A
E0-N780-2 A-C	E0-N780	4-32	6/15/2021	38.297	58.719	2.1	2.2	-5	N/A
E0-N940-5 A-C	E0-N940	4-33	6/15/2021	45.216	93.268	2.6	2.9	-10	N/A
E0-N1100-5 A-C	E0-N1100	4-34	6/15/2021	27.614	62.038	1.5	1.7	-12	N/A
E0-N1266-4 A-C	E0-N1266	4-35	6/15/2021	43.078	79.985	2.3	2.9	-21	N/A
E0-N1420-2 A-C	E0-N1420	4-36	6/15/2021	20.931	20.931	1.0	1.2	-17	N/A
E140-N5-8 A-C	E140-N5	4-37	6/17/2021	0.111	70.137	2.0	2.8	-29	N/A
E140-N150-7 A-C	E140-N150	4-38	6/17/2021	0.142	45.746	2.6	1.7	53	N/A
E140-N250-5 A-C	E140-N250	4-39	6/17/2021	0.111	65.284	1.9	3.0	3	N/A
E140-N355-3 A-C	E140-N355	4-40	6/17/2021	0.180	42.946	3.1	2.4	29	N/A
E140-N460-4 A-C	E140-N460	4-41	6/17/2021	0.151	62.873	2.6	2.4	8	N/A
E140-N562-4 A-C	E140-N562	4-42	6/17/2021	0.362	57.574	3.1	3.1	0	N/A
E140-N626-4 A-C	E140-N626	4-43	6/17/2021	3.400	92.807	3.0	3.6	-17	N/A
E140-N686-3 A-C	E140-N686	4-44	6/17/2021	2.759	58.799	2.5	2.9	14	N/A
E140-N780-5 A-C	E140-N780	4-45	6/17/2021	0.237	78.514	1.8	2.1	-14	N/A
E140-N1100-2 A-C	E140-N1100	4-46	6/17/2021	28.422	48.145	1.3	1.5	-13	N/A
E140-N1266-3 A-C	E140-N1266	4-47	6/17/2021	45.942	83.697	2.5	2.8	-11	N/A
E140-N1420-2 A-C	E140-N1420	4-48	6/15/2021	30.926	47.396	1.5	1.8	-17	N/A
E140-S90-5 A-C	E140-S90	4-49	6/17/2021	0.149	47.185	2.7	2.1	29	N/A
E140-S262-5 A-C	E140-S262	4-50	6/1/2021	18.317	55.338	2.0	2.2	-9	N/A

Table 4-1 Access Drifts Data Analysis (continued)

Convergence Points									
Field Tag	Location	Figure Number	Last Reading 2020-2021		Cumulative Displacement (inches)	Closure Rate 2020 to 2021 (in/year)	Closure Rate[1] 2019 to 2020 (in/year)	Rate Change Percent[1]	Comments
			Date	Inches					
E140-S460-8 A-C	E140-S460	4-51	3/11/2021	9.292	69.566	2.0	2.2	-9	N/A
E140-S550-8 A-C	E140-S550	4-52	6/1/2021	2.116	61.993	2.0	N/A	N/A	New replacement point
E140-S700-9 A-D	E140-S700	4-53	6/24/2021	2.624	62.501	2.4	2.4	0	N/A
E140-S850-10 A-C	E140-S850	4-54	6/24/2021	22.552	80.288	3.1	3.1	0	N/A
E140-S1000-4 A-C	E140-S1000	4-55	6/24/2021	14.532	54.879	1.8	1.9	-5	N/A
E140-S1025-6 A-C	E140-S1025	4-56	6/24/2021	9.922	44.786	2.2	2.2	0	N/A
E140-S1075-5 A-E	E140-S1075	4-57	6/24/2021	26.130	54.932	3.5	3.5	0	N/A
E140-S1150-7 A-G	E140-S1150	4-58	6/24/2021	1.094	69.907	3.3	3.3	0	N/A
E140-S1225-7 A-E	E140-S1225	4-59	6/24/2021	1.287	64.585	3.1	3.3	-6	N/A
E140-S1300-7 A-C	E140-S1300	4-60	6/24/2021	0.557	49.183	0.3	N/A	N/A	New replacement point
E140-S1378-4 A-E	E140-S1378	4-61	6/24/2021	27.614	70.155	3.0	3.1	-3	N/A
E140-S1450-6 A-G	E140-S1450(1456)	4-62	6/1/2020	30.394	111.2	3.5	3.6	-3	N/A
E140-S1496 A-E	E140-S1496 (Test Area)	4-63	6/03/2021	7.153	7.153	3.2	3.2	0	N/A
E140-S1496 B-D	E140-S1496 (Test Area)	4-64	6/03/2021	2.973	2.973	1.5	1.5	0	N/A
E140-S1496 H-F	E140-S1496 (Test Area)	4-65	6/03/2021	3.840	3.840	1.9	2.0	-5	N/A
E140-S1524 A-E	E140-S1524 (Test Area)	4-66	12/1/2020	4.424	4.424	2.8	2.8	0	N/A
E140-S1524 B-D	E140-S1524 (Test Area)	4-67	1/06/2021	4.020	4.020	2.6	2.6	0	N/A
E140-S1524 H-F	E140-S1524 (Test Area)	4-68	1/06/2021	5.931	5.931	5.1	3.4	50	N/A
E140-S1534-5 A-E	E140-S1534 (Test Area)	4-69	6/03/2021	6.574	77.088	2.91	3.0	-3	N/A
E140-S1534-6 B-D	E140-S1534 (Test Area)	4-70	6/03/2021	6.646	55.533	3.5	N/A	N/A	No reading last year
E140-S1534-5 H-F	E140-S1534 (Test Area)	4-71	6/03/2021	6.758	59.808	2.9	N/A	N/A	No reading last year
E140-S1548 A-E	E140-S1548 (Test Area)	4-72	6/03/2021	6.329	6.329	3.0	3.2	-6	N/A
E140-S1548 B-D	E140-S1548 (Test Area)	4-73	6/03/2021	3.574	3.574	1.6	2.0	-20	N/A
E140-S1548 H-F	E140-S1548 (Test Area)	4-74	6/03/2020	5.615	5.615	2.8	3.0	-7	N/A
E140-S1600-8 A-C	E140-S1600	4-75	6/24/2021	1.173	69.265	3.5	4.4	-20	N/A
E140-S1667 B-D	E140-S1667 (Test Area)	4-76	6/03/2021	6.531	6.531	3.0	3.4	-12	N/A
E140-S1667 H-F	E140-S1667 (Test Area)	4-77	6/03/2021	6.509	6.509	2.9	3.1	-6	N/A
E140-S1687-5 A-E	E140-S1687(S1699)	4-78	6/24/2021	12.187	75.641	3.4	3.5	-3	N/A

Table 4-1 Access Drifts Data Analysis (continued)

Convergence Points (continued)									
Field Tag	Location	Figure Number	Last Reading 2020-2021		Cumulative Displacement (inches)	Closure Rate 2020 to 2021 (in/year)	Closure Rate[1] 2019 to 2020 (in/year)	Rate Change Percent[1]	Comments
			Date	Inches					
E140-S1699 B-D	E140-S1699 (Test Area)	4-79	6/03/2021	6.205	6.205	3.2	3.0	7	N/A
E140-S1699 H-F	E140-S1699 (Test Area)	4-80	6/03/2021	5.319	3.190	2.7	2.6	4	N/A
E140-S1717 B-D	E140-S1717 (Test Area)	4-81	6/03/2021	4.792	4.792	2.3	2.4	-4	N/A
E140-S1717 A-E	E140-S1717 (Test Area)	4-82	6/03/2021	6.737	6.737	3.3	3.4	-3	N/A
E140-S1717 H-F	E140-S1717 (Test Area)	4-83	6/03/2021	8.516	8.516	4.5	4.2	7	N/A
E140-S1775-5 A-G	E140-S1775 (1784)	4-84	1/19/2021	30.791	98.977	3.7	3.7	0	N/A
E140-S1862-5 A-E	E140-S1862	4-85	6/24/2021	1.162	82.705	3.5	3.7	-5	N/A
E140-S1950-8 A-C	E140-S1950	4-86	6/24/2021	1.573	89.702	3.7	4.4	-16	N/A
E140-S2007-8 A-C	E140-S2007	4-87	6/24/2021	38.506	83.033	4.1	4.6	-11	N/A
E140-S2065-8 A-C	E140-S2065	4-88	6/24/2021	15.307	79.057	3.4	3.8	-11	N/A
E140-S2122-8 A-C	E140-S2122	4-89	5/19/2021	16.51	76.463	3.9	4.2	-7	N/A
E140-S2170 A-C	E140-S2170	4-90	6/29/2021	1.021	1.021	4.5	N/A	N/A	New Installation
E140-S2190 A-C	E140-S2190	4-91	6/29/2021	0.901	0.901	4.0	N/A	N/A	New Installation
E140-S2275-7 A-C	E140-S2275	4-92	6/02/2021	46.652	125.589	5.7	6.3	-11	N/A
E140-S2350-7 A-C	E140-S2350	4-93	6/02/2021	45.685	128.398	5.9	6.1	-3	N/A
E140-S2425-6 A-C	E140-S2425	4-94	6/02/2021	38.649	94.155	4.7	5.0	-6	N/A
E140-S2520-4 A-C	E140-S2520	4-95	6/02/2021	32.704	73.48	3.7	4.1	-10	N/A
E300-N45-2 A-E	E300-N45	4-96	6/17/2021	15.152	48.033	1.6	1.9	-16	N/A
E300-N170-3 A-E	E300-N170	4-97	6/17/2021	18.326	51.800	2.0	2.5	-20	N/A
E300-N250-5 A-C	E300-N250	4-98	6/17/2021	9.432	61.353	2.5	2.6	-4	N/A
E300-N280 A-C	E300-N280	4-99	6/17/2021	6.684	6.684	1.5	1.7	-12	N/A
E300-N360 A-C	E300-N360	4-100	6/17/2021	6.121	6.121	1.3	1.6	-19	N/A
E300-N440 A-C	E300-N440	4-101	6/17/2021	6.186	6.186	1.1	1.5	-27	N/A
E300-N500 A-C	E300-N500	4-102	6/17/2021	4.338	4.338	0.7	1.1	-36	N/A
N1100-E300-2 A-C	N1100-E300	4-103	6/17/2021	17.955	17.955	1.6	1.9	-16	N/A
E300-N1262-5 A-C	E300-N1262	4-104	6/15/2021	2.221	50.354	2.6	3.0	-13	N/A
E300-N1341-4 A-C	E300-N1341	4-105	6/15/2021	2.772	45.931	2.5	2.8	-11	N/A
E300-S45-3 A-E	E300-S45	4-106	6/17/2021	12.297	39.501	1.4	1.5	-7	N/A
E300-S90-3 A-C	E300-S90	4-107	6/17/2021	10.25	30.527	1.0	1.4	-29	N/A
E300-S250-2 A-C	E300-S250	4-108	6/17/2021	16.649	21.034	0.64	1.1	-42	N/A

Table 4-1 Access Drifts Data Analysis (continued)

Convergence Points (continued)									
Field Tag	Location	Figure Number	Last Reading 2020-2021		Cumulative Displacement (inches)	Closure Rate 2020 to 2021 (in/year)	Closure Rate[1] 2019 to 2020 (in/year)	Rate Change Percent[1]	Comments
			Date	Inches					
E300-S400 A-C	E300-S400	4-109	6/16/2021	1.820	1.820	1.1	1.2	-8	N/A
E300-S550 A-C	E300-S550	4-110	6/16/2021	0.945	0.945	0.5	0.6	-17	N/A
E300-S700-2 A-C	E300-S700	4-111	6/16/2021	15.505	35.235	1.5	1.6	-6	N/A
E300-S850-2 A-E	E300-S850	4-112	6/16/2021	7.937	23.019	0.8	0.9	-11	N/A
E300-S1000-2 A-C	E300-S1000	4-113	6/16/2021	10.732	30.277	1.0	1.0	0	N/A
E300-S1150-5 A-E	E300-S1150	4-114	6/16/2021	3.485	33.494	1.8	2.0	-10	N/A
E300-S1300-3 A-C	E300-S1300	4-115	6/16/2021	2.685	27.116	1.4	1.5	-7	N/A
E300-S1450-3 A-C	E300-S1450	4-116	6/16/2021	3.461	23.500	1.7	2.0	-15	N/A
E300-S1687-3 A-C	E300-S1687	4-117	2/17/2021	2.900	21.871	1.9	1.9	0	N/A
E300-S1775-3 A-C	E300-S1775	4-118	6/16/2021	3.047	22.775	1.7	1.9	-11	N/A
E300-S1862-3 A-C	E300-S1862	4-119	6/16/2021	2.963	24.417	1.6	1.8	-11	N/A
E300-S2065-3 A-C	E300-S2065	4-120	6/16/2021	3.334	27.556	1.9	1.9	0	N/A
E300-S2275-3 A-C	E300-S2275	4-121	6/16/2021	6.313	41.716	3.4	3.5	-3	N/A
E300-S2350-3 A-C	E300-S2350	4-122	6/16/2021	6.542	55.078	3.7	3.7	0	N/A
E300-S2425-3 A-C	E300-S2425	4-123	6/16/2021	5.629	45.626	3.2	3.2	0	N/A
N140-E90-3 A-C	N140-E90	4-124	6/17/2021	6.113	30.100	0.8	0.9	-11	N/A
W660-N150-2 A-C	W660-N150	4-125	6/15/2021	1.200	4.423	0.6	1.0	-40	N/A
N215-W500-2 A-C	N215-W500	4-126	6/15/2021	23.189	41.518	1.0	1.3	-23	N/A
N215-W620-2 A-C	N215-W620	4-127	6/15/2021	18.28	34.498	0.8	1.1	-27	N/A
N250-E220-4 A-E	N250-E220	4-128	6/17/2021	9.385	62.136	2.6	2.9	-10	N/A
N300-W170-2 A-C	N300-W170	4-129	6/18/2020	29.326	51.586	1.6	1.7	-6	N/A
N460-E70-3 A-C	N460-E70	4-130	6/17/2021	30.458	46.904	1.5	1.8	-17	N/A
N460-E310 A-C	N460-E310	4-131	6/17/2021	7.300	7.300	1.3	1.8	-28	N/A
N780-E70 A-C	N780-E70	4-132	6/15/2021	26.079	26.079	1.4	1.6	-13	N/A

Table 4-1 Access Drifts Data Analysis (continued)

Convergence Points (continued)									
Field Tag	Location	Figure Number	Last Reading 2020-2021		Cumulative Displacement (inches)	Closure Rate 2020 to 2021 (in/year)	Closure Rate[1] 2019 to 2020 (in/year)	Rate Change Percent[1]	Comments
			Date	Inches					
N1420-E79 A-C	N1420-E79	4-133	6/15/2021	6.568	6.568	1.4	1.6	-13	N/A
N1420-E212 A-C	N1420-E212	4-134	6/15/2021	5.988	5.988	1.2	1.4	-14	N/A
N1420-E300 A-C	N1420-E300	4-135	6/15/2021	30.623	30.623	1.6	1.9	-16	N/A
S90-E220 A-C	S90-E220	4-136	6/17/2021	7.952	7.952	0.9	1.1	-18	N/A
S90-W120 A-C	S90-W120	4-137	6/08/2021	13.632	13.632	0.6	0.6	0	N/A
S90-W400-3 A-C	S90-W400	4-138	6/08/2021	4.438	23.29	0.6	0.6	0	N/A
S90-W590-2 A-C	S90-W590	4-139	6/8/2021	9.610	18.939	0.6	0.6	0	N/A
S400-E10 A-C	S400-E10	4-140	6/1/2021	0.280	0.280	0.93	N/A	N/A	New installation this period
S90-W620 A-C	S90-W620	4-141	6/8/2021	35.385	35.385	1.0	1.0	0	N/A
S400-E360 A-C	S400-E360	4-142	6/16/2021	1.931	1.931	1.1	1.3	-15	N/A
S400-E420 A-C	S400-E420	4-143	6/16/2021	1.659	1.659	0.9	1.2	-25	N/A
S700-E180-2 A-C	S700-E180	4-144	6/01/2021	0.204	28.063	2.3	1.9	21	N/A
S700-E205-4 A-C	S700-E205	4-145	6/01/2020	0.183	46.212	2.0	2.0	0	N/A
S700-W98-4 A-C	S700-W98	4-146	6/10/2021	3.408	42.439	2.1	2.2	-5	N/A
S1000-E120-3 A-C	S1000-E120	4-147	6/01/2021	18.843	27.283	1.1	1.2	-8	N/A
S1000-E160 -3 A-C	S1000-E160	4-148	6/01/2021	12.18	20.390	1.0	1.0	0	N/A
S1000-E58-4 A-C	S1000-E58	4-149	6/01/2021	21.625	37.091	1.3	1.5	-13	N/A
S1000-W98-2 A-C	S1000-W98	4-150	6/10/2021	33.895	52.643	1.7	2.3	-26	N/A
S1000-W120 A-C	S1000-W120	4-151	6/10/2021	2.700	2.700	1.5	1.8	-17	N/A
S1300-E120 A-C	S1300-E120	4-152	6/01/2021	24.238	24.238	0.95	1.1	-16	N/A
S1300-E160 A-C	S1300-E160	4-153	6/01/2021	44.815	44.815	2.6	2.7	-4	N/A
S1300-E24-2 A-C	S1300-E24	4-154	6/10/2021	6.692	32.675	1.5	1.9	-21	N/A
S1300-W100-4 A-C	S1300-W100	4-155	6/10//2021	4.025	60.174	2.5	2.3	9	N/A
S1300-W155 A-C	S1300-W155	4-156	6/8/2021	0.425	0.425	1.9	N/A	N/A	New installation this period

Table 4-1 Access Drifts Data Analysis (continued)

Convergence Points (continued)									
Field Tag	Location	Figure Number	Last Reading 2020-2021		Cumulative Displacement (inches)	Closure Rate 2020 to 2021 (in/year)	Closure Rate[1] 2019 to 2020 (in/year)	Rate Change Percent[1]	Comments
			Date	Inches					
S1600-E110-2 A-C	S1600-E110	4-157	6/01/2021	9.313	26.035	1.1	1.3	18	N/A
S1600-W100-2 A-C	S1600-W100	4-158	5/19/2021	15.513	16.53	3.5	3.8	-8	N/A
S1950-E113-5 A-C	S1950-E113	4-159	6/01/2021	0.248	24.955	0.9	1.6	-78	N/A
S1950-E160-2 A-C	S1950-E160	4-160	6/01/2021	0.713	7.347	2.0	2.1	-5	N/A
S1950-E226 A-C	S1950-E226	4-161	6/01/2021	7.666	7.666	1.8	2.1	-14	N/A
S1950-E281-3 A-C	S1950-E281	4-162	6/16/2021	27.345	33.887	1.3	1.3	0	N/A
S1950-W96-2 A-C	S1950-W100	4-163	6/10/2021	16.048	17.019	3.7	4.0	-8	N/A
S2180-E220-2 A-C	S2180-E220	4-164	6/16/2021	3.314	28.073	1.8	1.9	-5	N/A
S2180-W100-3 A-C	S2180-W100	4-165	6/2/2021	37.829	56.012	3.6	3.7	-3	N/A
S2520-E220 A-C	S2520-E220	4-166	6/16/2021	37.037	37.037	1.8	1.9	-5	N/A
S2520-W100-2 A-C	S2520-W100	4-167	3/03/2021	30.527	50.207	3.7	3.8	-3	N/A
S2520-E55-3 A-C	S2520-E55	4-168	6/2/2021	0.481	39.289	3.1	3.0	3	N/A
W170-N150-3 A-C	W170-N150	4-169	6/8/2021	8.506	16.858	0.6	0.7	-14	N/A
S400-W20-2 A-C	S400-W20	4-170	6/10/2021	0.168	0.289	1.461	N/A	N/A	N/A
W170-S5-2 A-C	W170-S5	4-171	6/08/2021	4.684	20.88	0.6	0.6	0	N/A
W170-S90-3 A-C	W170-S90	4-172	6/08/2021	17.674	24.876	1.0	0.9	11	N/A
W30-S90-2 A-C	W30-S90	4-173	6/10/2021	0.294	3.971	0.9	1.1	-18	N/A
W170-S232-2 A-C	W170-S232	4-174	6/08/2021	12.675	18.264	0.7	0.8	-13	N/A
W170-S400 A-C	W170-S400	4-175	6/08/2021	22.463	22.463	0.5	0.9	-44	N/A
W170-S560-4 A-C	W170-S560	4-176	6/08/2021	10.204	21.023	0.8	0.8	0	N/A
W170-S700-3 A-C	W170-S700	4-177	6/08/2021	8.124	33.402	1.1	1.1	0	N/A
W170-S850-8 A-E	W170-S850	4-178	6/08/2021	5.99	26.944	0.8	1.0	-20	N/A
W170-S1000-4 A-C	W170-S1000	4-179	6/08/2021	0.713	38.148	1.1	1.2	-8	N/A
W170-S1150-5 A-E	W170-S1150	4-180	6/08/2021	7.414	32.455	1.1	1.1	0	N/A
W170-S1300-4 A-C	W170-S1300	4-181	6/08/2021	28.767	49.725	2.4	2.4	0	N/A
W170-S1445-4 A-C	W170-S1445	4-182	6/08/2021	25.722	37.014	2.2	2.6	-15	N/A

Table 4-1 Access Drifts Data Analysis (continued)

Convergence Points (continued)									
Field Tag	Location	Figure Number	Last Reading 2020-2021		Cumulative Displacement (inches)	Closure Rate 2020 to 2021 (in/year)	Closure Rate[1] 2019 to 2020 (in/year)	Rate Change Percent[1]	Comments
			Date	Inches					
W170-S1600-5 A-C	W170-S1600	4-183	6/08/2021	2.002	50.356	3.2	4.0	-20	N/A
W170-S1779-3 A-C	W170-S1779	4-184	6/10/2021	28.47	43.441	2.7	3.0	-10	N/A
W170-S1950-3 A-C	W170-S1950	4-185	6/10/2021	23.456	36.637	2.2	2.1	5	N/A
W170-S2060-3 A-C	W170-S2060	4-186	11/5/2020	15.97	34.214	2.2	2.1	5	N/A
W170-S2180-3 A-C	W170-S2180	4-187	6/02/2021	20.996	44.56	2.3	2.5	-8	N/A
W170-S2275 A-C	W170-S2275	4-188	6/02/2020	32.678	32.678	2.1	2.2	-5	N/A
W170-S2350 A-C	W170-S2350	4-189	6/02/2021	43.047	43.047	2.5	2.6	-4	N/A
W170-S2425 A-C	W170-S2425	4-190	6/02/2021	34.454	34.454	2.0	2.0	0	N/A
W170-S2520-2 A-C	W170-S2520	4-191	3/03/2021	32.818	53.413	3.7	3.7	0	N/A
W30-S120-4 A-C	W30-S120	4-192	6/10/2021	0.28	34.422	0.9	1.1	-18	N/A
W30-S250-5 A-C	W30-S250	4-193	6/10/2021	17.636	43.869	1.1	1.1	0	N/A
W30-S400-2 A-C	W30-S400	4-194	6/10/2021	14.283	32.111	1.0	0.9	11	N/A
W30-S500-3 A-C	W30-S500	4-195	6/10/2021	8.817	39.224	1.3	1.3	0	N/A
W30-S550 A-C	W30-S550	4-196	6/10/2021	1.285	1.285	0.5	0.8	-38	N/A
W30-S700-5 A-C	W30-S700	4-197	6/10/2021	24.387	58.664	2.3	2.4	-4	N/A
W30-S850-7 A-E	W30-S850	4-198	6/10/2021	2.117	45.077	1.8	2.4	-25	N/A
W30-S1000-5 A-C	W30-S1000	4-199	6/10/2021	21.79	59.969	1.9	2.1	-10	N/A
W30-S1150-3 A-C	W30-S1150	4-200	5/06/2021	7.515	42.154	3.0	3.1	3	N/A
W30-S1300-2 A-C	W30-S1300	4-201	6/10/2021	23.536	44.774	2.3	2.4	-4	N/A
W30-S1453-3 A-C	W30-S1453	4-202	6/10/2021	13.84	43.068	3.1	3.3	-6	N/A
W30-S1600-4 A-C	W30-S1600	4-203	5/06/2021	10.343	48.041	2.6	3.1	-16	N/A
W30-S1775-9 A-C	W30-S1775	4-204	6/10/2021	5.711	43.404	2.3	3.2	-28	N/A
W30-S1950-3 A-C	W30-S1950	4-205	6/10/2021	23.777	53.451	2.8	3.2	-13	N/A
W30-S2067-4 A-C	W30-S2067	4-206	6/10/2021	26.029	52.969	3.3	3.4	-3	N/A
W30-S2275-5 A-C	W30-S2275	4-207	10/13/2020	1.328	46.653	3.2	N/A	N/A	N/A
W30-S2350 A-C	W30-S2350 A-C	4-208	10/13/2020	0.535	49.717	3.2	N/A	N/A	N/A
W30-S2425-5 A-C	W30-S2425	4-209	6/02/2021	6.15	45.126	3.7	4.0	-8	N/A
W30-S2520-4 A-C	W30-S2520	4-210	4/21/2021	25.17	54.159	3.4	3.7	-8	N/A

Table 4-1 Access Drifts Data Analysis (continued)

Joint Meters								
Field Tag	Location	Figure Number	Date	Cumulative Displacement (inches)	Closure Rate 2020 to 2021 (in/year)	Closure Rate 2019 to 2020 (in/year)	Rate Change Percent	Comments
51X-CG-02876-2	E140-S1505	4-211	01/11/2021	-0.291	-0.024	N/A	N/A	N/A
51X-CG-02883-3	E140-S1529	4-212	01/11/2021	-0.3	-0.002	N/A	N/A	N/A
51X-CG-02885-2	E140-S1545	4-213	01/11/2021	0.892	-0.035	0.03	-100	N/A
51X-CG-02875-2	E140-S1795	4-214	01/11/2021	0.659	-0.041	-0.02	-100	N/A
Rock Bolt Load Cells								
Field Tag	Location	Figure Number	Date of Last Reading	Load (kips)	Comments			
51X-WG-00246	AIS North Brow	4-215	04/08/2021	35.7	N/A			
51X-WG-00248	AIS North Brow	4-216	10/01/2020	47.3	N/A			
51X-WG-00250	AIS North Brow	4-217	10/01/2020	10.8	N/A			
51X-WG-00251	AIS North Brow	4-218	05/14/2021	11.3	N/A			
51X-WG-00254	AIS North Brow	4-219	10/01/2020	5.7	N/A			
51X-WG-00255	AIS North Brow	4-220	10/01/2021	11.8	N/A			
51X-WG-00239	AIS South Brow	4-221	10/01/2020	53.3	N/A			
51X-WG-00242	AIS South Brow	4-222	04/08/2021	67.7	N/A			
51X-WG-00243	AIS South Brow	4-223	04/30/2021	29.3	N/A			
51X-WG-00244	AIS South Brow	4-224	04/30/2021	26.6	N/A			

[1] N/A – Insufficient data available to perform the calculation. This is usually due to the inability to read the instruments because of activities such as the removal of an instrument due to floor, rib, or back trimming; locations blocked by equipment or waste disposal; installation timing, access issues, etc.

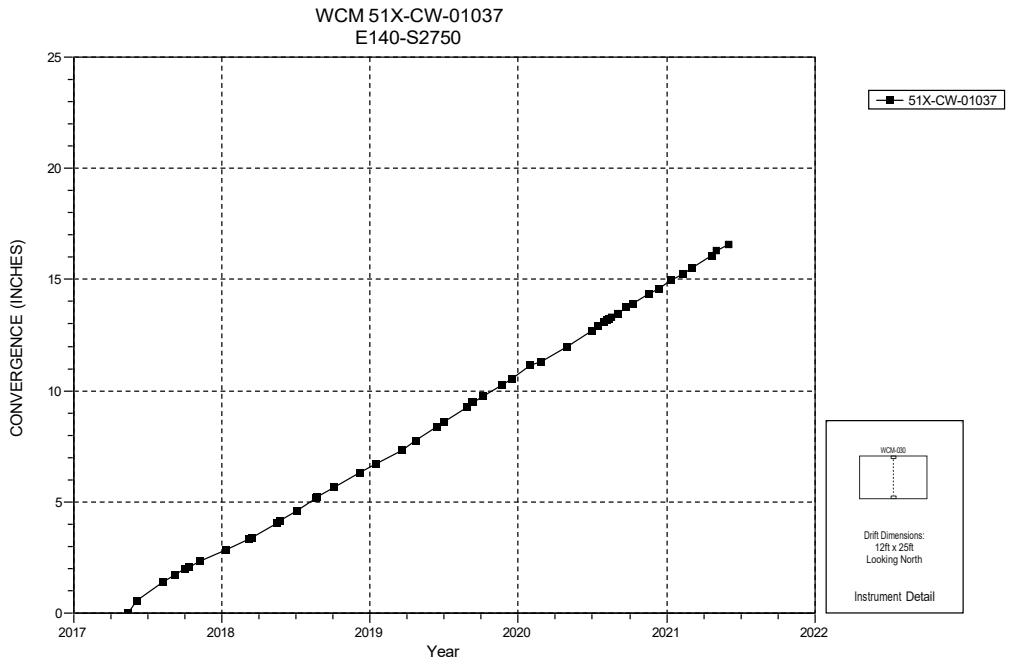


Figure 4-1 Wire Convergence Meter 51X-CW-01037 – Roof to Floor

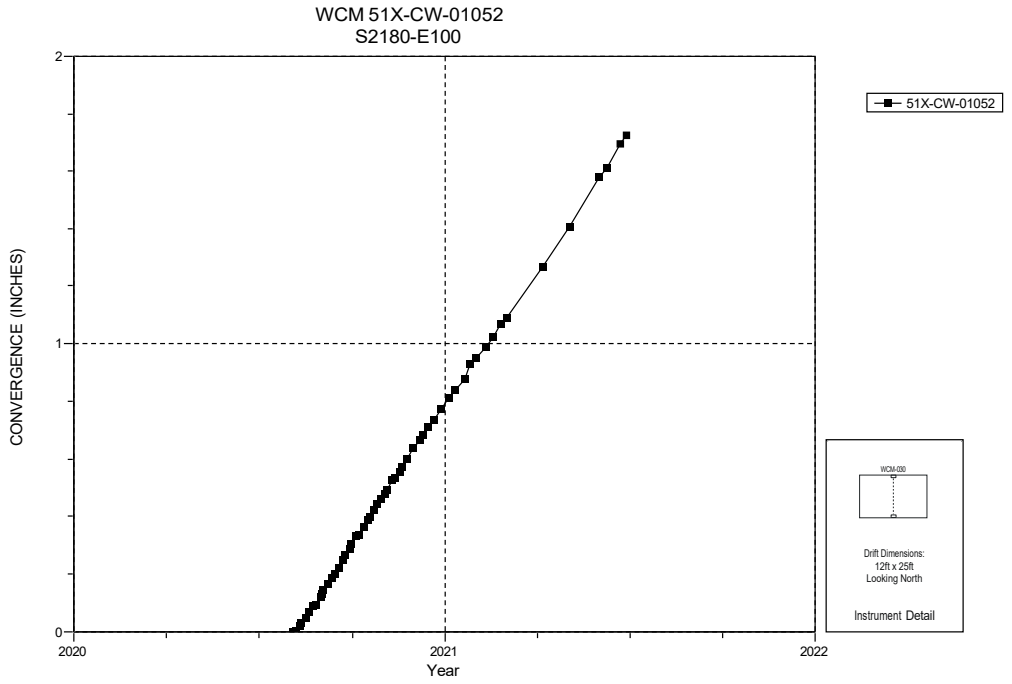


Figure 4-2 Wire Convergence Meter 51X-CW-01052 – Roof to Floor

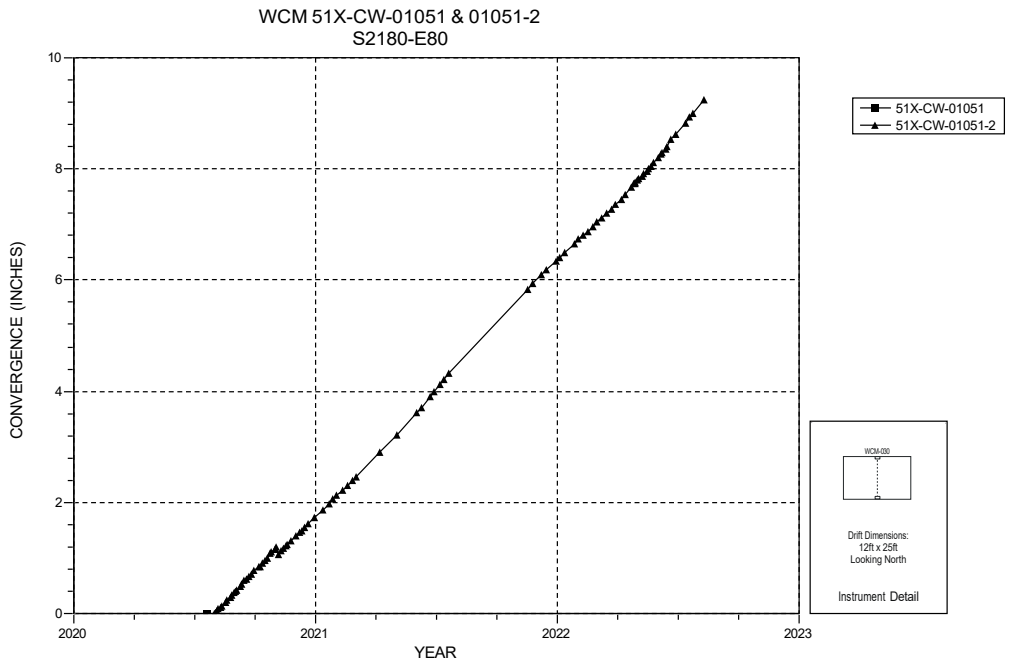


Figure 4-3 Wire Convergence Meters 51X-CW-01051 & 01051-2 – Roof to Floor

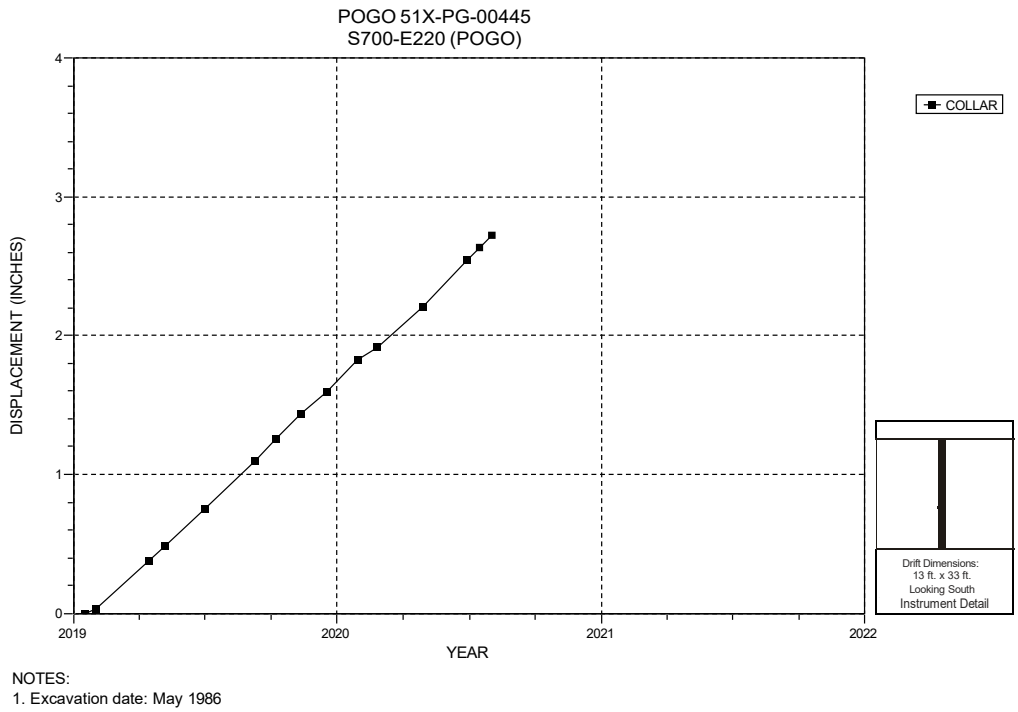
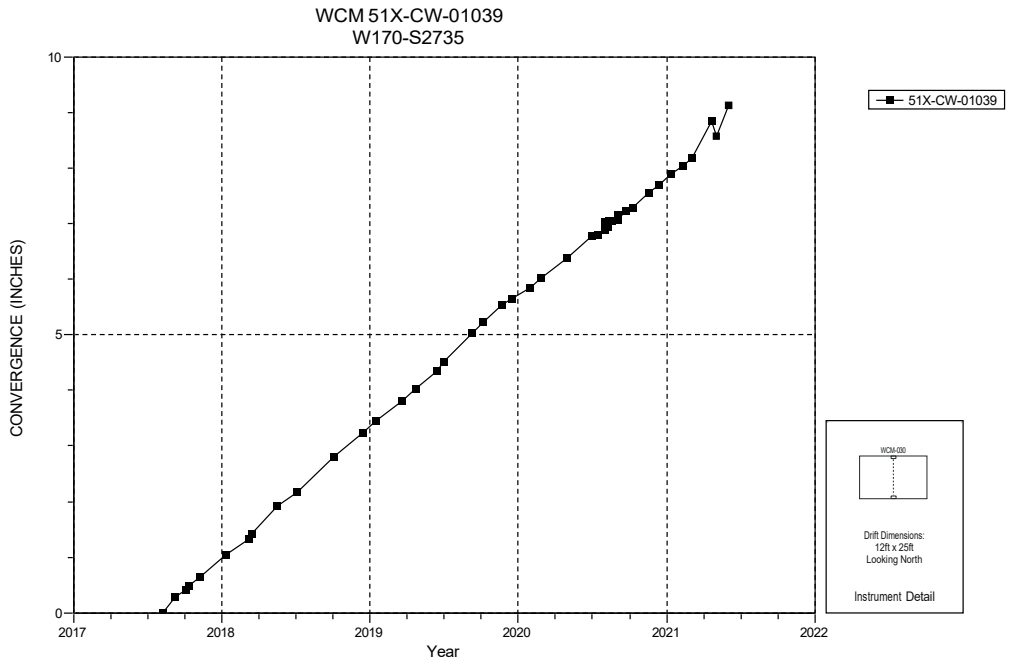
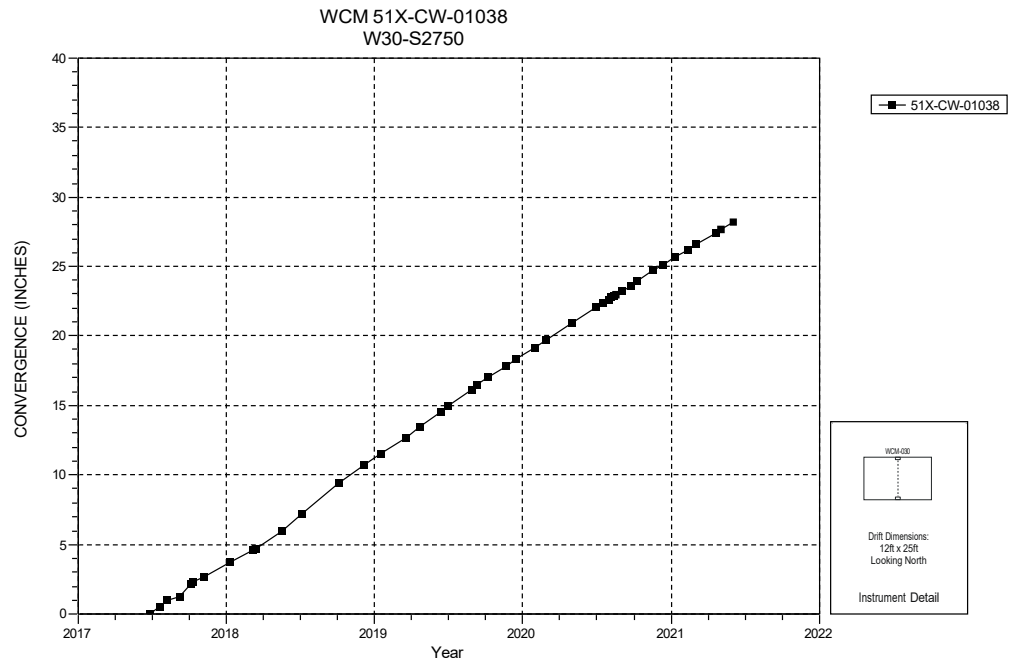


Figure 4-4 Wire Convergence Meter 51X-PG-00445 – Roof to Floor



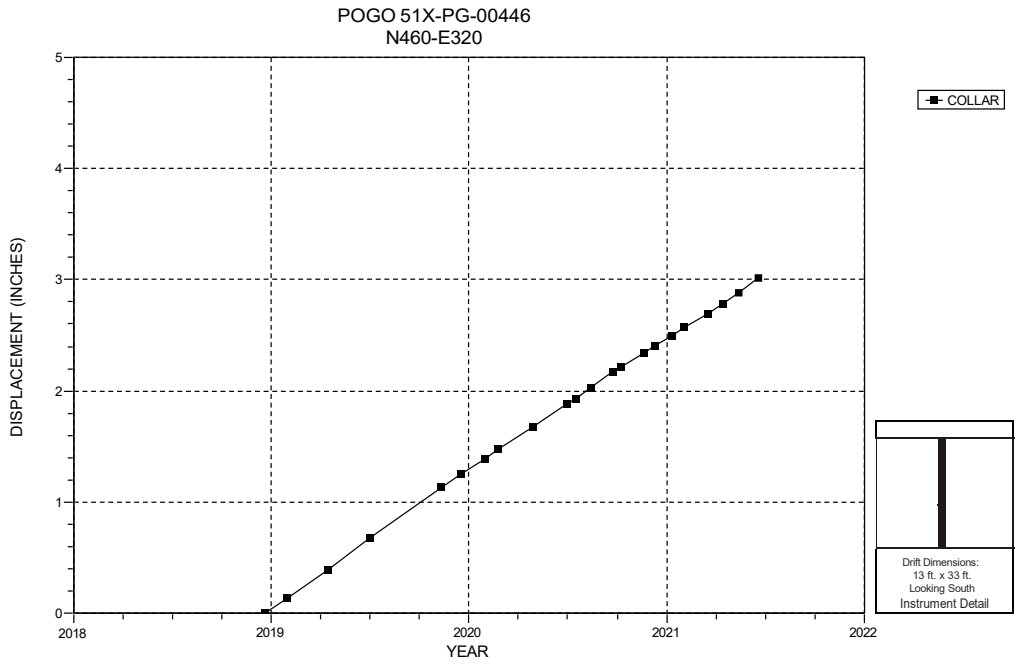
NOTES:
1. Excavation date: December 2000.

Figure 4-5 Wire Convergence Meter 51X-CW-01039 – Roof to Floor



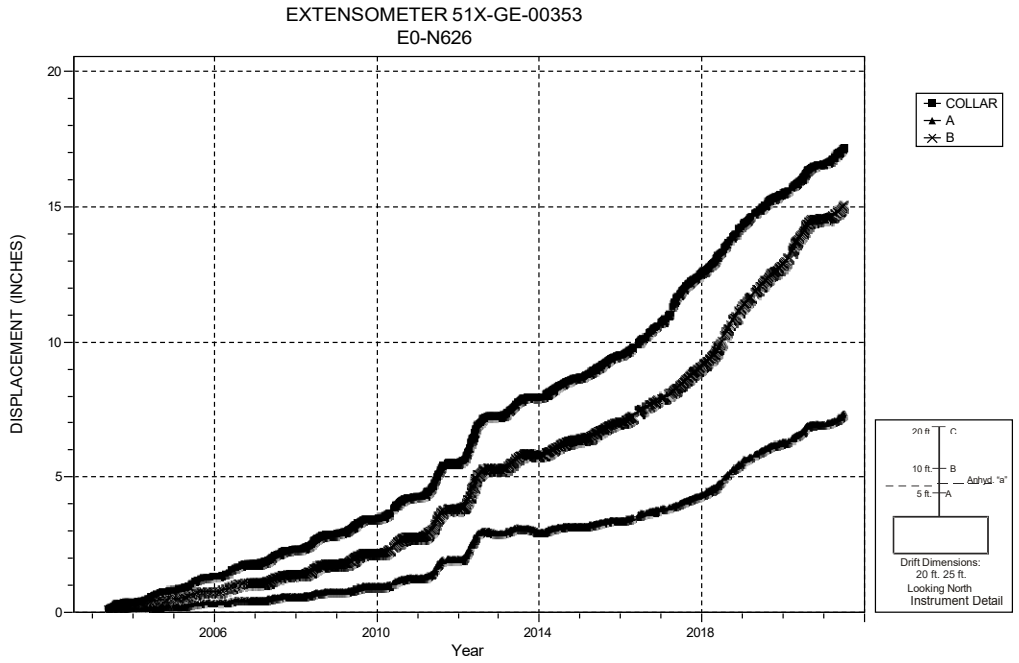
NOTES:
1. Excavation date: December 2000.

Figure 4-6 Wire Convergence Meter 51X-CW-01038 – Roof to Floor



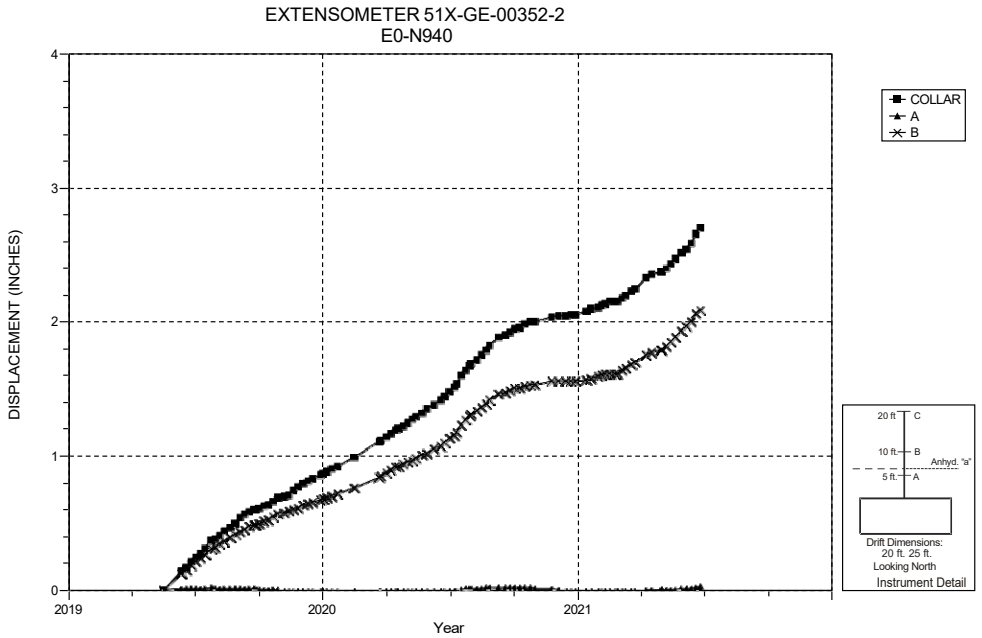
NOTES:
1. Excavation Date: January 1988.

Figure 4-7 Convergence Meter 51X-PG-00446 – Roof to Floor



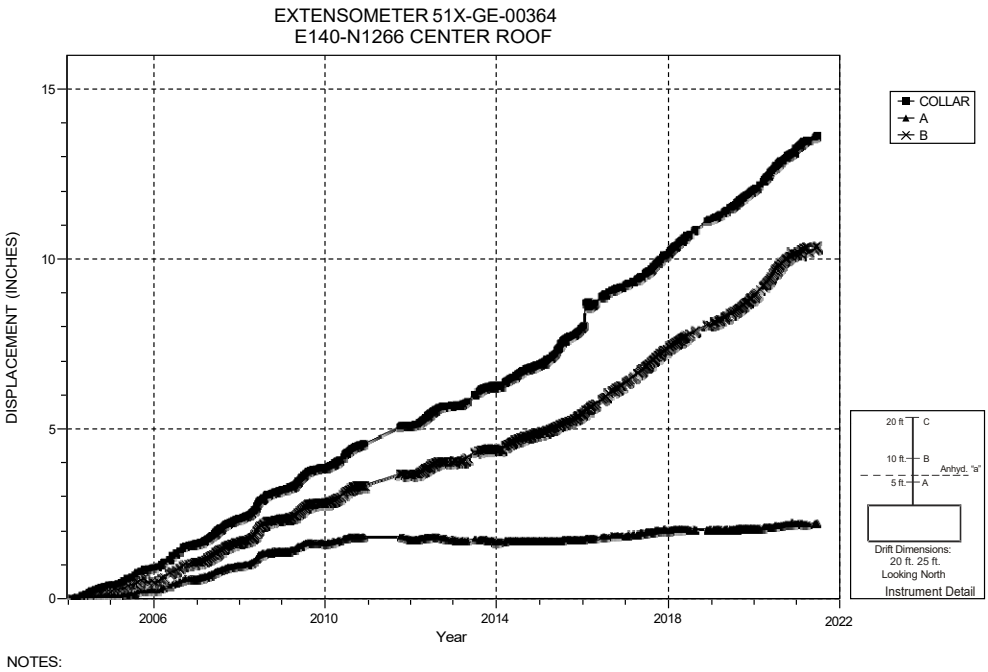
NOTES:
1. Excavation date: February 1983.

Figure 4-8 Extensometer 51X-GE-00353 – E0 N626 – Roof



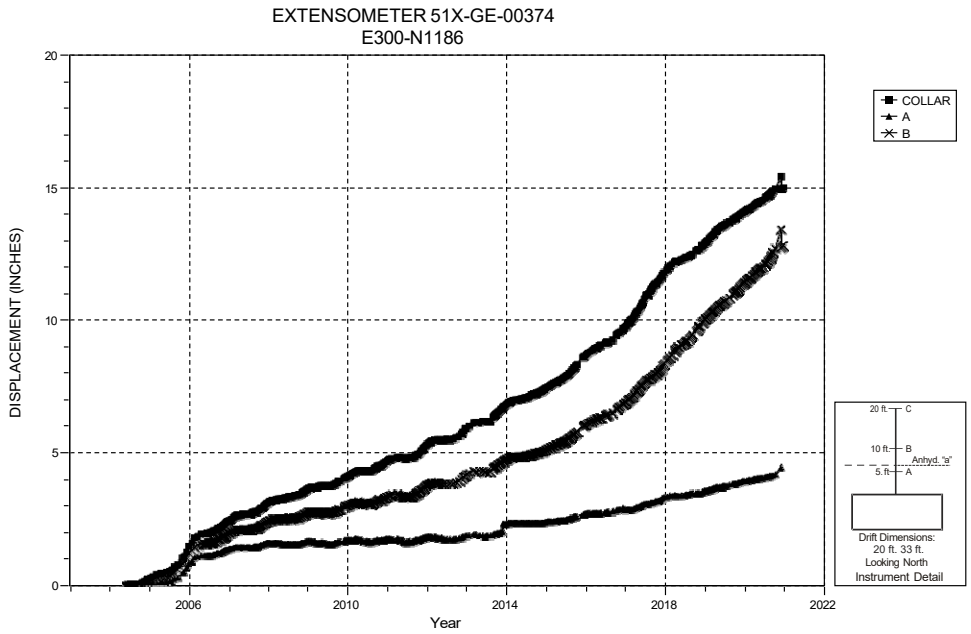
NOTES:
1. Excavation date: February 1983.
2. WEX Replacement. New WEX Field ID is 51X-GE-00352-2.

Figure 4-9 Extensometer 51X-GE-00352-2 – E0 N940 – Roof



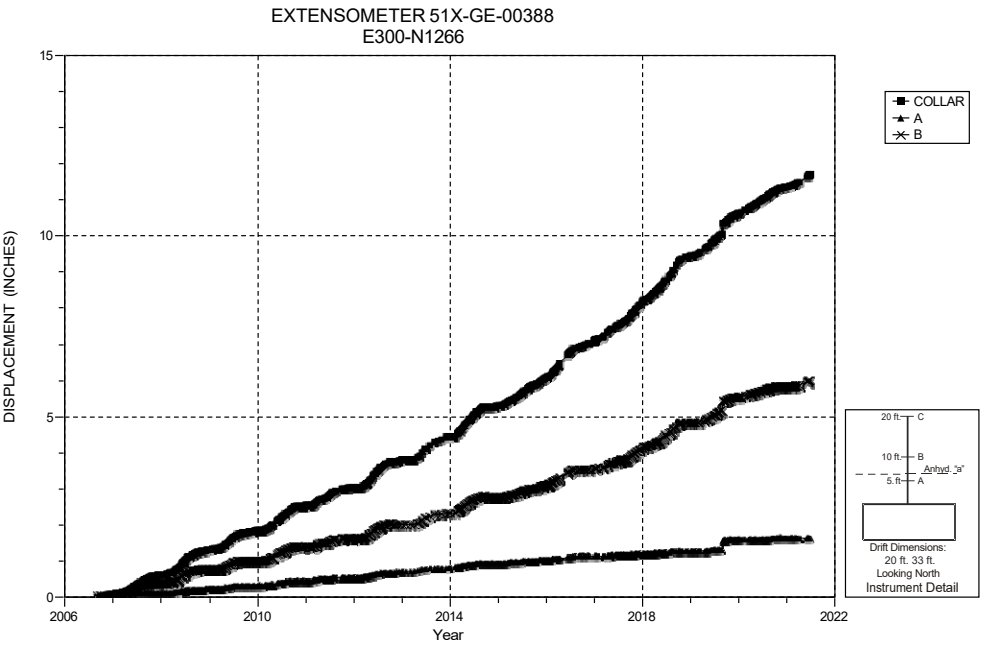
NOTES:
1. Excavation date: February 1983.

Figure 4-10 Extensometer 51X-GE-00364 – E140 N1266 – Roof



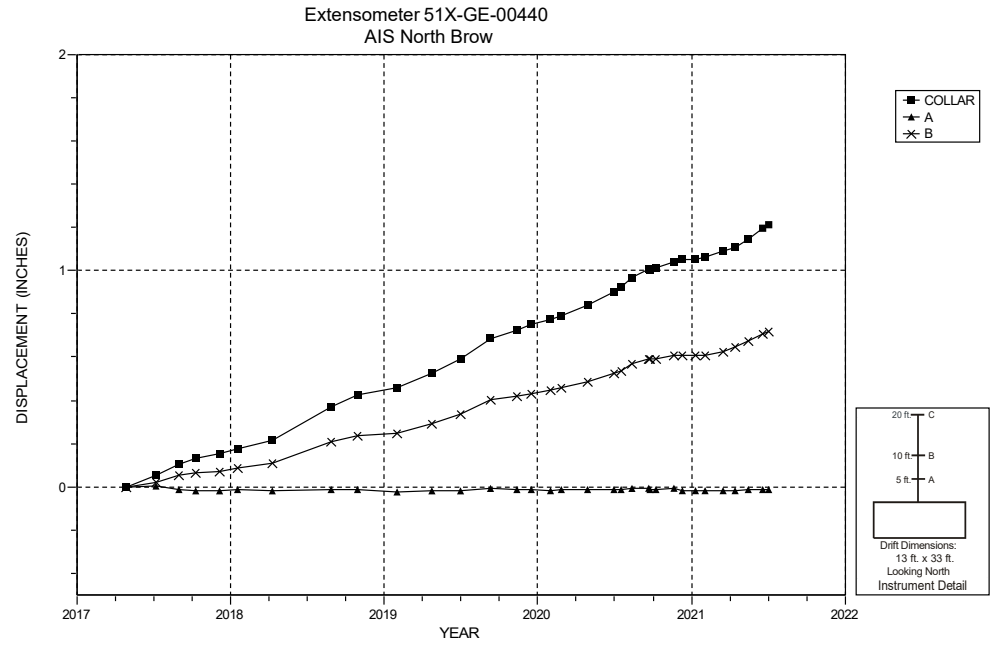
NOTES:
1. Excavation date: August 1989.

Figure 4-11 Extensometer 51X-GE-00374 – E300 N1186 – Roof



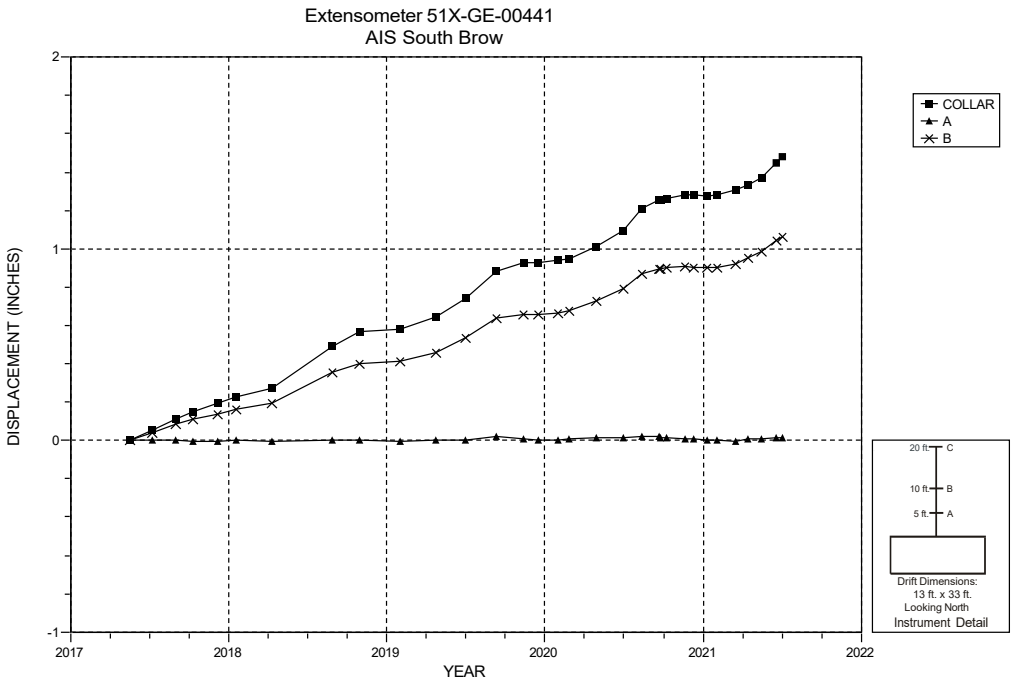
NOTES:
1. Excavation date: August 1989.
2. Instrument replaced in August 2006.

Figure 4-12 Extensometer 51X-GE-00388 – E300 N1266 – Roof



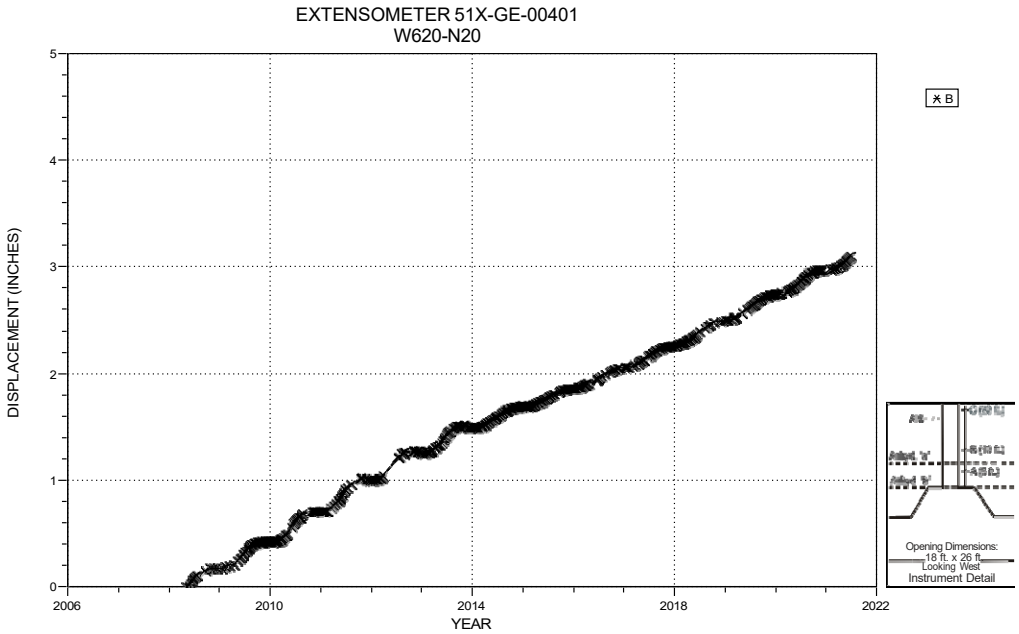
NOTES:
1. Excavation Date: January 1988.

Figure 4-13 Extensometer 51X-GE-00440 – AIS North Brow – Roof



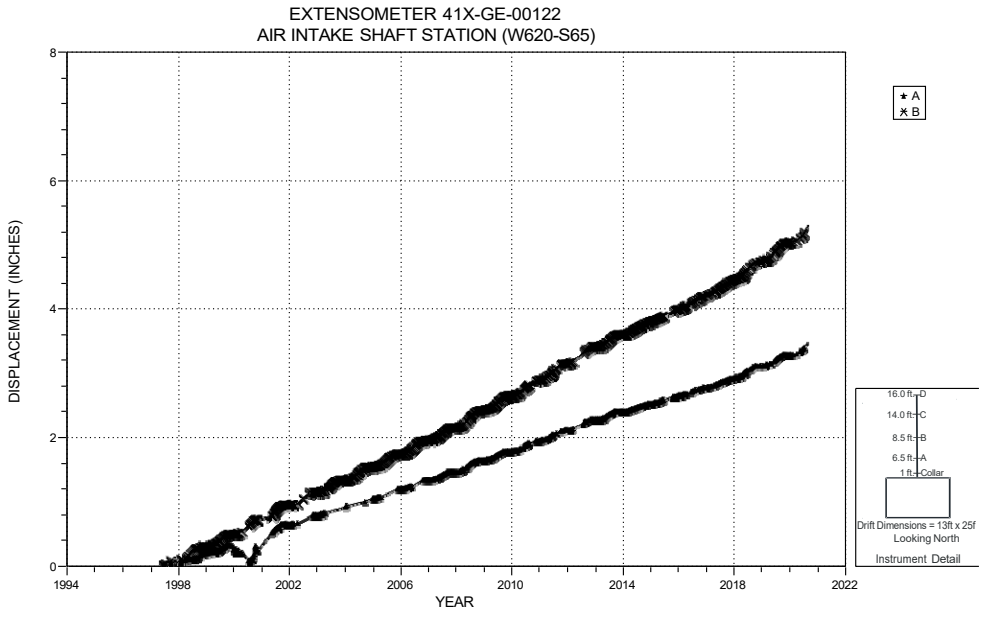
NOTES:
1. Excavation Date: January 1988.

Figure 4-14 Extensometer 51X-GE-00441 – AIS South Brow – Roof



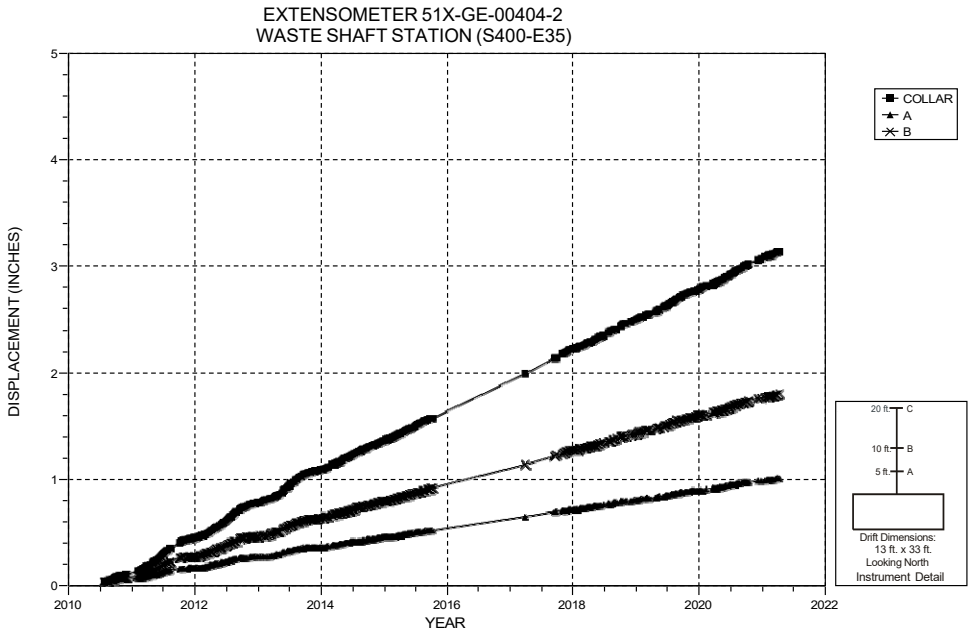
NOTES:
1. Excavation date: January 1988.
2. The mechanical connection to anchors "A" & "C" have failed, select CFI to view the plot.

Figure 4-15 Extensometer 51X-GE-00401 – W620-N20 – Roof



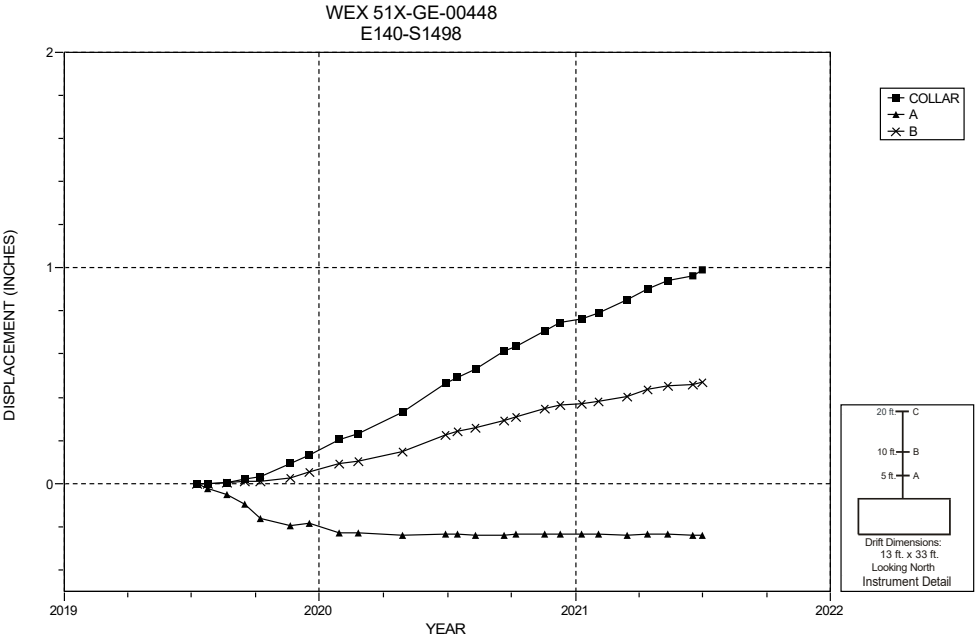
NOTES:
1. Excavation date: January 1988.
2. The Collar (Anchor 'D') and Anchor 'C' have exceeded their maximum ranges

Figure 4-16 Extensometer 41X-GE-00122 – W620-S65 – Roof



NOTES:
1. Excavation date: November 1982.
2. Extensometer 51X-GE-00404 was replaced by 51X-GE-00404-2 in July 2010.

Figure 4-17 Extensometer 51X-GE-00404-2 – Waste Shaft Station (S400-E35) – Roof



NOTES:
1. Excavation date: November 1982.
2. New installation: Test Area 1.

Figure 4-18 Extensometer 51X-GE-00448 – E140 S1498 – Roof

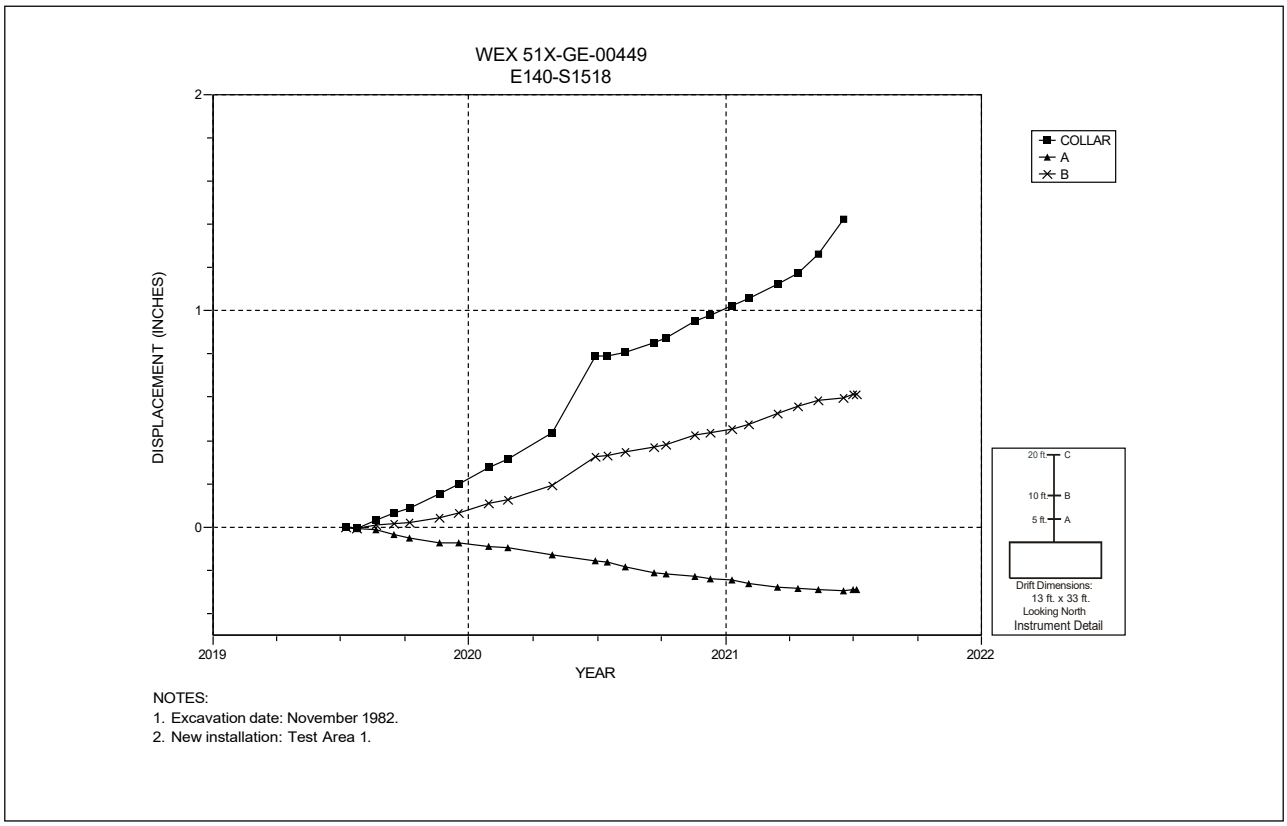


Figure 4-19 Extensometer 51X-GE-00449 – E140 S1518 – Roof

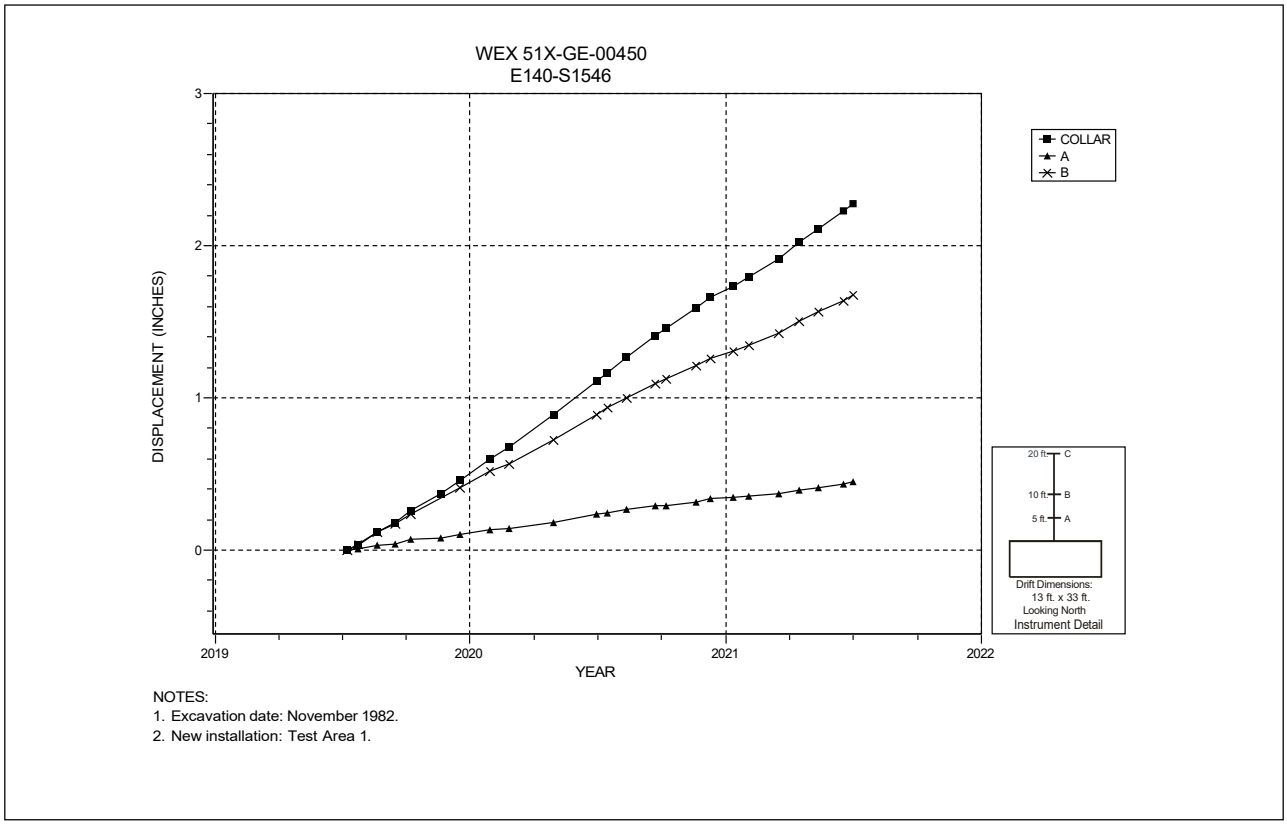


Figure 4-20 Extensometer 51X-GE-00450 – E140 S1546 – Roof

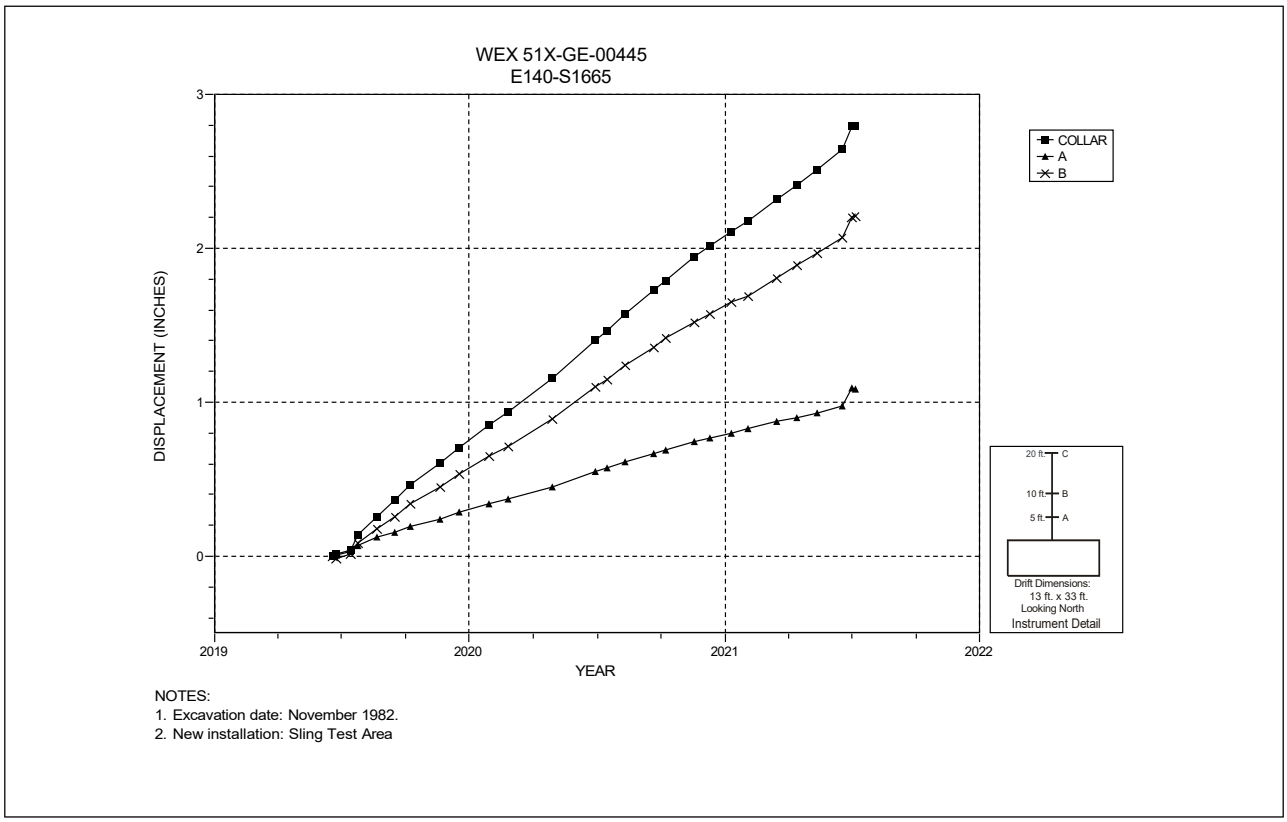


Figure 4-21 Extensometer 51X-GE-00445 – E140 S1665 – Roof

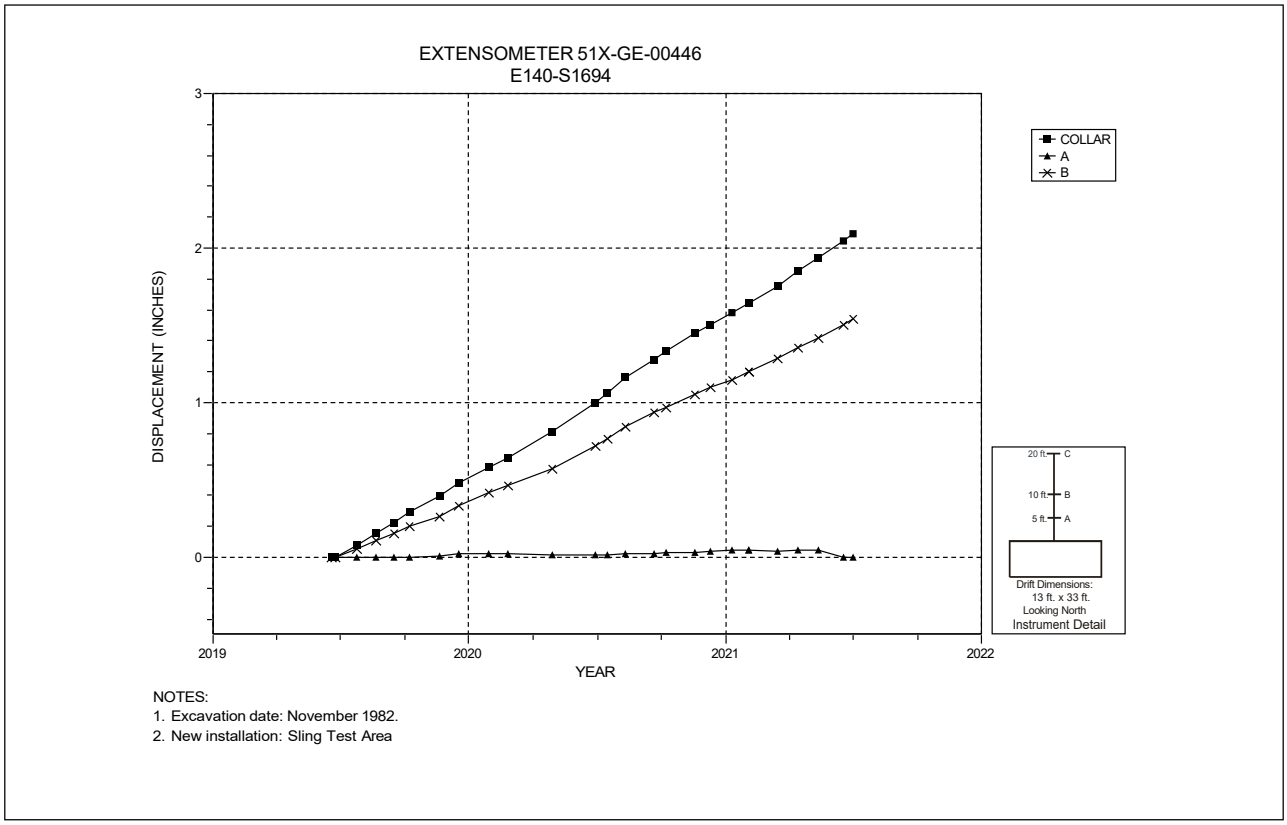


Figure 4-22 Extensometer 51X-GE-00446 – E140 S1694 – Roof

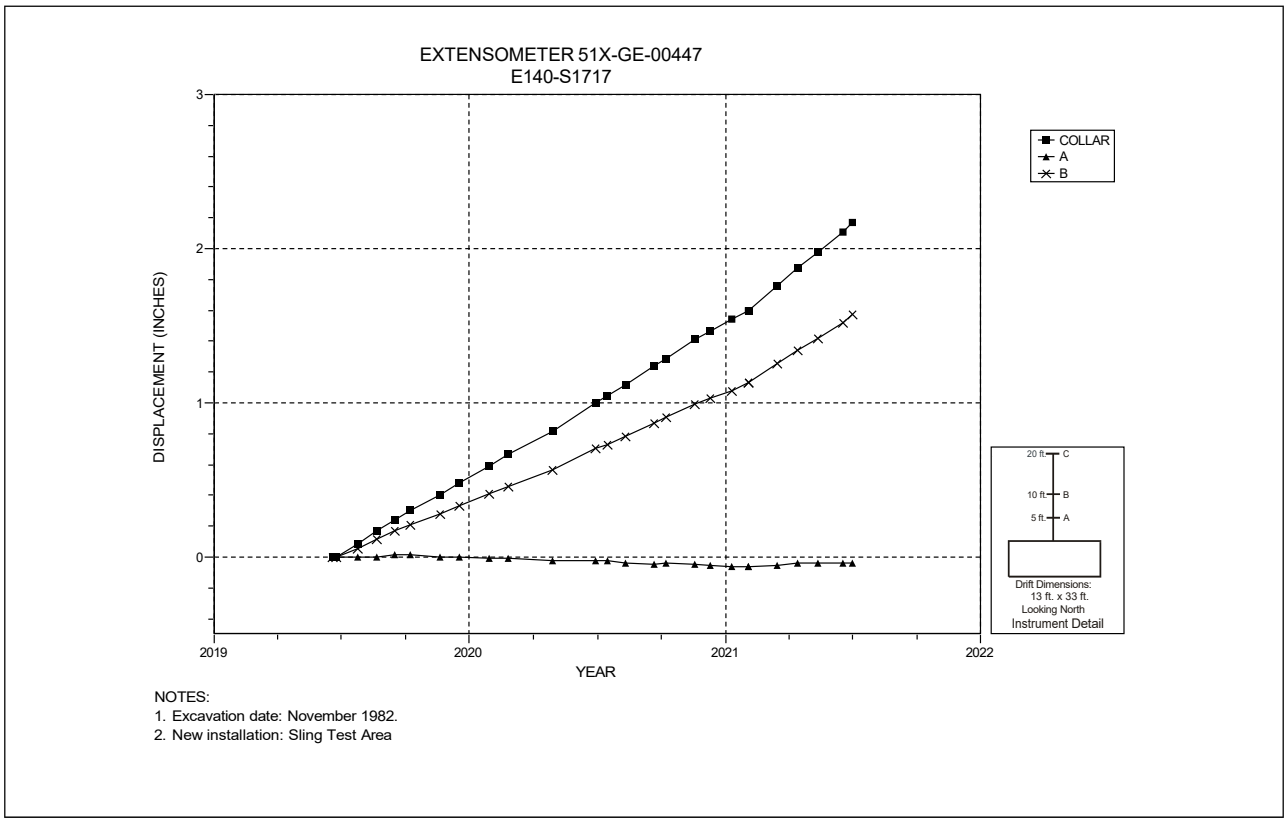


Figure 4-23 Extensometer 51X-GE-00447 – E140 S1717 – Roof

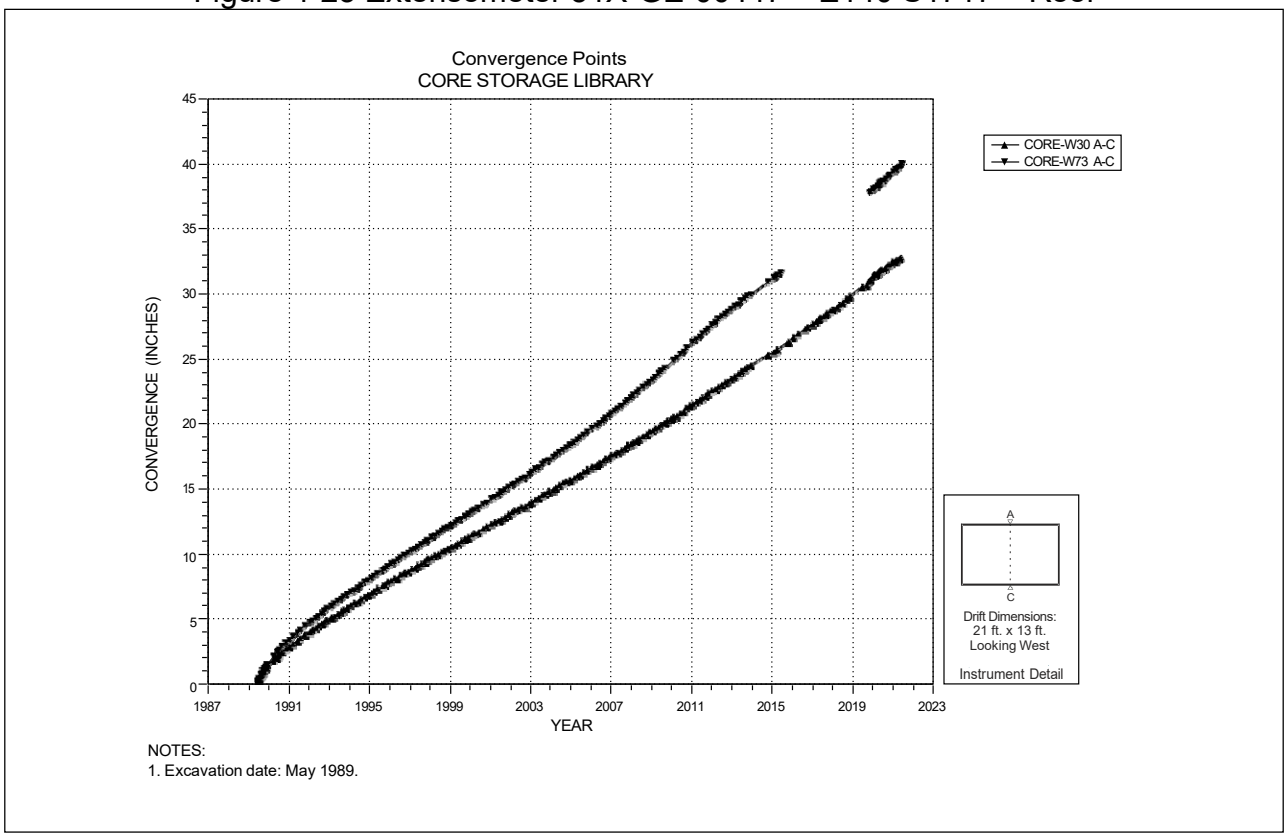
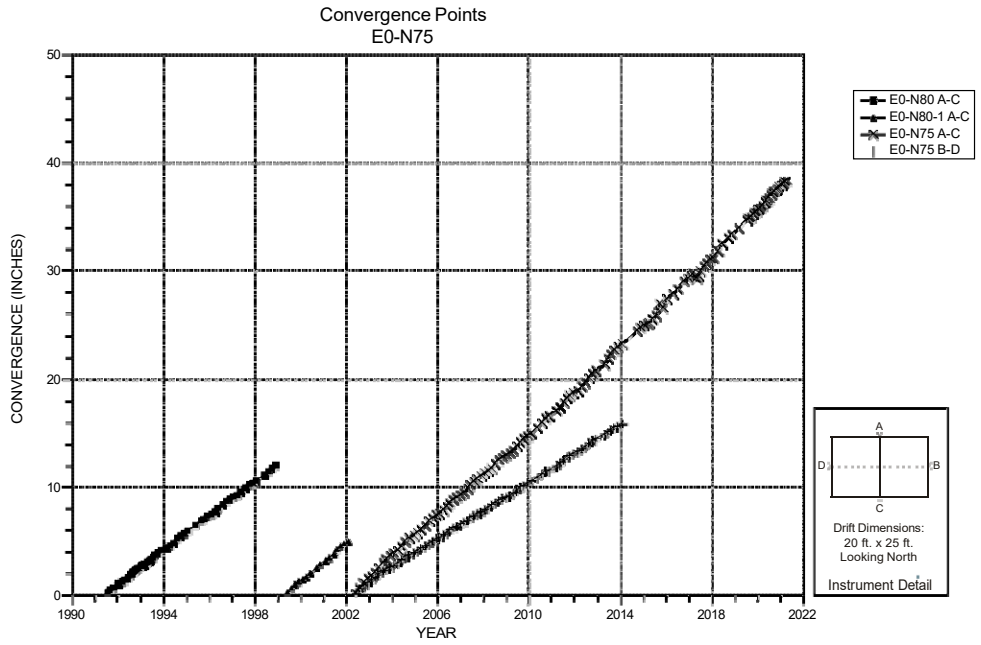
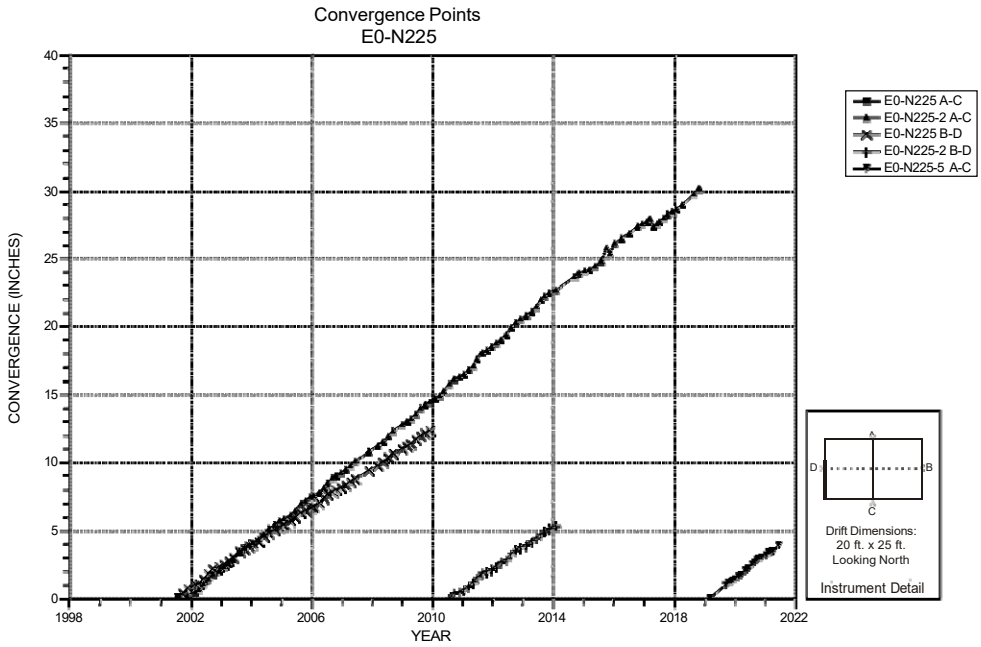


Figure 4-24 Core Storage Library – Roof to Floor



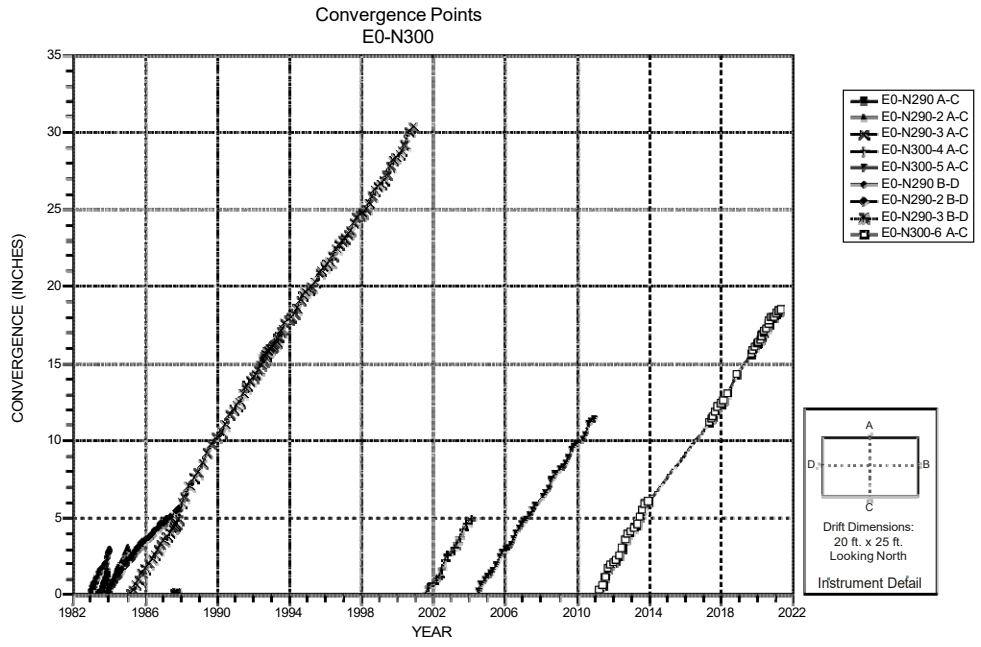
NOTES:
1. Excavation date: October 1982.
2. Roof excavated to Anhydrite "b".

Figure 4-25 Convergence Point Array – E0 N75 – All Chords



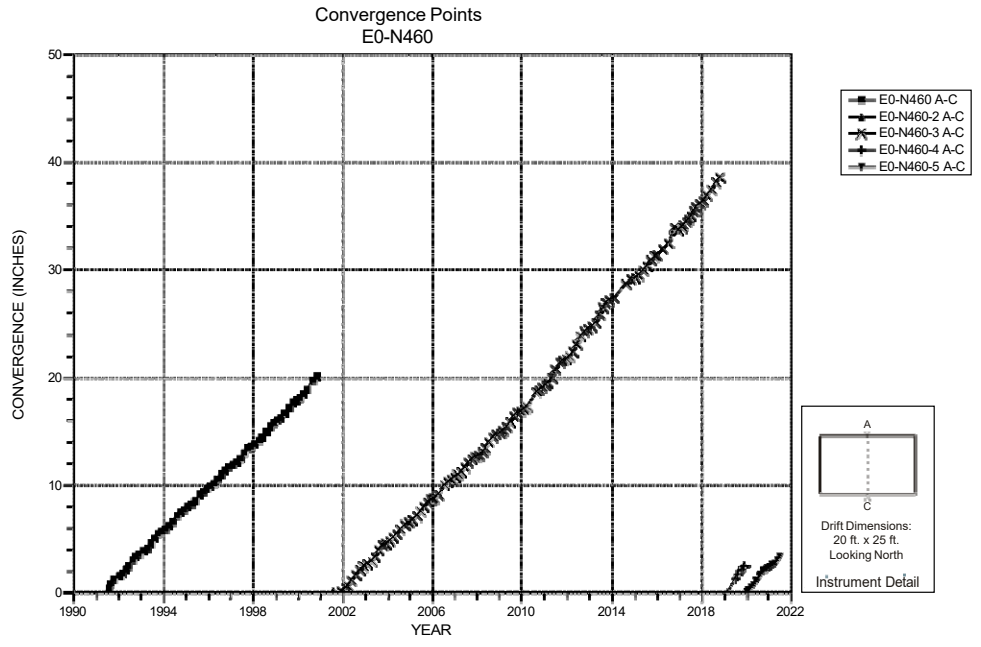
NOTES:
1. Excavation date: November 1982.
2. Roof excavated to Anhydrite "b".

Figure 4-26 Convergence Point Array – E0 N225 – All Chords



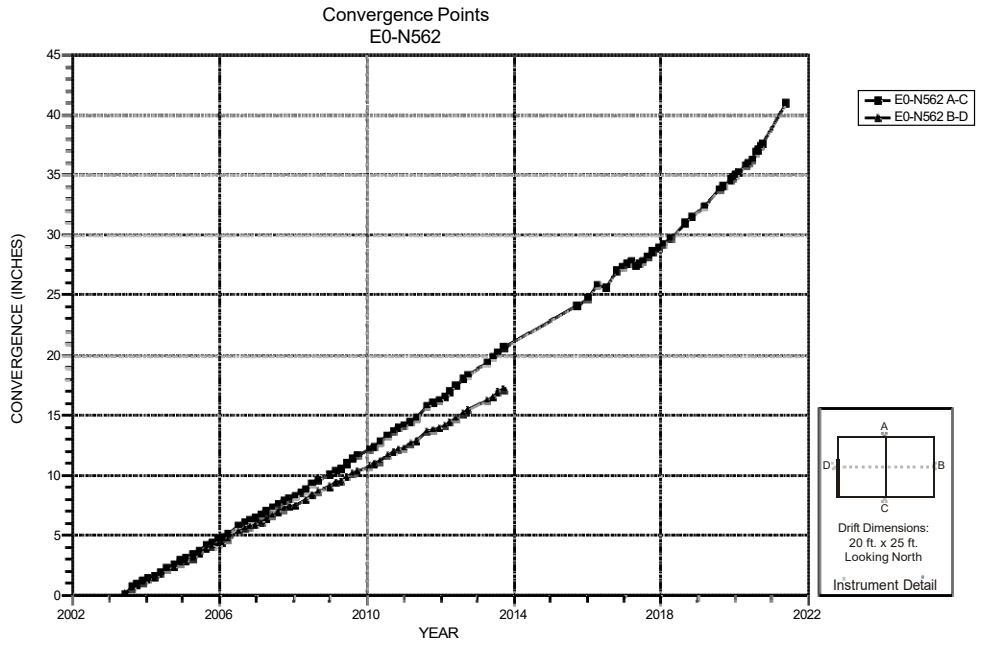
NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b".
3. The RC floor point is covered by a muck pile.

Figure 4-27 Convergence Point Array – E0 N300 – All Chords



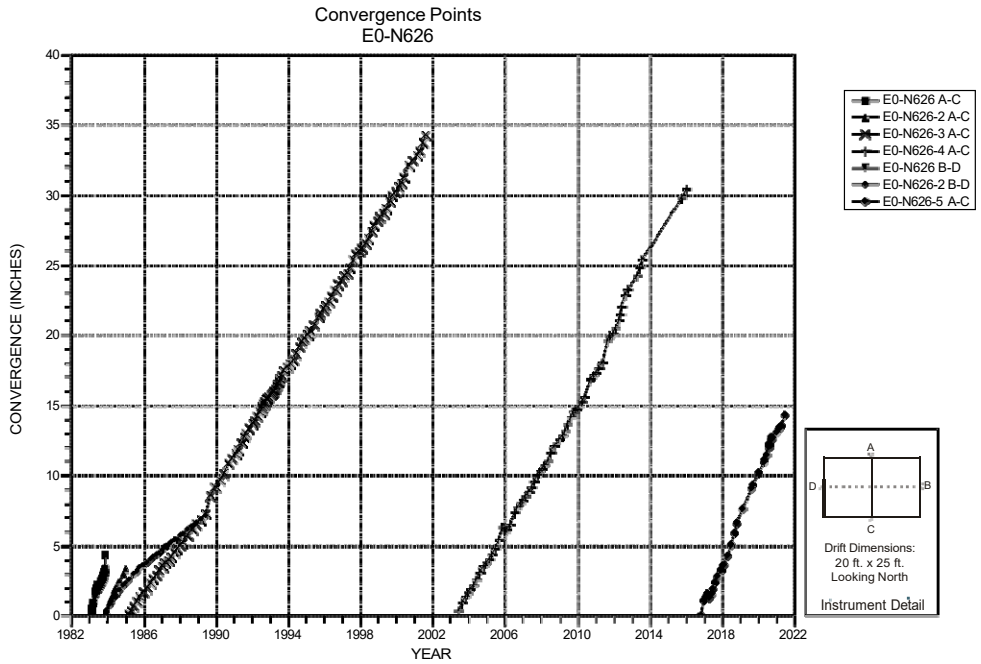
NOTES:
1. Excavation date: January 1983.
2. Roof excavated to Anhydrite "b".

Figure 4-28 Convergence Point Array – E0 N460 – Roof to Floor



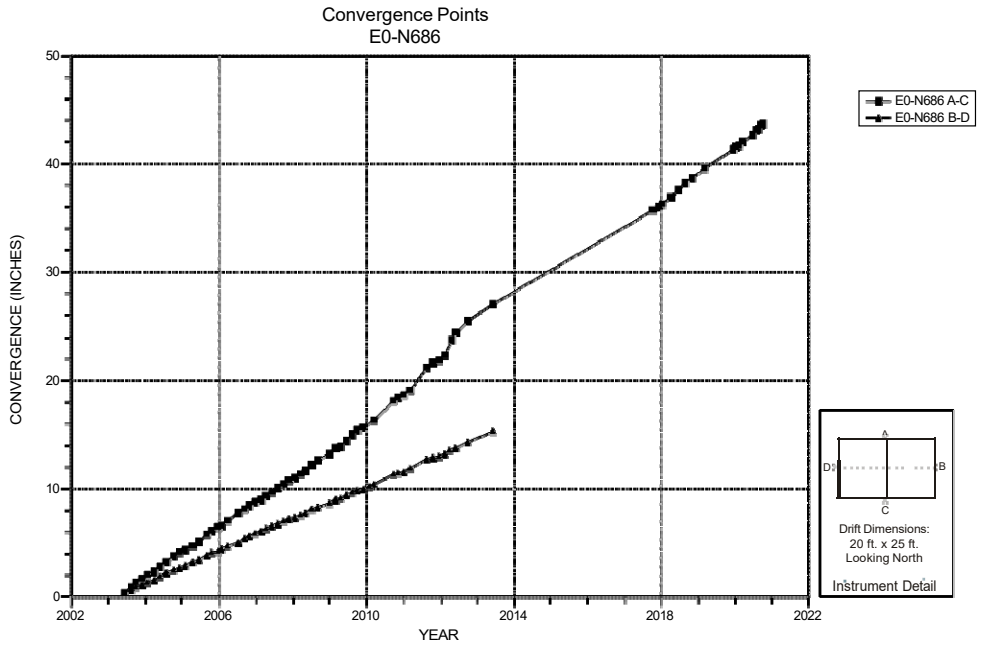
NOTES:
1. Excavation date: February 1983.
2. The RC floor point is covered by a muck pile.

Figure 4-29 Convergence Point Array – E0 N562 – All Chords



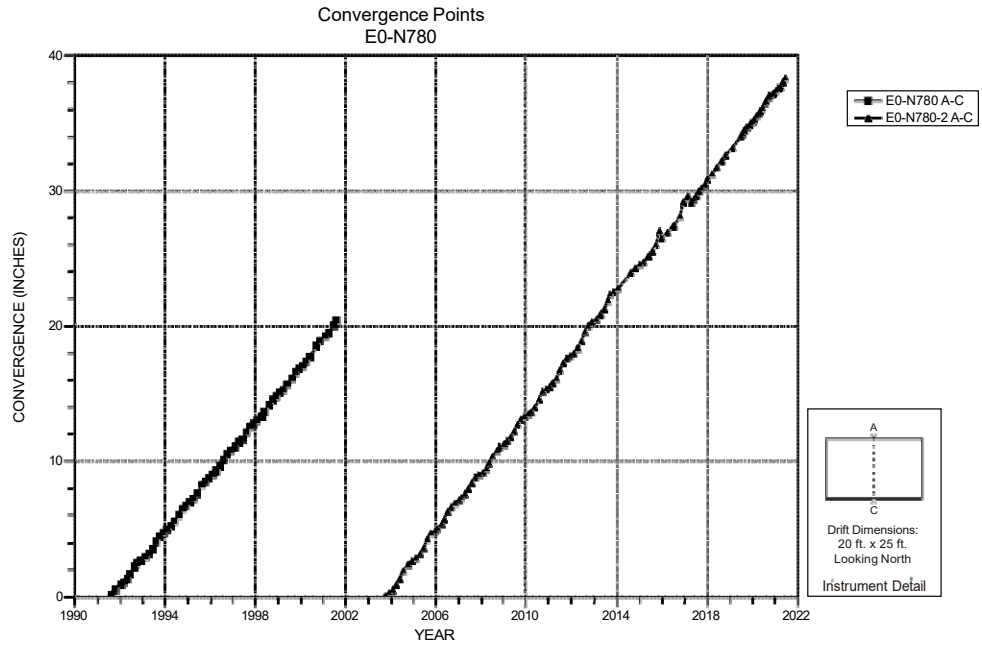
NOTES:
1. Excavation date: February 1983.
2. Roof excavated to Anhydrite "b".

Figure 4-30 Convergence Point Array – E0 N626 – All Chords



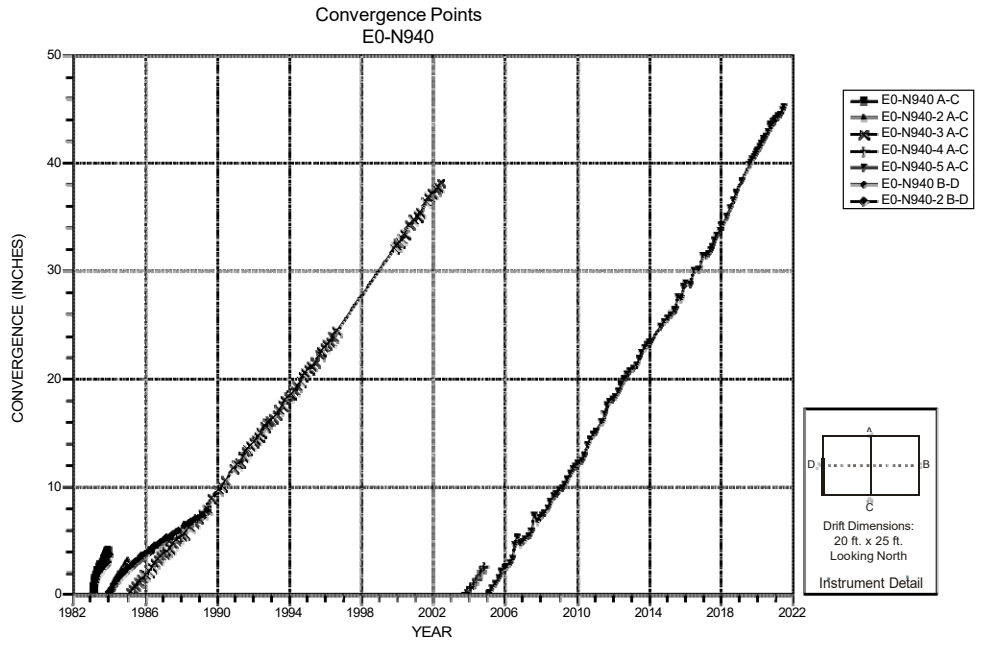
NOTES:
1. Excavation date: February 1983.
2. The RC floor point is covered by a muck pile.

Figure 4-31 Convergence Point Array – E0 N686 – All Chords



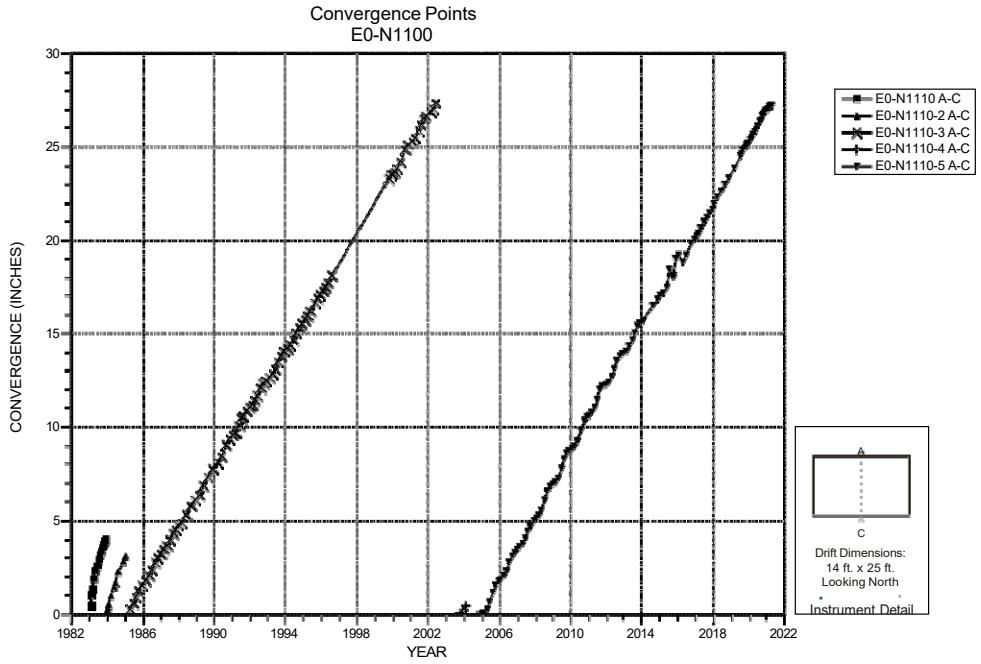
NOTES:
1. Excavation date: February 1983.

Figure 4-32 Convergence Point Array – E0 N780 – Roof to Floor



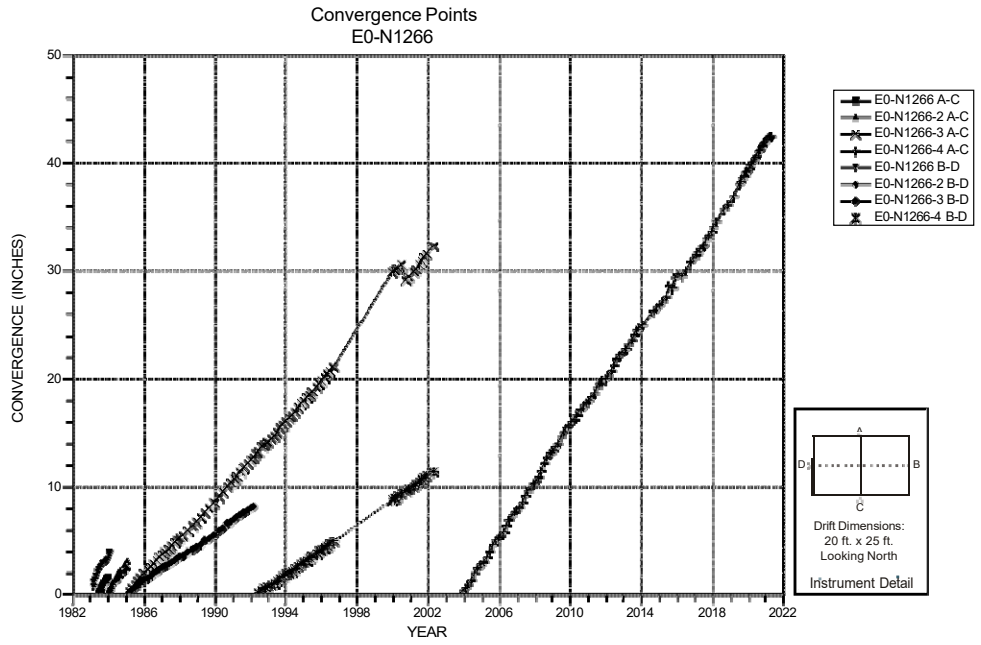
NOTES:
1. Excavation date: February 1983.

Figure 4-33 Convergence Point Array – E0 N940 – All Chords



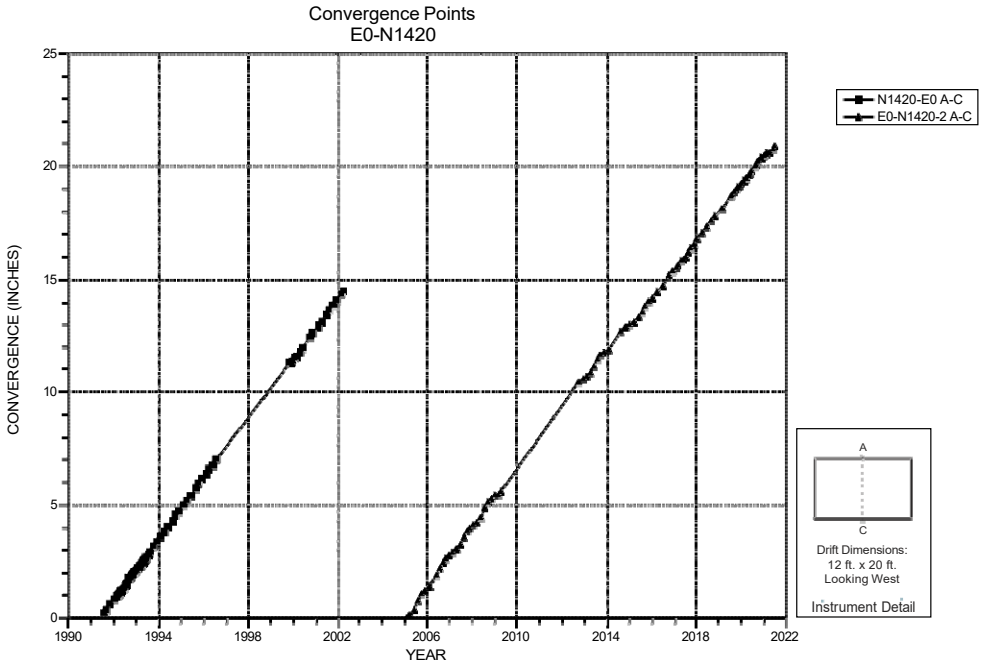
NOTES:
1. Excavation date: February 1983.

Figure 4-34 Convergence Point Array – E0 N1100 – Roof to Floor



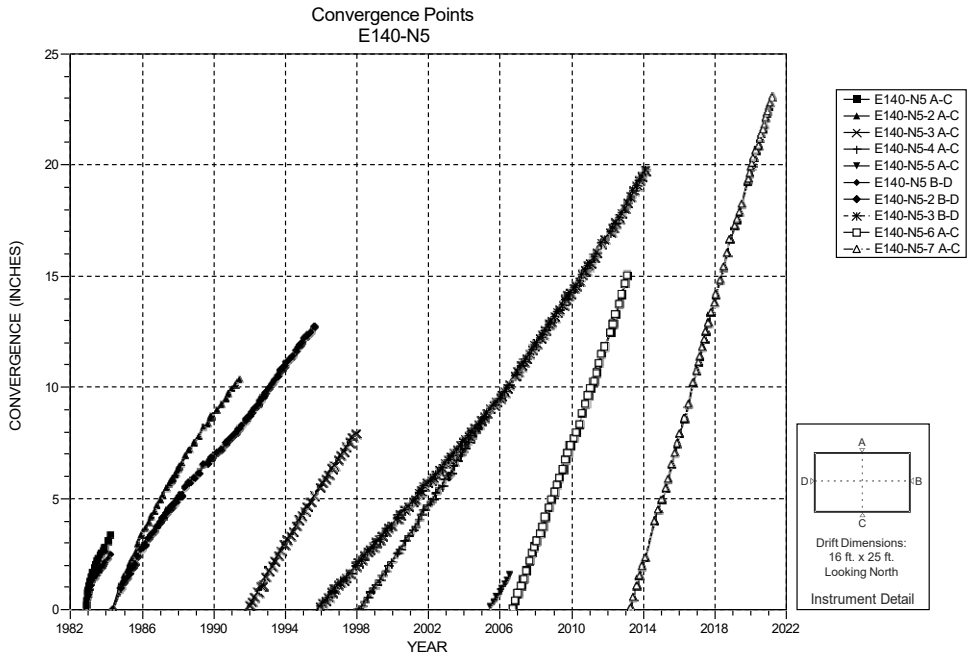
NOTES:
1. Excavation date: February 1983.

Figure 4-35 Convergence Point Array – E0 N1266 – All Chords



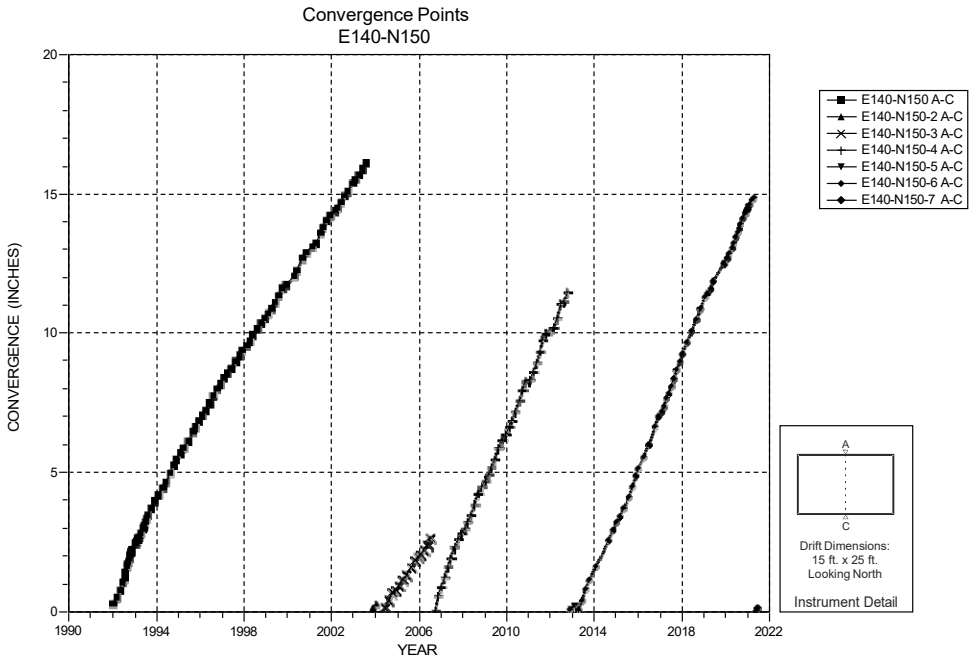
NOTES:
1. Excavation date: February 1983.

Figure 4-36 Convergence Point Array – E0 N1420 – Roof to Floor



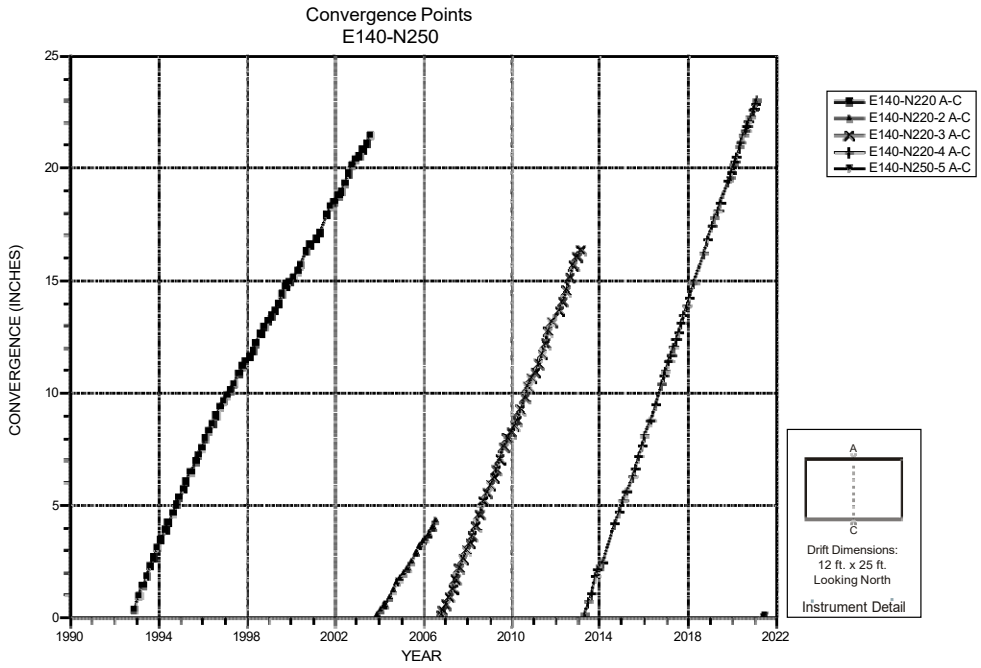
NOTES:
1. Excavation date: November 1982.

Figure 4-37 Convergence Point Array – E140 N5 – All Chords



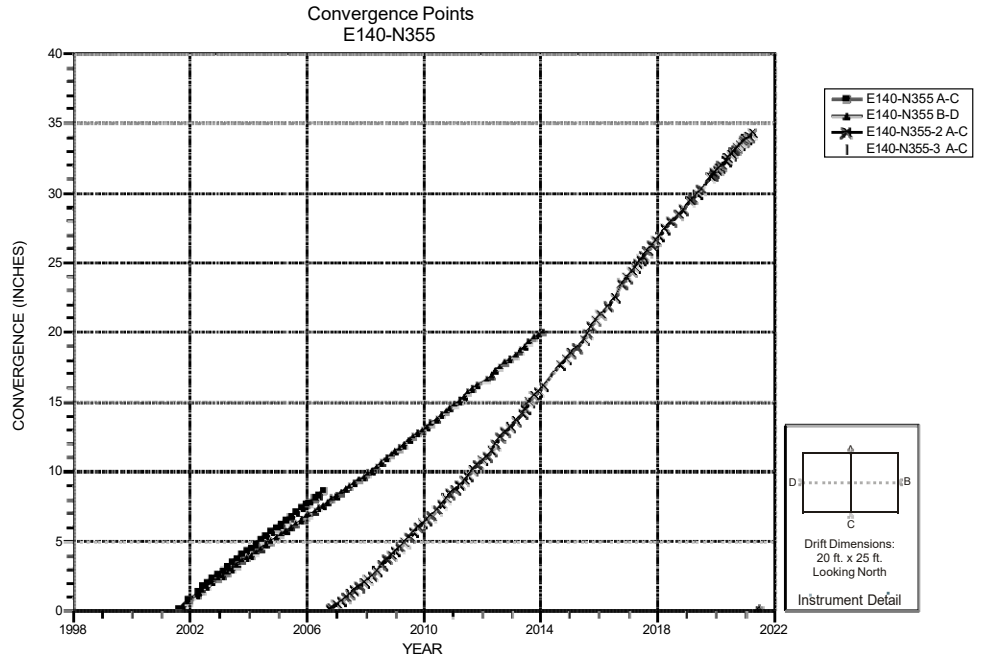
NOTES:
1. Excavation date: November 1982.

Figure 4-38 Convergence Point Array – E140 N150 – Roof to Floor



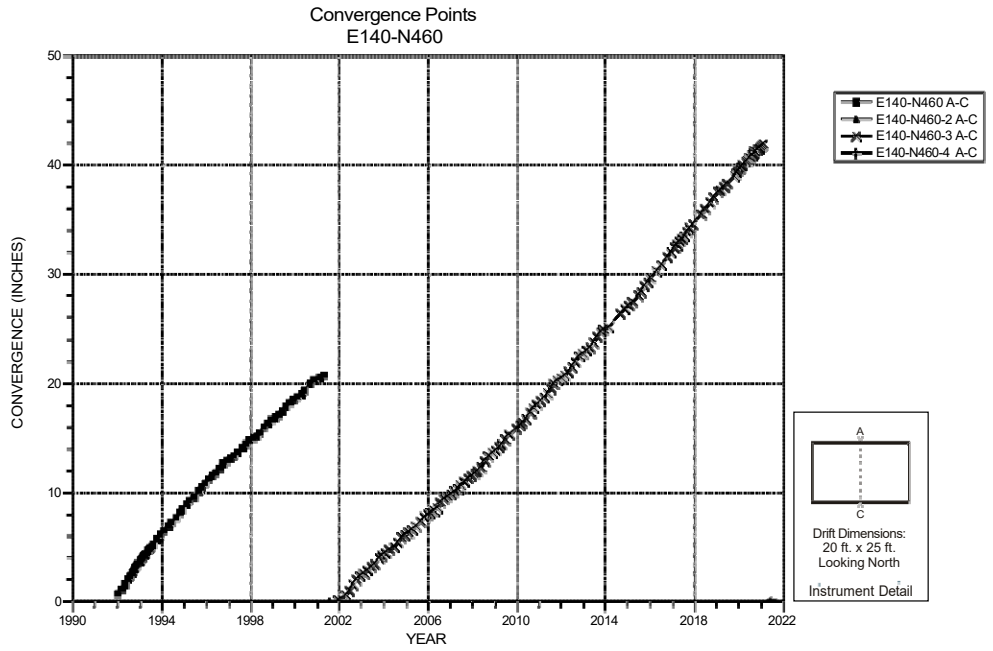
NOTES:
1. Excavation date: November 1982.

Figure 4-39 Convergence Point Array – E140 N250 – Roof to Floor



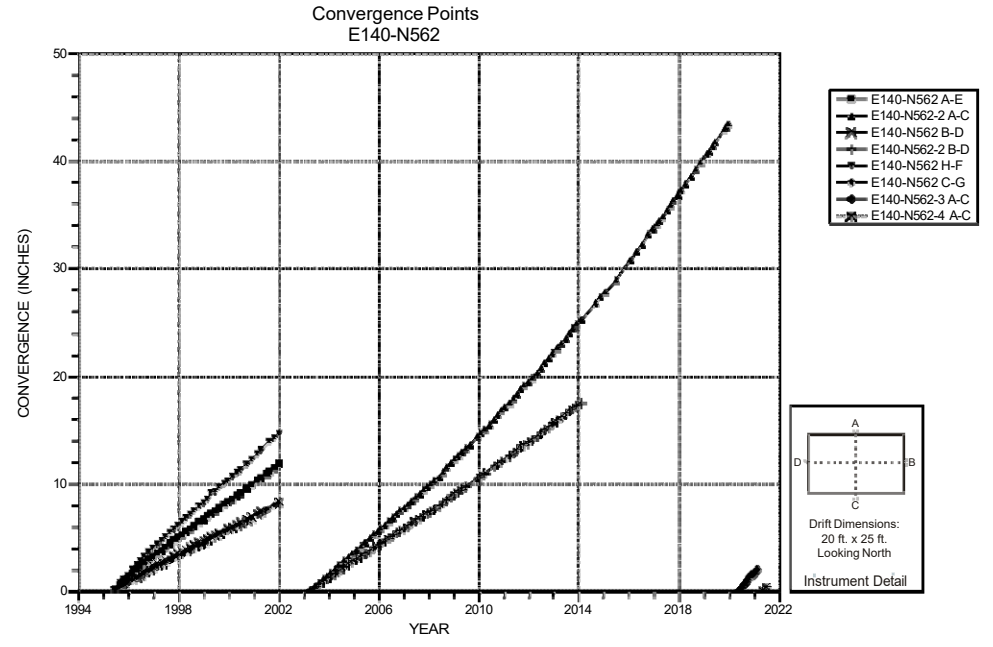
NOTES:
1. Excavation date: February 1983.
2. Roof excavated to Anhydrite 'b' in mid 2001.

Figure 4-40 Convergence Point Array – E140 N355 – All Chords



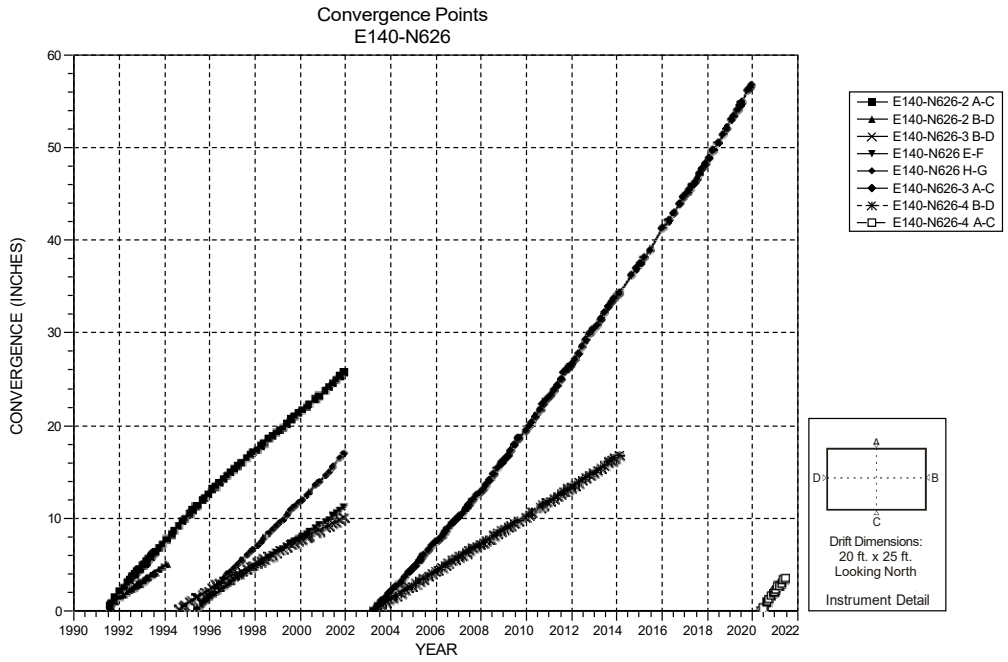
NOTES:
1. Excavation date: February 1983.
2. Roof excavated to Anhydrite 'b' in mid 2001.0

Figure 4-41 Convergence Point Array – E140 N460 – Roof to Floor



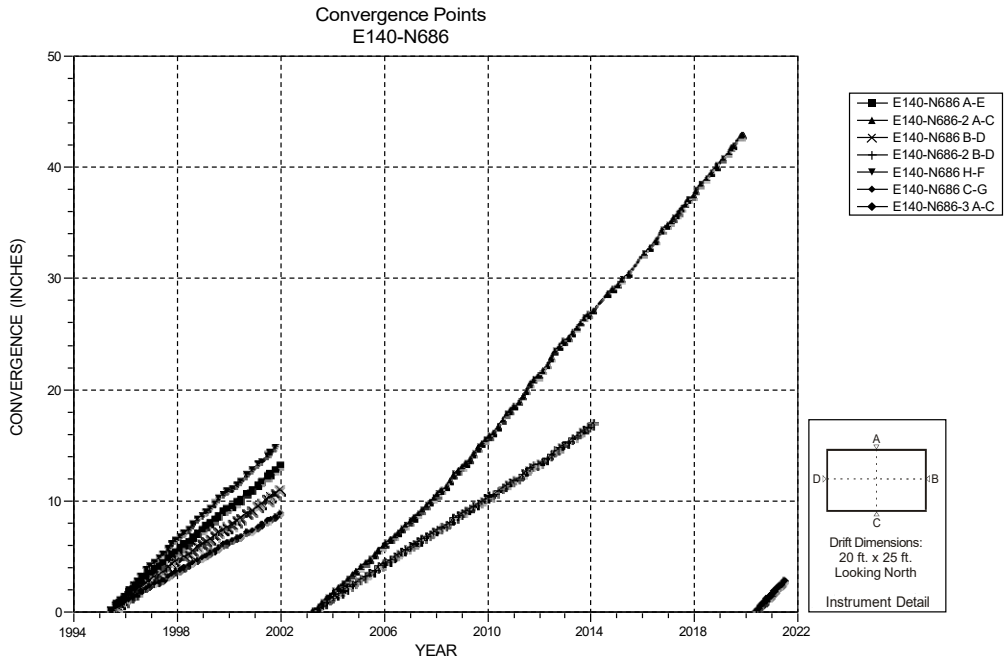
NOTES:
1. Excavation date: February 1983.
2. Roof excavated to Anhydrite "b" in early 2002.
3. Initially this location had three vertical chords: A-E, B-D, and H-F and a horizontal chord, G-G.

Figure 4-42 Convergence Point Array – E140 N562 – All Chords



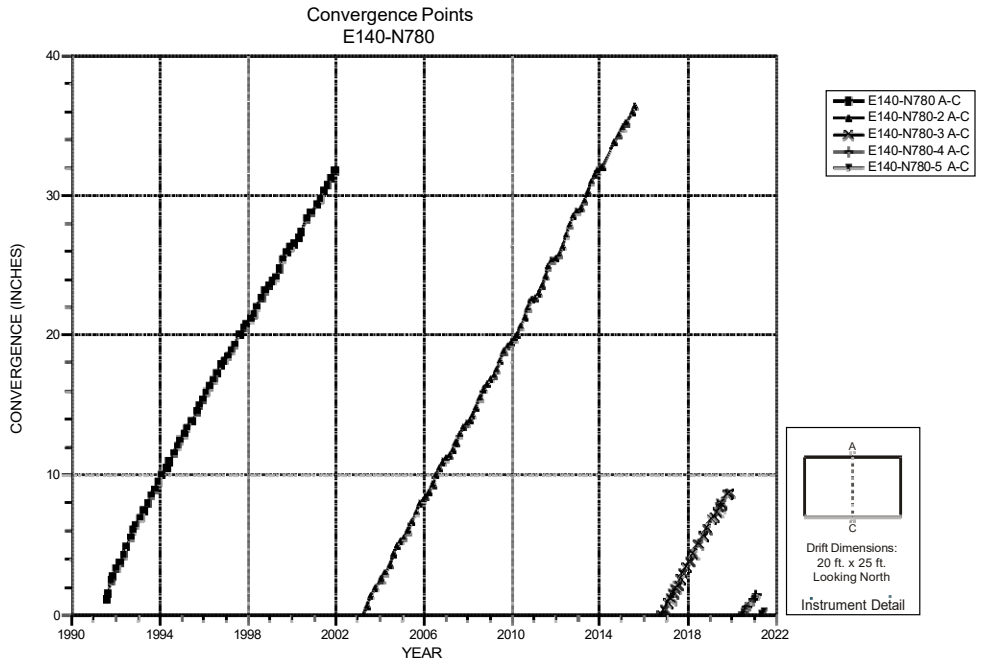
NOTES:
1. Excavation date: February 1983.
2. Roof excavated to Anhydrite "b" in early 2002.

Figure 4-43 Convergence Point Array – E140 N626 – All Chords



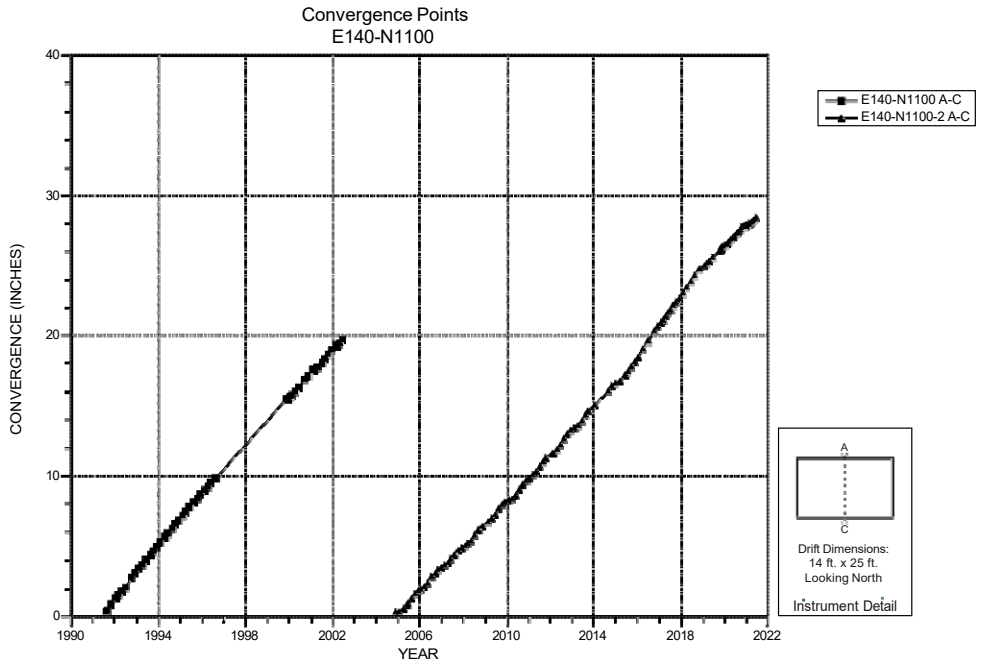
NOTES:
1. Excavation date: February 1983.
2. Roof excavated to Anhydrite "b" in early 2002.
3. Initially this location had three vertical chords: A-E, B-D, and H-F and a horizontal chord, G-G.

Figure 4-44 Convergence Point Array – E140 N686 – All Chords



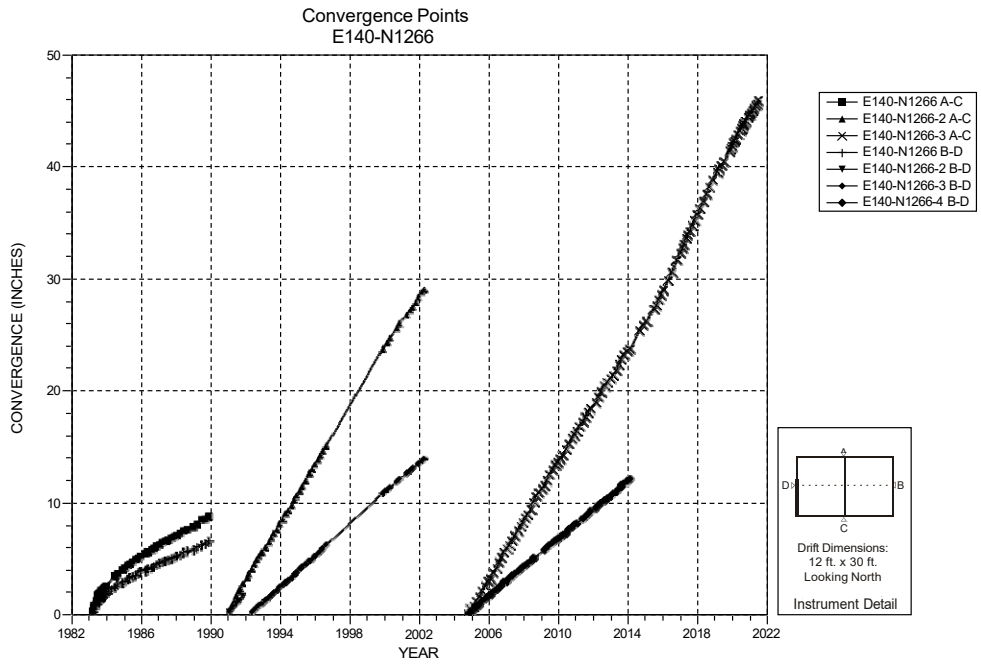
NOTES:
1. Excavation date: February 1983.
2. Roof excavated to Anhydrite 'b' in early 2002.

Figure 4-45 Convergence Point Array – E140 N780 – Roof to Floor



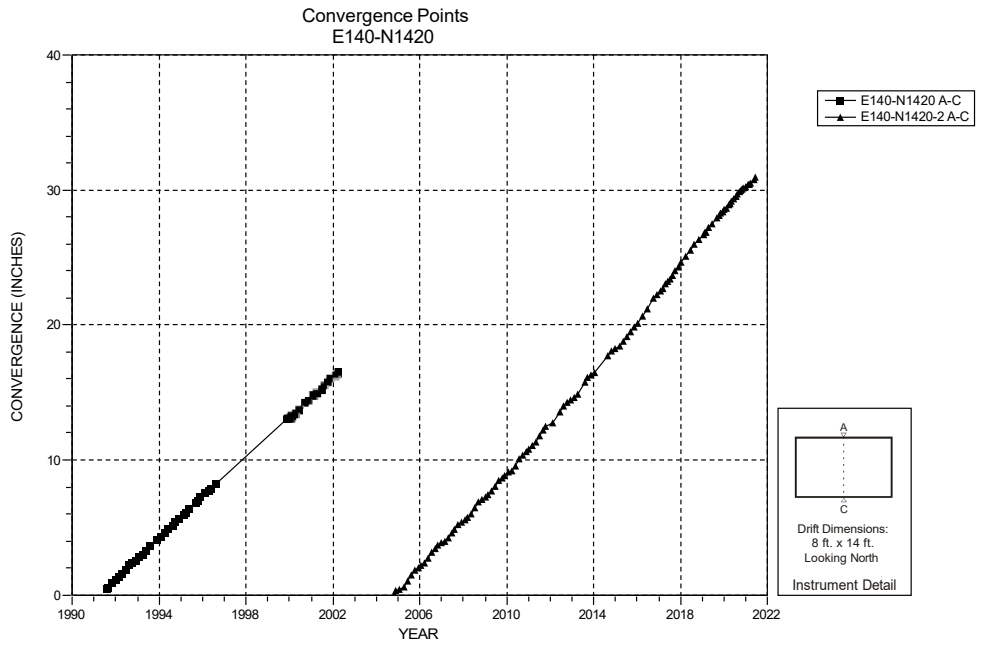
NOTES:
1. Excavation date: February 1983.

Figure 4-46 Convergence Point Array – E140 N1100 – Roof to Floor



NOTES:
1. Excavation date: February 1983.
2. Enlarged from 8ft x 14ft in January 1990.

Figure 4-47 Convergence Point Array – E140 N1266 – All Chords



NOTES:
1. Excavation date: February 1983.
2. Inaccessible from August 1996 to November 1999.

Figure 4-48 Convergence Point Array – E140 N1420 – Roof to Floor

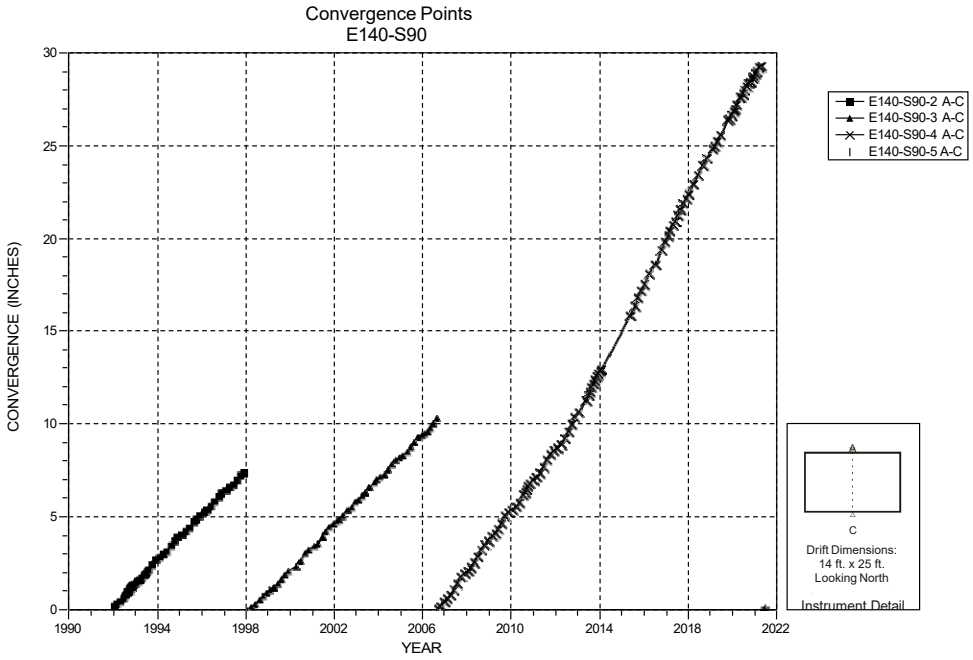


Figure 4-49 Convergence Point Array – E140 S90 – Roof to Floor

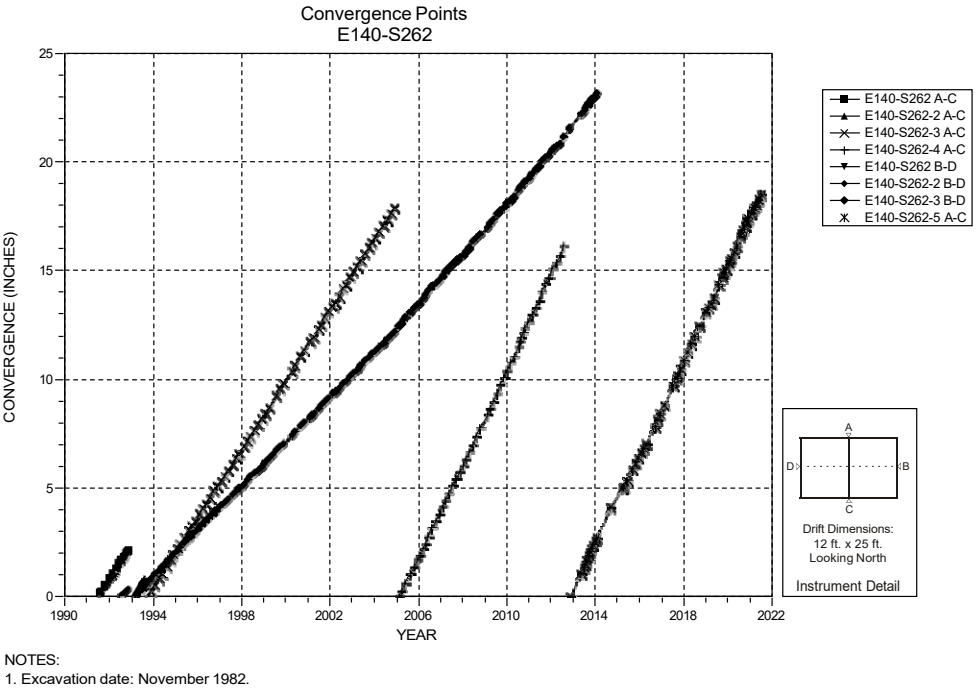
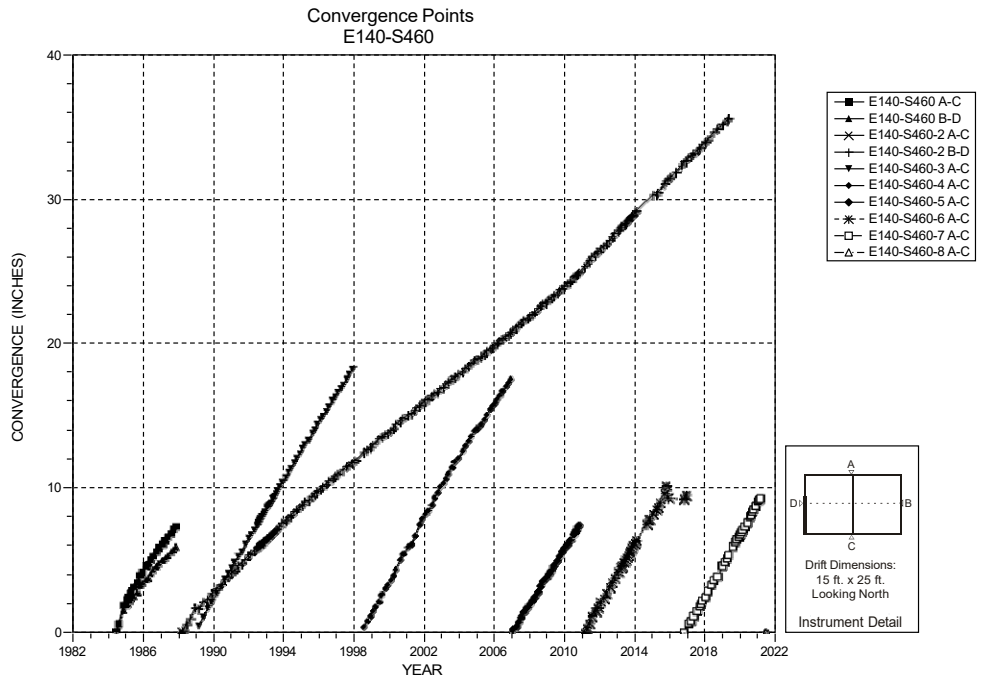
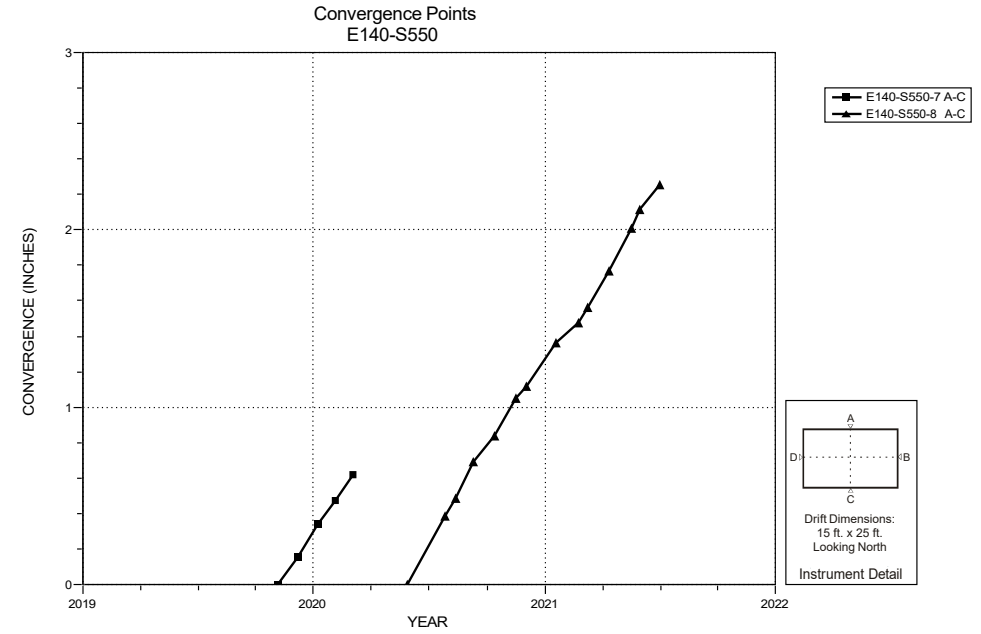


Figure 4-50 Convergence Point Array – E140 S262 – All Chords



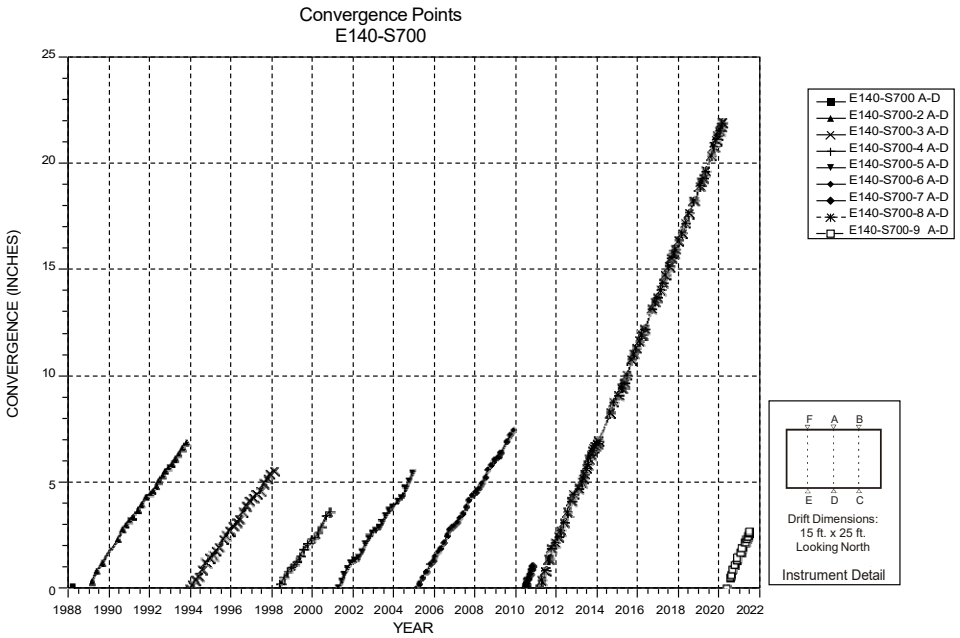
NOTES:
1. Excavation date: December 1982.

Figure 4-51 Convergence Point Array – E140 S460 – All Chords



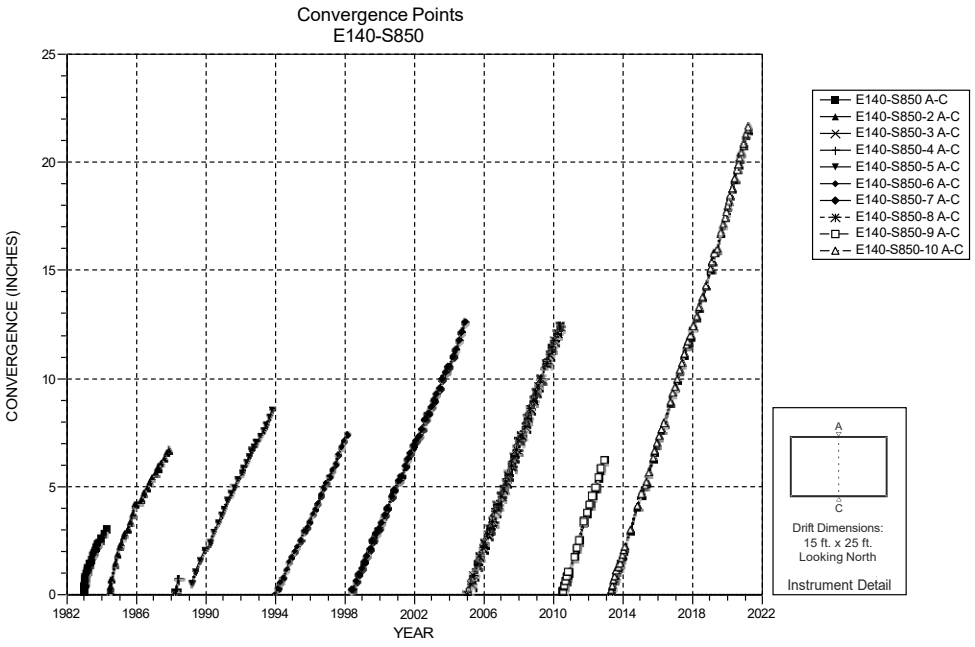
NOTES:
1. Excavation date: December 1982.
2. See FIGID 1745 for prior history.

Figure 4-52 Convergence Point Array – E140 S550 – All Chords



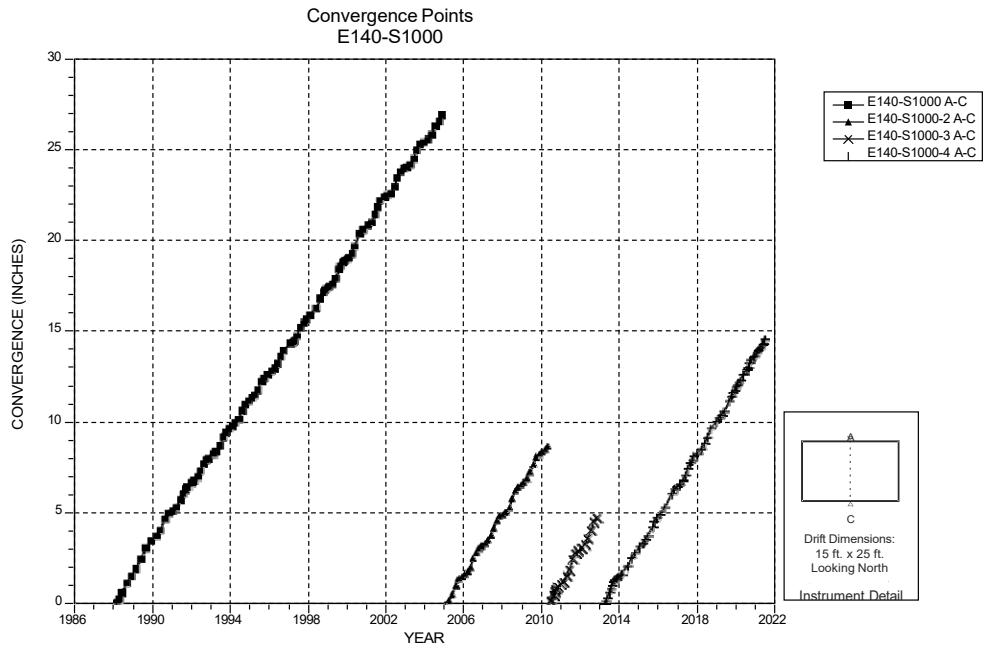
NOTES:
1. Excavation date: December 1982.

Figure 4-53 Convergence Point Array – E140 S700 – Roof to Floor



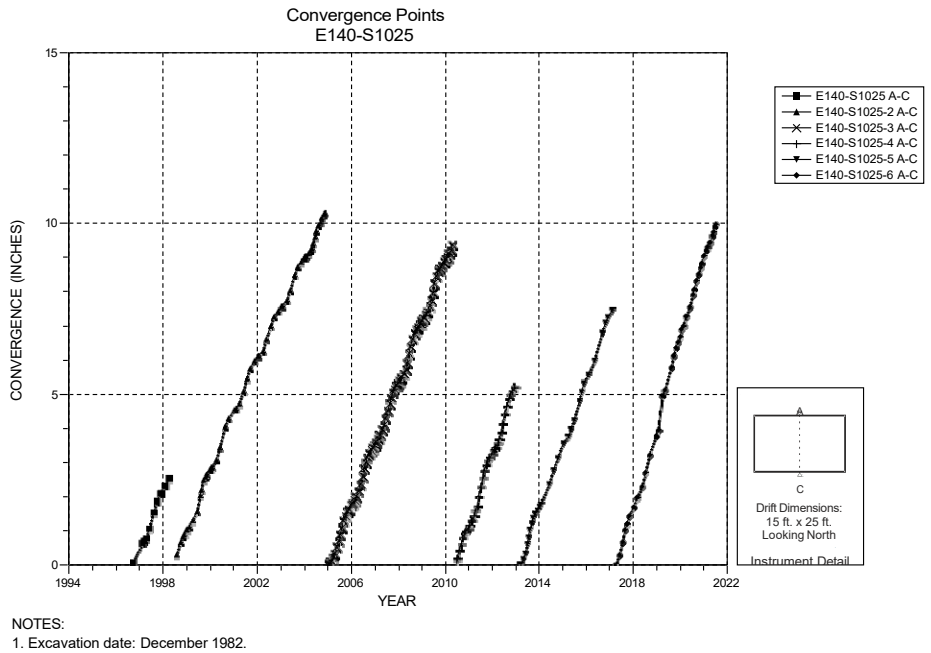
NOTES:
1. Excavation date: December 1982.

Figure 4-54 Convergence Point Array – E140 S850 – Roof to Floor



NOTES:
1. Excavation date: December 1982.

Figure 4-55 Convergence Point Array – E140 S1000 – Roof to Floor



NOTES:
1. Excavation date: December 1982.

Figure 4-56 Convergence Point Array – E140 S1025 – Roof to Floor

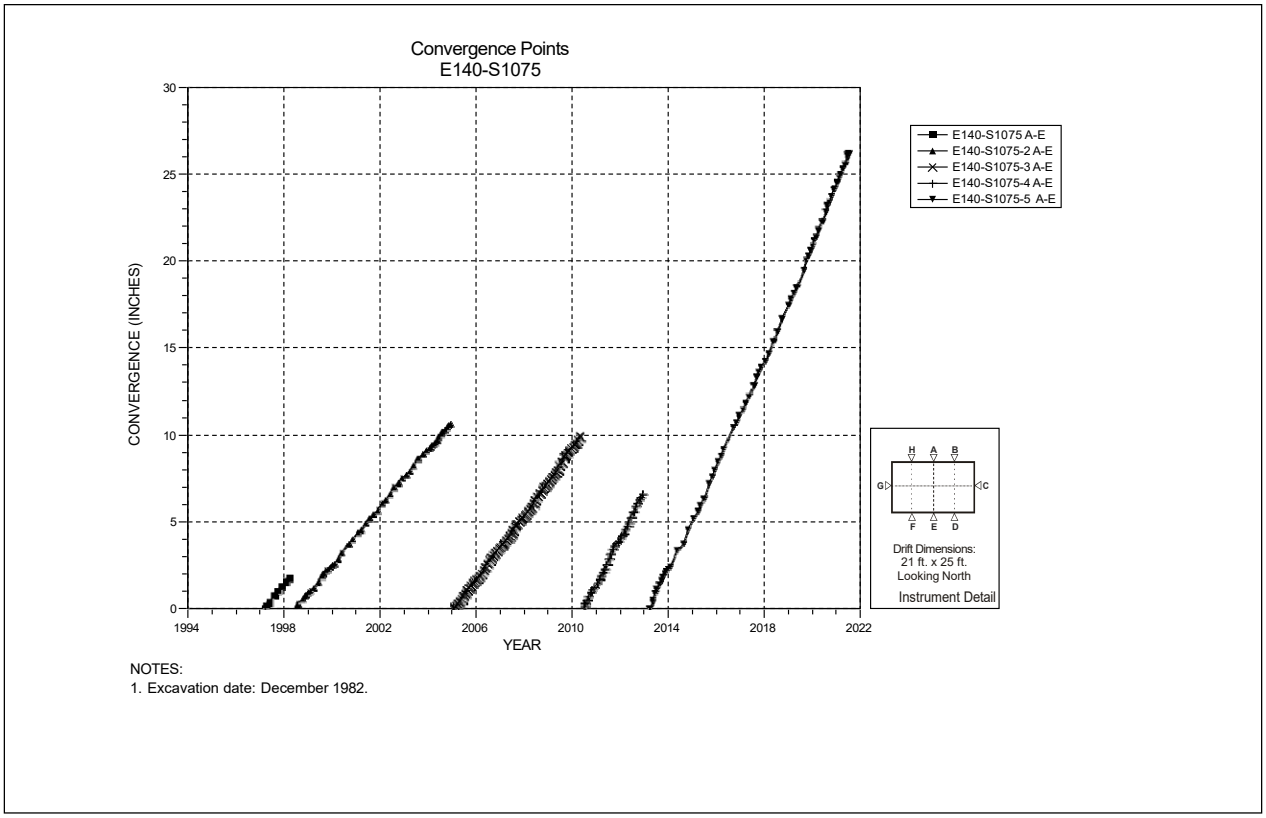


Figure 4-57 Convergence Point Array – E140 S1075 – Roof to Floor

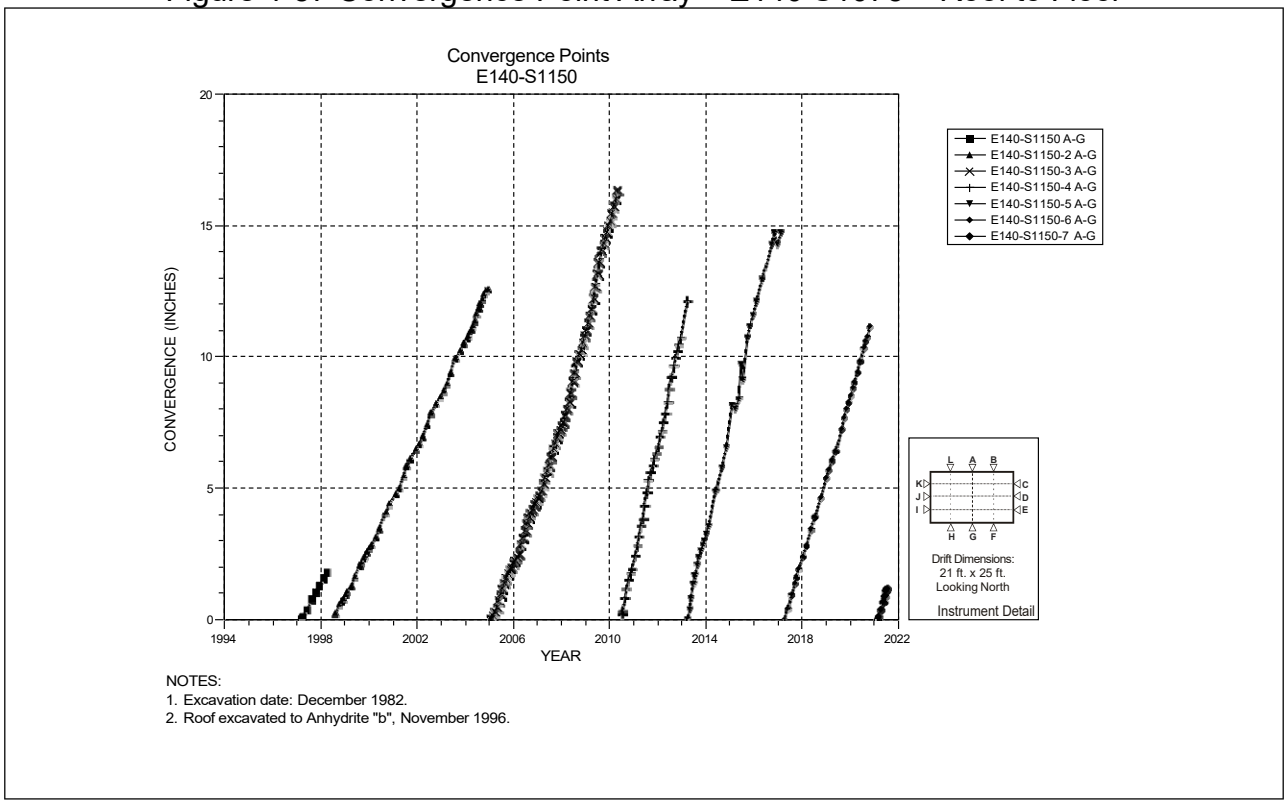
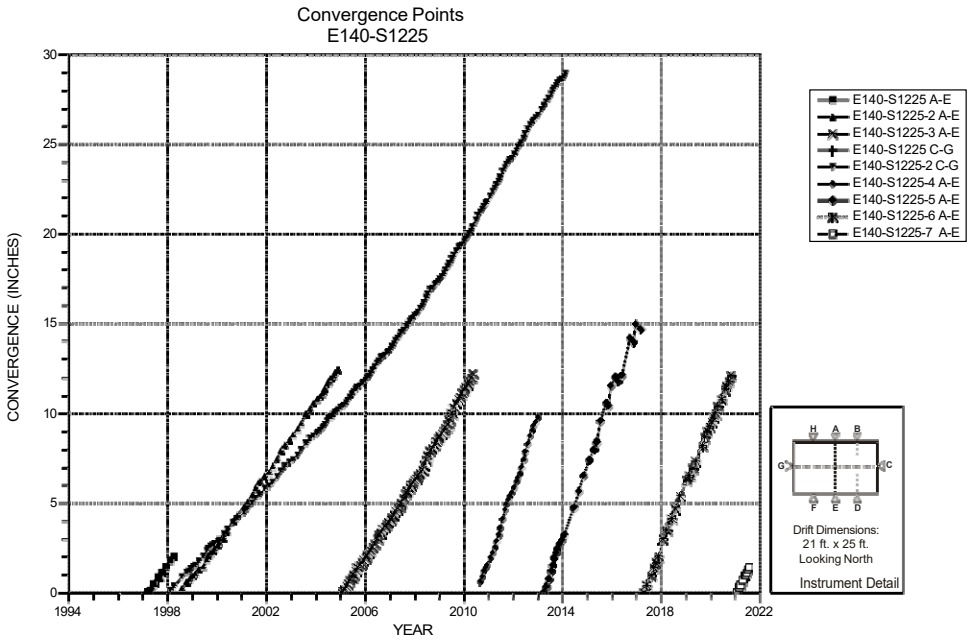
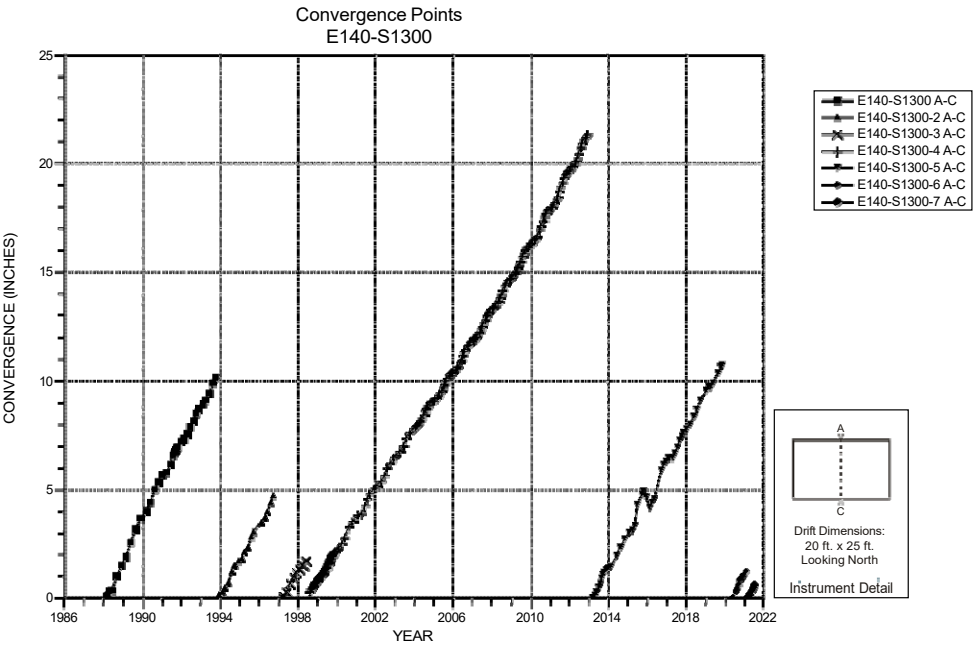


Figure 4-58 Convergence Point Array – E140 S1150 – Roof to Floor



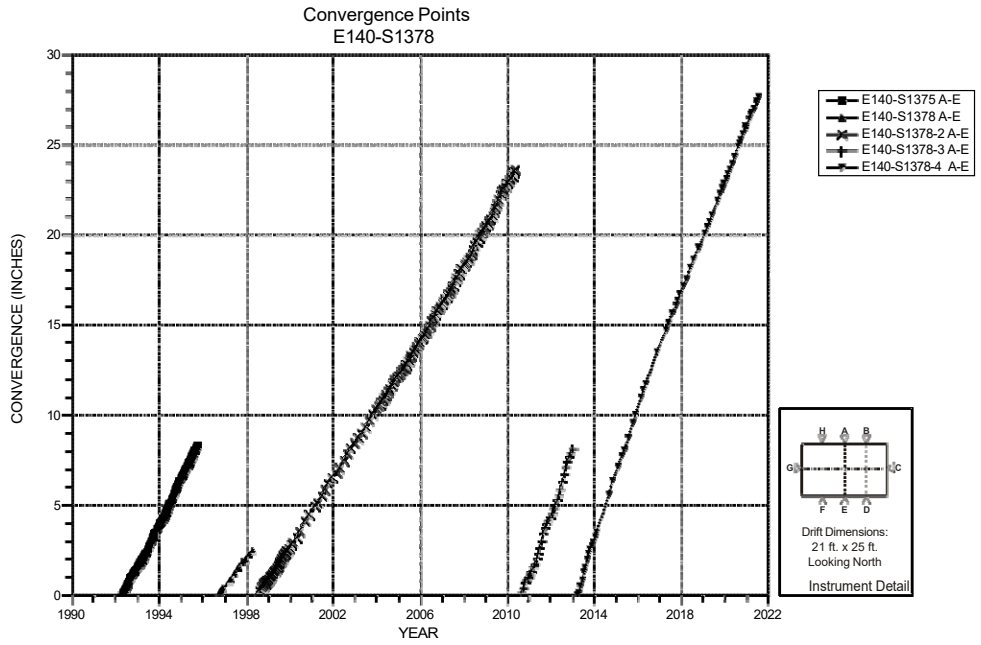
NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b", November 1996.

Figure 4-59 Convergence Point Array – E140 S1225 – All Chords



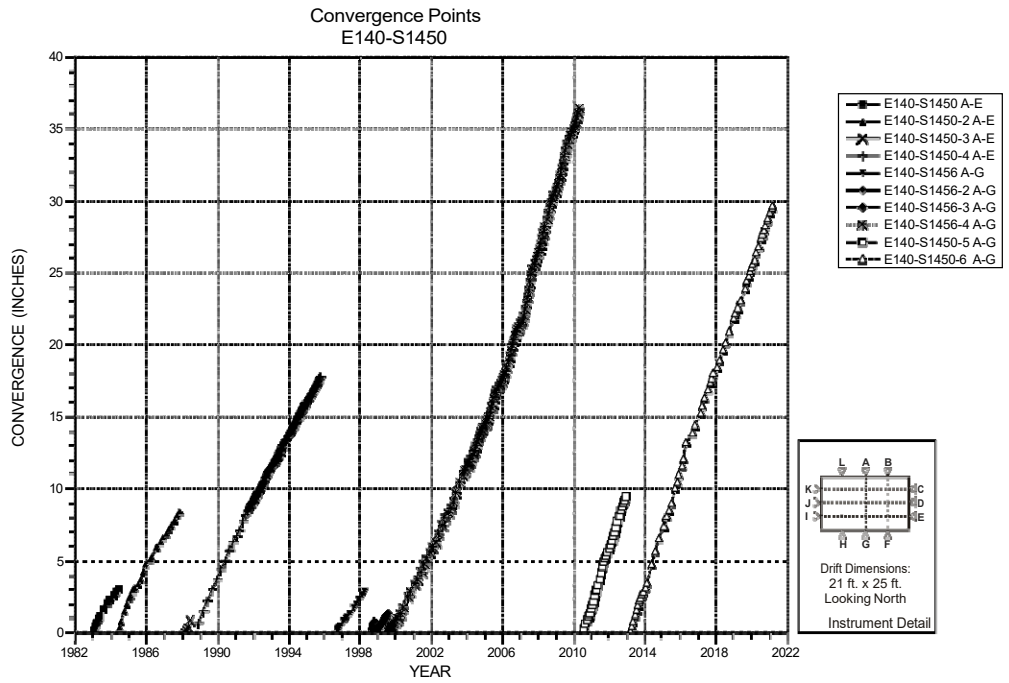
NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b" in December 1996.

Figure 4-60 Convergence Point Array – E140 S1300 – Roof to Floor



NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b" in December 1995.

Figure 4-61 Convergence Point Array – E140 S1378 – Roof to Floor



NOTES:
1. Excavation date: December 1982.

Figure 4-62 Convergence Point Array – E140 S1450 – Roof to Floor

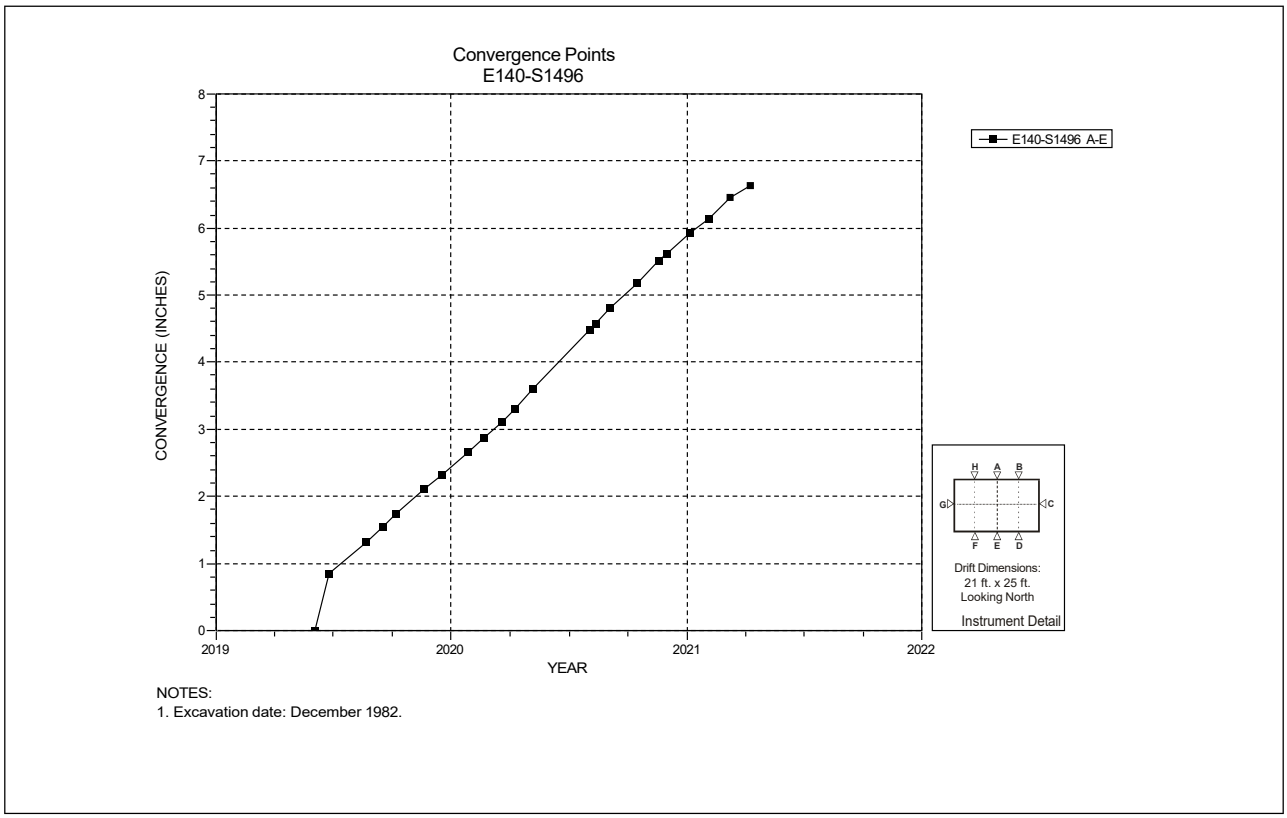


Figure 4-63 Convergence Point Array – E140 S1496 – Roof to Floor – Test Area

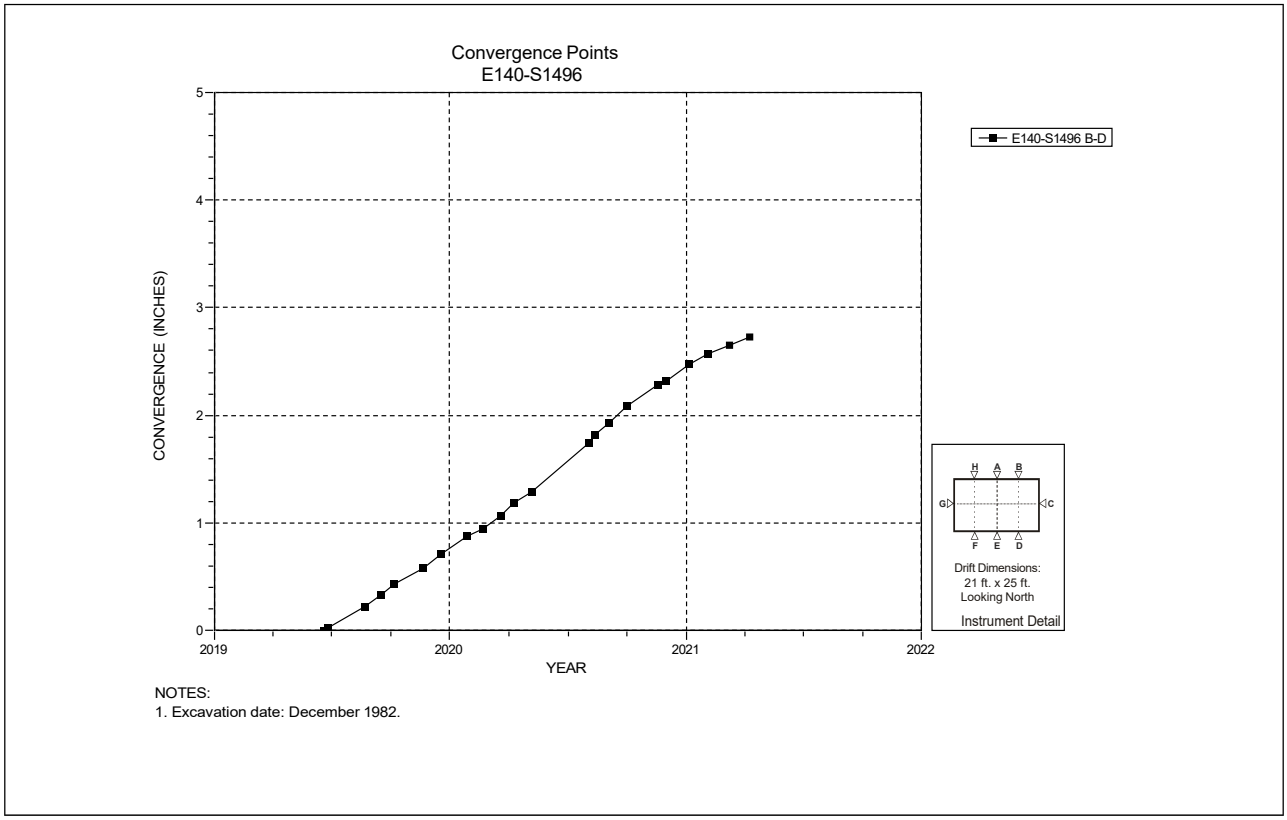
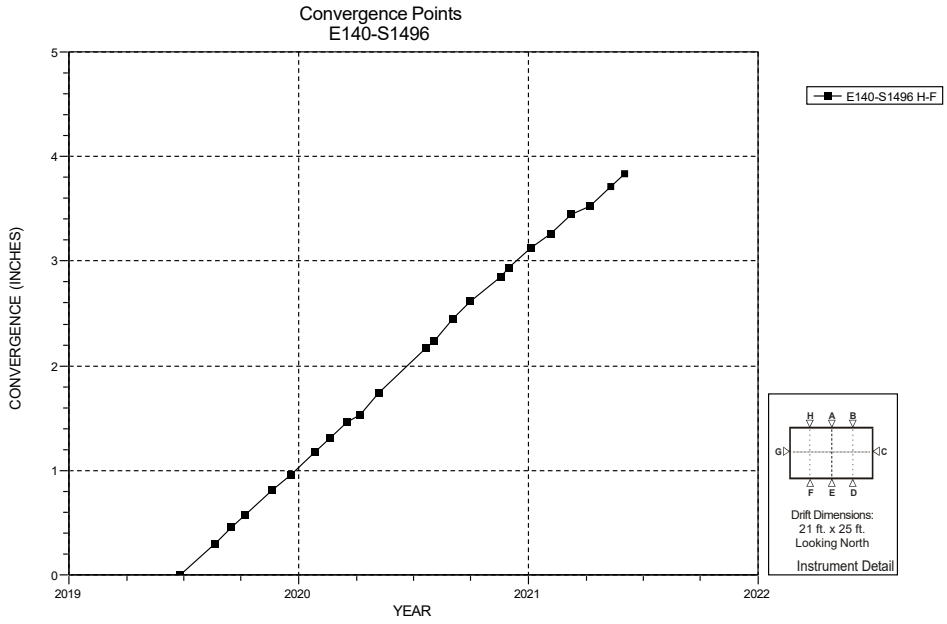
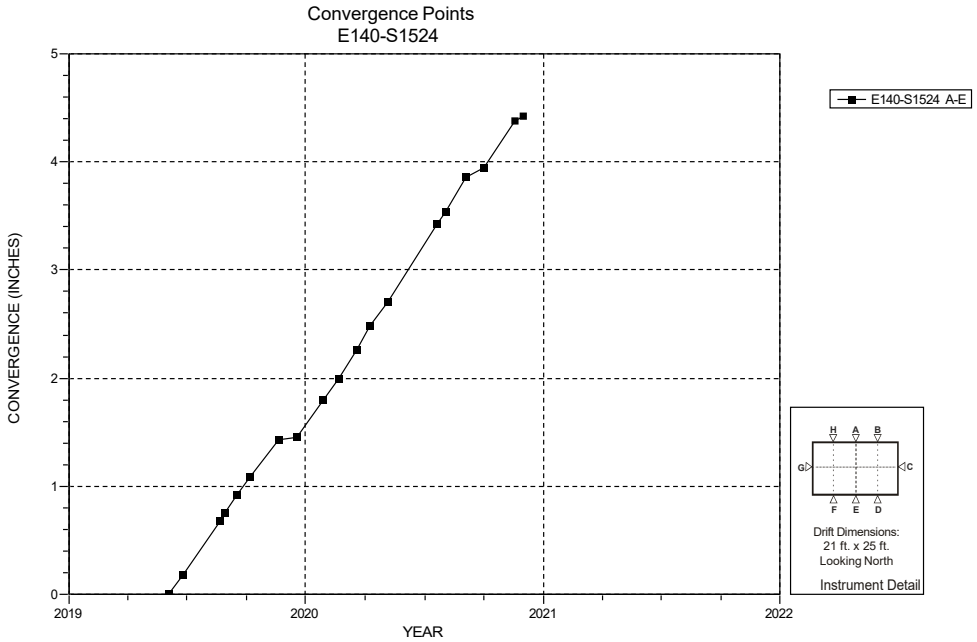


Figure 4-64 Convergence Point Array – E140 S1496 – Roof to Floor – Test Area



NOTES:
1. Excavation date: December 1982.

Figure 4-65 Convergence Point Array – E140 S1496 - Roof to Floor – Test Area



NOTES:
1. Excavation date: December 1982.

Figure 4-66 Convergence Point Array – E140 S1524 – Roof to Floor – Test Area

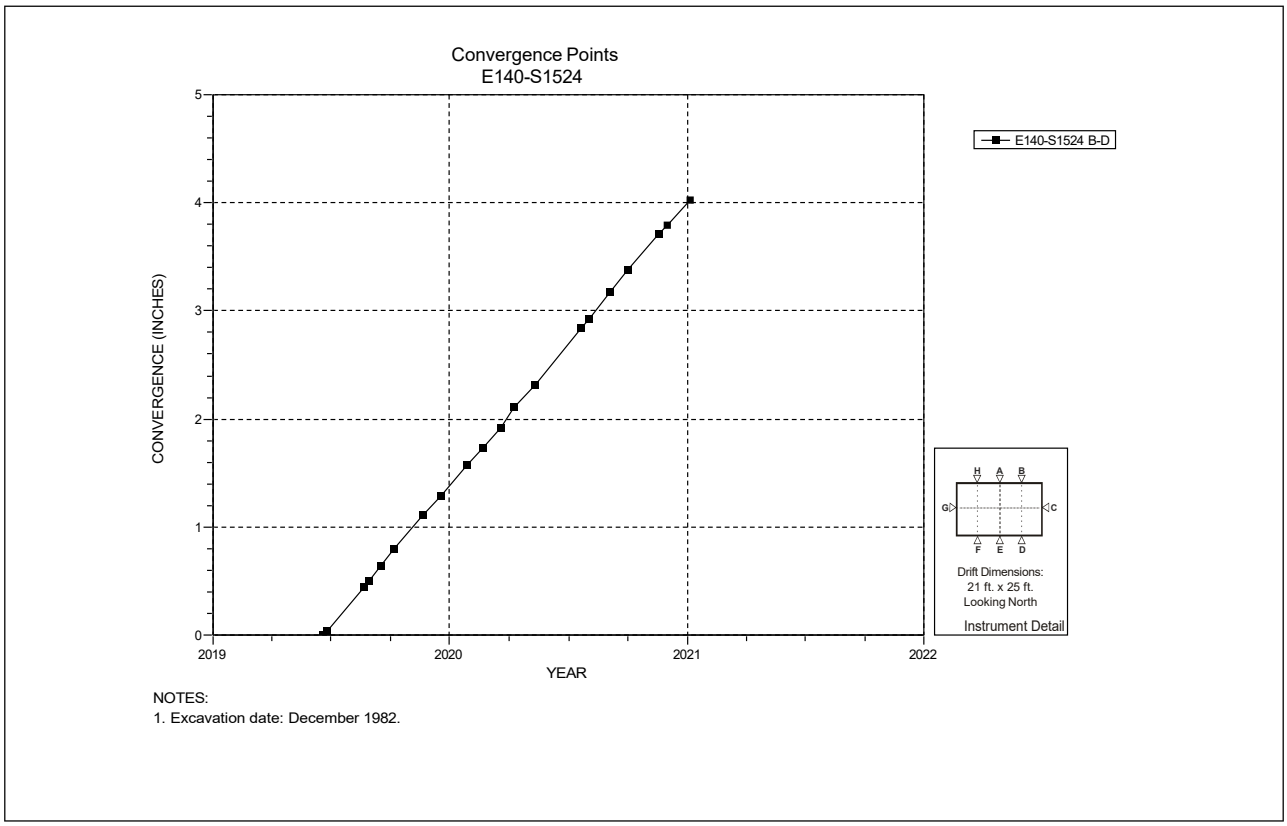


Figure 4-67 Convergence Point Array – E140 S1524 – Roof to Floor – Test Area

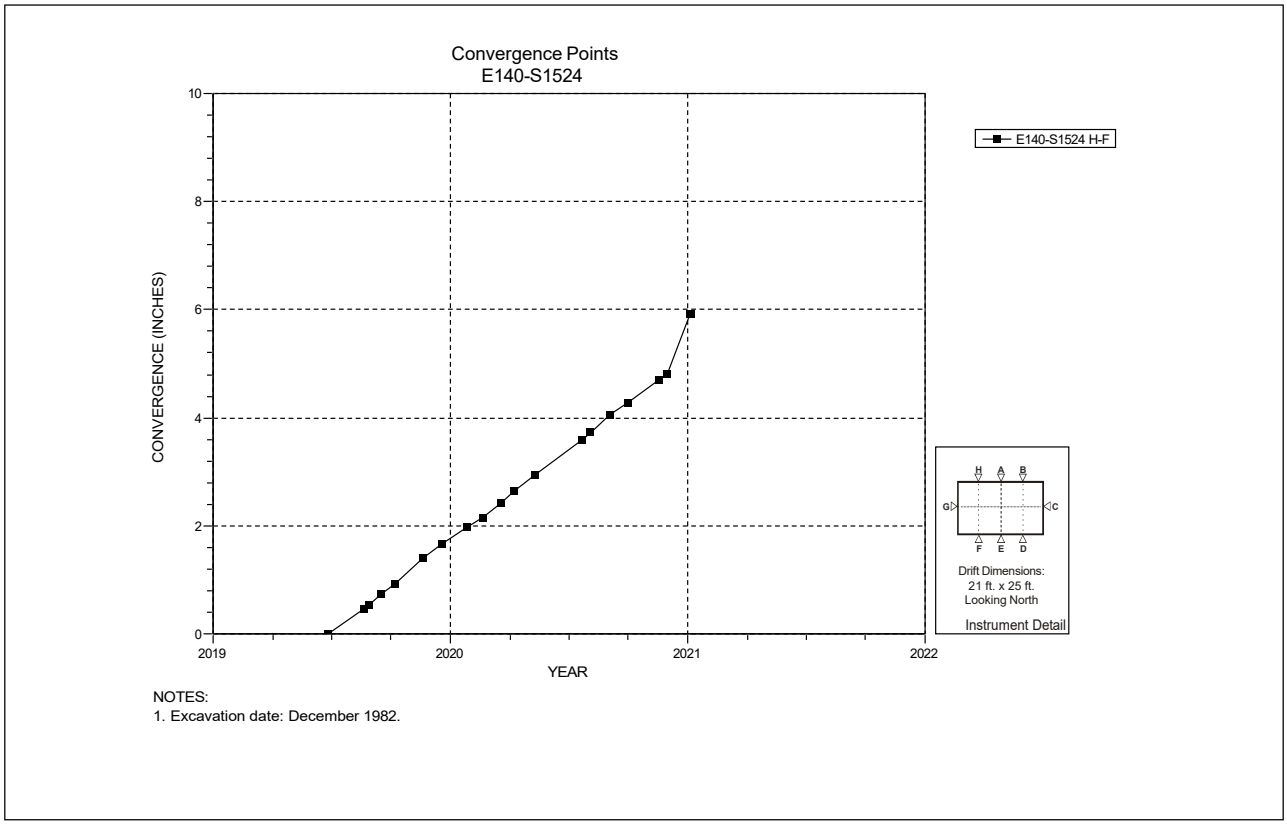
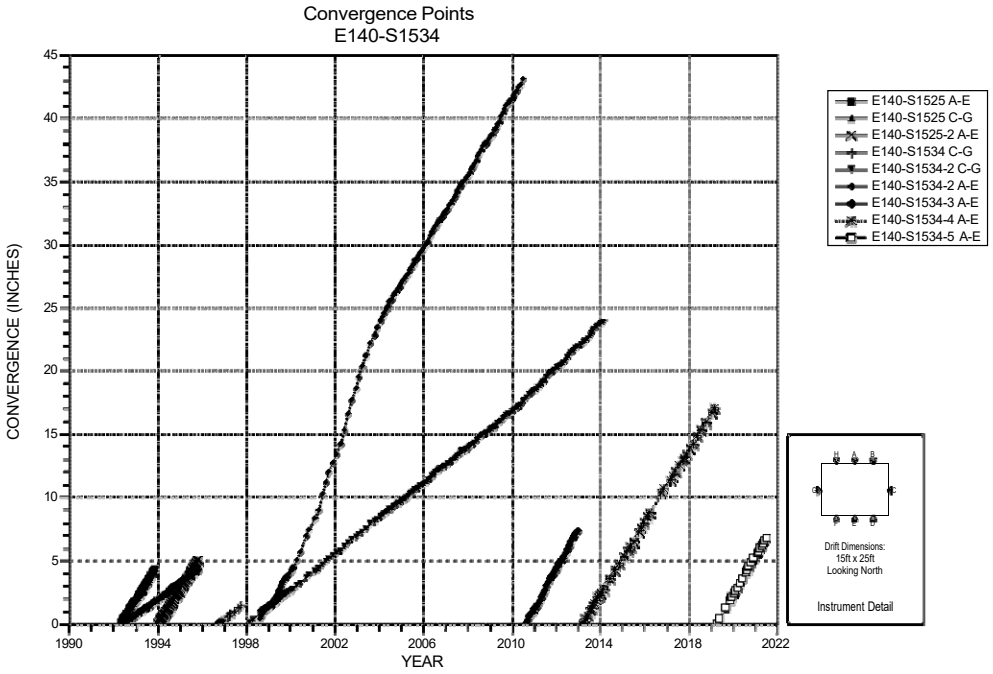
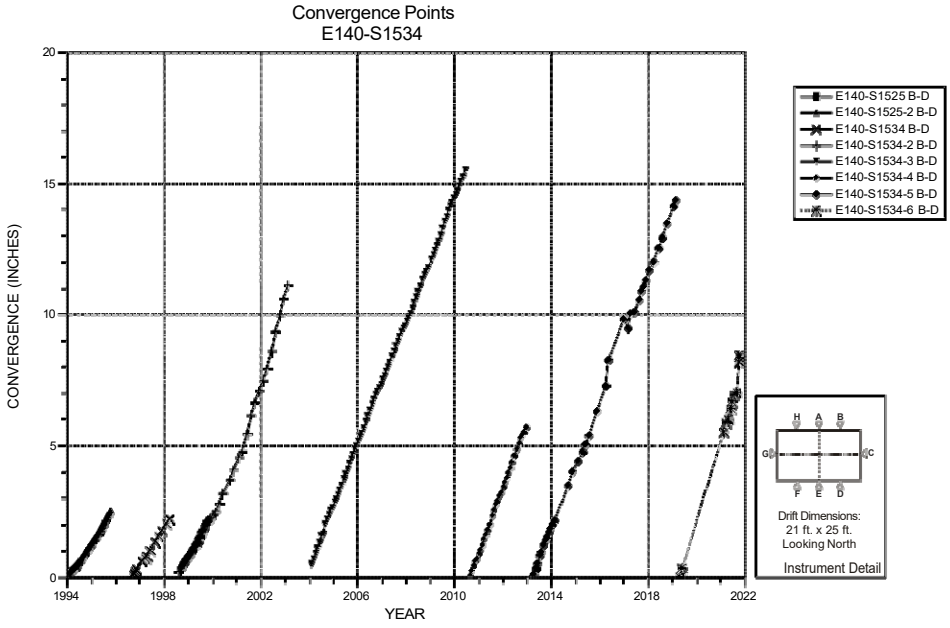


Figure 4-68 Convergence Point Array – E140 S1524 – Roof to Floor – Test Area



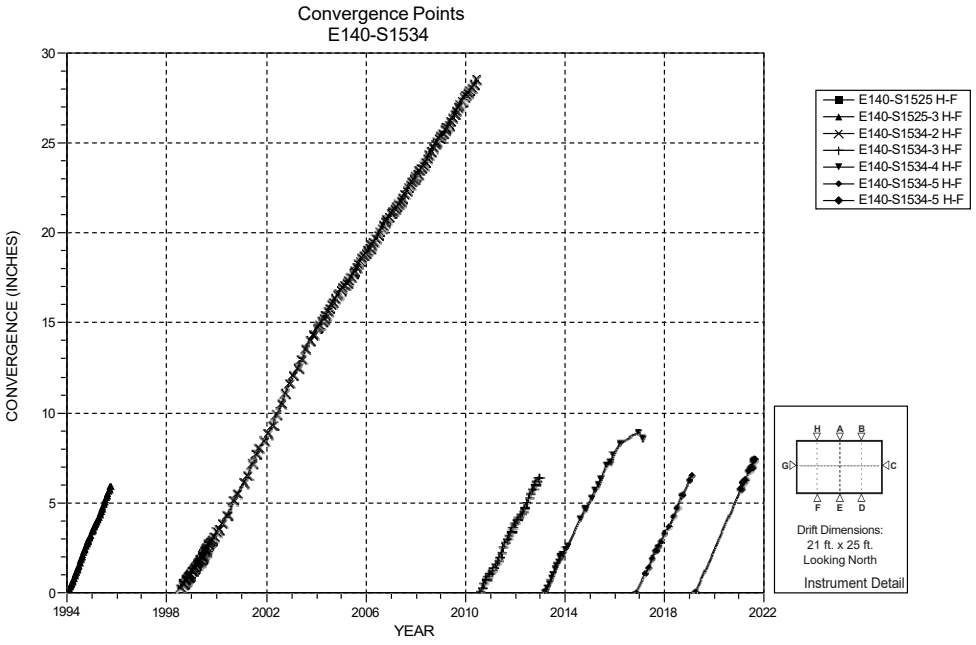
NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b" in December 1995.

Figure 4-69 Convergence Point Array – E140 S1534 – All Chords – Test Area



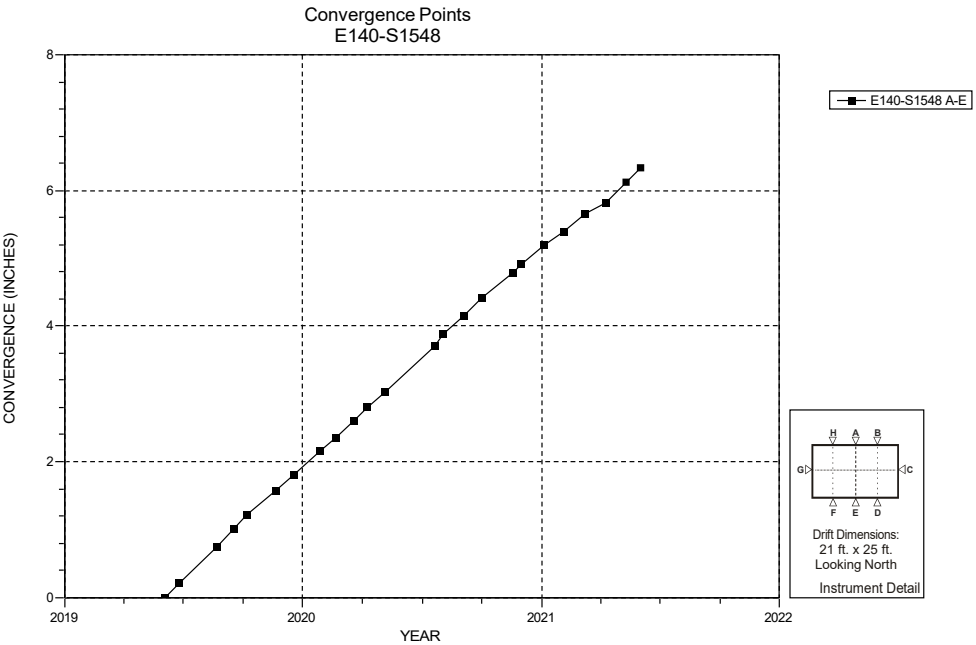
NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b" in late 1995.

Figure 4-70 Convergence Point Array – E140 S1534 – Roof to Floor – Test Area



NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b" in late 1995.

Figure 4-71 Convergence Point Array – E140 S1534 – Roof to Floor – Test Area



NOTES:
1. Excavation date: December 1982.

Figure 4-72 Convergence Point Array – E140 S1548 – Roof to Floor – Test Area

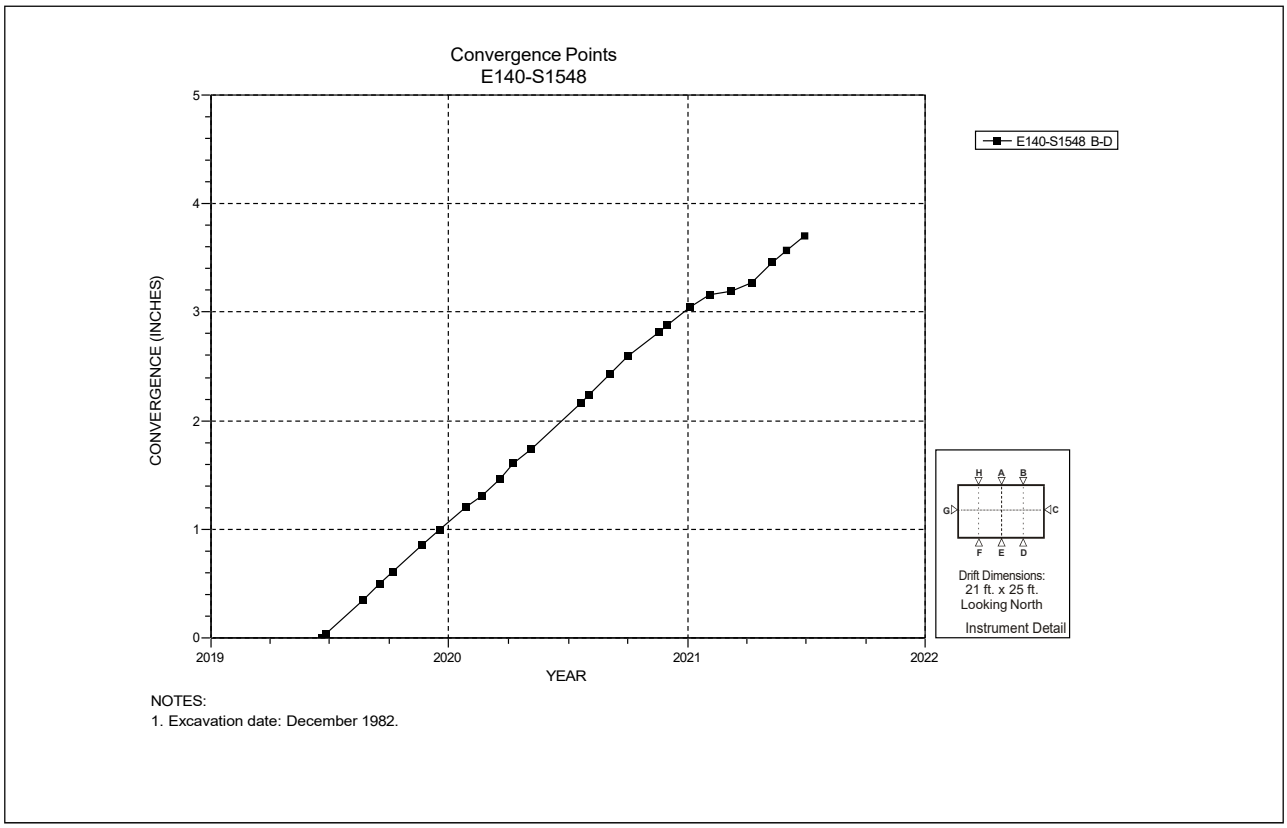


Figure 4-73 Convergence Point Array – E140 S1548 – Roof to Floor – Test Area

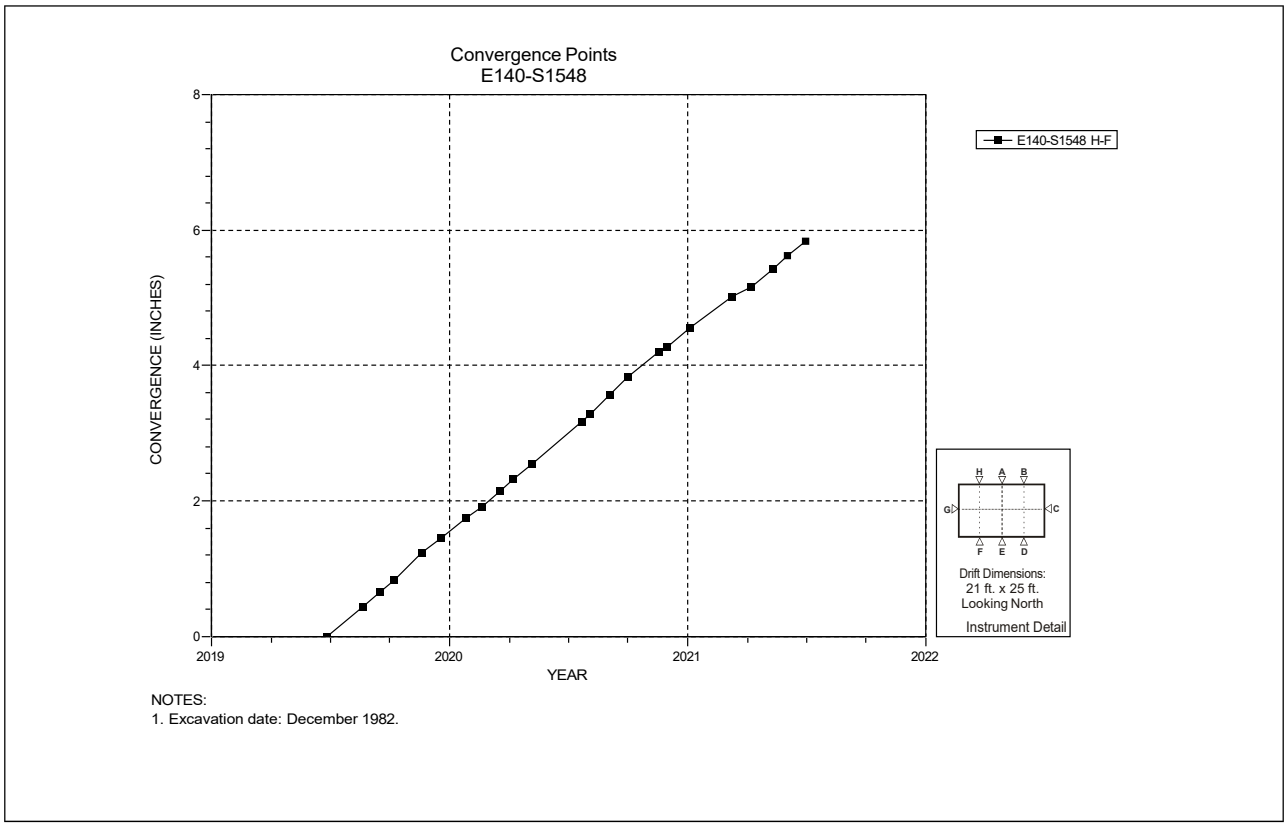
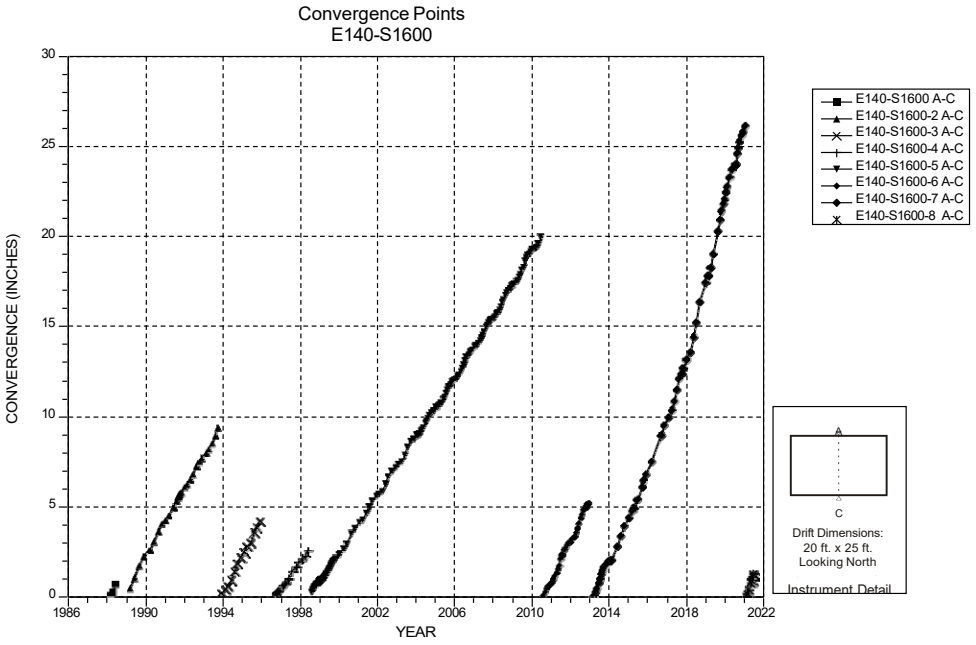
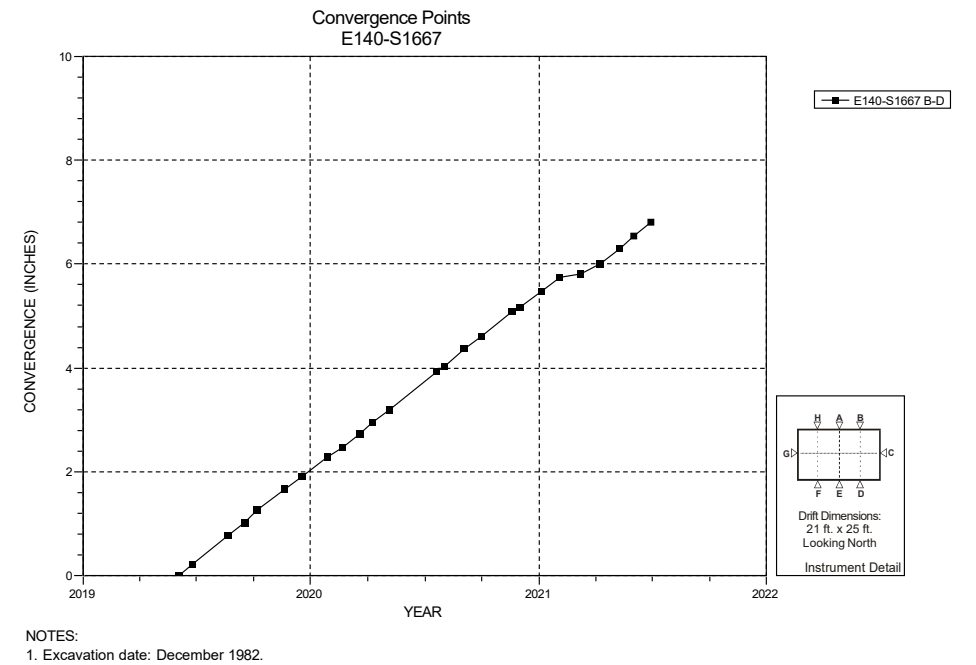


Figure 4-74 Convergence Point Array – E140 S1548 – Roof to Floor – Test Area



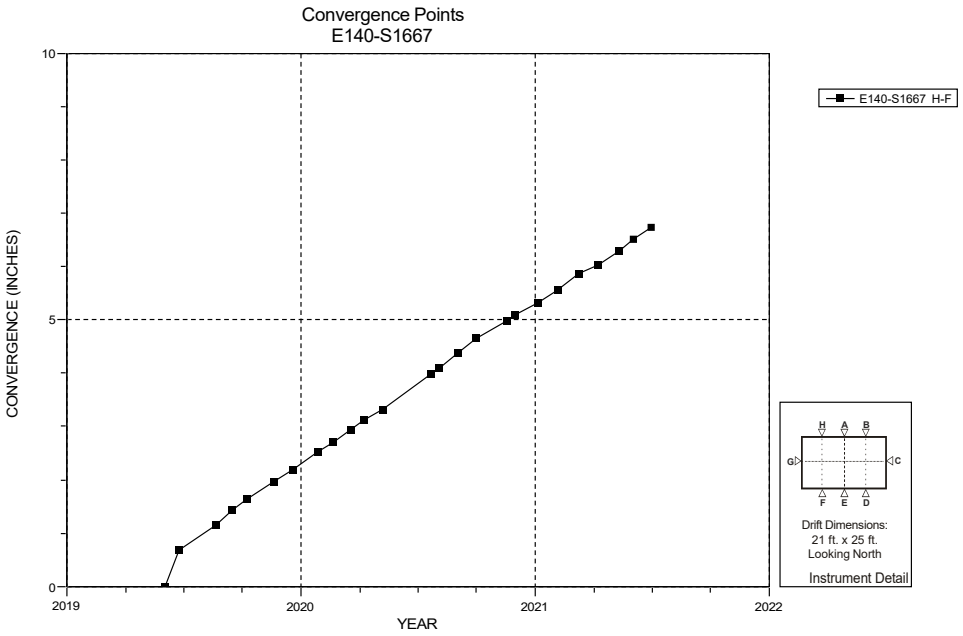
NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b" in December 1996.

Figure 4-75 Convergence Point Array – E140 S1600 – Roof to Floor



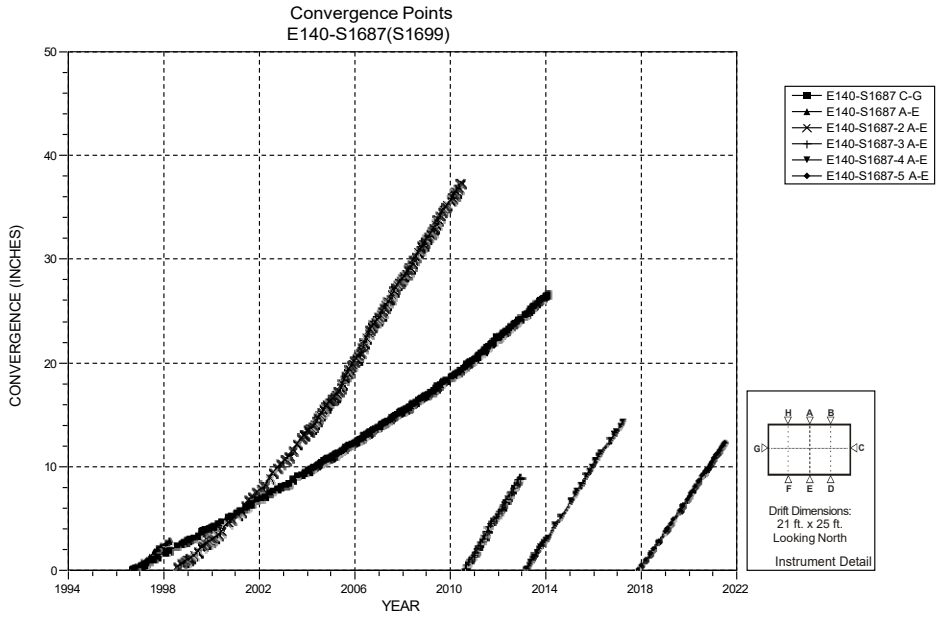
NOTES:
1. Excavation date: December 1982.

Figure 4-76 Convergence Point Array – E140 S1667 – Roof to Floor – Test Area



NOTES:
1. Excavation date: December 1982.

Figure 4-77 Convergence Point Array – E140 S1667 H-F – Roof to Floor – Test Area



NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b" in early 1996.

Figure 4-78 Convergence Point Array – E140 S1687 – All Chords – Test Area

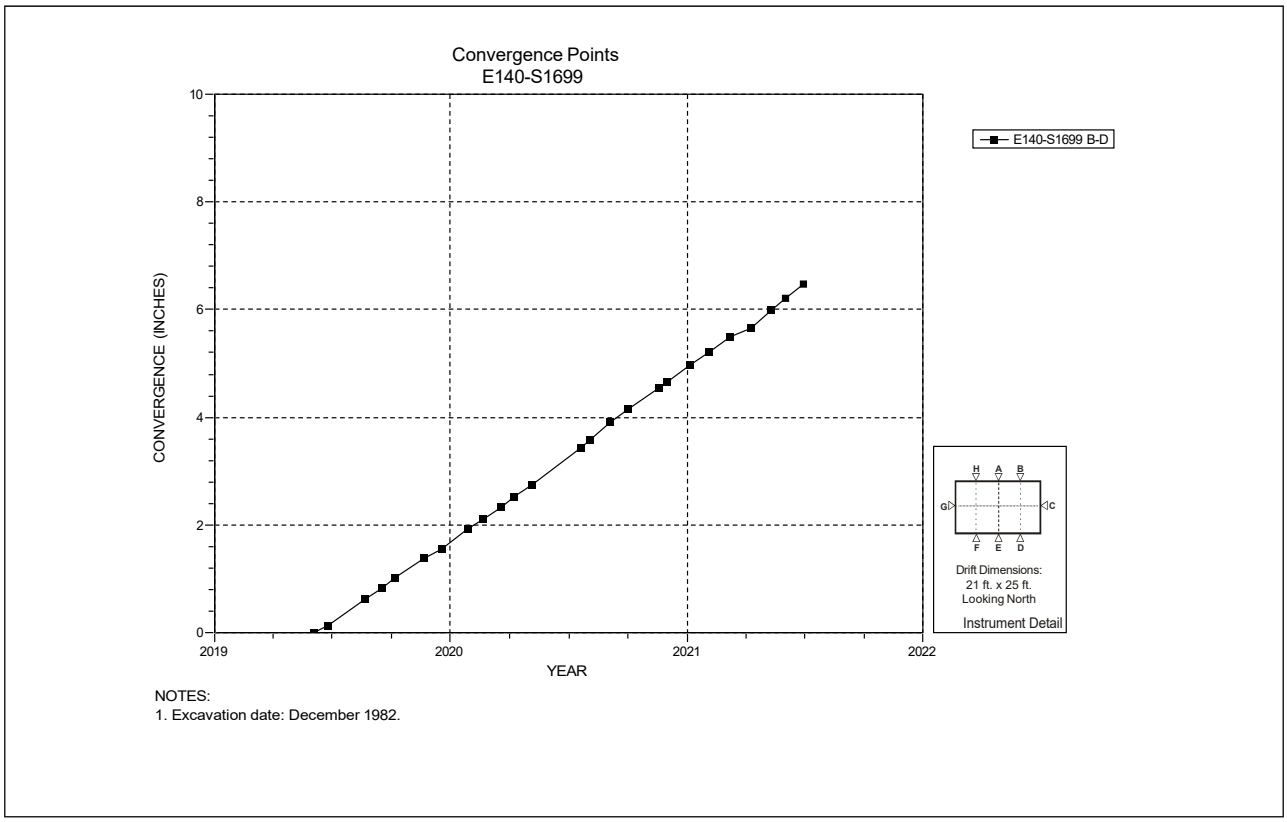


Figure 4-79 Convergence Point Array – E140 S1699 – Roof to Floor – Test Area

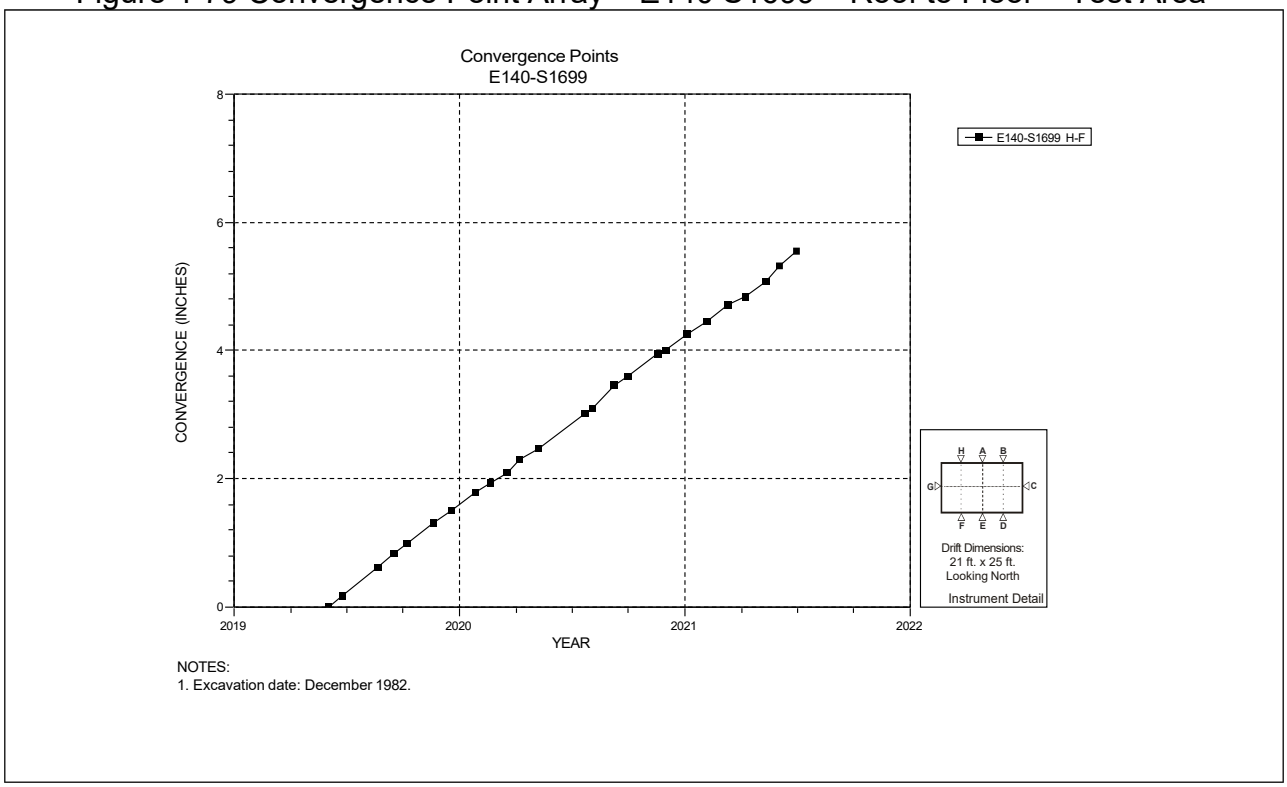


Figure 4-80 Convergence Point Array – E140 S1699 – Roof to Floor – Test Area

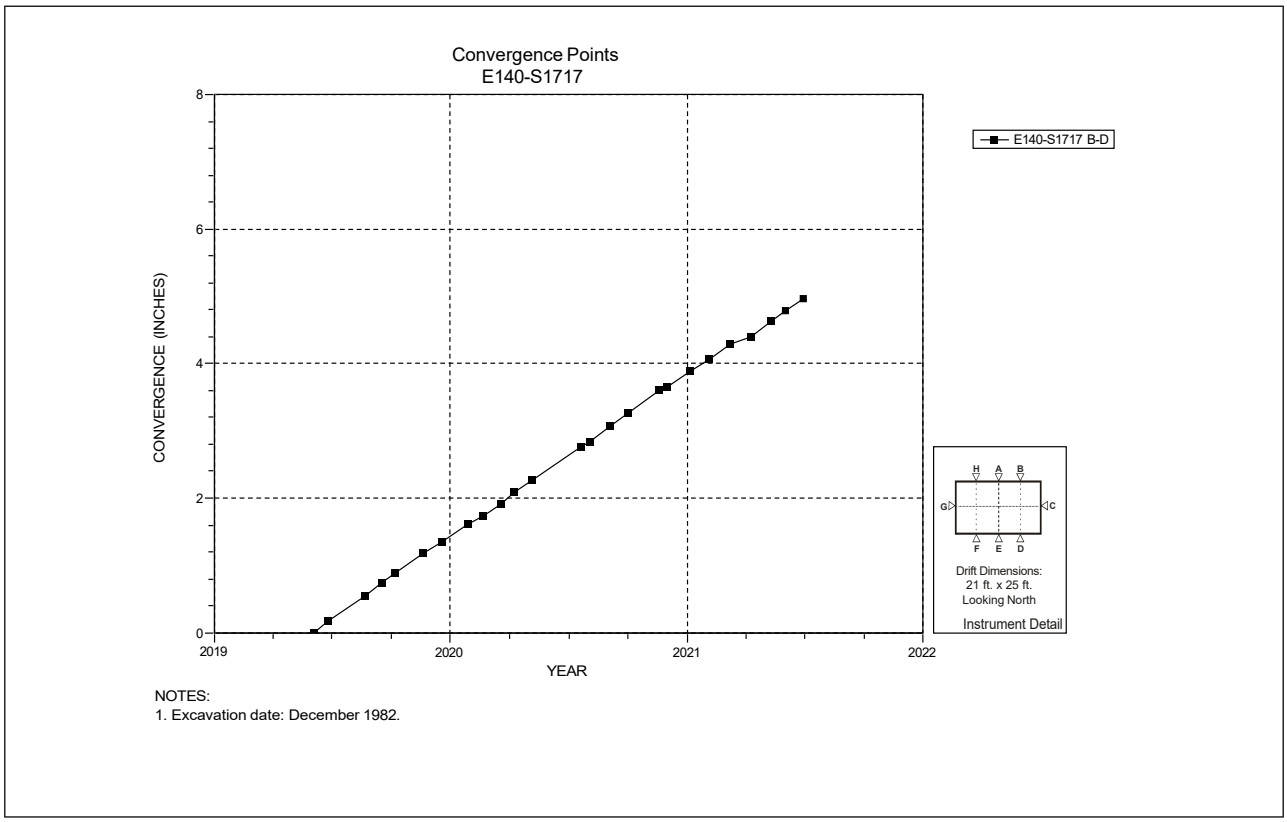


Figure 4-81 Convergence Point Array – E140 S1717 – Roof to Floor – Test Area

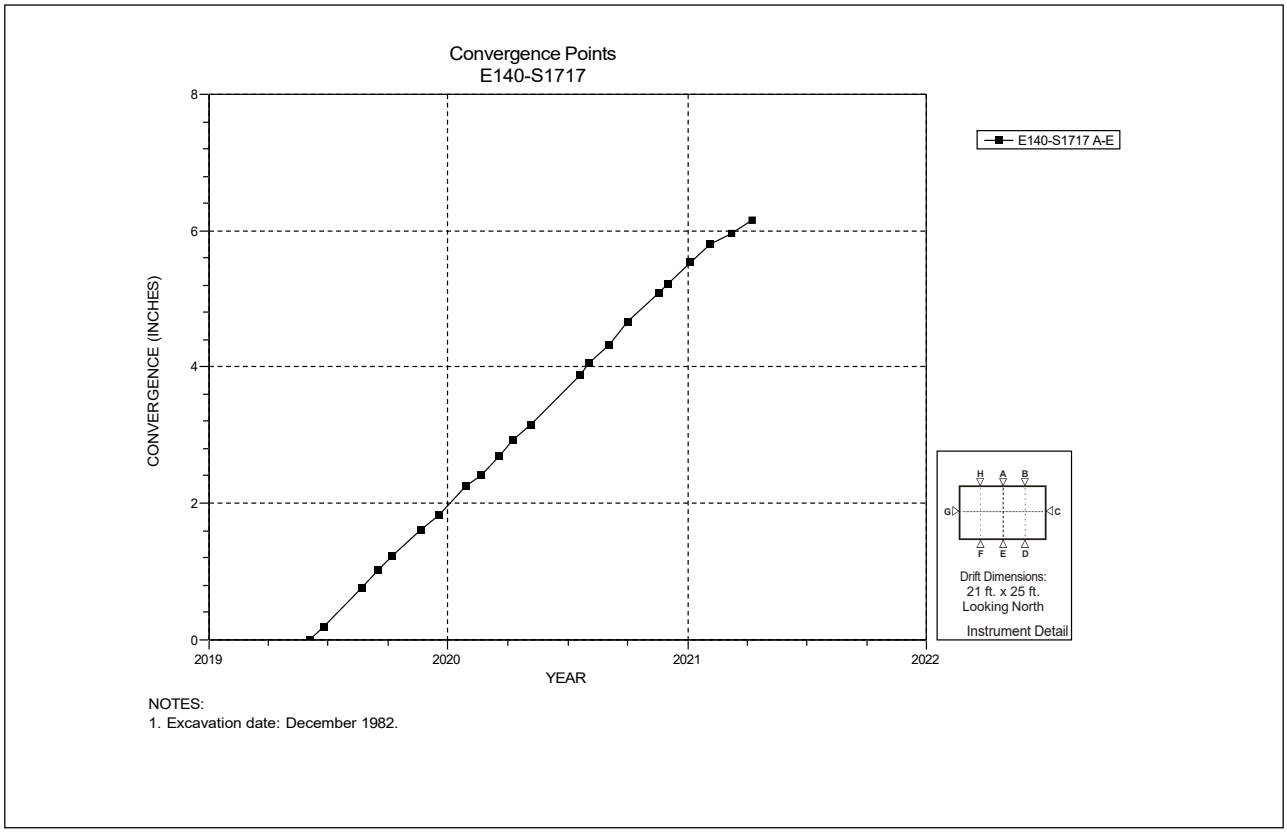
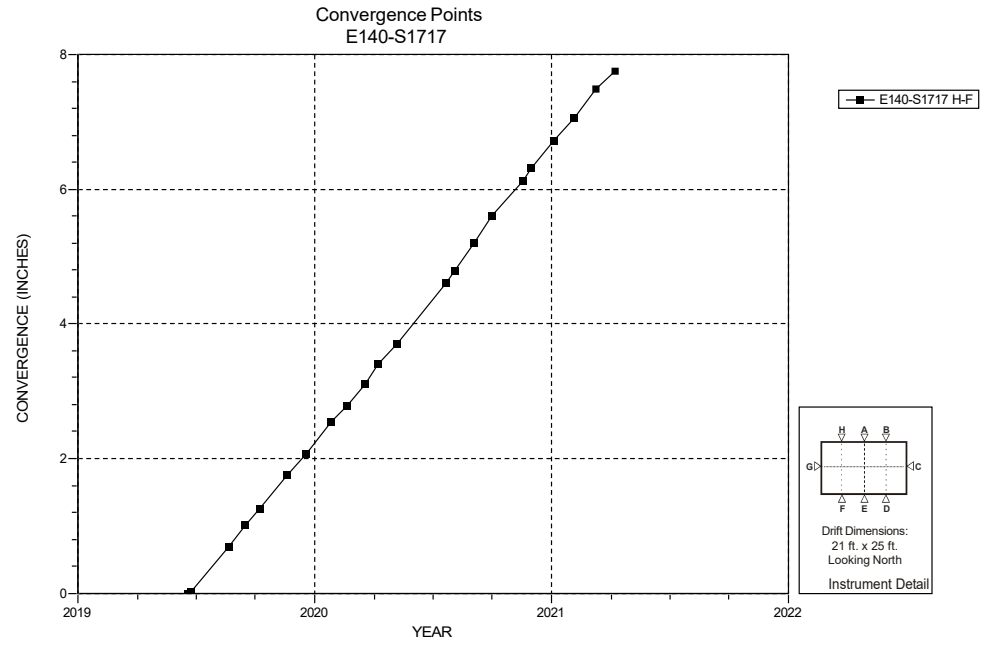
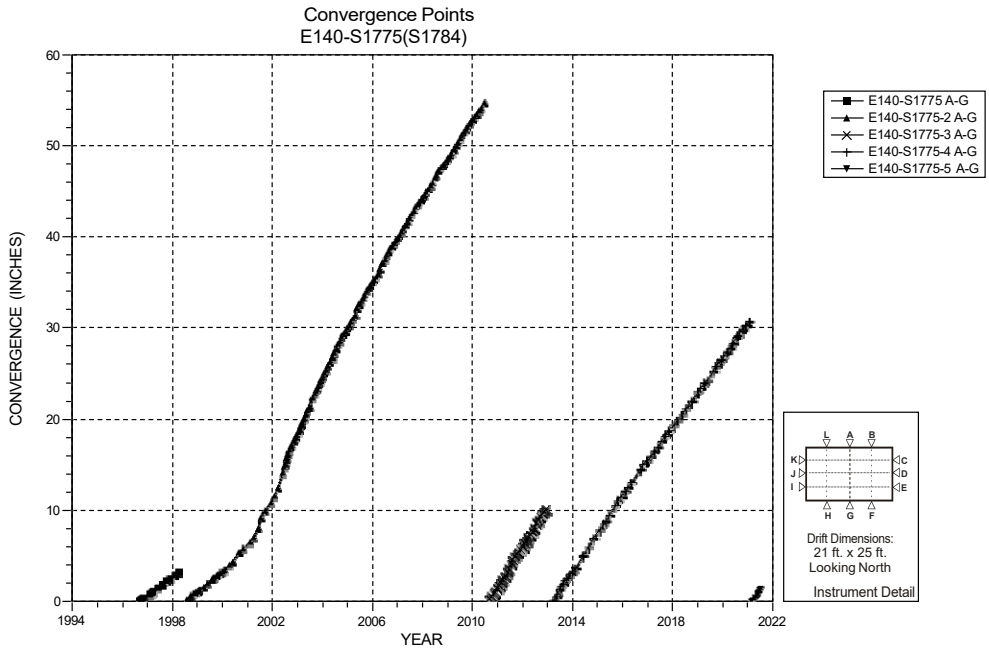


Figure 4-82 Convergence Point Array – E140 S1717 – Roof to Floor – Test Area



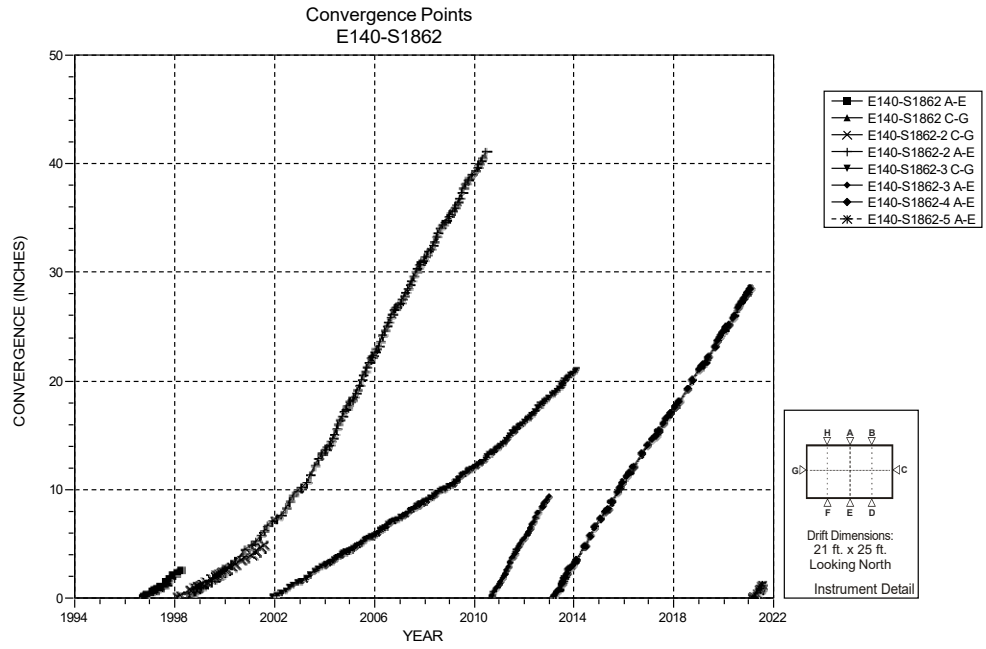
NOTES:
1. Excavation date: December 1982.

Figure 4-83 Convergence Point Array – E140 S1717 – Roof to Floor – Test Area



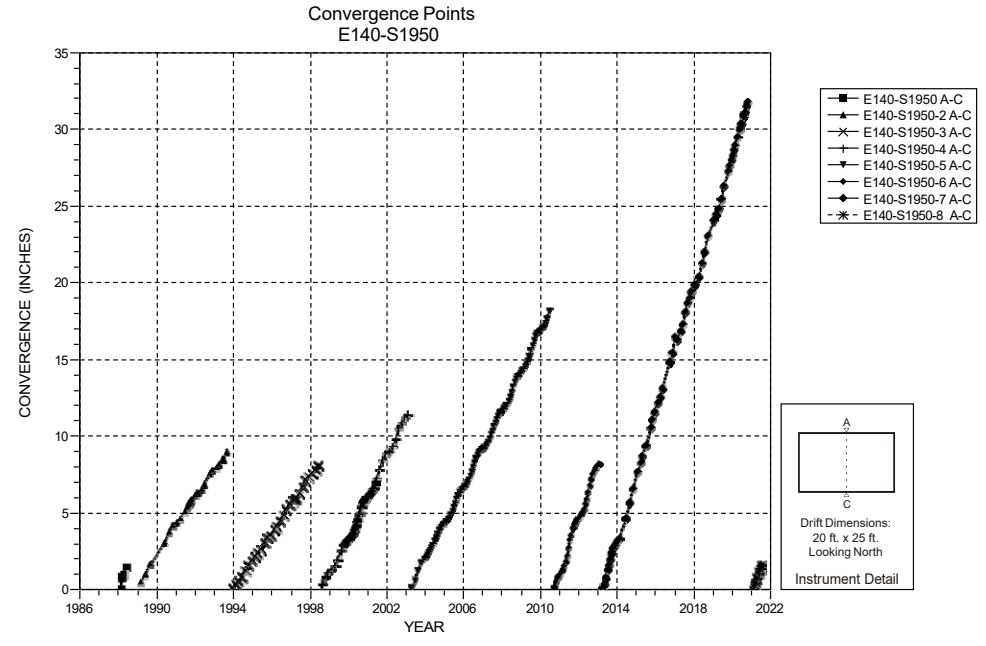
NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b" in early 1996.

Figure 4-84 Convergence Point Array – E140 S1775 – Roof to Floor



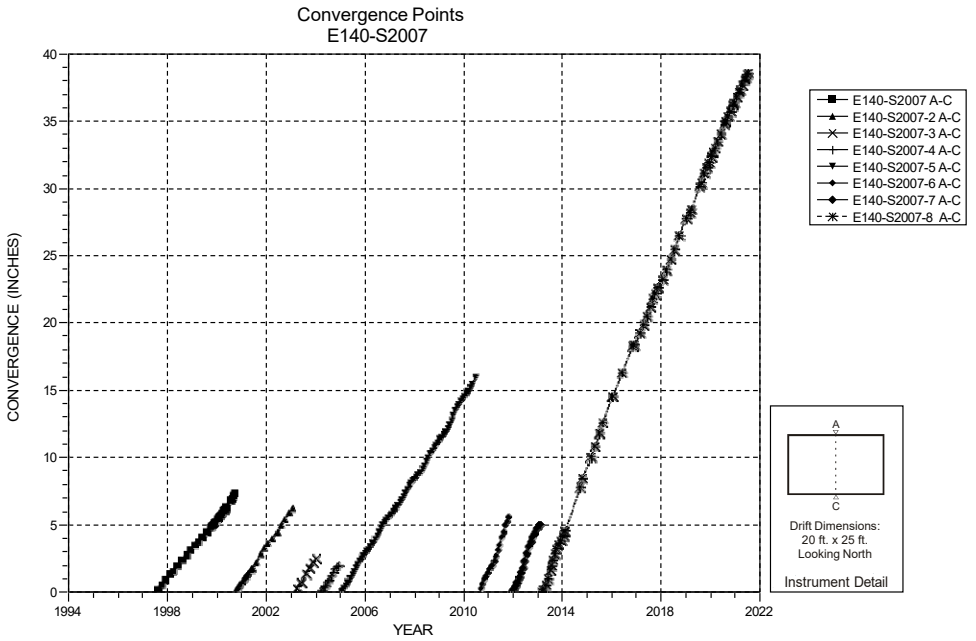
NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b" in early 1996.

Figure 4-85 Convergence Point Array – E140 S1862 – All Chords



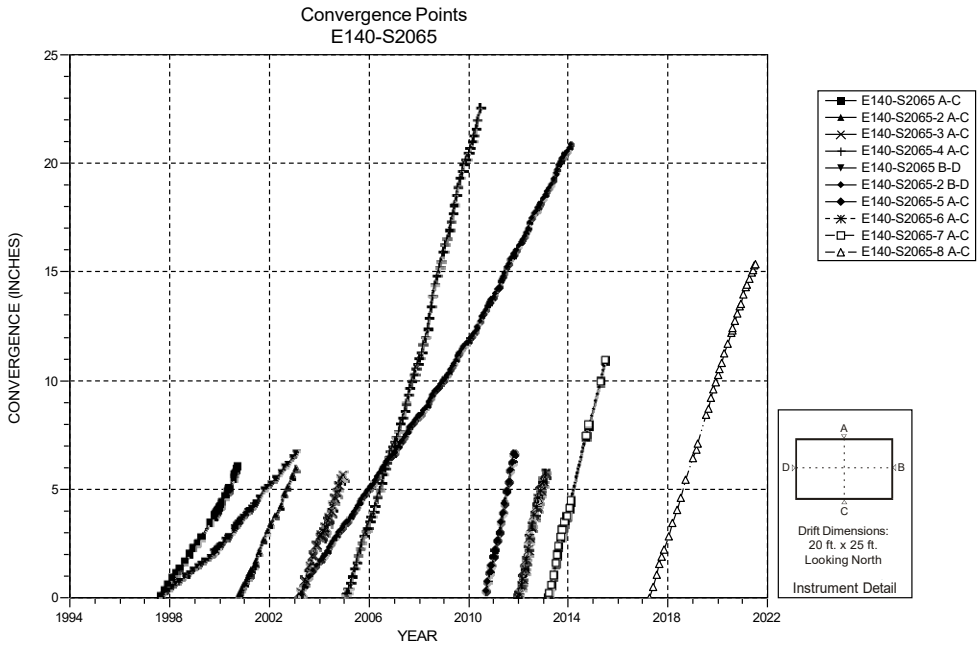
NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b", March 2003.

Figure 4-86 Convergence Point Array – E140 S1950 – Roof to Floor



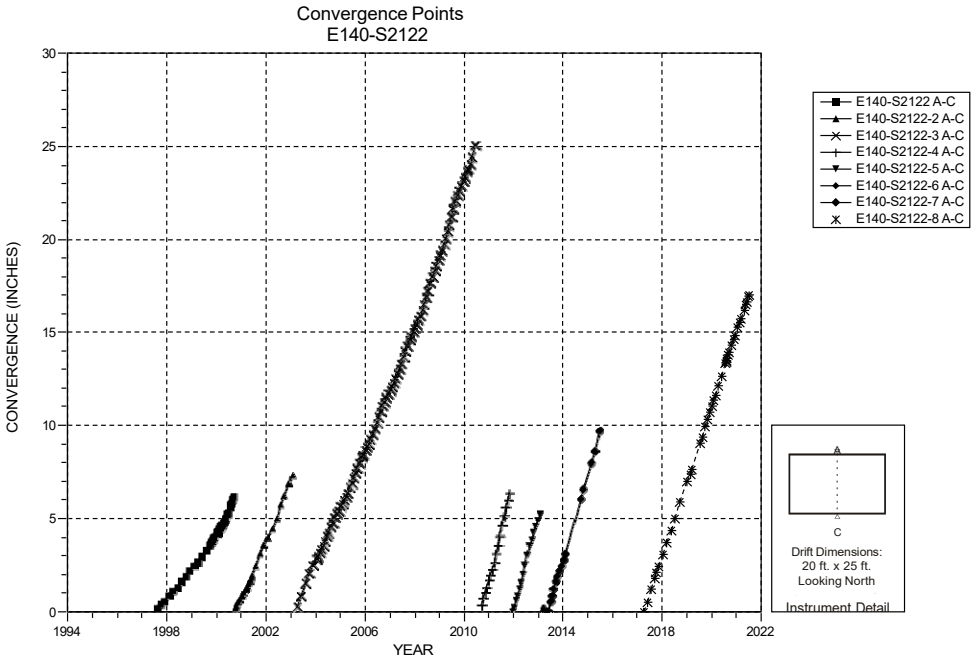
NOTES:
1. Excavation date: January 1993.
2. Roof excavated to Anhydrite "b", March 2003.

Figure 4-87 Convergence Point Array – E140 S2007 – Roof to Floor



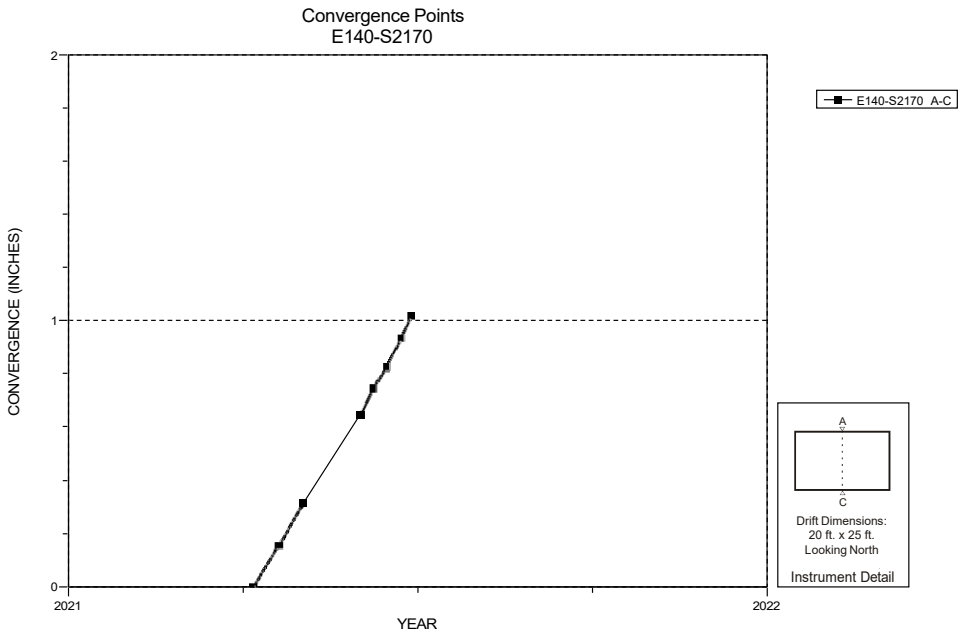
NOTES:
1. Excavation date: January 1993.
2. Roof excavated to Anhydrite "b", March 2003.

Figure 4-88 Convergence Point Array – E140 S2065 – All Chords



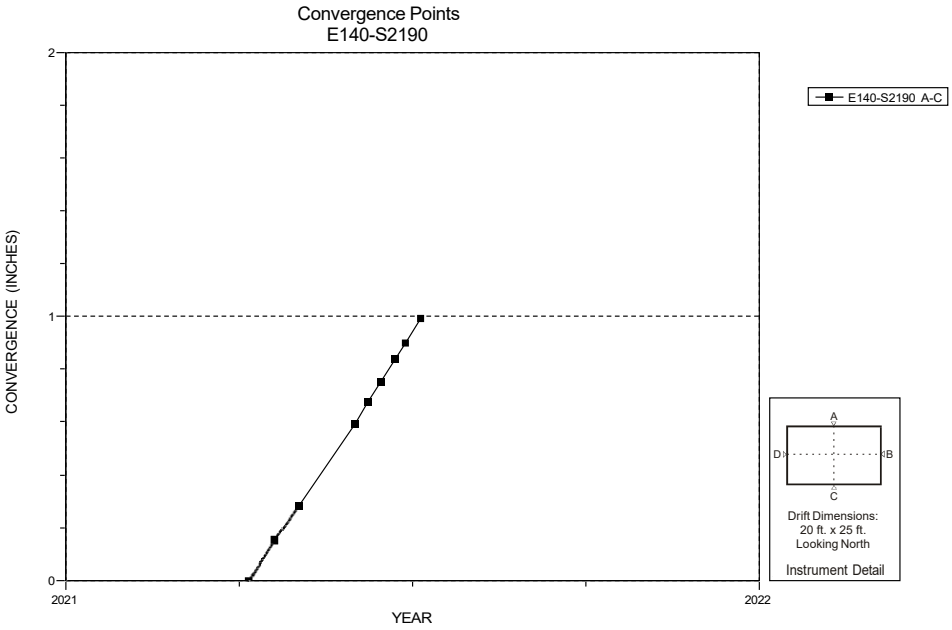
NOTES:
1. Excavation date: January 1993.

Figure 4-89 Convergence Point Array – E140 S2122 – Roof to Floor



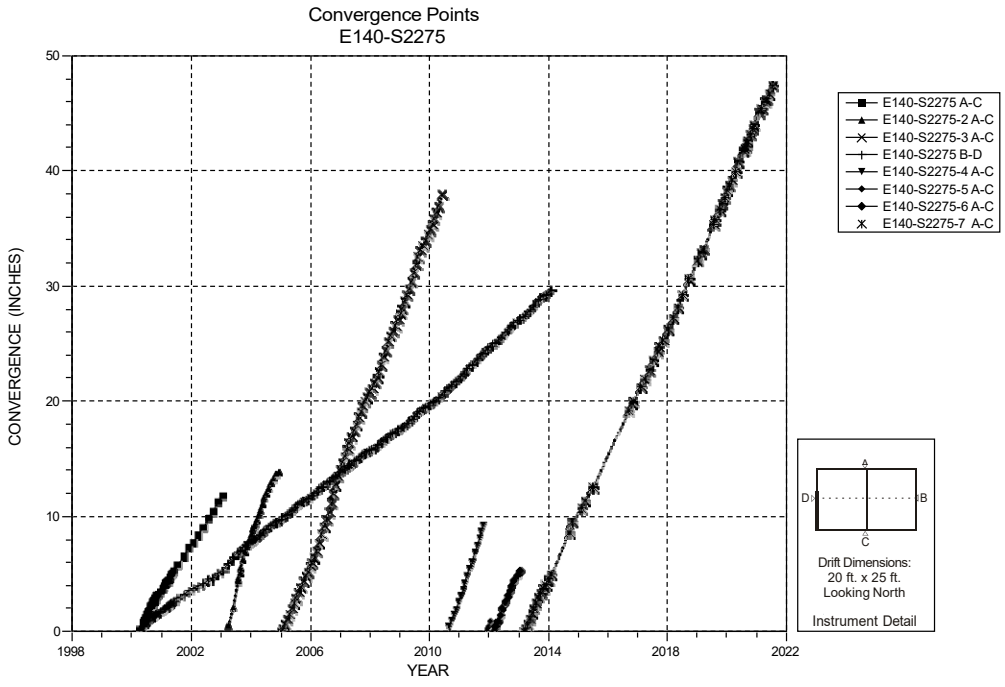
NOTES:
1. Excavation date: January 1993.
2. Roof excavated to Anhydrite "b", March 2003.

Figure 4-90 Convergence Point Array – E140 S2170 – Roof to Floor



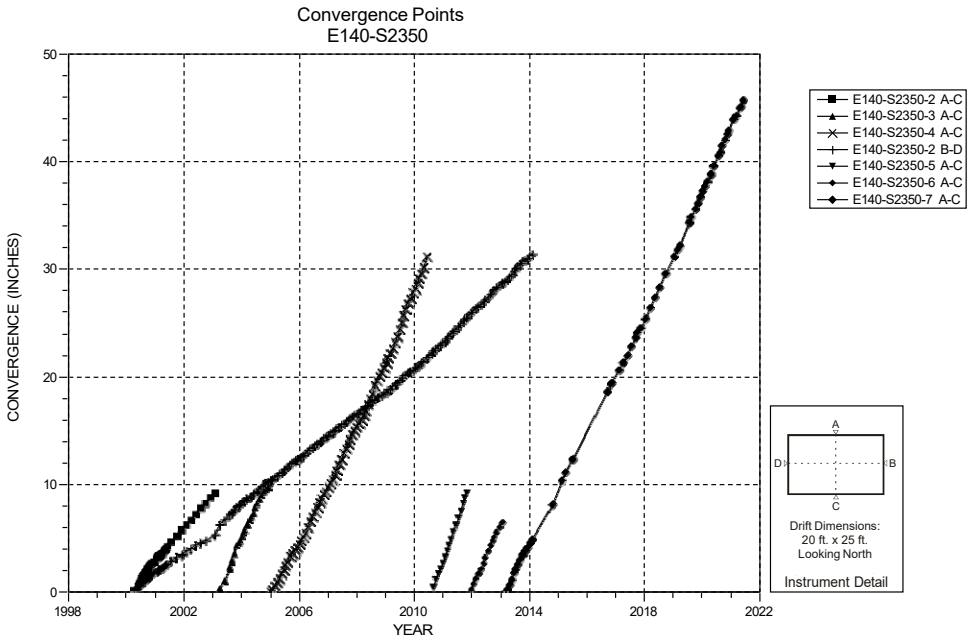
NOTES:
1. Excavation date: January 1983.
2. Roof excavated to Anhydrite "b", March 2003.

Figure 4-91 Convergence Point Array – E140 S2190 – Roof to Floor



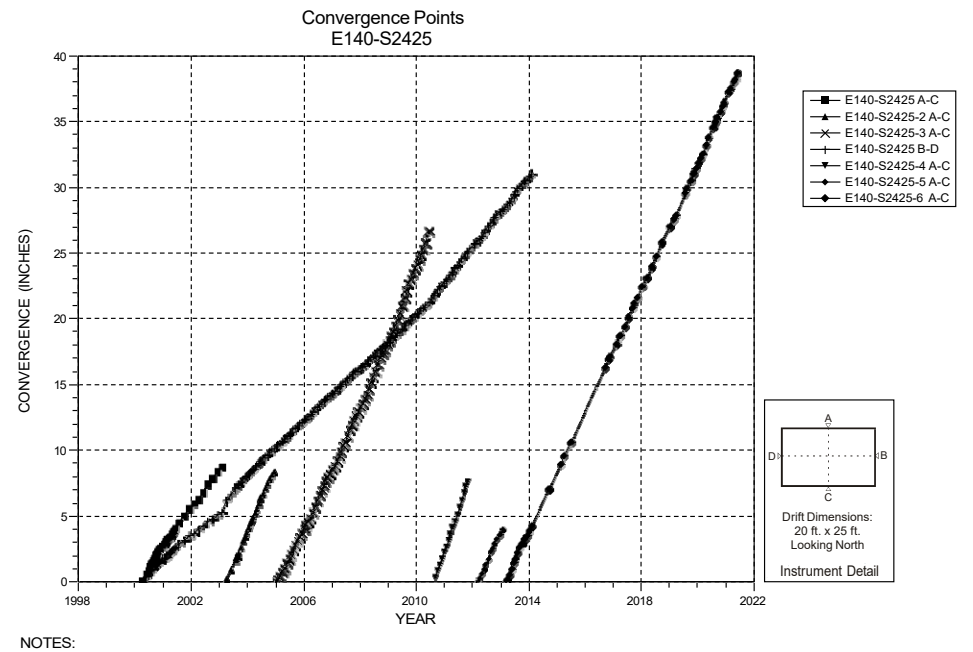
NOTES:
1. Excavation date: January 1983.

Figure 4-92 Convergence Point Array – E140 S2275 – All Chords



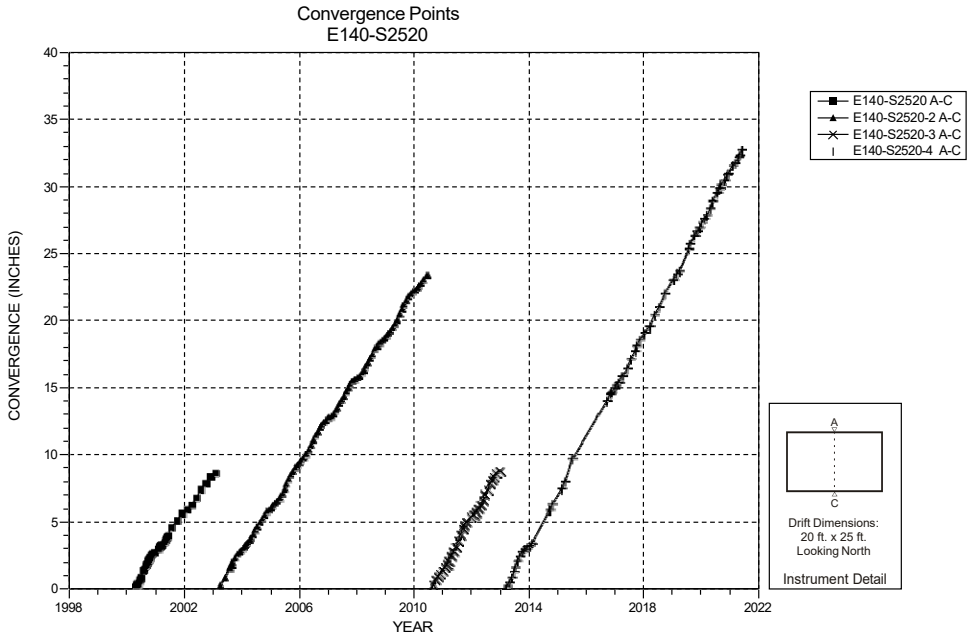
NOTES:
1. Excavation date: January 1983.
2. Roof excavated to Anhydrite "b", March 2003.

Figure 4-93 Convergence Point Array – E140 S2350 – All Chords



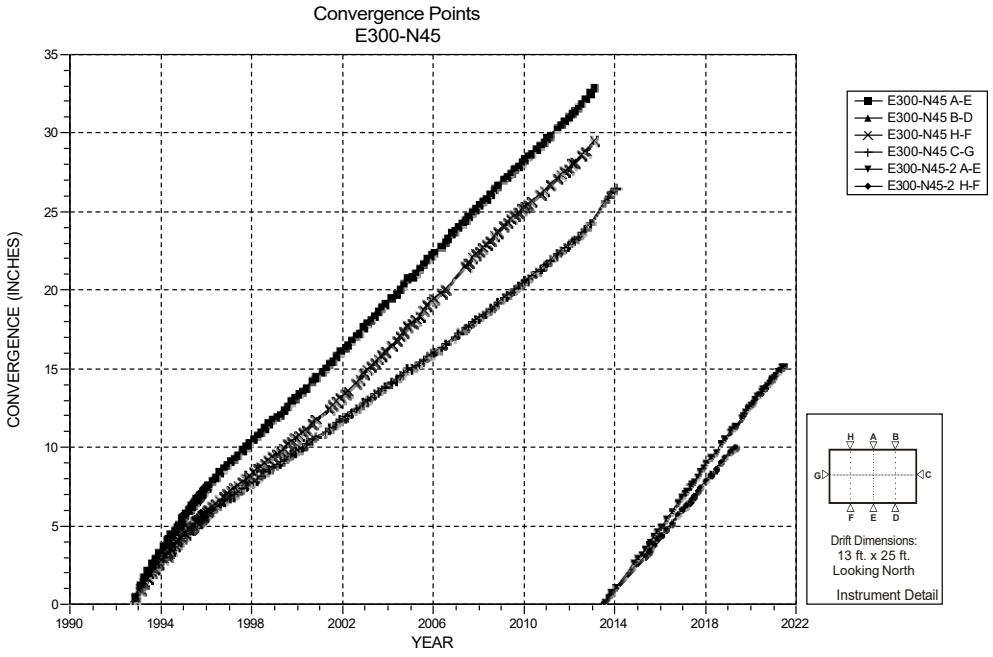
NOTES:
1. Excavation date: January 1983.
2. Roof excavated to Anhydrite "b", March 2003.

Figure 4-94 Convergence Point Array – E140 S2425 – All Chords



NOTES:
1. Excavation date: January 1983.
2. Roof excavated to Anhydrite "b", March 2003.

Figure 4-95 Convergence Point Array – E140 S2520 – Roof to Floor



NOTES:
1. Excavation date: October 1992.

Figure 4-96 Convergence Point Array – E300 N45 – All Chords

