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# Monitoring During Shaft and URL Construction and Operation

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# Introduction

- Shaft and URL construction provide an invaluable opportunity to monitor the effects of excavation on the surrounding rock mass
- The data collected can be used to derive rock properties (e.g., permeability) and to develop and/or confirm models
- Data can also be used to evaluate excavation methods, design seals, and evaluate other engineering measures

# Types of Monitoring Data

- Hydraulic head (pressure or water level)—provides insight into stress changes and flow
- Acoustic emissions and velocity—provides information on rock dilation and fracturing
- Displacement—rock mass response to excavation
- Can also perform “before” and “after” permeability testing

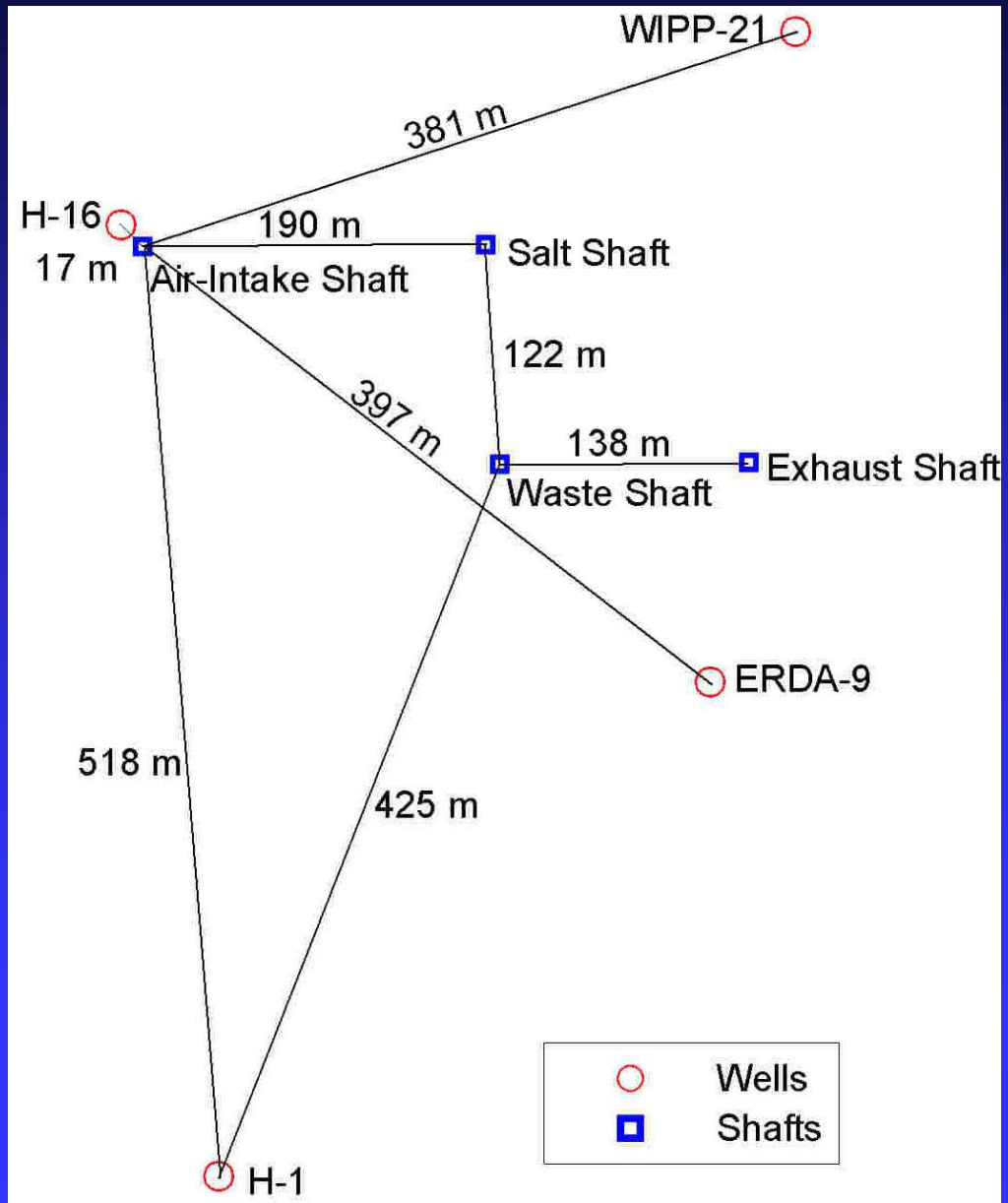
# Monitoring Procedure

- Drill boreholes and install instruments parallel to planned shaft or URL excavations
- Perform baseline measurements of pre-excavation properties
- Monitor changes that occur during and after excavation

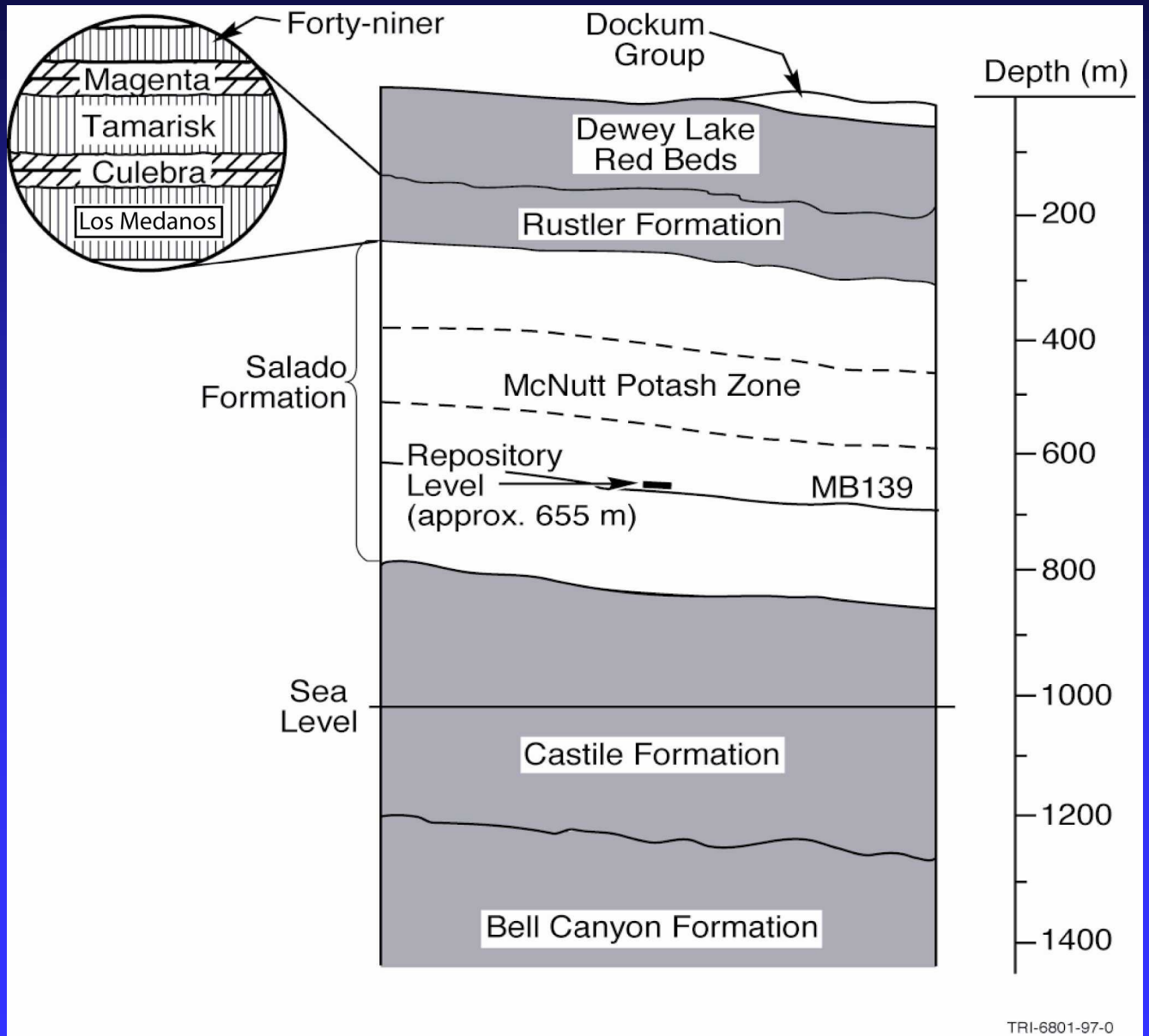
# Water-Level Monitoring During Shaft Construction

- When the first two shafts at WIPP (Salt Shaft and Waste Shaft) were constructed in 1981-82, only three wells existed within 1.2 km
- Water-level responses to shaft construction were observed in the two hydrologic units being monitored

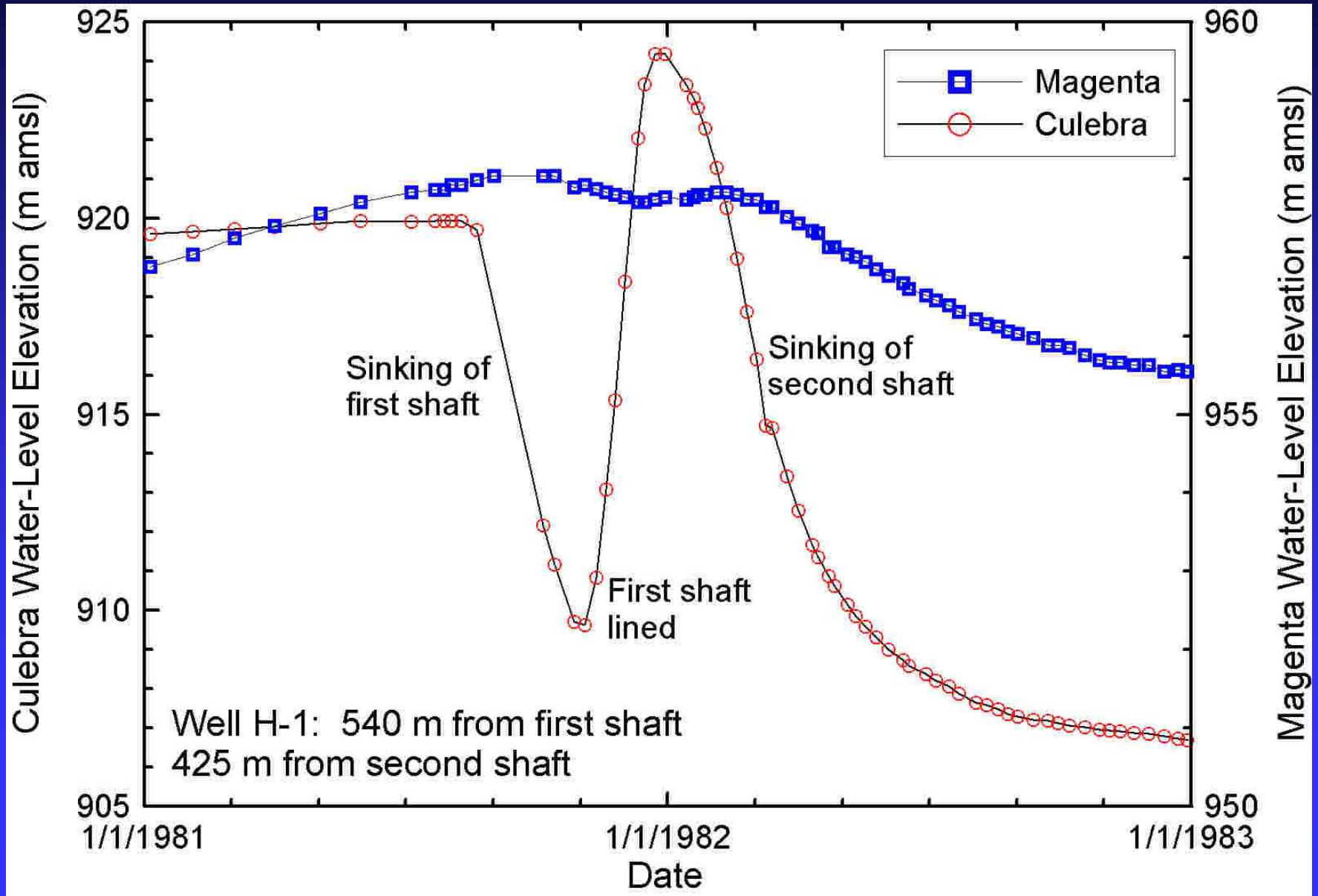
# WIPP Shafts and Responding Wells



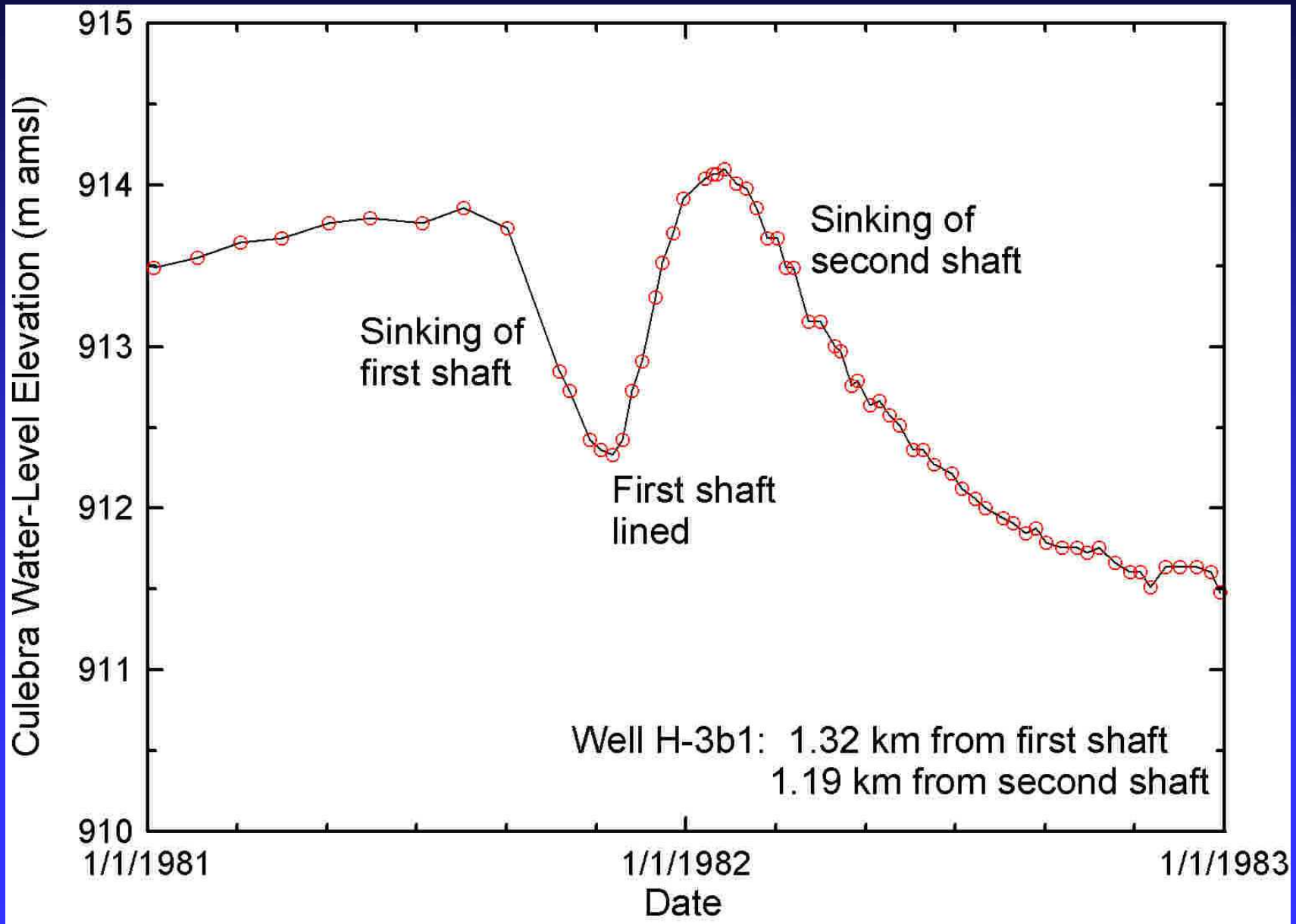
# WIPP Stratigraphy



# Effects of Shafts on Water Levels



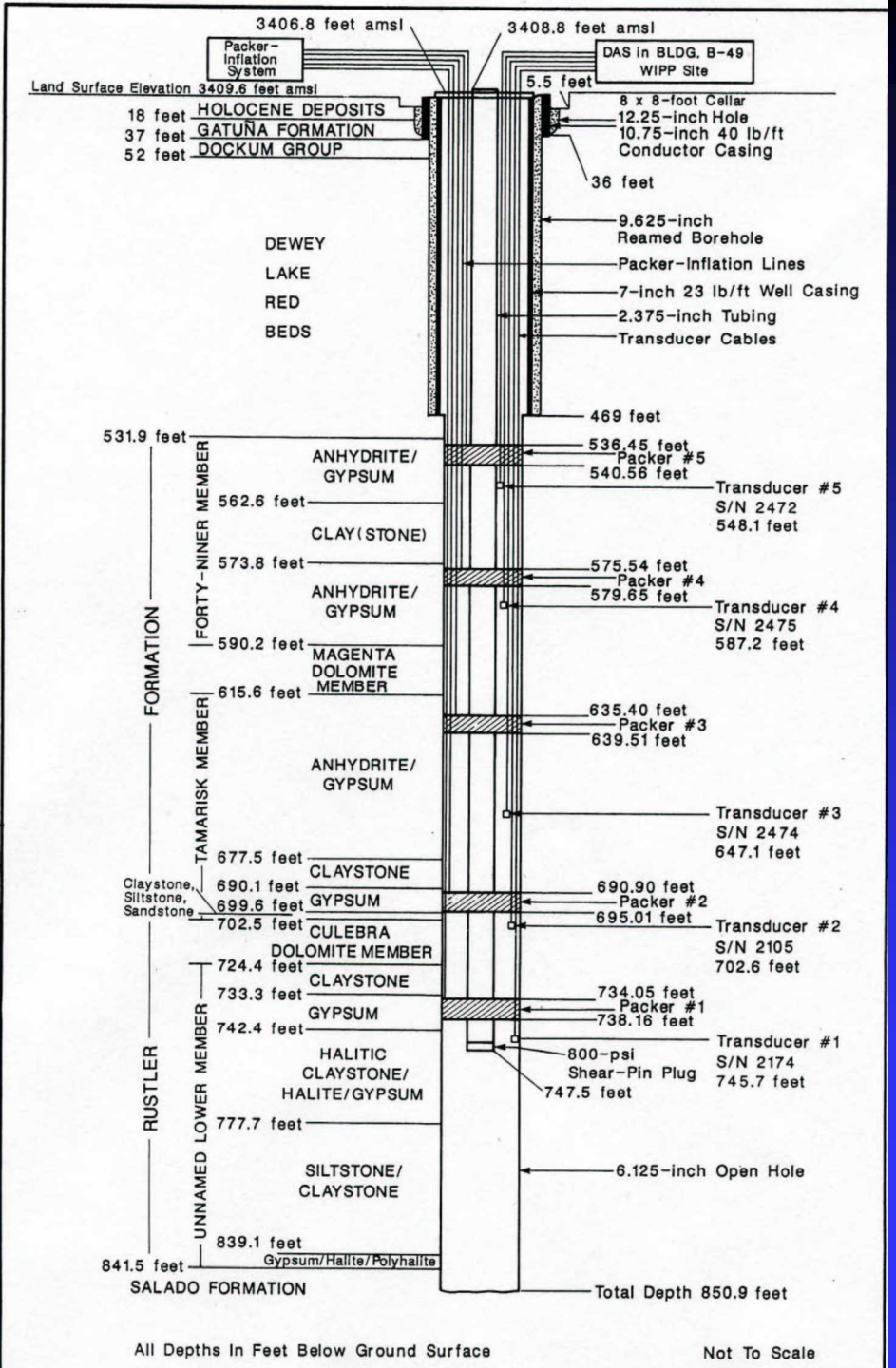
# Effects of Shafts on Water Levels (2)

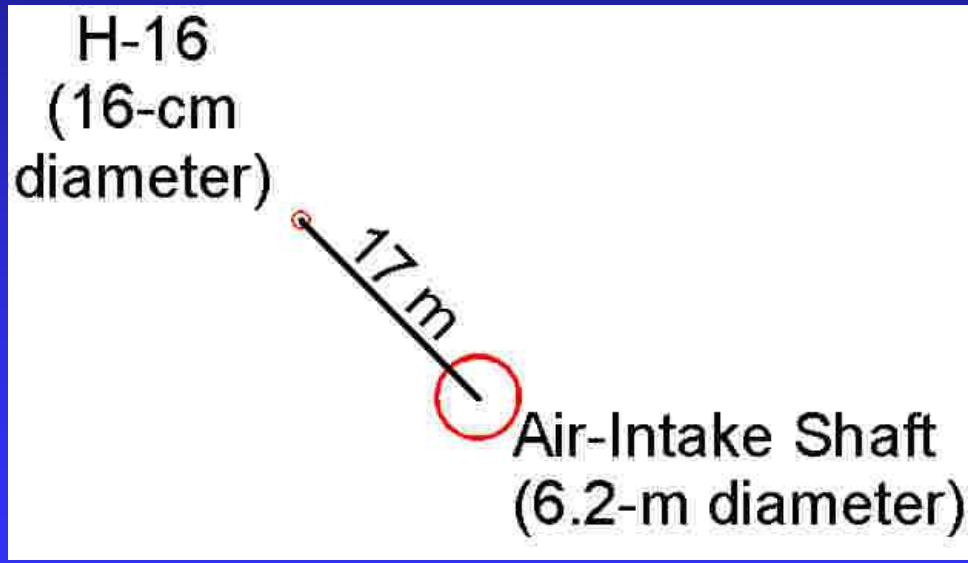


# Water-Level Monitoring During Air-Intake Shaft Construction

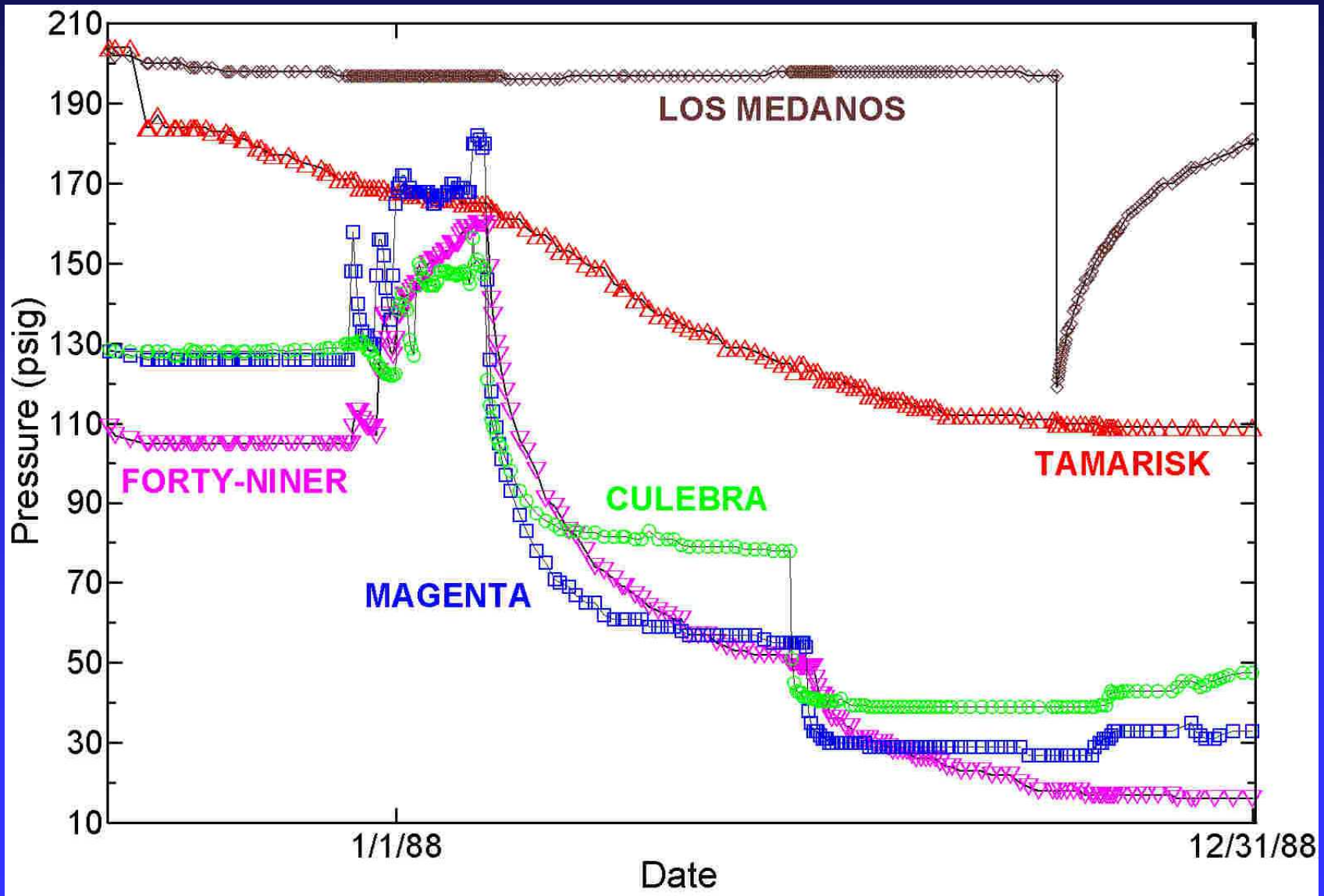
- Before the last shaft at WIPP (Air-Intake Shaft) was constructed in 1987, a well (H-16) was installed 17 m away to monitor the effects of shaft construction
- A 5-packer tool string was installed in H-16 to allow monitoring of all five members of the Rustler Formation
- Responses were also observed in three other Culebra wells

# Monitoring Multiple Zones in a Single Well During Shaft Construction

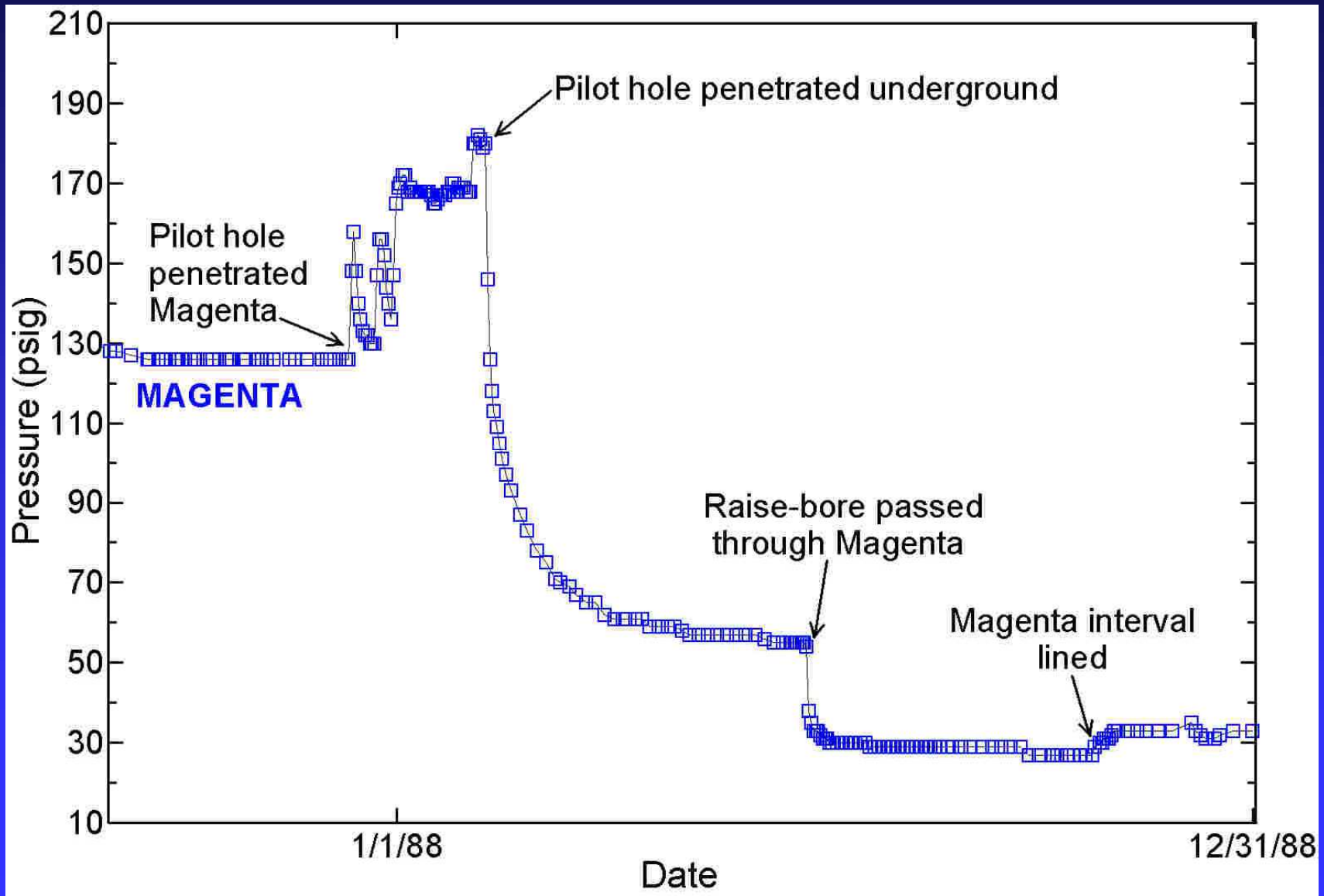


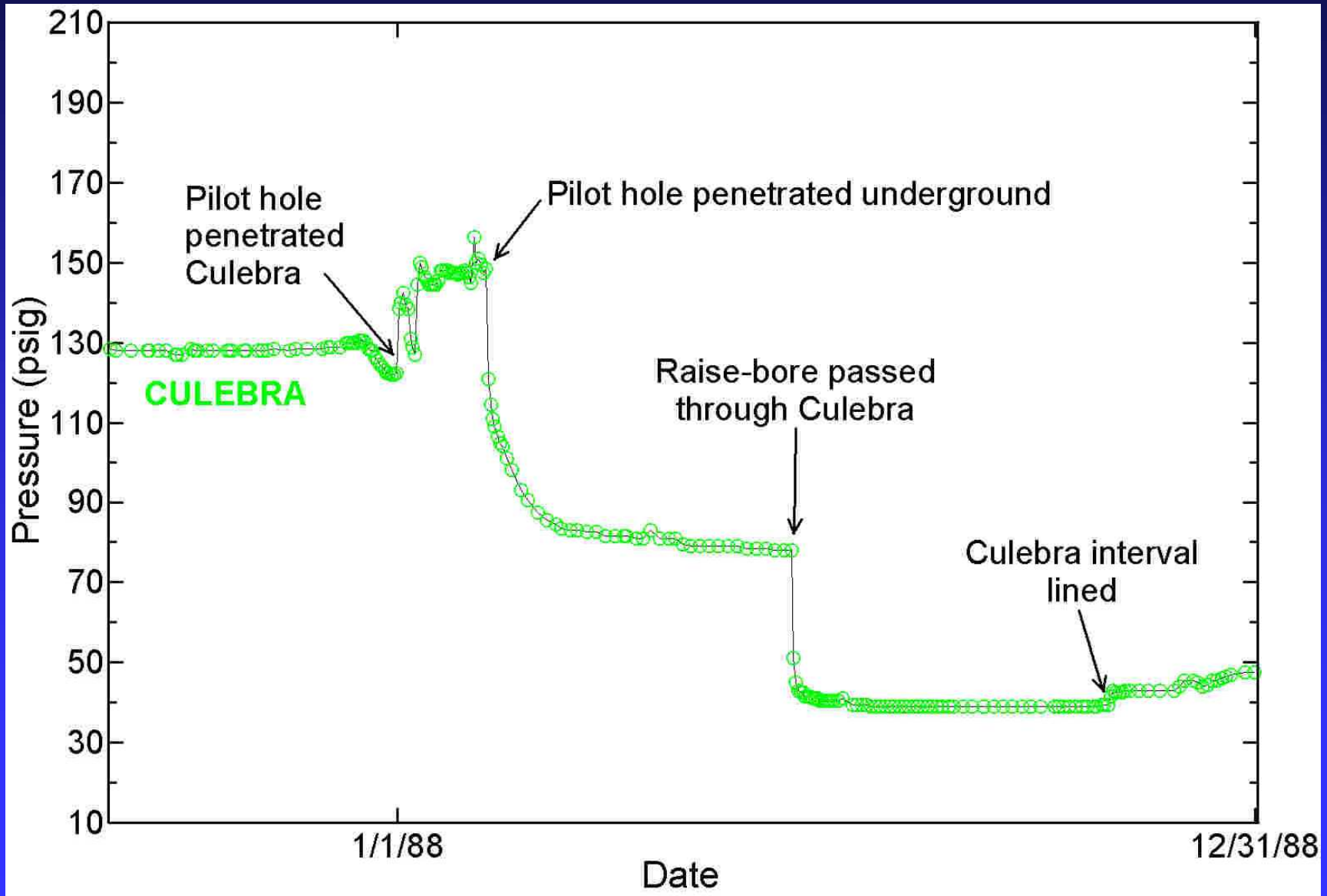
# Responses of Multiple Zones to Air-Intake Shaft Construction



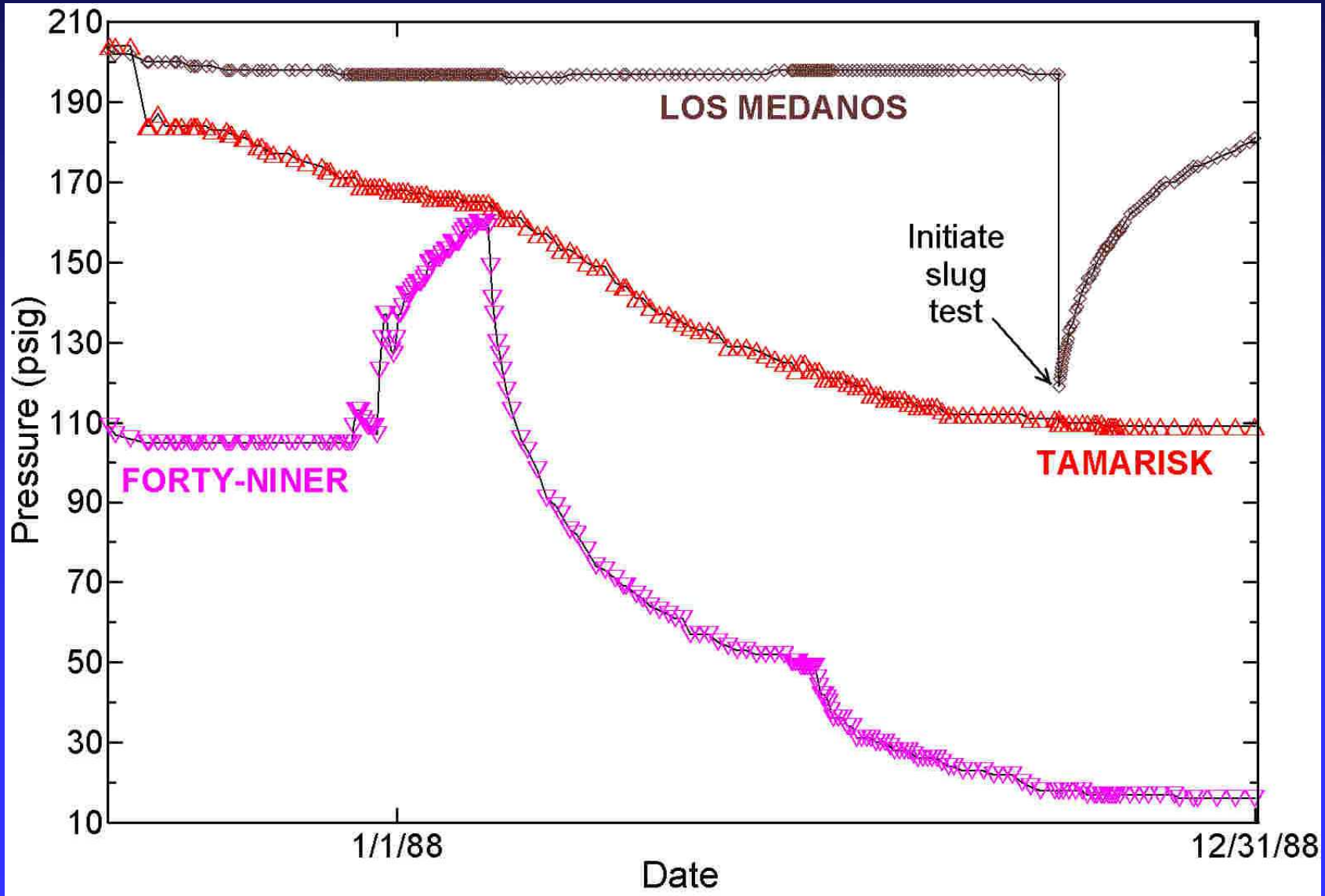
# Response of Magenta to Air-Intake Shaft Construction



# Response of Culebra to Air-Intake Shaft Construction



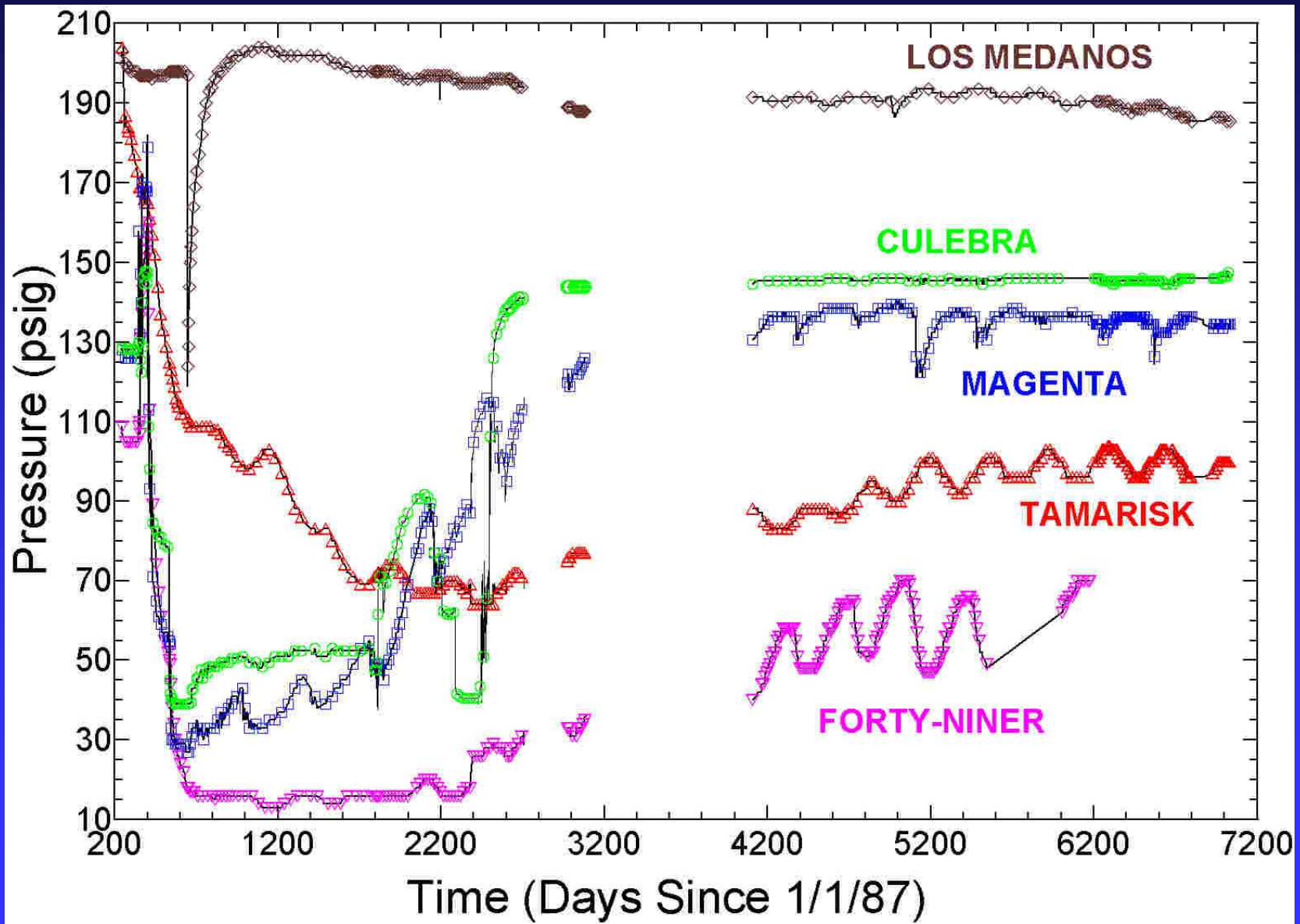
# Responses of Tighter Zones to Air-Intake Shaft Construction



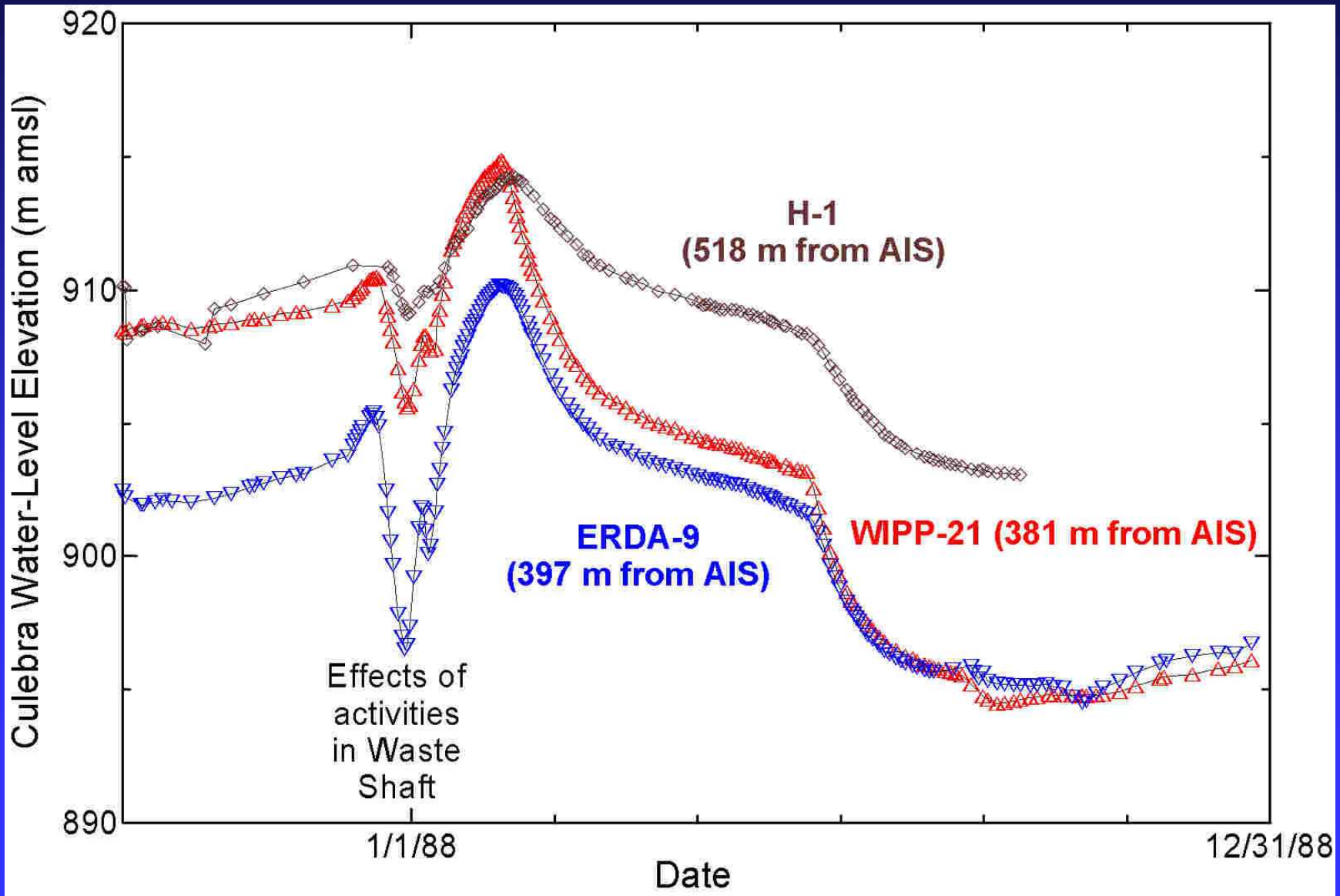
# H-16 Responses to AIS Construction

- Relative transmissivities of units were easily inferred from clarity and magnitude of responses to shaft events -- Culebra T > Magenta > Forty-niner > Tamarisk > Los Medaños
- Transmissivities inferred from simulating responses confirmed values from previous testing
- Monitoring is still on-going after ~20 years, providing feedback on the efficacy of shaft-sealing measures

# H-16 Monitoring 1987-2006

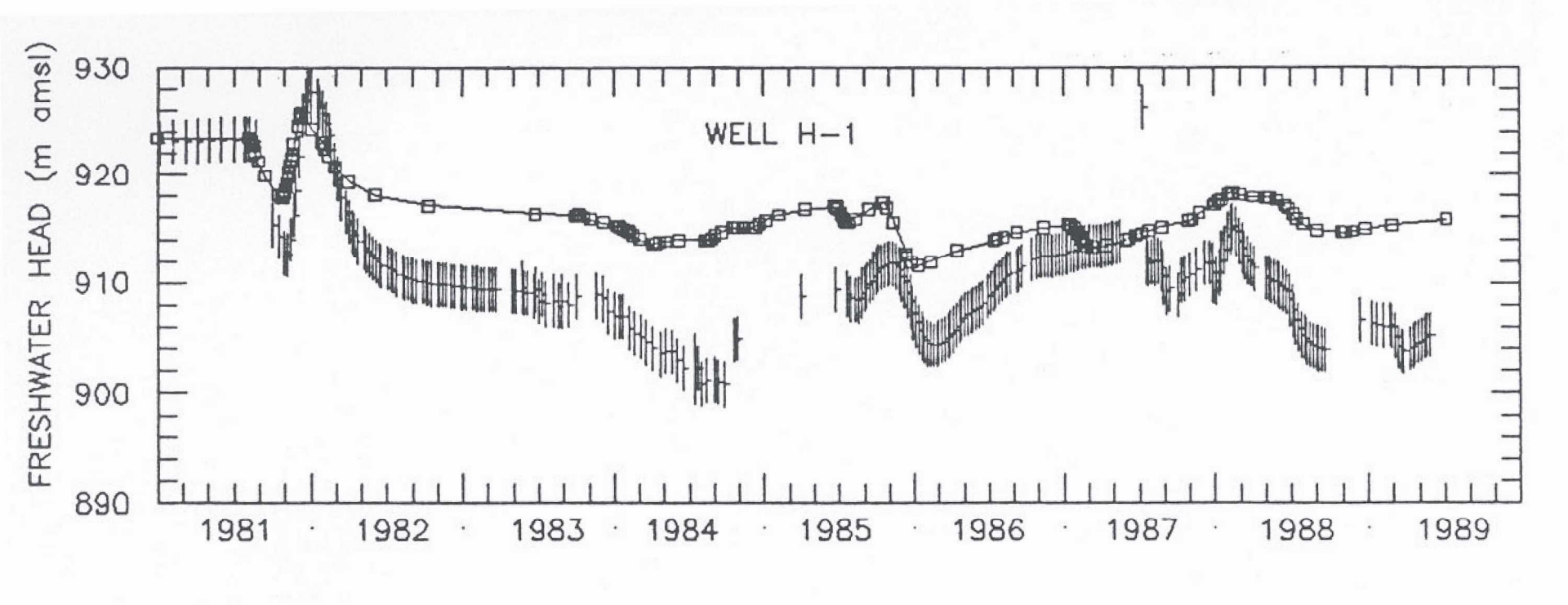


# Responses of Other Wells to Air-Intake Shaft Construction



# Calibration to Shaft Response

- Responses observed to shaft construction in more distant wells were used to calibrate the groundwater flow model for the WIPP site



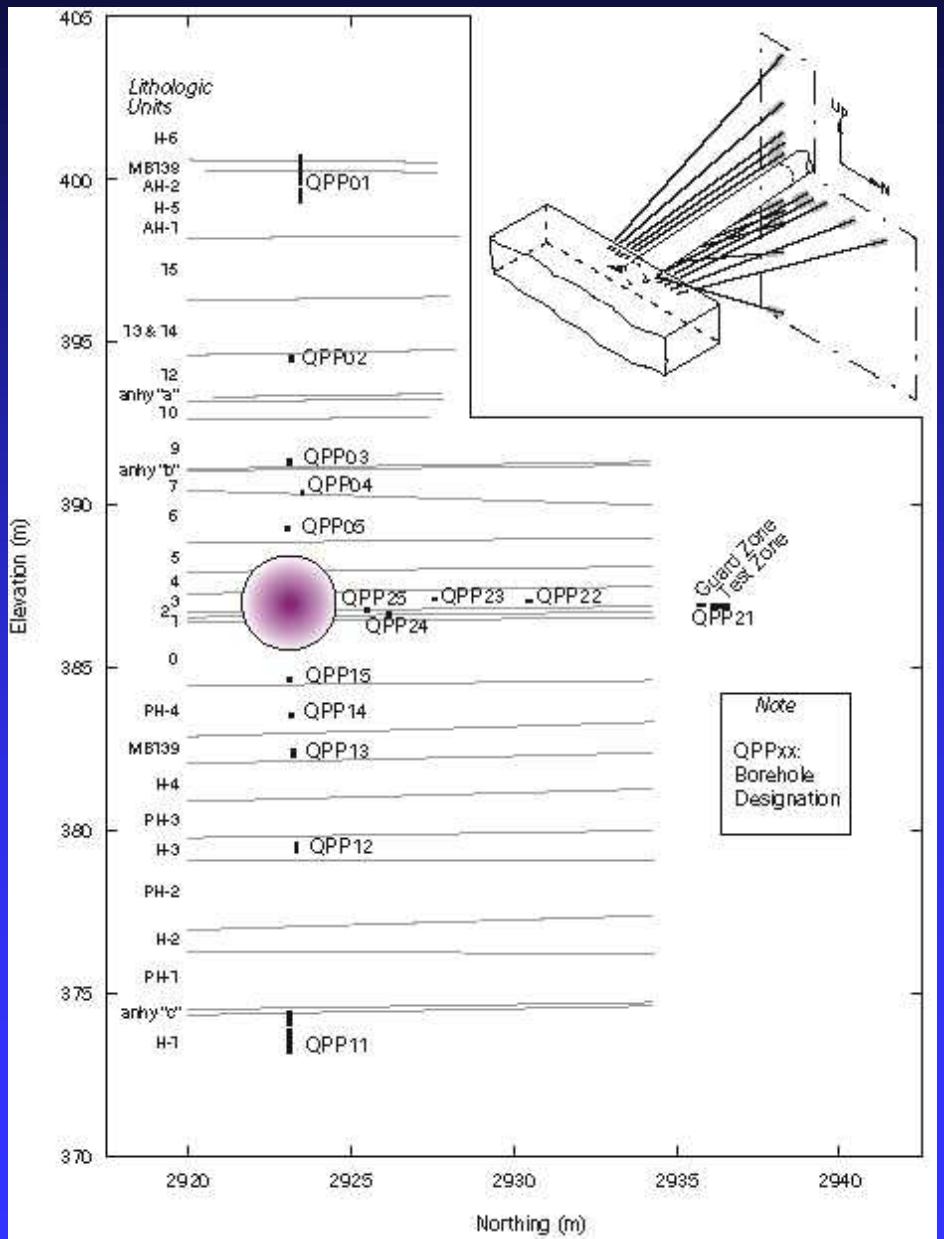
# Monitoring in URL

- Having an existing URL provides the opportunity to emplace instruments around planned excavations to monitor the effects of their construction
  - WIPP Room Q:  monitoring around planned cylindrical room
  - Andra's Meuse/Haute Marne (MHM) URL: monitoring ahead of shaft

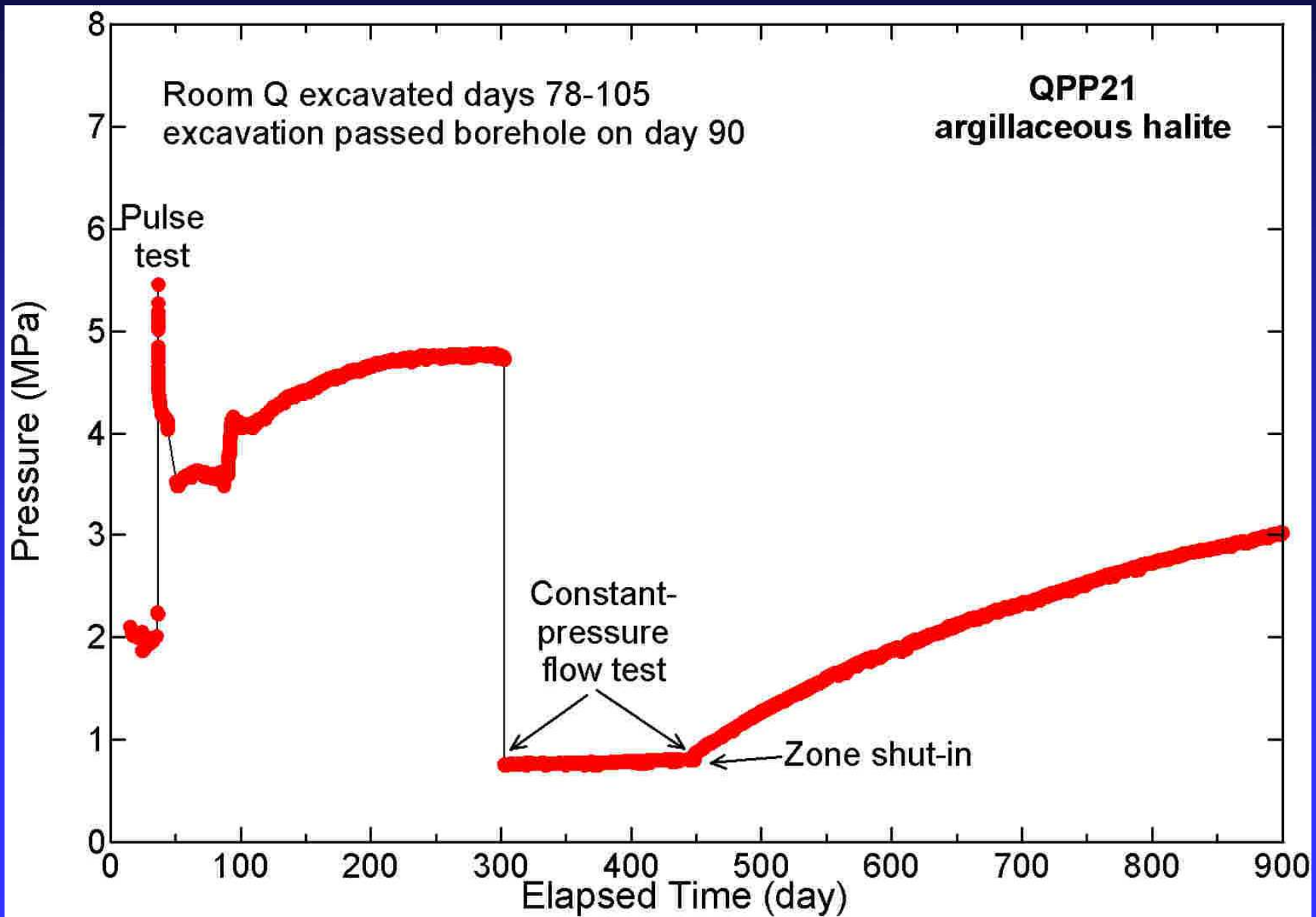
# Room Q

- Room Q is a 109-m-long cylindrical excavation, 2.9 m in diameter
- Before excavating Room Q, 15 boreholes were drilled to terminate in a plane 22.9 m along the length of the room
- 3 arrays of 5 boreholes terminated ~2.4, 3.3, 4.5, 7.6, and 13.6 m from the centerline of the room, vertically above and below and horizontally north of the room
- The ends of the boreholes were isolated with packers to allow pressure monitoring and hydraulic testing

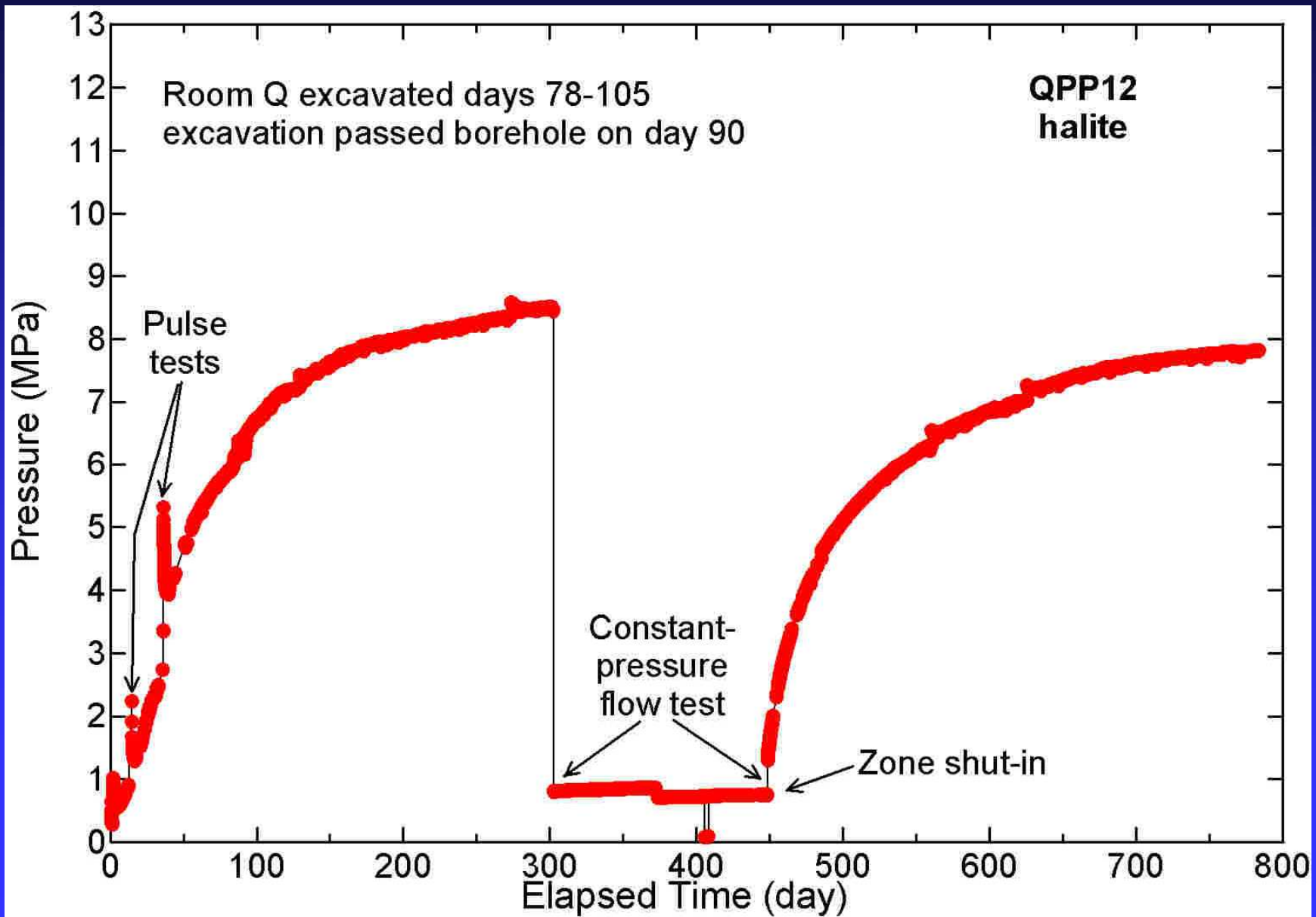
# Monitoring Locations Around Room Q



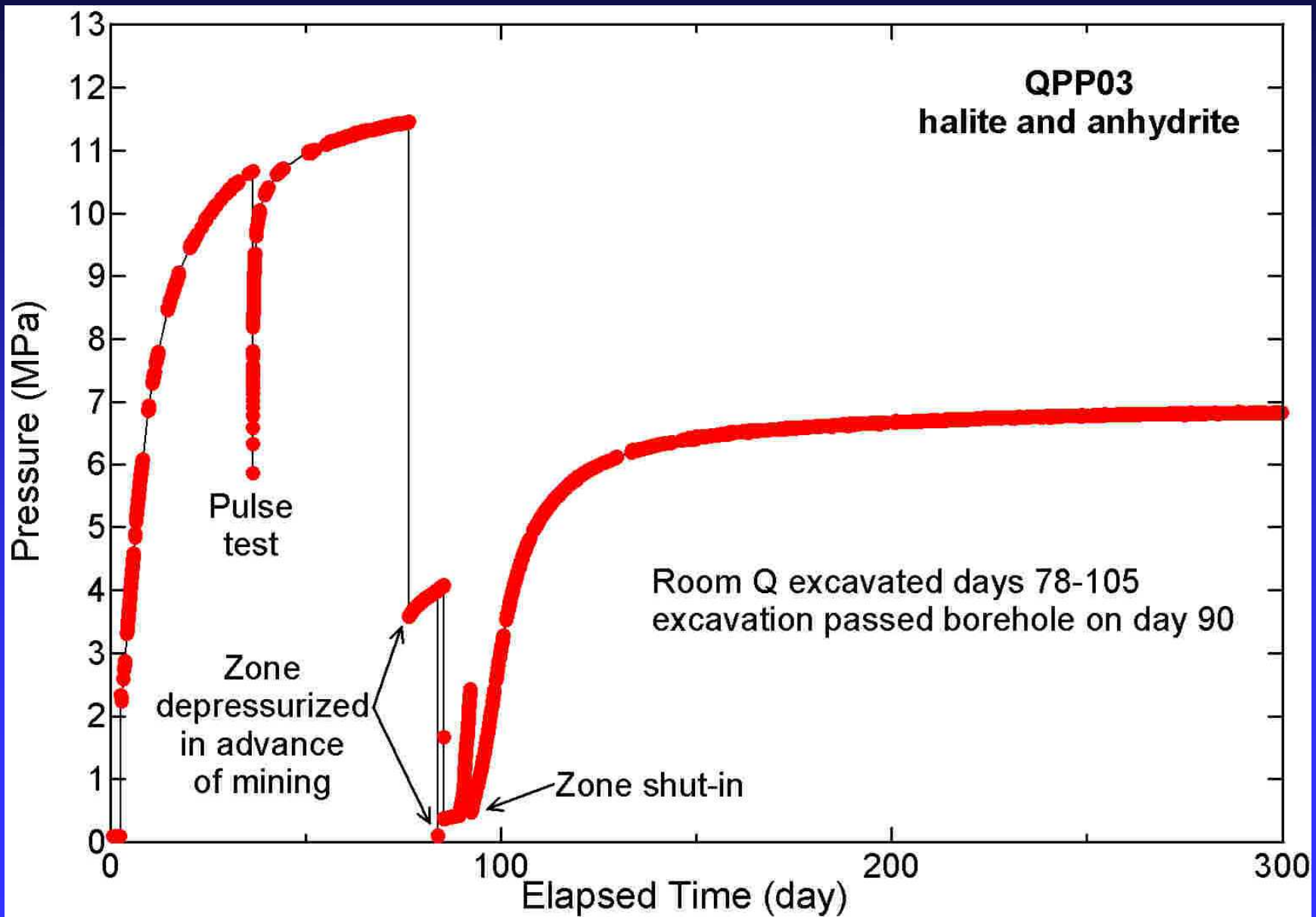
# Response 13.4 m from Room Q



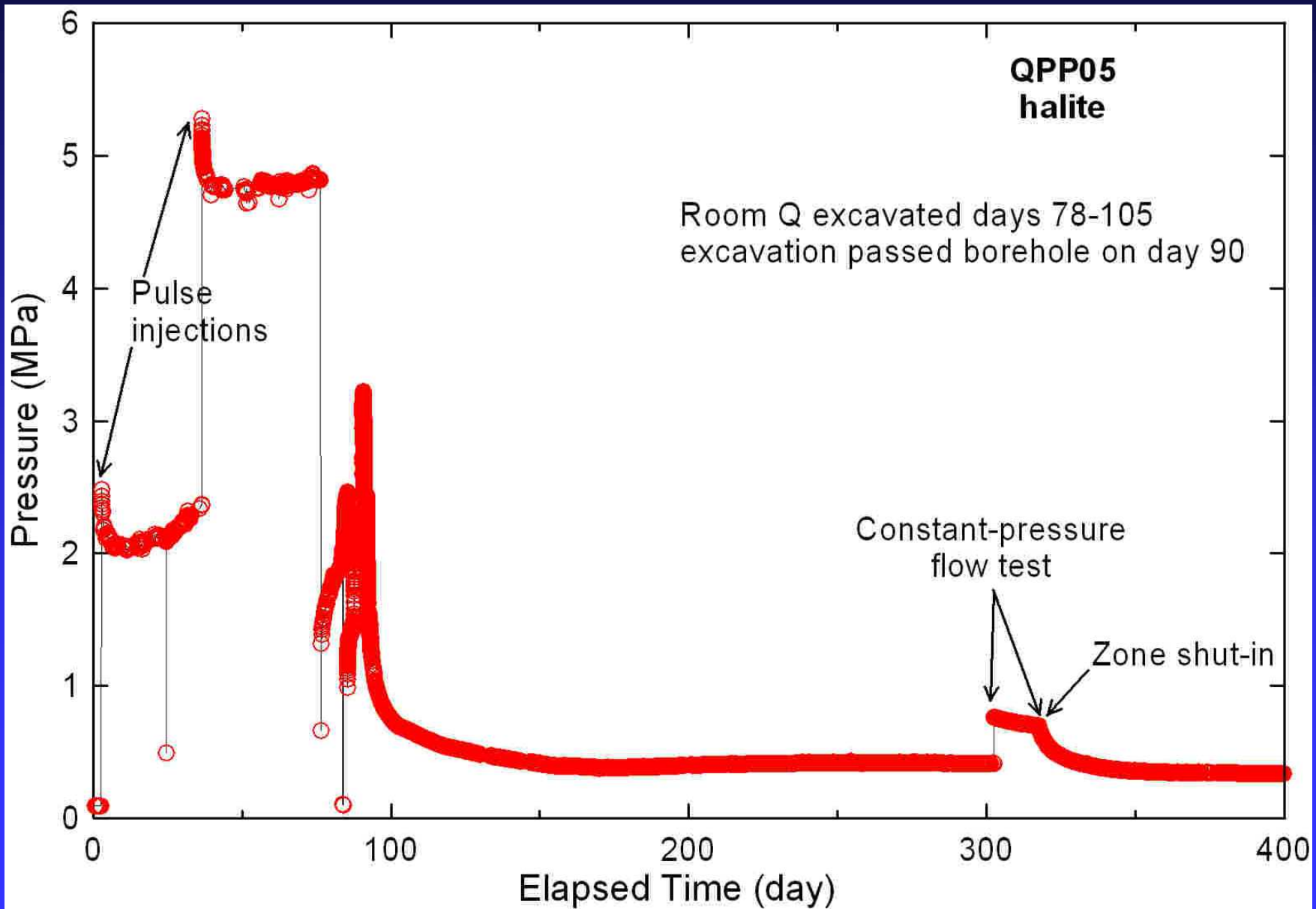
# Response 7.6 m from Room Q



# Response 4.4 m from Room Q



# Response 2.3 m from Room Q



# Summary of Room Q Observations

- Pore pressure reductions were observed in all boreholes except one
- Pore pressures were reduced by:
  - Stress relief
  - Flow to Room Q
- Pore connectivity (permeability) was increased in boreholes closest to Room Q

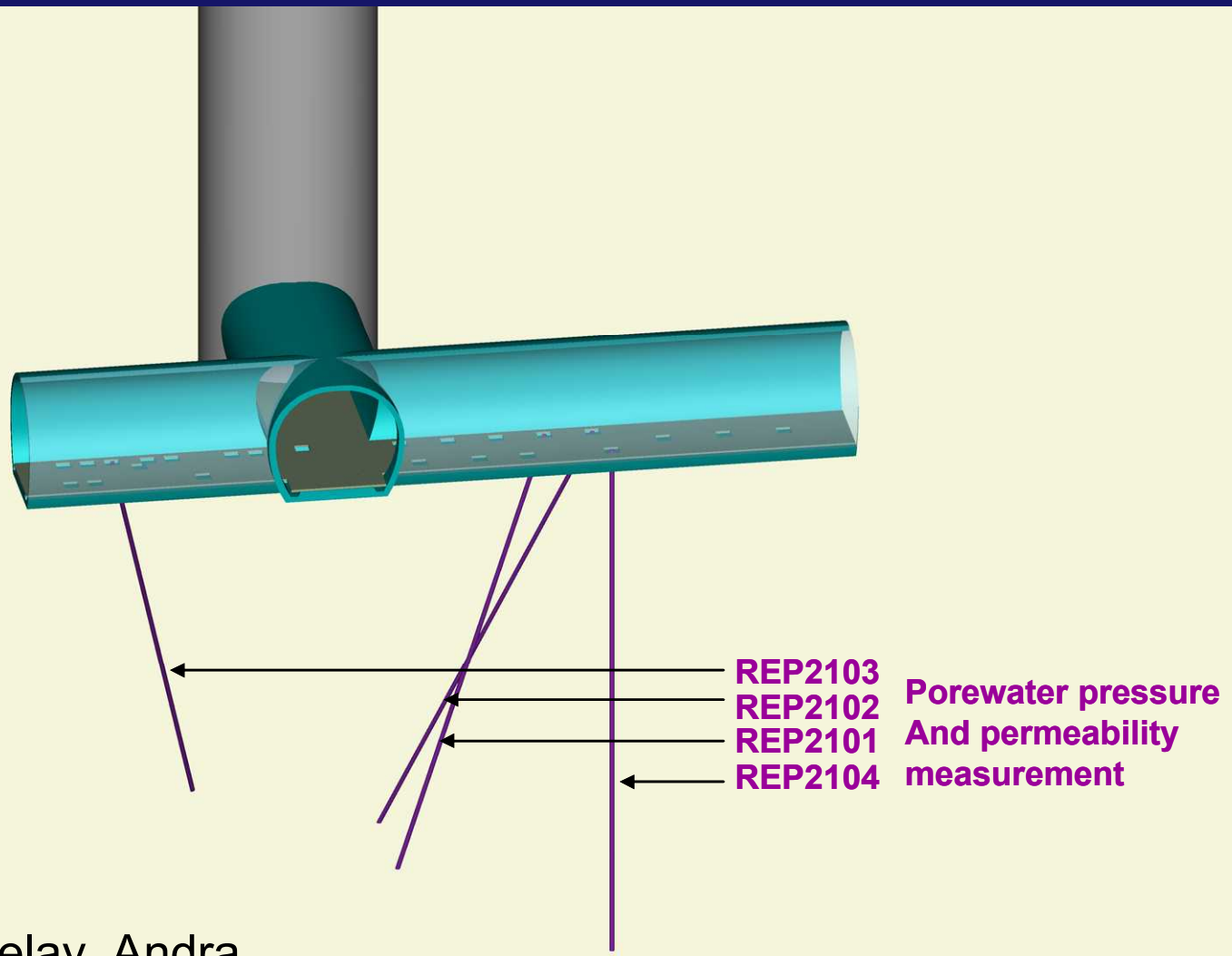
# Monitoring During Shaft Construction at Andra's MHM URL

- During sinking of the main shaft for the Meuse/Haute Marne URL, Andra stopped at a depth of 445 m and excavated an experimental niche
- 15 boreholes were drilled downward and instrumented for the Hydromechanical Response of Argillite to Shaft Sinking (REP) experiment
- Once all instruments were operational, shaft sinking continued and responses were monitored

# Monitoring During Shaft Construction at MHM URL (2)

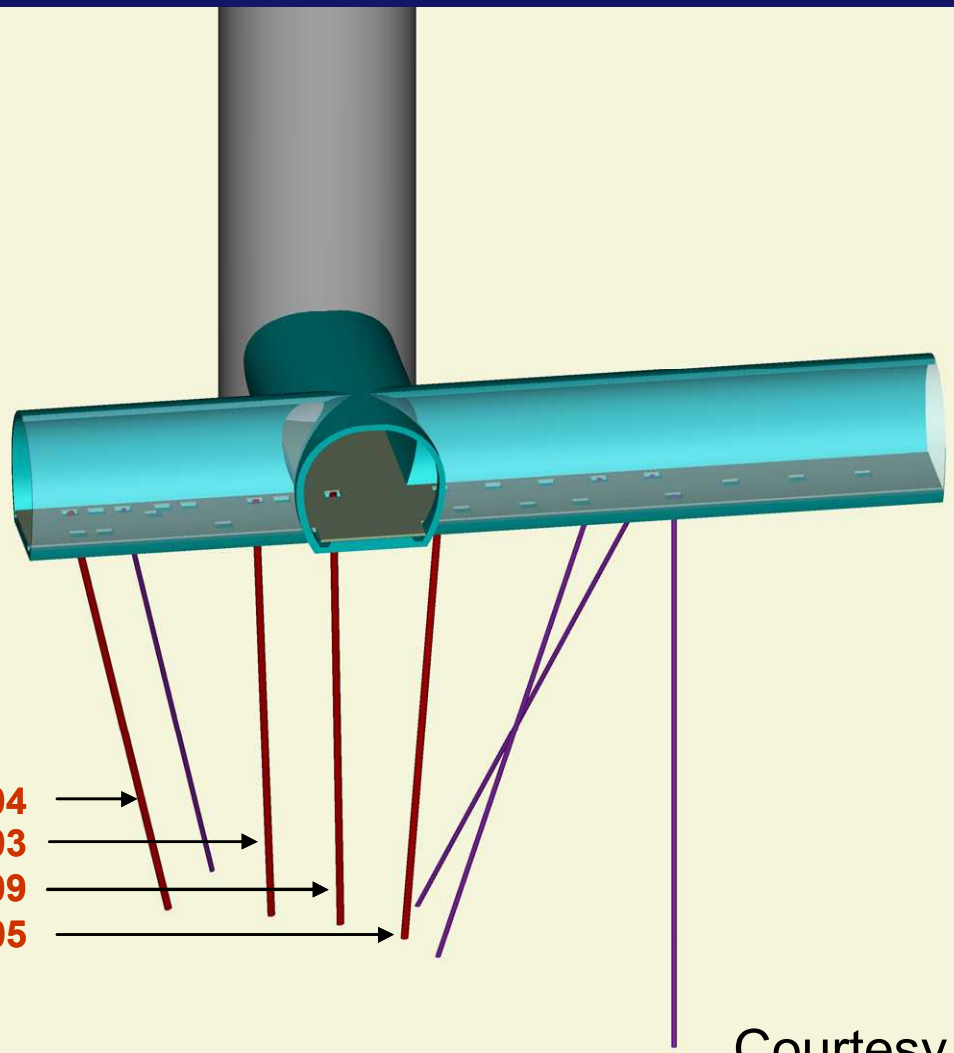
- The aim was to measure excavation effects on the hydromechanical properties of the host rock (argillite)
- Three items monitored :
  - Variation of the pore pressure during the shaft excavation
  - Variation in the rock's mechanical properties as a function of time
  - Evolution of permeability over time

# Monitoring of Pore Pressure at MHM URL



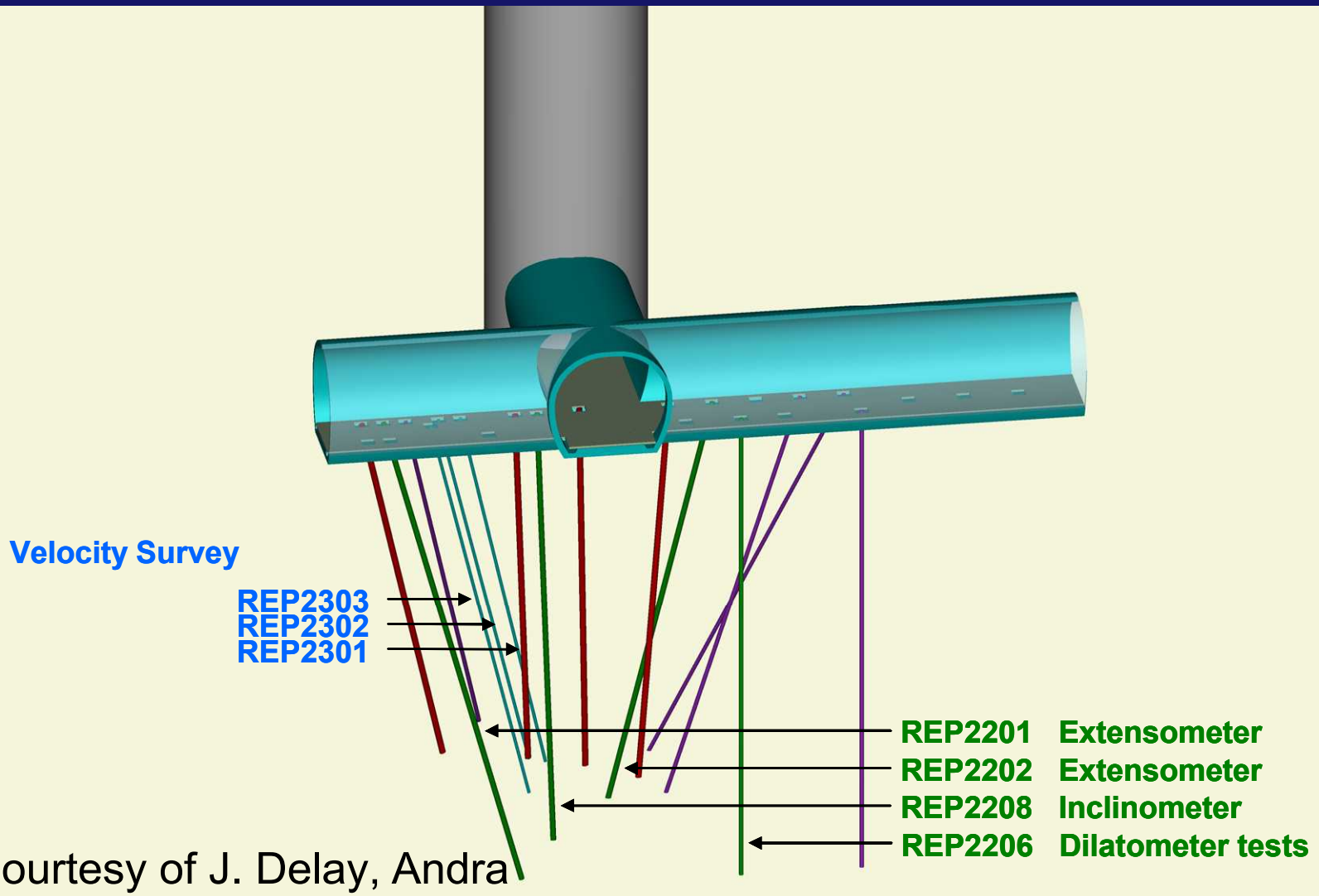

Courtesy of J. Delay, Andra

# Monitoring of Strain at MHM URL



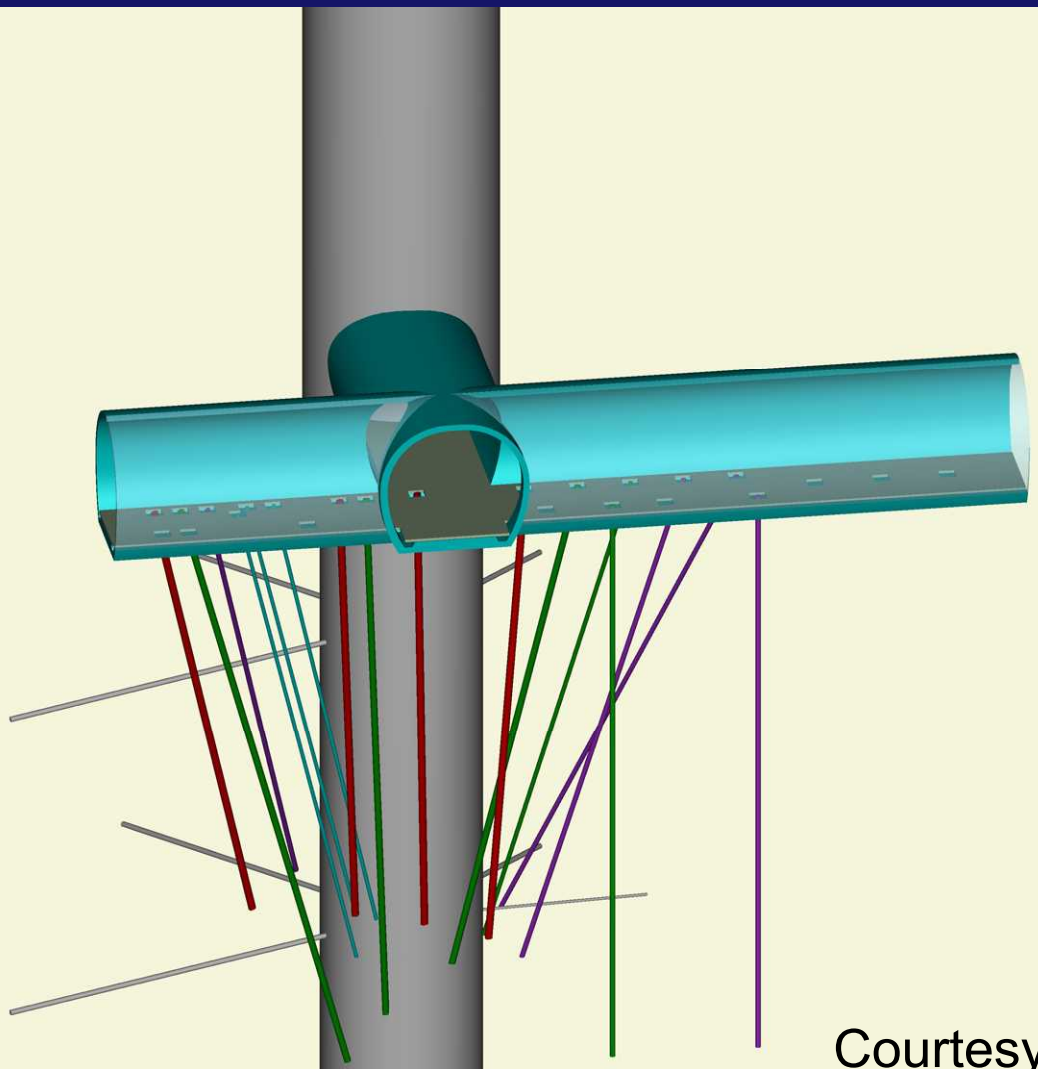

Courtesy of J. Delay, Andra

# Monitoring of Velocity and Deformation at MHM URL



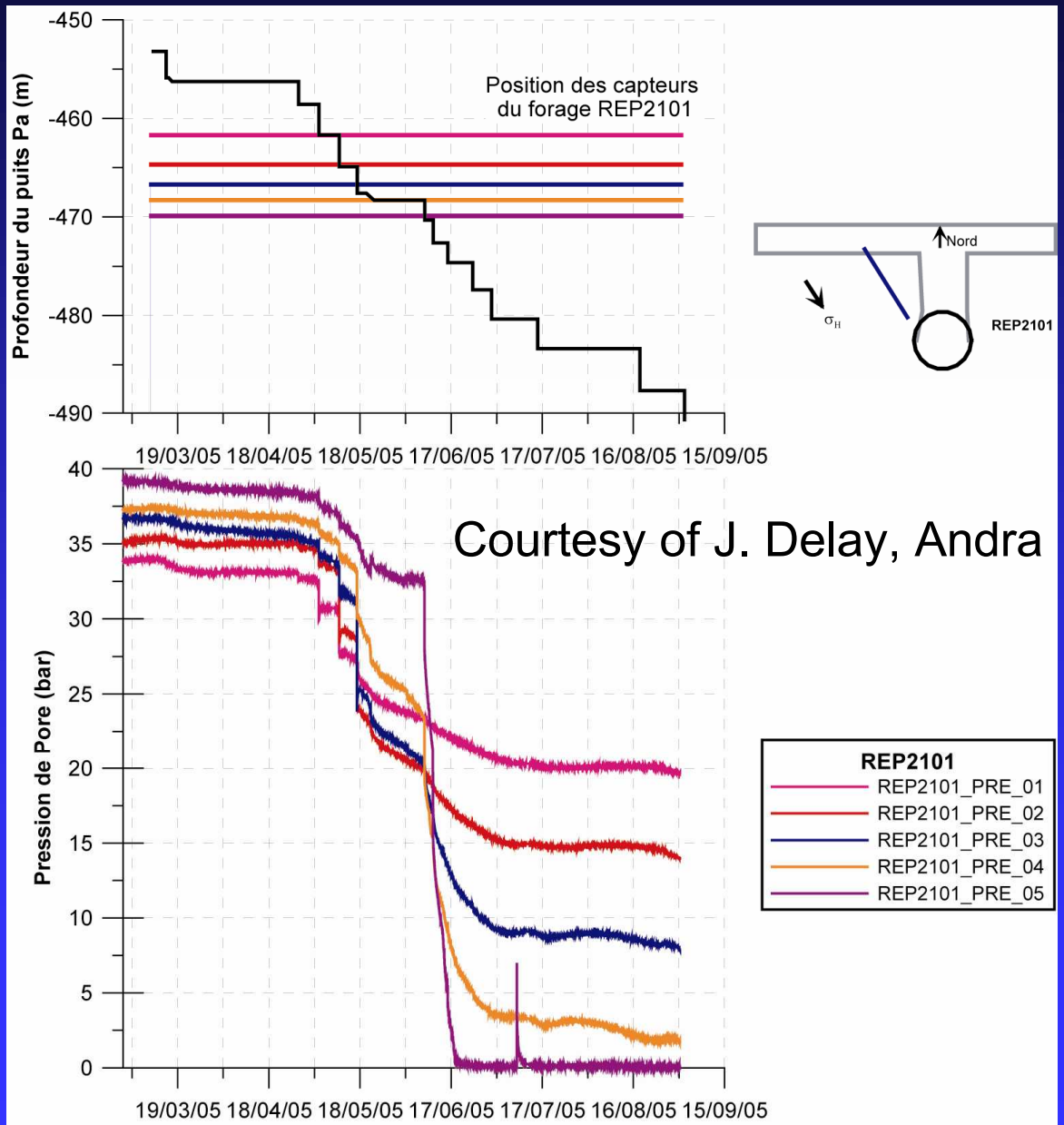

Courtesy of J. Delay, Andra

# Mining Past Monitoring Instruments at MHM URL

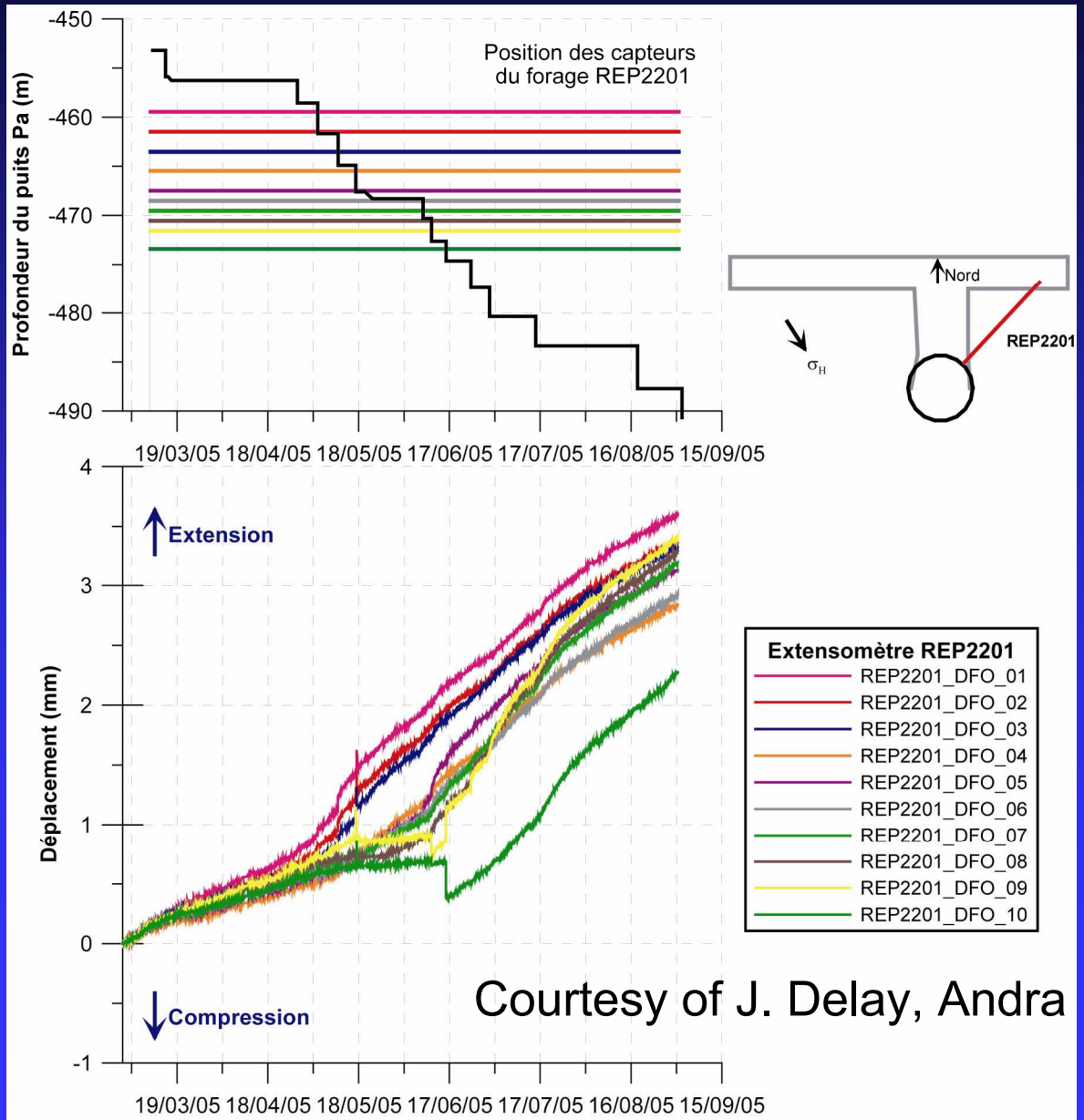


Courtesy of J. Delay, Andra

# Pore Pressure Results from MHM URL



# Extensometer Results from MHM URL




Courtesy of J. Delay, Andra

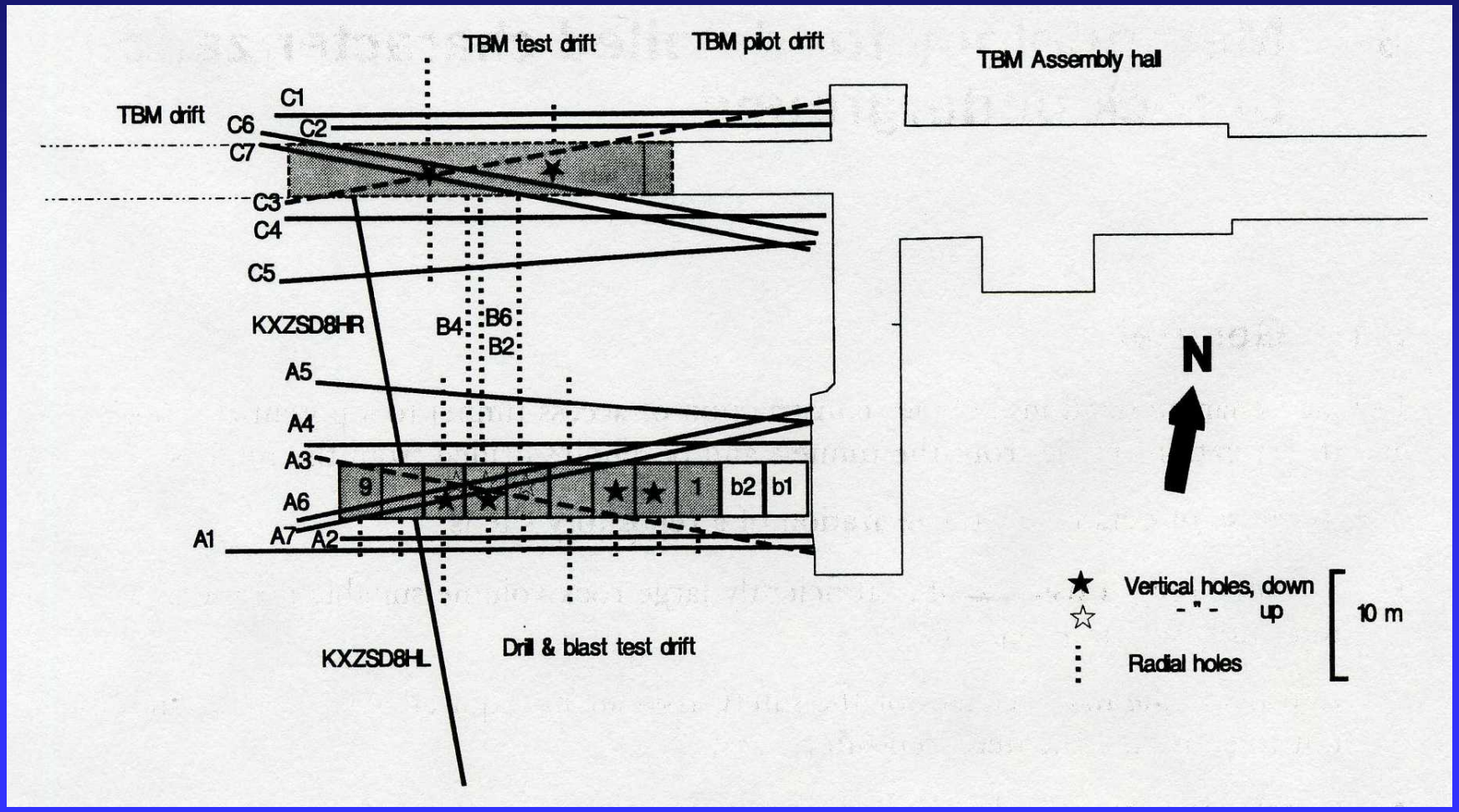
# Summary of Observations from MHM URL

- Clear decreases in pore pressure were observed in all zones as shaft sinking occurred, and distinct gradients toward the shaft were created
- Measured deformations were low, suggesting a small EDZ
- Permeability generally increased by a factor of up to 45 as a result of shaft sinking, with the smallest changes occurring in the test intervals farthest from the shaft (~14 m)

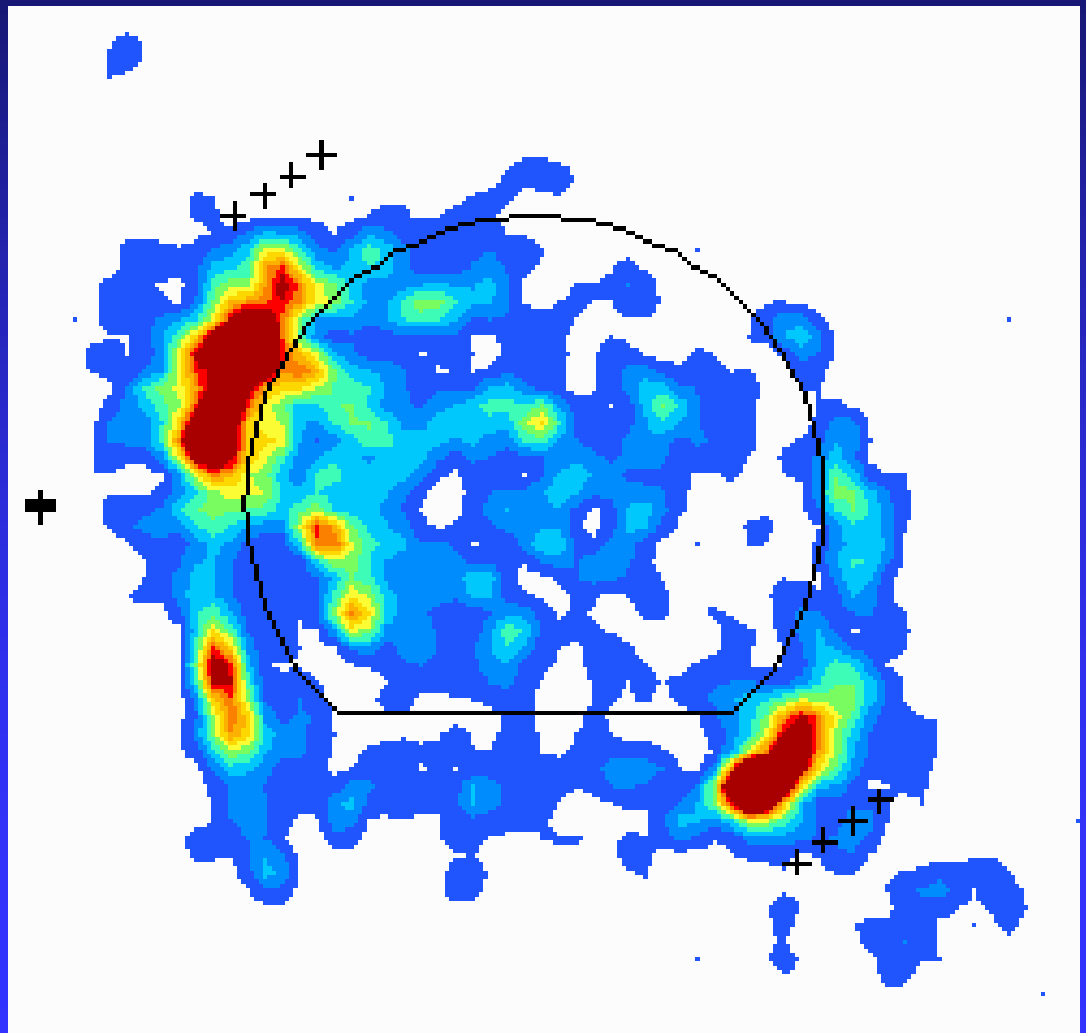
# Äspö Zone of Excavation Disturbance Experiment (ZEDEX)

- Used seismic tomography and acoustic emissions to evaluate and compare the disturbance caused by drill and blast mining methods with that caused by a tunnel boring machine (TBM)
- Instruments emplaced in boreholes drilled in advance of excavation
- Acoustic emission monitoring also performed on newly excavated face before continuing excavation

# Äspö ZEDEX Layout



# Acoustic Emission Monitoring at Face of ZEDEX Drill and Blast Excavation



# Results of ZEDEX

- Drill and blast  created an EDZ 30-80 cm thick, principally around the blast holes
- TBM created a homogeneous EDZ 3 cm thick
- No change in seismic properties >2 m from either excavation

# Conclusions on Monitoring During Shaft and URL Construction

- Monitoring systems should be put in place (and baseline data collected) to measure the effects of shaft and URL construction
- Data can be used to infer changes in hydraulic and geomechanical properties, confirm or calibrate models, and provide guidance on excavation methods and other engineering measures