Yeh and Associates, Inc.
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DRAFT
INTERIM GEOTECHNICAL DATA REPORT

CDOT I-70 TWIN TUNNELS WIDENING PROJECT
IDAHO SPRINGS, COLORADO

PROJECT NO. 211-231
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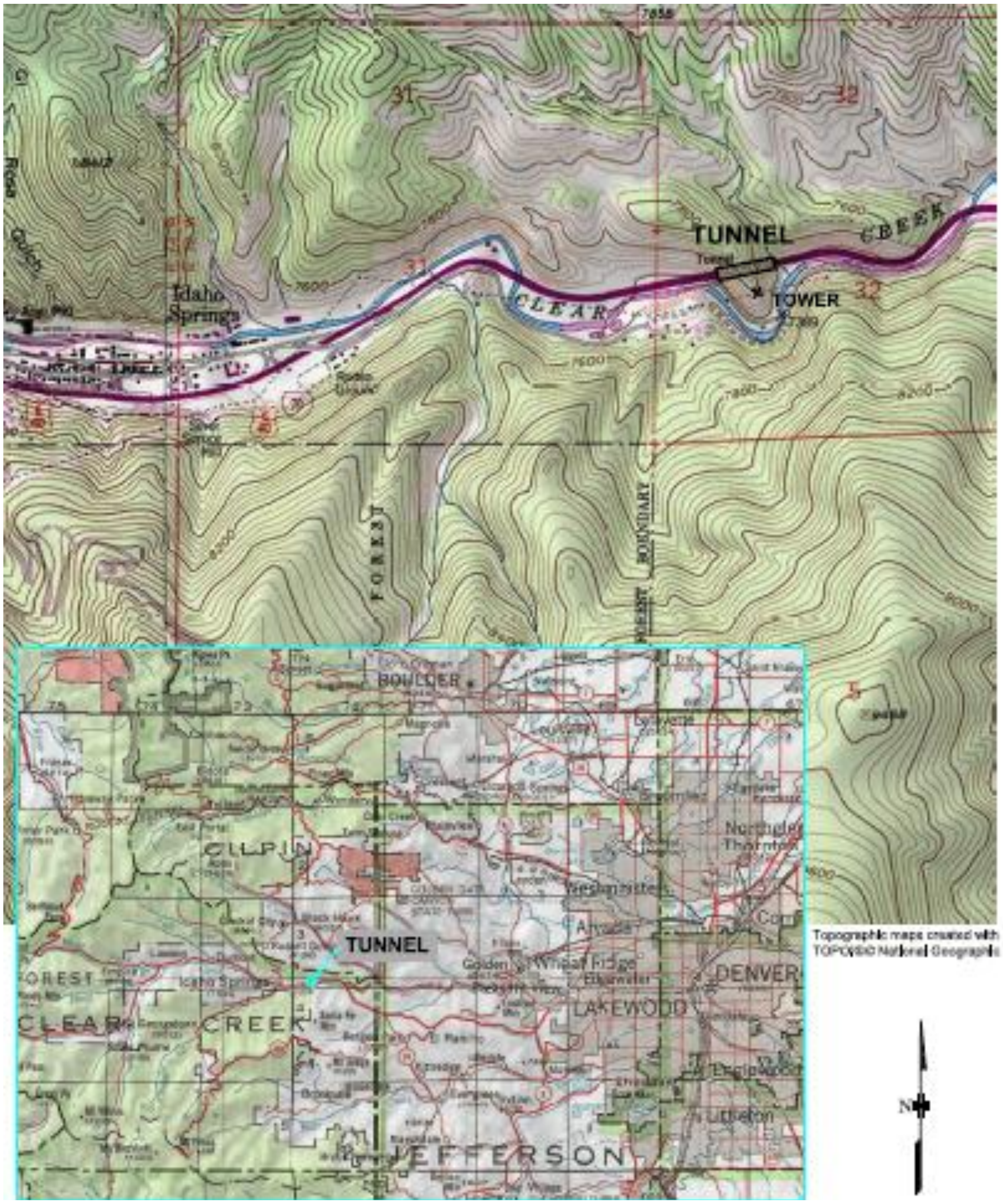
INTRODUCTION

This report presents geotechnical data for the proposed widening of the eastbound Twin Tunnels on Interstate Highway I-70 east of Idaho Springs. The location of the tunnel is shown in Figure 1.



Topographic maps created with TOPO!© National Geographic

Figure 1. Tunnel Location Map.

Purpose and Scope

The scope of the investigation was to determine the geotechnical conditions impacting the design and construction related to the widening of the eastbound bore of the Twin Tunnels. Currently the approach is to widen the two-lane eastbound (EB) bore to accommodate an additional lane and provide room for two, four and eight feet shoulders respectively plus barriers on each side of the tunnel for a total finished internal width of about 51 feet.

The scope of this evaluation included the following tasks:

- Conduct a preliminary field investigation to characterize the rock mass. The Investigation included:
  - Structural mapping.
  - Drilling 6 borings within the tunnel. Drilling inside the tunnel was performed to characterize three tunnel cross sections, each with two core borings into the existing rock mass surrounding the EB tunnel (see Figure 2).
  - Borehole televiewing of the interior of each hole.
  - Perform laboratory testing on rock samples obtained during the investigation to determine the engineering characteristics of the rock.
  - Prepare this Geotechnical Data Report that summarizes the field and laboratory data.

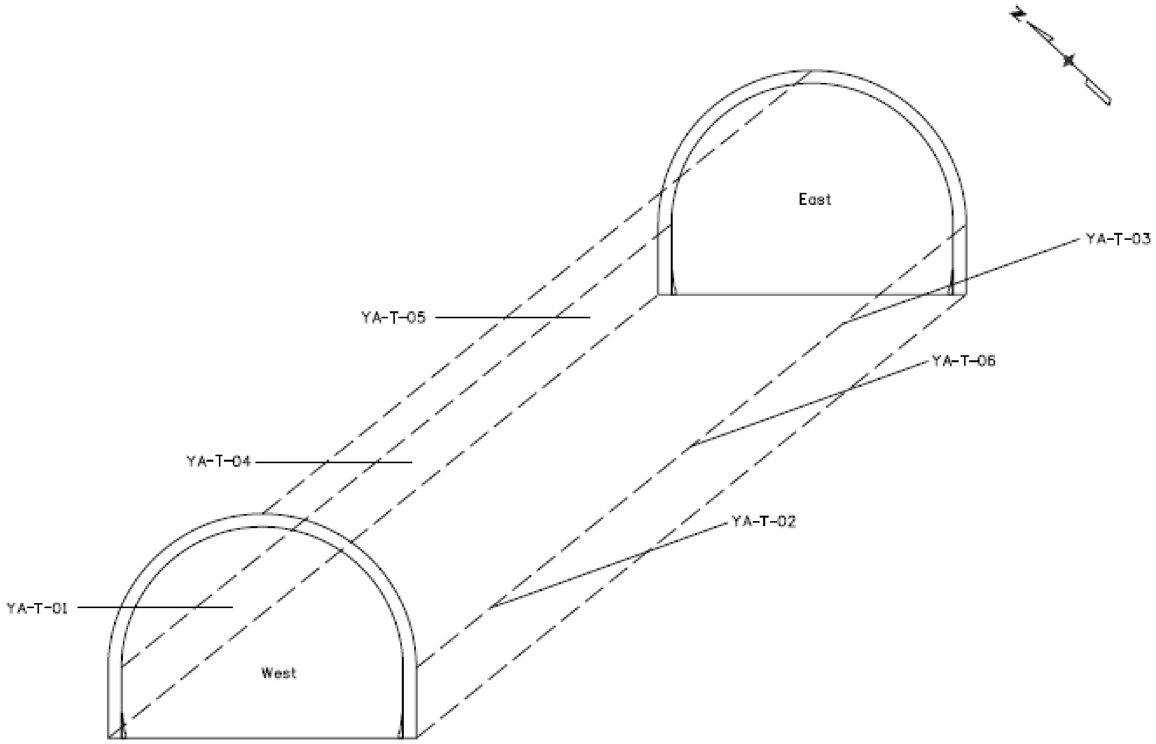


Figure 2. Layout of Boreholes in Eastbound I-70 Twin Tunnel (Not To Scale).

Survey Control

Survey control was based on interpretation of existing topographic maps. Boring locations were surveyed by Woolpert Inc.

Report Organization

This report includes background information, a summary of the field investigation, with a discussion of the rock core borings, structural geologic mapping and groundwater conditions and a summary of the laboratory testing program. Detailed information and supporting documents are provided in Appendices A through H.

Report Limitations

The data submitted in this report were obtained as part of an initial tunnel investigation that was performed as a means of obtaining data in advance of conceptual tunnel design. The data are based on exploratory borings, laboratory testing, field mapping and reconnaissance included in our investigation in addition to appropriate historical data obtained from CDOT archives.

It has been anticipated from the outset of the preliminary investigation that additional supplemental data would be obtained during the design phase of the Twin Tunnels Widening project.

BACKGROUND INFORMATION

General

Located at approximately milepost 242 on Interstate Highway I-70, the Twin Tunnels were constructed in 1961 to replace the existing US Highway 40 that paralleled Clear Creek. Tunnels allowed the Interstate Highway System to pass through the large rock outcrop that the previous highway had curved around. Travelling east from Idaho Springs, US 40 followed along the north bank of Clear Creek proceeding southeast, around the outcrop. At the southern point of the outcrop, US 40 crossed Clear Creek on the Dog House Rail Bridge and continued to the east on the south bank of the creek on the current alignment of County Road 314 toward Denver. Southwest of the bridge, the Colorado Division of Wildlife operated a game check, and parking lanes were added south of the highway.

With the completion of the Interstate, the original US 40 alignment around the outcrop was abandoned, and the segment along the south bank of Clear Creek passed to county ownership and maintenance. The original highway pavement was left intact, but a guardrail was placed preventing motorists on I-70 from turning onto US 40 at the west end of the tunnels.

The tunnel alignment is driven through an outcrop of felsic gneiss, with localized mineralization, as further described in the geology section of this report. Previous site usage is unclear, but there appeared to be evidence of mining on the slope above and south of the west portal. Site drainage is in the form of channelized flow, following existing drainages and game trails. Vegetation across the site ranged from evergreen trees to natural grass and shrubs. Other site features included a high-tension power line approximately 300 feet south of the tunnels, a related tower south of the tunnels, and a deep slot canyon and draped mesh north of I-70 near the east portal. The slot canyon is not vegetated, and drains the plateau north of the rock outcrop. The draped mesh is approximately 200 feet east of the east portal and serves to prevent debris from falling onto the highway from the rock cut on the north side of I-70.

The Idaho Springs Twin Tunnels are approximately 690 to 740 feet long and 32 feet wide, allowing for two travel lanes in each direction. Concrete portals, with electrical utility panels, are present on both ends of the tunnel. A single array of lighting fixtures extends the length of both tunnels, mounted to the exterior of the concrete liner. Rock bolts are present in the outcrop at the east portal, to prevent rockfall/rockslide that may result due to the foliation plane of the rock outcrop that is steeply dipping toward I-70. A small rock fall fence is present at the west portal and has required repair and replacement from normal service.

Both tunnels have an underdrain system that discharges to an open bottomed concrete culvert outside of the east portal. The underdrain system in the tunnel was originally constructed with steel pipe and concrete cleanout boxes with manhole covers. Drains are present in the north lanes of both tunnels and were intended to drain only the rock. No inlets are present in either tunnel. The steel pipe outlets observed draining into the concrete culvert appeared to be severely corroded. The cleanouts were inspected in the south tunnel. At least two of the manhole covers had corroded and disintegrated and the cleanout boxes were visible below the roadway. Only one cover could be opened allowing further inspection of the cleanout box.

Other covers were either buried under asphalt pavement or roadway tracked sediment. Water flowing through the pipes and box was clear and did not appear to be transporting sediment at the time of investigation. At least 5 inches of deep orange colored sediment was observed in the bottom of the box, which could be easily disturbed by increased flow.

The culvert drains both the tunnels and a deep slot canyon to the north. Debris flows and rock fall are common down this canyon and deposits of both were present in the culvert.

Other investigations

Copies of historical tunnel-related documents can be found in Appendix E, Historical Tunnel Data. The information comes from the CDOT Geotechnical office archives. Some archive documents are difficult to read and have been transcribed. Not all documents are dated, but it is estimated that the original investigation and construction was performed from the late nineteen fifties to the early nineteen sixties.

An initial geologic reconnaissance of the tunnel area was performed by Colorado Department of Highways (CDOH) between August and October of 1958. The pilot bore was completed the summer of 1959, and the following December it was geologically mapped by CDOH. As described in the 1958 map, the “mica schist and gneiss bedrock exhibits a distinct stratification dipping 30 to 45 degrees to the north, with joint planes intersecting this at right angles.” Bedrock was observed to be “quite sound” except for the west portal where faulting has resulted in “highly fractured, folded rock that exhibits fault gouge, ground to a clayey mass.”

A geologic map, complete with plan and cross section, was developed circa 1960, after investigation of the outcrop and surrounding area. The entire bedrock outcrop was mapped as quartz-monzonite gneiss transected by a single large mineralized vein. A high tension tower shown at the top of this vein is still present and is a reliable reference point. The vein was mapped as dipping toward the tunnel alignment at 70 degrees from horizontal, but it was not mapped in its entirety. There was a large talus slope shown covering the entire west portal area and part of the slope above. Some pegmatites were mapped above the talus slope.

An undated map of the pilot bore indicated the presence of flowing water and faults in the rock. The pilot bore followed centerline of the north tunnel and was destroyed when the tunnel was further excavated. The map indicated that approximately 100 feet east from the west portal water seepage from the roof was estimated at "1 to 2 gallons per minute." Further east into the tunnel water was noted coming out of the base of the north wall at 1 gallon per minute. The documents indicated the water flowing out of the tunnel contained very little acidity or presence of sulfates as tested by CDOH.

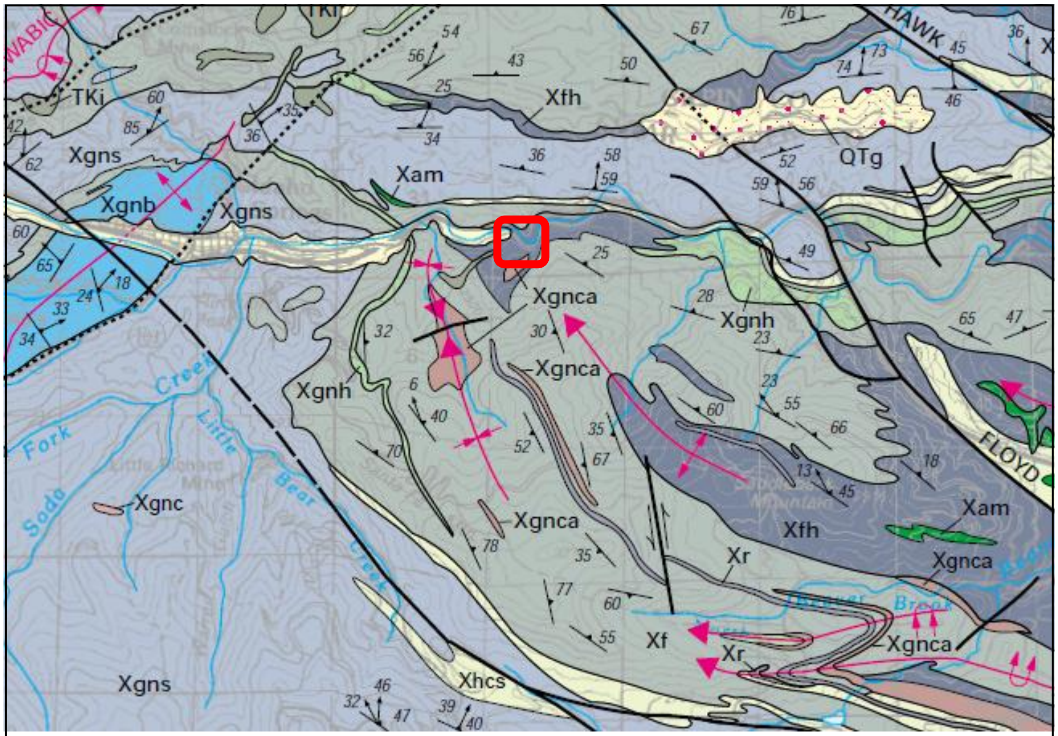
There are eight photographs of the tunnel construction in all, showing the north tunnel and pilot bore looking east, the east portal prior to the concrete facing and six views of the south tunnel. Photographs taken inside both tunnels show steel sets with extensive wood blocking between steel and rock. The floor of the tunnel shows damp areas.

Regional Geologic Setting

A wide range of geologic conditions are represented and exposed along the I-70 corridor due to the large period of time represented in the multiple rock formations. The geologic time reflected along the corridor ranges from recent river, debris and mudflow deposits to Precambrian rocks between 1 and 2 billion years old. The Precambrian age metamorphic and igneous rocks are intruded by Precambrian, Tertiary and Cretaceous age stocks and numerous porphyritic dikes. The regional rock types of most relevance to the tunnel are feldspar gneiss (Xf) and interlayered feldspar and hornblende gneiss (Xfh) identified in Figure 3. The most common porphyries range in composition from quartz monzonite to Bostonite and Alaskite. The sulfide ore deposits are Late Cretaceous to Tertiary in age and are genetically related to the porphyries. The ore contains deposits of precious metals (gold and silver) and base metals (iron, copper, lead, nickel, and zinc; as well as small quantities of arsenic, cadmium and manganese).

The tunnel project is located along the eastern fringe of historic metal mining activity known as the Idaho Springs Mining District. The area is one of the many mining districts within the Colorado Mineral Belt, a zone of highly mineralized rock that trends northeast-southwest across the mountainous regions of Colorado. This zone extends from the La Plata Mountains west of Durango to the north end of Boulder County near Denver. The Idaho Springs-Ralston Shear Zone (IRSZ) is a local expression within the Colorado Mineral Belt. The IRSZ is a northeast trending zone of cataclastic and ductile deformation in the Front Range. The shear zone parallels the axial plane of folds that occur to the southeast of the zone and within the project limits.

Most of the present configuration of the area is characterized by moderately rugged topographic relief. The mountains to the south and north are deeply incised by Clear Creek Canyon and its tributaries. The maximum local relief is about 3000 feet. The elevation in the project area ranges from slightly over 7200 feet along Clear Creek to more than 10,000 feet at Santa Fe Mountain to the south. Slopes are typically steep, averaging approximately 35 degrees in Clear Creek Canyon. Topographic forms are generally influenced by minor faulting, fractures, and zones of weakness in rock. In addition, rain, snowmelt. freeze-thaw, wind and the Clear Creek have created deposits of alluvium (stream deposits), talus (rockfall deposits) and alluvial fans (debris flow deposits).



Xf **Feldspar-rich gneiss**—Light-gray, leucocratic, fine- to medium-grained, microcline-plagioclase-quartz-biotite gneiss. Conspicuously foliated; granitic in appearance. Locally garnetiferous and ubiquitously interlayered with conformable thin to thick layers and lenses of hornblende gneiss, amphibolite, biotite gneiss, and locally calc-silicate rock

Xfh **Interlayered feldspar-rich gneiss and hornblende gneiss**—Feldspar-rich gneiss may contain hornblende and is generally darker than the feldspar-rich gneiss unit (Xf). Interlayered hornblende gneiss is black, white, and dark gray or greenish gray and similar in composition to the hornblende gneiss in hornblende gneiss unit (Xgh). Layers and lenses of biotite gneiss, amphibolite, calc-silicate rock, and biotite-quartz-plagioclase gneiss make up 10–30 percent of

▭ **Site**

Figure 3. Regional Geology of the Site Area (excerpt from USGS Squaw Pass Quadrangle).

LOCAL GEOLOGY

Bedrock

Bedrock is generally well exposed. Outcrops are most abundant on ridges and the sparsely vegetated south facing slopes. Bedrock in the project area consists primarily of metamorphic Precambrian aged quartz-feldspar gneiss, biotite gneiss, amphibolite and migmatite. The metamorphic rock is well foliated and trends at a regional strike of about 105 degrees (azimuthal bearing with respect to North) with a dip ranging from 35 to 65 degrees to the northeast. Locally, variations in the orientation in the rock structure are attributed to the numerous folds and minor faults along the corridor. Igneous intrusions of pink granite and pegmatite also reshaped the rock distribution and occur at various locations along the corridor.

In the vicinity of the Twin Tunnels, bedrock is composed of felsic gneiss, biotite gneiss, and hornblende gneiss (see sheet A-1 in Appendix A). Felsic gneiss is fine- to medium-grained light gray, tan, or pink and contains quartz, oligoclase, microcline, and colorless biotite. These units are interlayered on a scale ranging from about an inch to 30 feet or more.

According to the original mapping conducted for the north (westbound) tunnel pilot bore for the Twin Tunnels (CDOH, 1959); the rock encountered within the first 200 feet of tunnel from the east consisted of weathered schist to schistose gneiss. The strike of the foliation is 065 degrees with a dip ranging from 60 to 70 degrees to the north. Two fault zones were encountered in this area, one with a strike of 100 degrees and the other with a strike of 145 degrees. The remaining 500 feet of rock to the east was composed of gneiss to schistose gneiss with a foliation strike of approximately 075 degrees and a dip ranging from 31 to 61 degrees to the north.

Mineralized Rock

Small plutons of porphyritic rock are numerous in the mining district. The area is generally zoned with a large area of gold bearing pyrite-quartz veins in the interior, an intermediate zone of pyrite-quartz veins bearing copper, lead and zinc, minerals, and a peripheral one containing galena-sphalerite-quartz-carbonate veins (Sims, 1988). The veins are typically fault-filled fissures that strike northeast to east and dip north to northwest at medium angles. The principal vein minerals are pyrite, sphalerite, galena, chalcopyrite, arsenopyrite, tennanite, quartz and local carbonate minerals.

One of the “faults” identified during the original Twin Tunnels construction is exposed at the surface above the west portals. The original mapping indicate that a zone containing fault gouge, soft seams, platy crushed rock and some veins of pyrite was encountered in the first 100 to 150 feet of the tunnels. Recent mapping above the west portals confirms that a zone of weak mineralized rock is present in the area (Figure 5). The mineralized zone appeared to continue along a plane that appeared to strike northeast and dip to the northwest and was exposed in the area of the power line tower. The zone ranges in thickness from 6 to 12 feet and is comprised of fractured, altered and porphyritic rock. Orientation of the seam appears to be consistent with the original pilot bore mapping. The mineralized zone investigated at the west portal appeared to be similar to the Cretaceous age fine grained Bostonite porphyry (Figures 6, 7 and 8) described and mapped west of the site in the 1976 USGS Squaw Pass Geologic map. Minerals that were observed in the samples collected from the altered zone at the site included arsenopyrite, iron pyrite, and biotite. Minerals observed in samples of the gneiss included those found in the altered zone and garnet, magnetite, and hematite. A thin yellow coating was present on the surface of the rocks at the west portal, possibly formed by leaching. A strong sulfur-like odor was noticed when the porphyry was excavated to collect samples. Most other veins observed within the project area are rarely more than a foot wide.

Figure 4. Zone of Porphyritic Rock above West Portals. Note Yellow Staining on Rock and Retaining Wall.

Figure 5. Zone of Poor Quality Rock above the West Portal of the EB Bore.

Figure 6. Zone of Porphyry above West Portal.

Figure 7. Bostonite Porphyry with Pyrite.

Mineral Resources

The Idaho Springs district represents a succession of gold deposits extending from Idaho Springs to Central City and Blackhawk in Gilpin County. Total production in this district was estimated to be about 1,800,000 ounces of gold. The district has an area of about 25 square miles and its principal towns are Central City, Blackhawk, and Idaho Springs. Gold, silver, copper, lead, zinc, and uranium ores occur in the district, but the area is known primarily for its gold and silver production. The ore deposits are found in veins and stockworks and are genetically related to porphyritic intrusive rocks. The district is on the southeast side of the main porphyry belt at a place where the eastern edge of the mineralized part swings from east-northeast to north.

The Cold Bar Placer mine was an underground placer mine located within the Hidden Valley area. Extensive workings are indicated on the 1884 mining claim map but likely only represent a portion of what was actually mined in the area. During construction of the current Hidden Valley Interchange in 1994, three drifts were encountered in the vicinity of the retaining wall along the south side in the interchange and in the area of the west bridge abutment. Some of these drifts are not indicated on the Cold Bar Placer claim map. Other workings are also evident by the numerous subsidence features that occurred in the area until the mid 1990s when a grouting program was implemented to fill many of the voids.

A strip mine is identified near Milepost 241.8 on the 1976 USGS geologic map of the area (Sheridan and Marsh 1976). Visual evidence of the workings no longer exists today and appears to have been covered by the Interstate highway, chaining area and the earthen berm located between the highway and Clear Creek.

Intermittent placer mining continues in the district along Clear Creek, primarily in the valley of North Clear Creek and in Russell Gulch, in spite of the fact that nearly all this ground has been worked and reworked several times. As would be expected, present yields are low.

There is no visual evidence that there were any high-grade ore bodies mined within the project area such as glory holes or shallow workings. These are typical features that indicate that some evidence of precious metal deposits such as gold and silver may be present in the area. It is unlikely that these minerals will be encountered during construction of the proposed improvements.

Geologic Hazards

The varied and complex geologic and geomorphic processes have led to the development of several zones of instability and marginal subsurface material. Although a natural process, these features can pose a risk to the public either directly by an encounter with the hazard or indirectly through effect of the hazard on the highway, railway or multi-use trails. Geologic Hazards that may adversely affect the public and/or the proposed improvements in the corridor include but ar eno tlimited to, debris flows, unstable slopes, rockfall, and the potential for mine subsidence.

Unstable Slope Hazard Areas

Existing rock slopes along I-70 through the project area generate rock falls that occasionally impact the interstate. Isolated areas in these road cuts, particularly above the west portals of the existing Twin Tunnels, have generated larger and more problematic rockslides. Some of the slides have been of sufficient size to close portions of I-70 for short periods of time. As a result of one of these failures, a low-capacity fence was damaged between the two portals on the west side of the tunnels (Figure 8). The fence was replaced by a higher capacity rockfall barrier.

The highly fractured metamorphic and igneous rocks along the highway are vulnerable to rock fall along many of the existing cut slopes and natural slopes. Rock fall may occur during construction when new cut slopes adversely affect the boundaries between rock types, weakening the rock, or where they are subject to construction activities such as blasting. The vulnerability of the rock slopes depends on the material strength and the character and geometric relationships of discontinuities in the rock mass.

The CDOT Rockfall Program has identified and rated 7 unstable slopes along I-70 in the project area with potential for rock fall. One of the sites occurs directly above the west portal of the Twin Tunnels and has received a level of mitigation as described above. Details on the locations and ratings for unstable slopes may be found in the Colorado Rockfall Hazard Rating System performed from 1991 to 1994 and subsequently updated as part of the CDOT Rockfall Management Plan.

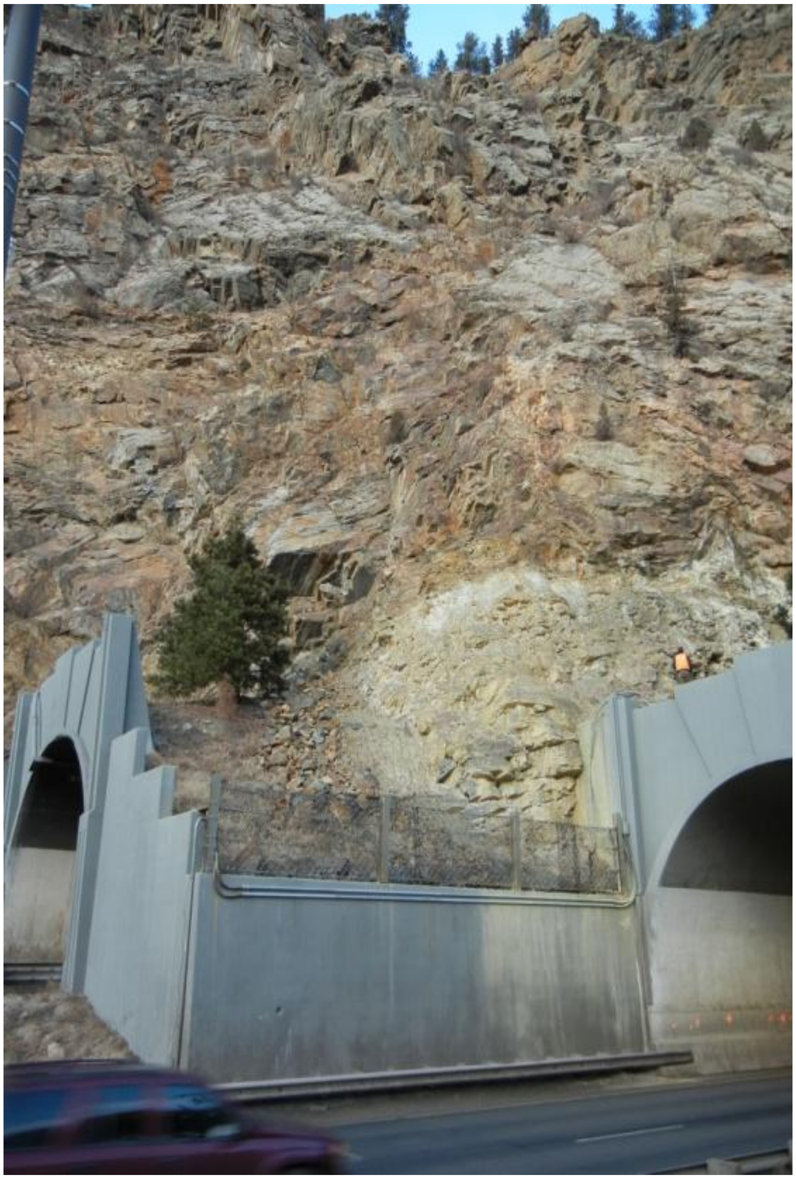


Figure 8. Rockfall Source Area and Rockfall at the West Portals.

Debris Flows

A debris flow is a flood that incorporates, transports, and deposits enough solid material (such as rock debris, valley fill, bed load, and/or large woody debris) that the solid material is a major component of the event, drastically increasing the destructive power of the flood and the resulting damage. Infrequent, intense rains fall on the hillside cause flooding. The mountain watersheds can add to the flood waters both inorganic (rocky debris) and organic (woody debris) materials that can increase the destructiveness of the flood on the highway.

Debris flows in the project area occur at relatively infrequent intervals as compared to other locations to the west of the project. There are several debris flow deposits in the local area, with the largest located along the south slope of the Hidden Valley Interchange.

Mine Subsidence

Mine subsidence occurs when a void at depth collapses and causes vertical displacement (settlement) to the surface. Mine subsidence occurs at depth, rather than near the surface, as with collapsing soils. Underground placer mining occurred in the vicinity of the Hidden Valley Interchange in the 1880s, using a drift and pillar technique in which a placer deposit was mined into "chambers." Based on observations of the openings that were uncovered during construction of the interchange, many of these drifts were likely unsupported workings and those that were supported, used timber sets. Because the gravel deposits in the placer do not resist stress well, subsidence typically occurs relatively soon after mining ceases. In addition, in many of the mines, the pillars were removed when mining was completed to encourage collapse of the void space. Over time, the empty void propagates to the surface creating a collapse feature.

A series of subsurface investigations were conducted by the Colorado Department of Highways from 1981 to 1996 evaluating the potential for collapse. Investigation methods used both geophysical and exploratory borings to determine the extent of the workings. Over this time, several opening had propagated to the surface until the mid 1990s when a grouting program was implemented to fill the voids that affect the Interstate roadway platform.

Faults

The project area is considered to be in a seismically-inactive area. There are no known active faults either on or adjacent to the I-70 corridor, so the potential for surface fault rupture is low. A westerly finger of the Floyd Hill Fault passes through the project near Milepost 242.7 and several other minor faults were noted within the extents of the proposed project. All of the faults are believed to have been inactive for at least the last 45 million years. Therefore, seismic hazards at this site are a consequence of ground shaking caused by events on distant, active faults.

Soils

Soils are primarily a product of their parent material, climate, ecological system, slope and time. The varied geologic conditions in the corridor provide source material for the soils from gneiss, granite, to colluvium, alluvium and various glacial deposits. The slope angles vary from near horizontal along the valley bottoms, becoming steep to vertical valley sides on nearly all aspects.

Generalized soils from Idaho Springs to the junction of Highway 6 and I-70 are primarily Resort-Cathedral-Rubble land and Rock outcrop. Cathedral soils typically occur on 30-70 percent slopes and ridges primarily derived from weathered mica schist or granite. Resort soils are typically found on 30-60 percent slopes and ridges primarily derived from weathered mica schist or granite. Rubble land occurs on talus slopes at 30 to 60 percent. The Rock outcrop is found on 30-70 percent slopes and is typically composed of weathered mica schist or granite. All of these soils are severely susceptible to erosion.

Seismicity

The area generally has a low seismic hazard ranking. The Site Class has been selected as B therefore the Site Factor is 1 (modification factor). The seismicity of the local area based on the 2007 AASHTO Bridge Design Guidelines shows a peak ground acceleration (PGA) of 0.068g. Mapped Spectral Acceleration Values, Ss and S1 (period of 0.2 second and 1 second respectively), are presented below. The design ground motion parameters As, SDs, SD1 (design equivalent of PGA, Ss and S1 respectively) are the same as the ground motion parameters. These acceleration data have a 7% probability of exceedance in 75 years (equivalent to a recurrence interval of 1,033 years).

Site Class B

Data are based on a 0.05 deg grid spacing.

Period (sec)	Sa (g)	
0.0	0.068	PGA - Site Class B
0.2	0.141	Ss - Site Class B
1.0	0.036	S1 - Site Class B

Spectral Response Accelerations As, SDs and SD1

Period (sec)	Sa (g)	
0.0	0.068	As - Site Class B
0.2	0.141	SDs - Site Class B
1.0	0.036	SD1 - Site Class B

FIELD INVESTIGATIONS

The preliminary investigation program included site reconnaissance, site structural mapping, subsurface core drilling, internal borehole visualization, laboratory testing and geologic data interpretation.

Tunnel Coring

A total of six test borings were drilled to lengths of between 19.3 to 60.0 feet from the tunnel liner into the rock (see Figure 2). Of the six borings, three were drilled in the column between the north and south tunnels and 3 were drilled on the south side of the south tunnel. The borings were advanced with a skid-mounted Ingetrol Explorer 75E drilling rig owned and operated by Agapito Associates. Coring of the rock was performed using NX size equipment. Photographs taken in the tunnel during the drilling operation are presented in Appendix B. Approximate field boring locations within the tunnel and the angle of drilling, measured above horizontal, are described in Table 1.

Table 1. Summary of Approximate Boring Orientations and Locations Measured from Portal Face.

Boring	**Length (ft)**	**Angle (above horiz.)**	**Lane**	**Location (approx.)**
YA-T-01	20.1	0 degrees	Left	75 ft East of West Portal
YA-T-02	48.4	45 degrees	Right	75 ft East of West Portal
YA-T-03	22.9	45 degrees	Right	52 ft East of West Portal
YA-T-04	19.3	0 degrees	Left	350 ft East of West Portal
YA-T-05	20.0	0 degrees	Left	52 ft West of East Portal
YA-T-06	60.0	45 degrees	Right	350 ft East of West Portal

The borings were located in the field by measuring in from the east and west portals of the south tunnel. Distances were measured using a wheel. Setting the drill angle was determined using a Brunton compass or a digital level. Accurate boring locations in the tunnel were later surveyed by Woolpert Inc. Hole collar survey coordinates are provided in Table 2. Engineering geology sheets showing the position, representative orientation and logs of holes bored within the tunnel are shown on sheets A-2 through A-4 in Appendix A.

Table 2. Hole Collar Survey Coordinates.

Boring	N	E	ELEV
YA-T-01	696113.585	1006831.090	7391.60
YA-T-02	696084.827	1006836.097	7400.04
YA-T-03	696190.610	1007392.707	7393.92
YA-T-04	696164.341	1007091.385	7388.57
YA-T-05	696221.408	1007389.984	7384.55
YA-T-06	696134.471	1007097.835	7397.28

All borings in the tunnel required drilling and setting anchor bolts into the concrete liner. The bolts were used in anchoring the drill to the tunnel wall, to prevent pushback of the rig while drilling. The concrete liner was cored with a separate concrete coring barrel, unless difficult conditions were encountered, which required using the rock coring barrel. After the concrete was cored a manifold was sealed into the hole to allow for circulation of drilling fluids. Drilling fluids were circulated and only minor loss was noted.

Logs of subsurface conditions were recorded for each boring during the drilling operations. These logs can be found in Appendix C. The following information is recorded on each graphic core log:

- Hole coordinates,
- Collar elevation,
- Depth,
- Sample type,
- Core per cent recovery,
- RQD,
- Fracture frequency (fractures per foot),
- Joint spacing,

- Degree of weathering,
- Lithology,
- Material type,
- Laboratory test results, and
- Field notes.

Fractures present in the rock mass are highly variable, ranging from horizontal to vertical. But several major joint sets and faults were observed in the rock core. Generally the direction of the discontinuities appears to be perpendicular to the tunnel axis, based on the borings drilled in the right lane.

The rock core recovered (see photographs in Appendix D) shows fractures roughly following the drilling inclination, which is approximately in the range of the foliation dip angle of the rock mass. Many joints and fractures in the rock mass are healed. Weathering of the rock appears to occur mainly in joints and fractures and occurs more commonly in biotite rich rock. Most iron oxide deposition is along or through biotite gneiss. Clay infilling and scouring of the rock is along fractures, and shows indications of water transport. Boring YA-T-03 encountered highly fractured rock at approximately 19 feet and coring was very difficult to 22.9 feet, where the core barrel seized and could not be recovered.

TUNNEL LINER OBSERVATIONS

As presented on the boring logs, the concrete tunnel liner ranges in thickness from 2.0 to 2.7 feet. The concrete liner was cast-in-place in consecutively constructed sections. The original specifications for the tunnel liner included steel rib supports on 4-foot centers, embedded in a 1.5 foot thick concrete lining. Spreaders between the supports were specified as angle iron. Rock bolts were installed in the pillar on 10 feet centers longitudinally according to the as-built drawings in Appendix E.

Some efflorescence was observed in both tunnels, originating from cracks and joints in the tunnel liner. The staining appeared to be more prevalent in the ceiling of the tunnels, but did run down the full length of the tunnel wall.

During tunnel inspections, a small hole was observed in the liner of the south tunnel, approximately 50 feet from the west portal. Further investigation of the liner hole determined that a large void was present behind the concrete liner and that steel rebar and beams were exposed in that section. The void was documented and reported to CDOT and Parsons. CDOT representatives opened the void for further inspection to expose the steel and concrete which were very corroded. Wood that had been used for blocking during construction was rotted and ice and frost were present inside the void. A marked temperature difference between the tunnel and the interior of the liner was noted. Several small cobble-size boulders had fallen from the rock face above and were resting on the inside of the liner.

Mapping

Mapping is an essential component of rock mass structural characterization. It can be accomplished using physical mapping, geophysical, photogrammetric or borehole methods. The most commonly used approach is visual field mapping in conjunction with field measurements.

The current investigation utilized structural mapping, data from tunnel core logging and optical downhole borehole viewing.

STRUCTURAL MAPPING

Structural mapping of contacts and dip-dip directions was performed at several mapping windows located across the site wherever rock was accessible. Dip data was collected at the west and east portals, the southernmost rock promontory, the slopes directly south of the portals, the mineralized "vein" from the west portal to the power line tower and from the borehole televiewer data obtained from holes drilled inside the tunnel (see sheets A-5 and A-6 in Appendix A).

Measurements were made along bedrock foliation planes, major joint sets, and fractures. The mineralized vein, as defined in early tunnel mapping prior to the construction of the current tunnel, was difficult to accurately measure because of the decomposed state of the rock and the talus cover. Mapping done during construction of the tunnel shows intersecting faults at the west end of the tunnel. The mineralized, or altered zone, may be following a fault. No offset was observed in the field during this investigation, so there is insufficient evidence to confirm a fault.

Data was also collected in the immediate vicinity of the power line tower, at the approximate apex of the vein

Above the west portal of the south tunnel the zone of mineralization was largest striking north and dipping to the east approximately 20 to 25 degrees. There is evidence that the mineralized zone may be present elsewhere in the vicinity, but additional excavation or drilling would be required for confirmation. Minerals including arsenopyrite and iron pyrite were observed and sampled in the exposure.

A complete record of the window mapping, core and borehole televiewer foliation and fracture data are provided in Appendix F. Orientation data are displayed on lower hemisphere stereonet projections.

Foliation

The average of all the outcrops mapped for this investigation indicated the foliation bands were found to dip 25 degrees with a dip direction of 343 degrees, as calculated using Dips. Average foliation measurements for the tunnel borings had dip angles that ranged between 38 and 71 degrees, dip directions that ranged between 13 and 243 degrees. Average foliation measurements at each outcrop mapping window and for each borehole are shown in Table 3 below and indicate the undulating nature, or folds, of the foliation plane. No foliation was observed at Outcrop #3.

Table 3. Average Foliation Measurements from Dips Program (Degrees Clockwise with respect to North).

Mapping Area or Borehole	**Dip angle**	**Dip Direction**	**Strike**	**Strike wrt Tunnel Axis**
Outcrop #1 (west end)	22	115	25	167
Outcrop #2 (west side)	22	004	274	82
Outcrop#4 (east side)	35	343	253	61
Outcrop#5 (east end)	50	329	239	47
West side near tower	20	328	238	46

Mapping Area or Borehole	Dip angle	Dip Direction	Strike	Strike wrt Tunnel Axis
Borehole YA-T01, west	38	214	124	68
Borehole YA-T02, west	70	013	283	89
Borehole YA-T04, mid-tunnel	46	243	153	39
Borehole YA-T05, east	50	186	96	96
Borehole YA-T06, mid-tunnel	71	014	284	88

Joints and Fractures

Rock discontinuities include joint or fracture sets, folds and faults. Joint sets are generally parallel sets of fractures in the rock mass. In the recently mapped outcrops overall, the joint sets were found to dip 86 degrees with a dip direction of 009 degrees as calculated using Dips. Average joint and fractures measurements for the tunnel borings had dip angles that ranged between 9 to 82 degrees and dip directions that ranged between 21 and 292 degrees. Average joint/fracture measurements at each outcrop mapping window and for each borehole are shown in Table 4 below. No measurable fractures were visible at Outcrop #1. In general the joint set labeled as J1 (sheets A-5 and A-6 in Appendix A) show dip angles between 74 and 87 degrees dipping north easterly or south westerly along a strike direction between 326 and 347 degrees. The dip direction on these steep joints varies, but these joints appear to be nearly parallel.

Table 4. Average Joint/Fracture Measurements from Dips Program (Degrees Clockwise with respect to North).

Mapping Area or Borehole	Type	Dip angle	Dip Direction	Strike	Strike wrt tunnel axis
Outcrop #2 (west side)	Joint J1	87	236	146	46
Outcrop #2 (west side)	Fracture	86	164	74	118
Outcrop #3 (south end)	Joint J1	83	257	167	25
Outcrop #3 (south end)	Joint	90	162	72	120
Outcrop #4 (east side)	Joint	45	179	89	103
Outcrop #4 (east side)	Joint J1	86	056	326	46
Outcrop #5 (east end)	Joint J1	76	253	163	29
Outcrop #5 (east end)	Fracture	56	224	134	58
West side near tower	Joint	2	230	140	52
West side near tower	Joint	87	352	262	70
Regional north of tunnel	Joint J1	77	067	337	35
Borehole YA-T01, west	Fracture	9	021	291	81
Borehole YA-T01, west	Fracture	17	200	110	82
Borehole YA-T02, west	Fracture	48	292	202	10
Borehole YA-T02, west	Fracture	20	042	312	60
Borehole YA-T02, west	Fracture	12	220	130	62
Borehole YA-T04, mid-tunnel	Fracture	82	028	298	74
Borehole YA-T04, mid-tunnel	Fracture/J1	76	242	152	40
Borehole YA-T04, mid-tunnel	Fracture	48	119	29	163
Borehole YA-T05, east	Fracture/J1	74	140	344	28
Borehole YA-T06, mid-tunnel	Fracture	34	227	146	46
Borehole YA-T06, mid-tunnel	Fracture	19	278	74	118

BOREHOLE TELEVIEWING

Rock core provided samples for determining rock strength and quality and for developing an understanding of rock fabric, mineralogy and general character. Borehole televiewing added an extra dimension that allowed in-hole views of in-situ conditions within the rock mass. The data collected from the televiewer was used to correlate the rock core to the rock mass conditions.

Internal borehole inspection was performed by Colog Inc. using an OBI-40 optical televiewer from Advanced Logic Technologies. The six tunnel borings were viewed and 360 degree optical images of the inside of each hole were obtained. These images were evaluated and discontinuities, foliation planes and any other major features were classified and compiled. Dip angle and strike/dip direction of foliation, joint discontinuities are summarized in the form of pole plots and rose diagrams and presented in Appendix G. Three of the borings (YA-T-1, YA-T-4 and YA-T-5) were inspected full length. The remaining three borings (YA-T-2, YA-T-3 and YA-T-6) were inspected as far into the holes as access allowed. This data was then incorporated into the overall structural mapping of the rock mass.

Discontinuity features were determined from the optical borehole televiewer images by Colog and were reviewed and verified by Yeh & Associates. Colog features labeled “0” or “1” appeared to follow the planes of foliation and were separated out as such. Features labeled “2” or “3” represented fractures and were assigned to that category. Some features were reclassified after review and the associated data was reassigned. A list of those changes is included in Appendix F with the other structural mapping data.

Data for the televiewer features was calculated by Colog using WellCAD software. This software also calculated the true feature orientation which includes the dip direction and dip angle. The data from Colog did not include magnetic declination. Yeh & Associates transferred the Colog data to a spreadsheet and all dip directions were corrected to 9 degrees east (Natonal Oceanic and Atmospheric Administation data). Dip directions were also converted to strike direction using the American right hand rule. Features that were reassigned by Yeh were given new classifications in the spreadsheet. The converted spreadsheet data was transferred to the RocScience Dips program to produce stereonet representations of the prominent fracture and foliation planes. To compensate for under-representation of features that were parallel to the borings, a Terzaghi correction was applied to the data in Dips.

Rock Mass Classification

Rock structure and composition in both the center pillar and the southern limb of the tunnel appear to be highly variable. The character of discontinuities vary widely throughout the project area. Competency of the rock may increase in the middle of the tunnel, away from both portals, but overstressing of the rock from blasting may also be present. Some borings appear to be highly fractured in the first 3 to 5 feet of the core directly behind the concrete liner which may have been caused by previous blasting of the original tunnel.

Rock Quality Designation (RQD) and core recovery information obtained from the core drilling program is presented in Table 5. The recoveries and RQDs show averages over the entire length of the core as well as values for the lowest and highest intervals in the core Rock mass classification using Rock Mass Rating System (Bieniawski 1989) and the Tunneling Quality Index (Barton 1974) were performed, to produce RMR and Q ratings respectively, on the six core runs obtained from within the tunnel as shown in Tables 6 and 7.

Table 5. RQD and Recovery Values of Rock Core from Tunnel.

	Recovery (%)			**RQD (%)**		
	High	Wtd. Ave	Low	High	Wtd. Ave	Low
YA-T-01	-	100	-	81	61	45
YA-T-02	100	87	59	100	63	7
YA-T-03	100	93	64	100	82	36
YA-T-04	-	100	-	80	64	52
YA-T-05	-	100	-	100	72	46
YA-T-06	100	98	90	94	61	32

Table 6. RMR Ratings for the Tunnel Rock Core (Bieniawski 1989).

Core	1	2	3	4	5	Rating	RMR Class
YA-T-01	2	13	10	25	15	65	II
YA-T-02	7	13	8	20	15	63	II
YA-T-03	7	17	20	30	15	89	I
YA-T-04	7	13	10	25	15	70	II
YA-T-05	12	13	10	20	15	70	II
YA-T-06	12	13	8	10	15	58	III

Table 7. Q Ratings for the Tunnel Rock Core (Barton 1974.)

Boring	W.A. RQD	Jn Joint Set Number	Jr Joint Roughness Number	Ja Joint Alteration Number	Jw Joint Water Reduction Factor	SRF Stress Reduction Factor	Q
YA-T-01	61.5	9	2	2	1	2.5	2.7
YA-T-02	63.3	12	2	3	1	2.5	1.4
YA-T-03	81.7	9	4	0.75	1	2.5	19.4
YA-T-04	63.6	9	2	1	1	2.5	5.7
YA-T-05	72.0	9	3	1	1	2.5	9.6
YA-T-06	61.4	12	1.5	3	1	2.5	1.0

Groundwater Conditions

Groundwater was not observed in the borings at the time of drilling. No flowing water was observed in the south tunnel at the time of exploration. Ice formations were observed in two locations approximately one foot above the top of the barricade of the north wall of the north tunnel, near the west portal. The ice was apparently formed by water seeping out of tunnel liner joints, and formed 6-inch to 12-inch thick ice blocks. Water leaching out of rock into the space between the rock mass and the interior of the concrete liner void at the west end of the tunnel was frozen.

LABORATORY TESTING

Samples retrieved during the field exploration were returned to the laboratory for evaluation and samples of bedrock were classified in accordance with the general bedrock classification used in the Colorado Front Range area. A limited laboratory testing program was created to determine engineering properties of the bedrock. Following the completion of the laboratory testing, the field descriptions were confirmed or modified as necessary and boring logs were prepared. These logs are presented in Appendix C.

In order to determine small-sample rock strength, deformability and elastic constants, core obtained from the rock mass and the tunnel liner were tested by Advanced Terra Testing, Lakewood, Colorado. The following tests were performed on samples of the core:

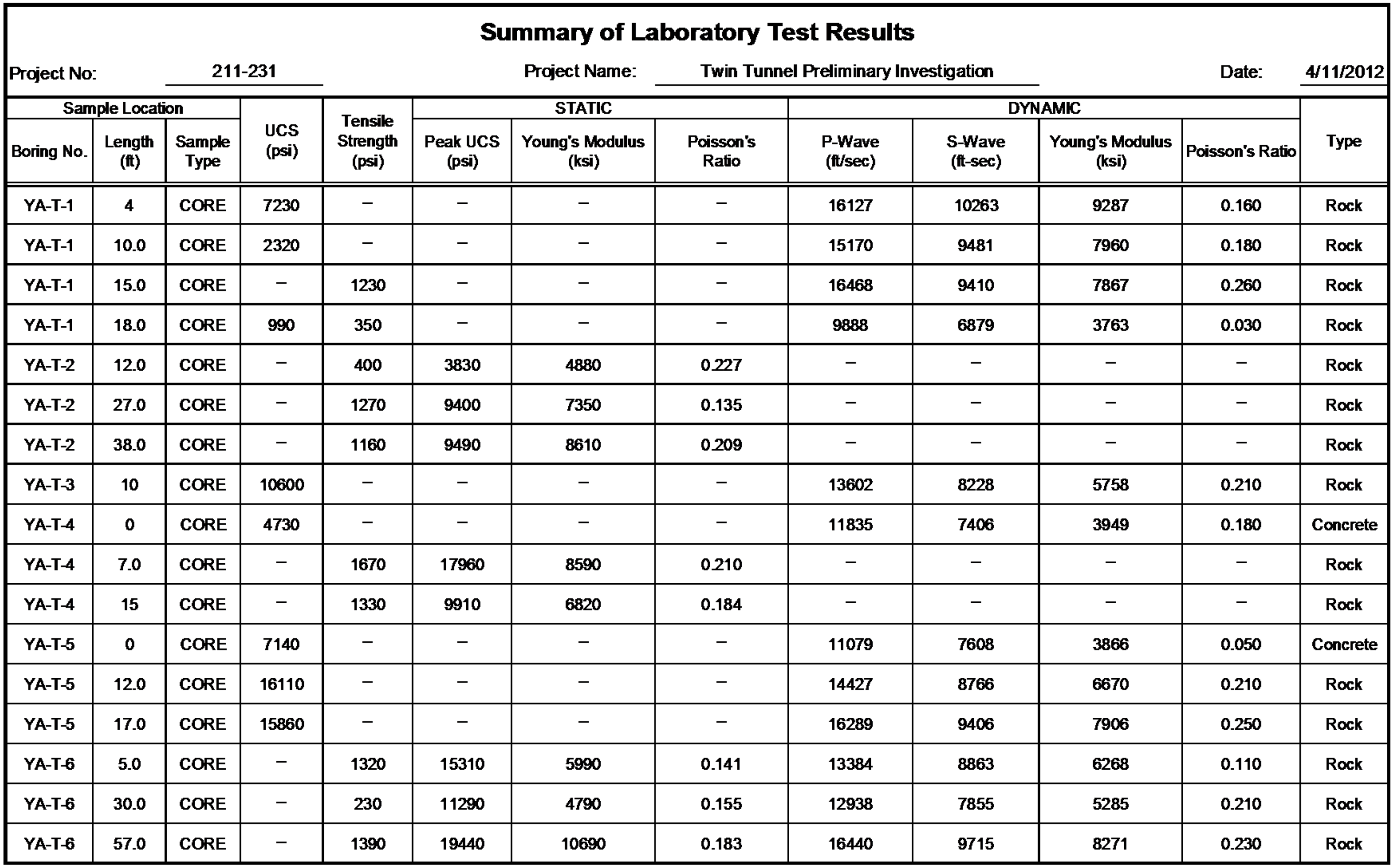
- Unconfined Compressive Strength – Peak compressive strength

- Unconfined Compressive Strength – Stress-Strain relationship, Static Young's Modulus, Poisson’s Ratio
- Sonic Velocity – P and S Wave velocities, Dynamic Young's Modulus, Poisson’s Ratio
- Brazilian Tensile Strength – Indirect Tensile Strength

Two core samples taken from the concrete tunnel liner were tested to get a measurement of concrete strength.

A summary of the test data is presented as Table 8. Complete rock testing results can be found in Appendix H.

Table 8. Summary of Laboratory Rock Testing Results Performed by Advanced Terra Testing.



Summary of Laboratory Test Results

Project No: 211-231 **Project Name:** Twin Tunnel Preliminary Investigation **Date:** 4/11/2012

Sample Location			UCS (psi)	Tensile Strength (psi)	STATIC			DYNAMIC				Type
Boring No.	Length (ft)	Sample Type			Peak UCS (psi)	Young's Modulus (ksi)	Poisson's Ratio	P-Wave (ft/sec)	S-Wave (ft-sec)	Young's Modulus (ksi)	Poisson's Ratio	
YA-T-1	4	CORE	7230	–	–	–	–	16127	10263	9287	0.160	Rock
YA-T-1	10.0	CORE	2320	–	–	–	–	15170	9481	7960	0.180	Rock
YA-T-1	15.0	CORE	–	1230	–	–	–	16468	9410	7867	0.260	Rock
YA-T-1	18.0	CORE	990	350	–	–	–	9888	6879	3763	0.030	Rock
YA-T-2	12.0	CORE	–	400	3830	4880	0.227	–	–	–	–	Rock
YA-T-2	27.0	CORE	–	1270	9400	7350	0.135	–	–	–	–	Rock
YA-T-2	38.0	CORE	–	1160	9490	8610	0.209	–	–	–	–	Rock
YA-T-3	10	CORE	10600	–	–	–	–	13602	8228	5758	0.210	Rock
YA-T-4	0	CORE	4730	–	–	–	–	11835	7406	3949	0.180	Concrete
YA-T-4	7.0	CORE	–	1670	17960	8590	0.210	–	–	–	–	Rock
YA-T-4	15	CORE	–	1330	9910	6820	0.184	–	–	–	–	Rock
YA-T-5	0	CORE	7140	–	–	–	–	11079	7608	3866	0.050	Concrete
YA-T-5	12.0	CORE	16110	–	–	–	–	14427	8766	6670	0.210	Rock
YA-T-5	17.0	CORE	15860	–	–	–	–	16289	9406	7906	0.250	Rock
YA-T-6	5.0	CORE	–	1320	15310	5990	0.141	13384	8863	6268	0.110	Rock
YA-T-6	30.0	CORE	–	230	11290	4790	0.155	12938	7855	5285	0.210	Rock
YA-T-6	57.0	CORE	–	1390	19440	10690	0.183	16440	9715	8271	0.230	Rock

UCS = unconfined compressive strength

This report transmits geotechnical data only, for use by Parsons Corporation and CDOT, for the proposed widening of the I-70 Twin Tunnels near Idaho Springs, Colorado. The data submitted are based on the exploratory borings, laboratory testing, field mapping and reconnaissance included in our investigation. This Investigation has been conducted in accordance with generally accepted geotechnical engineering practices in this area. The nature and extent of subsurface variations across the site may not become evident until excavation is performed. During construction conditions may be different from those described herein. No warranty, expressed or implied, is made.

YEH AND ASSOCIATES, INC.

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Appendix A

Drawings

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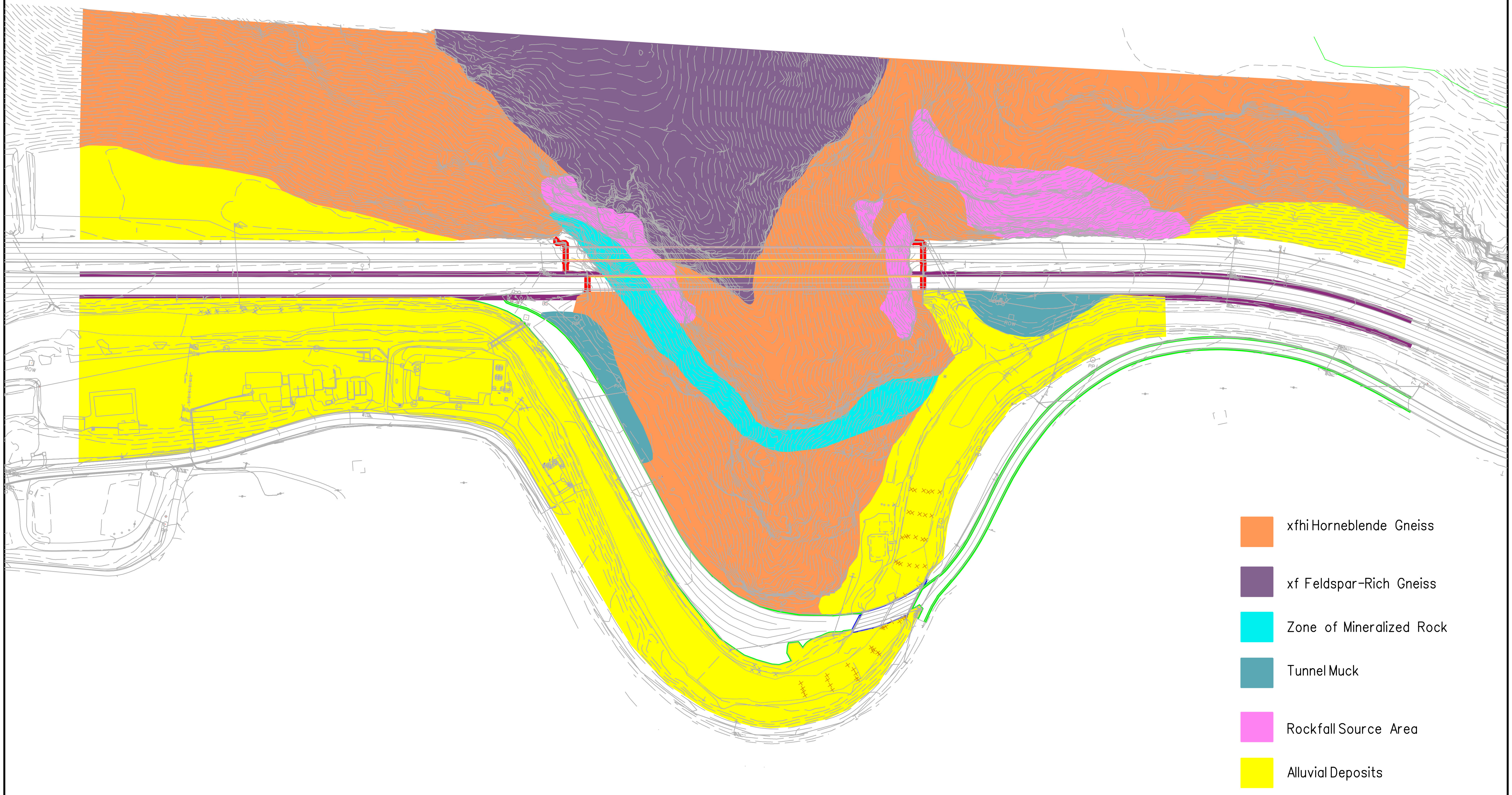

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US 70 - TWIN TUNNELS
LOCAL GEOLOGY AND ROCKFALL

Designer: H. Hume
Detailer: M. Walz
Sheet Subset: Geology
Structure Numbers
Subset Sheets: of

Project No./Code
Project Number
17502
Sheet Number A-1

Legend for Symbols Used on Borehole Logs

Sample Types

▮ Rock Core

Bedrock Lithology

▨ Concrete

▨ GNEISS

▨ QUARTZ PEGMATITE

▨ SCHIST

RQD
Rock Quality Designation

% Recovery
Length of Core Recovered/Length of Core Drilling Run

Joint Spacing
Noted near actual depth

Fracture Frequency
Fractures per foot

Weathering Grade

WI	Fresh
WII	Slightly Weathered
WIII	Moderately Weathered
WIV	Completely Weathered or Decomposed
WV	Residual Soil

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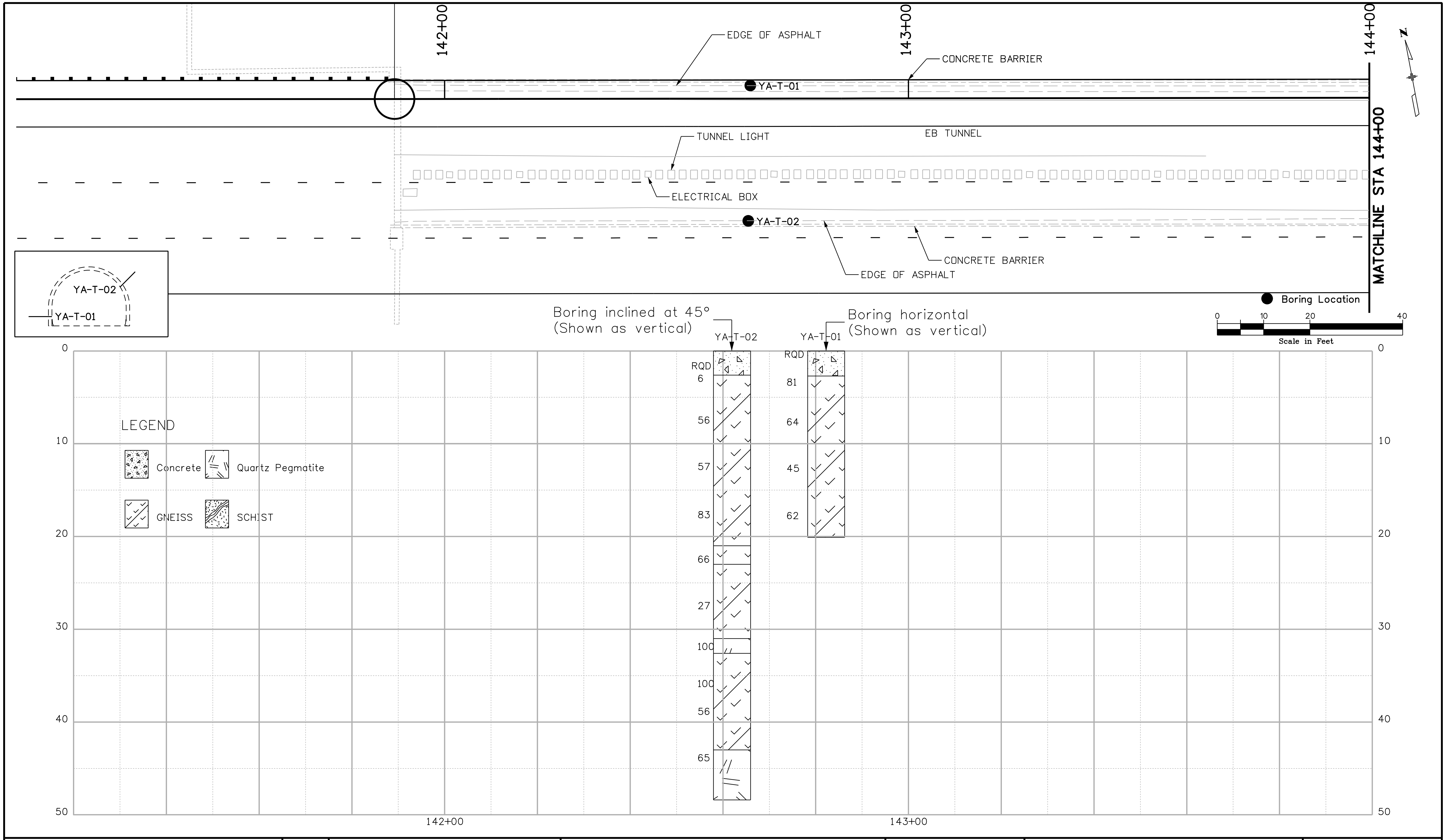

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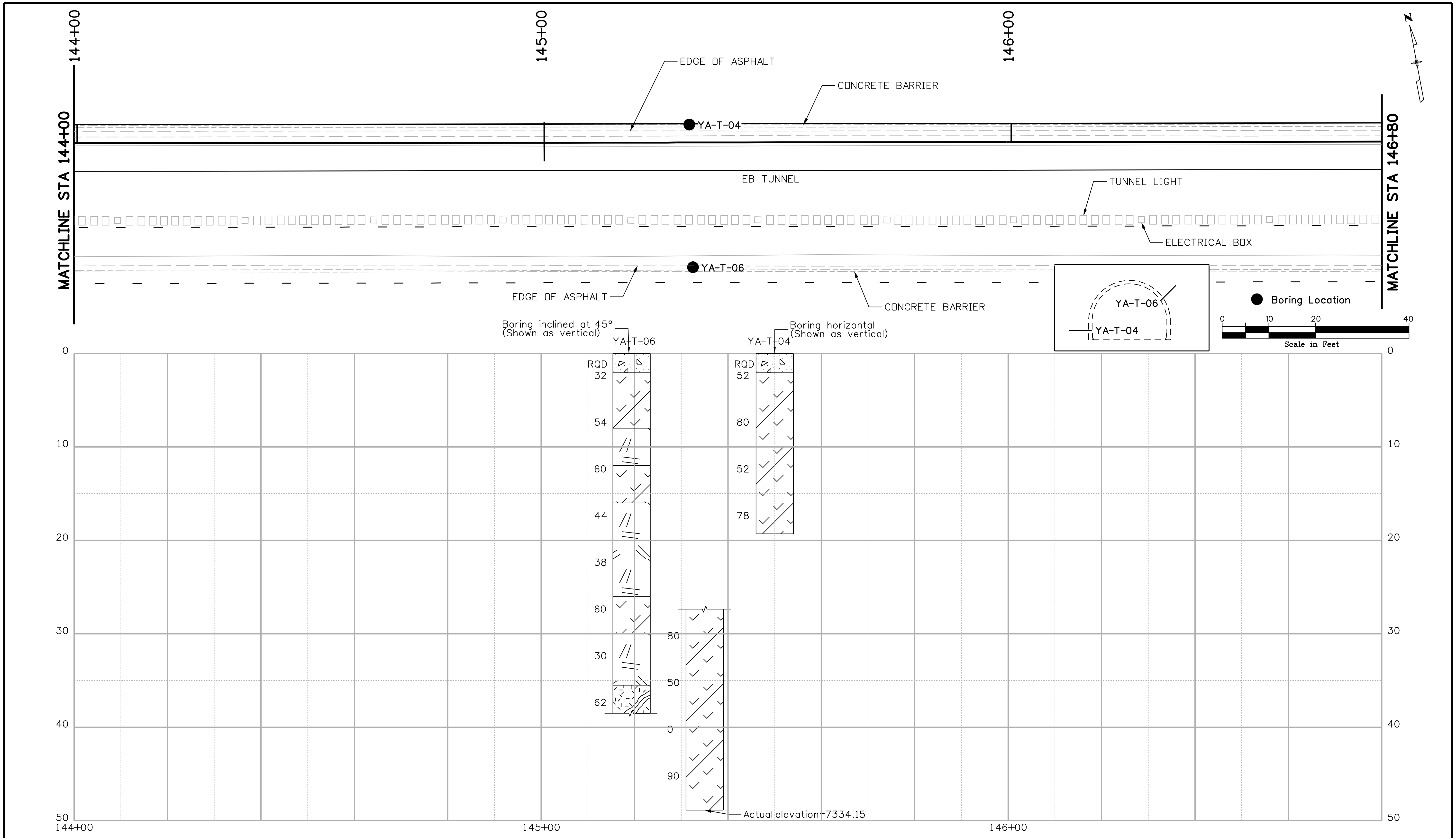

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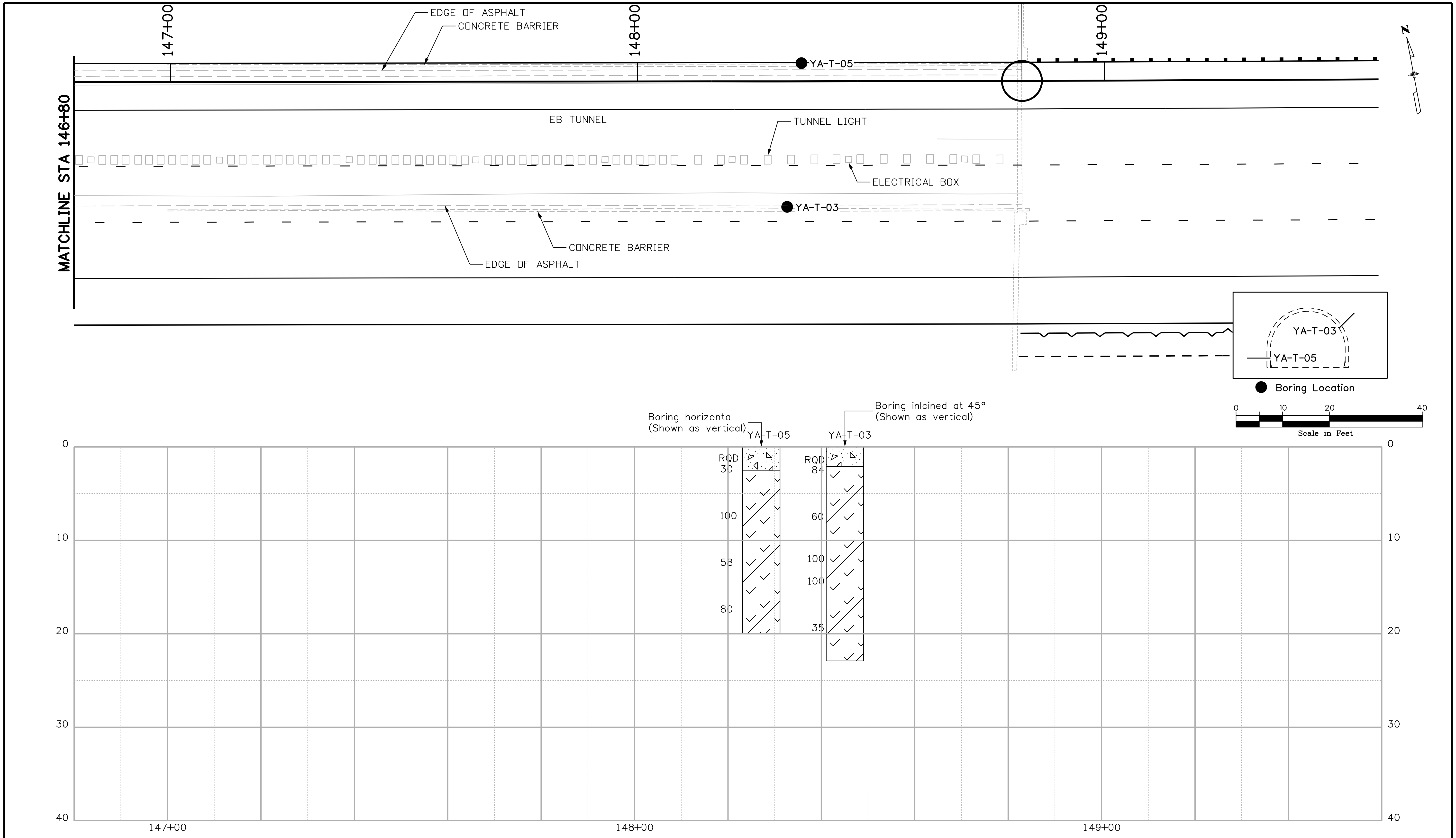

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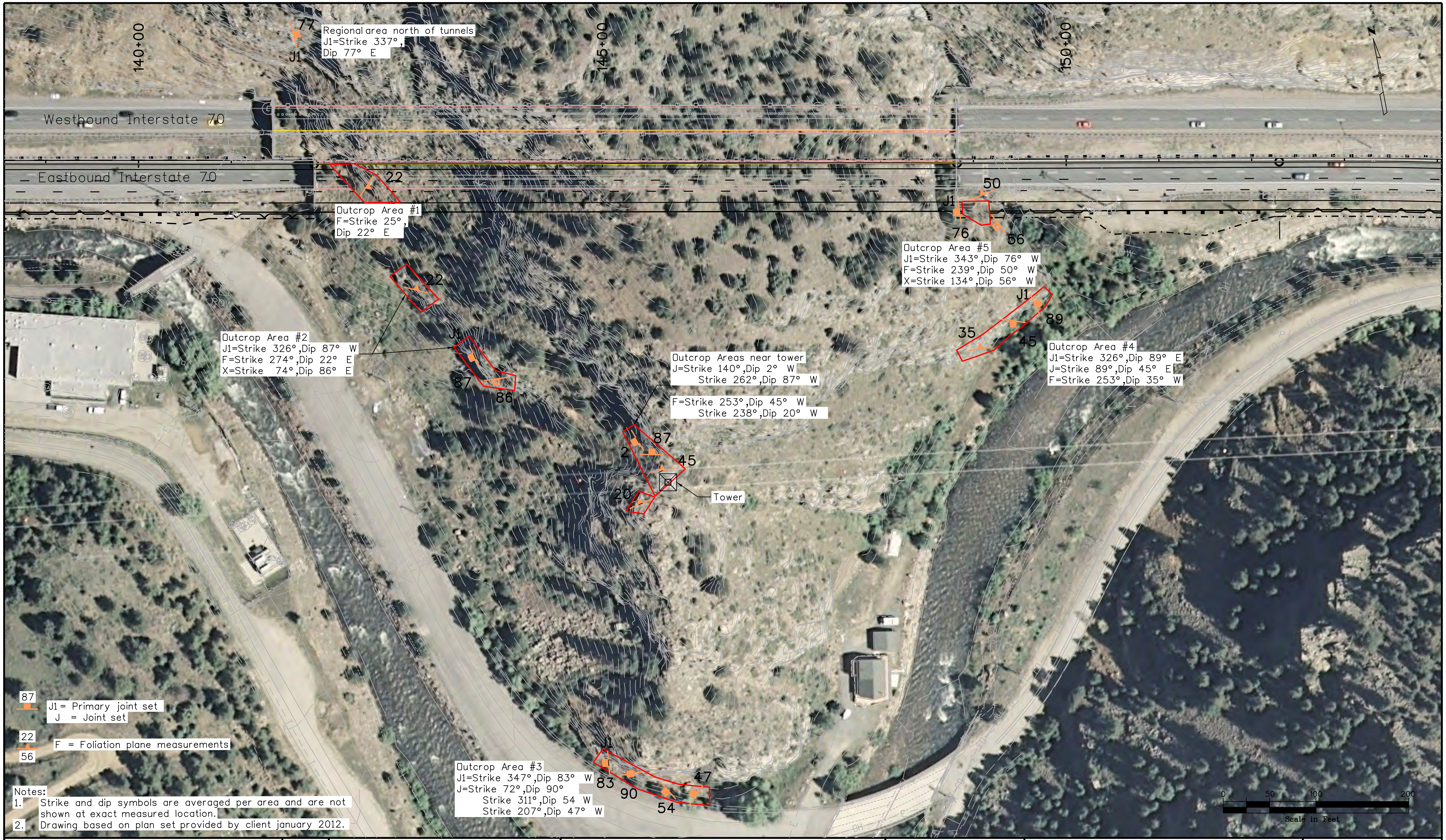

Notes:
1. Strike and dip symbols are averaged per area and are not shown at exact measured location.
2. Drawing based on plan set provided by client january 2012.

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US 70 - TWIN TUNNELS
WINDOW MAPPING LOCATIONS

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Project Number
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Sheet Number A-5

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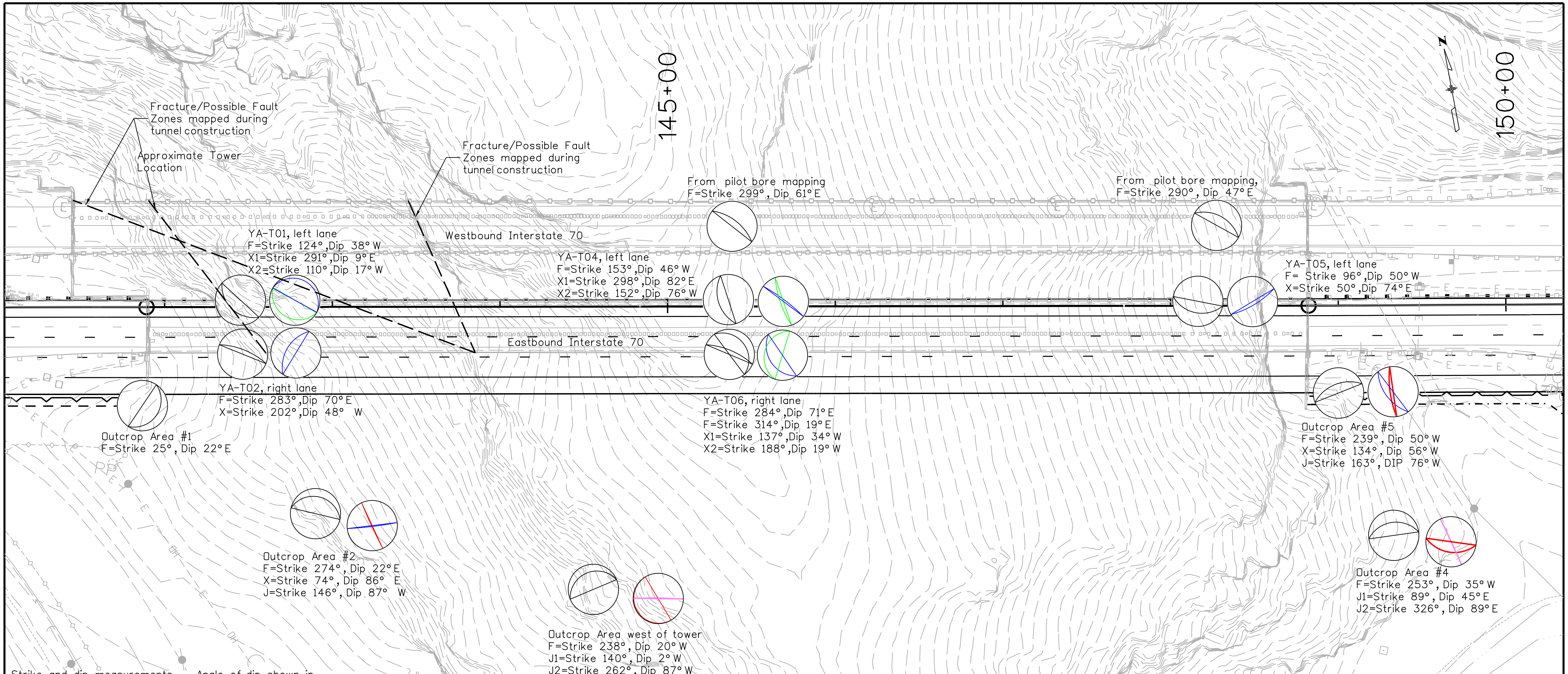

Strike and dip measurements - Angle of dip shown in degrees; taken from DIPS Program compilation from field mapping data or COLOG data. Stereonets are projected in lower, or southern, hemisphere.

Joint set stereonet
J1 = Red
J2 = Purple

Fracture plane stereonet
X1 = Blue
X2 = Green

Foliation plane stereonet

Notes:
1. Field mapping strike and dip symbols are averaged per area and are not shown at exact measured location.
2. Borehole strike and dip symbols based on data from colog and processed in dips program.
3. Drawing based on plan set provided by client January 2012.

☒ Approximate Tower Location

0 30 60 120
Scale in Feet

Print Date: 5/2/2012
File Name: 211-231 TunnelBedrock Structural01.dgn
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I 70 - TWIN TUNNELS
JOINT AND FOLIATION MEASUREMENT

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Detailer: M. Walz
Sheet Subset: Geology
Structure Numbers
Subset Sheets: of

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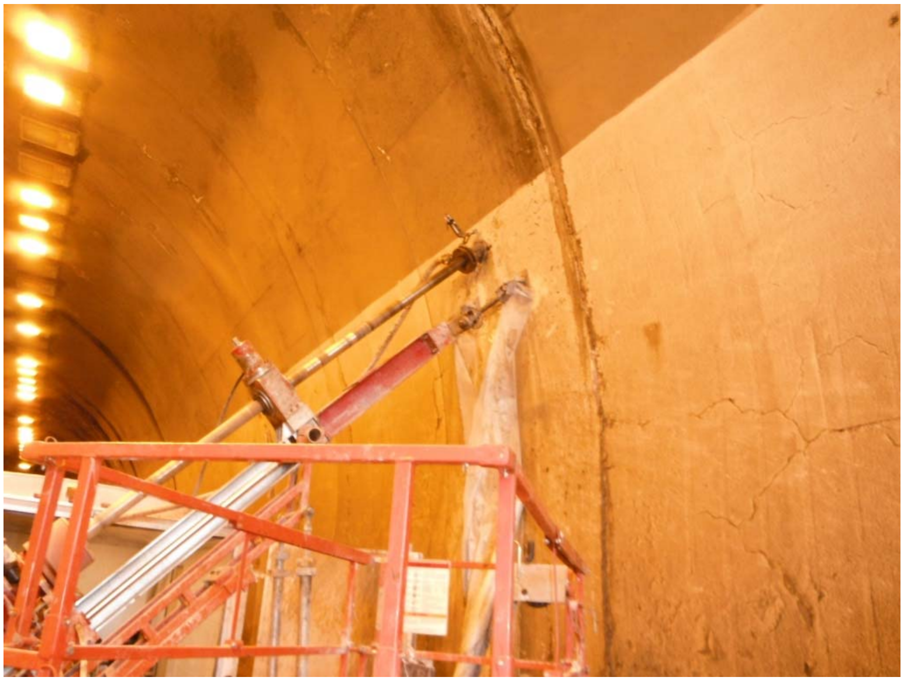
17502
Sheet Number A-6

Appendix B

Tunnel Investigation Photographs

Site setup and location for YA-T-01 in left/north lane of eastbound I-70. Total depth 20.1 ft, horizontal. This photo is also representative of borings YA-T-04 (19.3 ft, horizontal) and YA-T-05 (20.0 ft, horizontal)

Site setup and location for YA-T-02 in right/south lane of eastbound I-70. Total depth 48.4 ft, 45° angle from horizontal. This photo is also representative of YA-T-03 (22.9 ft, 45°) and YA-T-06 (60.0 ft, 45°).



Site setup and location for YA-T-06.

Site setup and location for YA-T-03.

West portal of eastbound tunnel, looking at YA-T-01 setup.

Looking east at left/north lane of eastbound tunnel, midesection.

Looking east at right/south lane of eastbound tunnel, midsection.

Appendix C

Boring Logs

Legend for Symbols Used on Borehole Logs

Sample Types

▮ Rock Core

Bedrock Lithology

▩	Concrete	▨	GNEISS	▧	QUARTZ PEGMATITE	▩	SCHIST

RQD
Rock Quality Designation

% Recovery
Length of Core Recovered/Length of Core Drilling Run

Joint Spacing
Noted near actual depth

Fracture Frequency
Fractures per foot

Weathering Grade

WI	Fresh
WII	Slightly Weathered
WIII	Moderately Weathered
WIV	Completely Weathered or Decomposed
WV	Residual Soil

Print Date: 4/26/2012	I 70 - TWIN TUNNELS LEGEND			Project No./Code
File Name: 211-231 Legend.dgn				Project Number
Horiz. Scale: 1:1				
Vert. Scale: As Noted	Designer: H. Hume	DOT DEPARTMENT OF TRANSPORTATION	Region: 1	17502
Unit Information	Detailer: M. Walz		Unit Leader: CRC	
Unit Leader Initials	Sheet Subset:		Sheet: of	Sheet Number

Mike Walz 4:05:19 PM W:\2011 Projects\211-231 CDOT I-70 Twin Tunnel Preliminary Investigation\Dwg\211-231 Legend.dgn

Yeh and Associates, Inc.
Consulting Engineers & Scientists

Project: Idaho Springs Tunnel

Boring: **YA-T-01**

Project Number: 211-231

Date:

Sheet 1 of 1

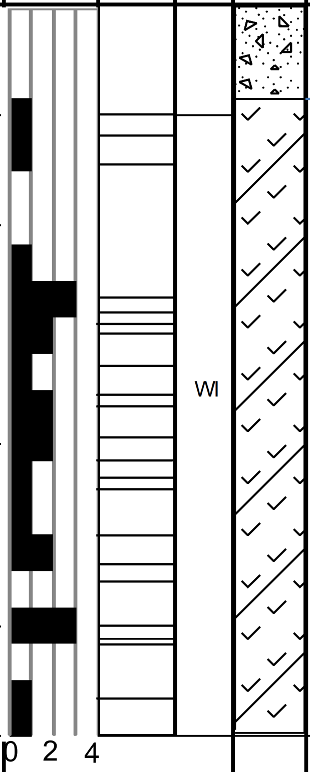
Boring Began: 1/24/12
Completec 1/25/12
Total Depth: 20.1 ft
Drilling Method: Coring
Drill Bit: NX
Ground Elevation: 7391.6
Drill: Integrol Explorer 75
Casing: Steel
Location: ~ 76 ft W/ Portal, LL
Driller: Agapito Associates
Weather:
Coordinates: N:696113.585 E:1006831.09

Logged By T. Hansen
Final By: T. Hansen
Inclination: 0

Ground Water Notes:

Depth:	Dry		
Date:	1/25/12		
Time:	--	--	

Elevation (ft)	Depth (ft)	Run/Sample Type	Recovery (%)	RQD	Fracture Frequency	Joint Spacing	Weathering	Lithology	Material Description	Field Notes and Lab Tests
									0.0- 2.7 ft. Tunnel Liner, 2.7 feet.	
	5		100	81					**2.7 - 20.1 ft., GNEISS,** dark gray -w hite, fresh, hard to very hard, joint foliation, closed fractures, no infilling, smooth surfaces, quartz pegmatite veins, biotite-quartz-plagioclase gneiss.	UCS Peak = 7230 psi Shear Wave = 10263 ft/sec Youngs Modulus = 9287 ksi Poisson's Ratio = 0.16
	10		100	64			WI		Possibly low RQD value from overpacked core barrel	UCS Peak = 2320 psi Shear Wave = 9481 ft/sec Youngs Modulus =7960 ksi Poisson's Ratio = 0.18
	15		100	45						Tensile Strength= 1230 psi Shear Wave = 9410 ft/sec Youngs Modulus = 7867 ksi Poisson's Ratio = 0.26
	20		100	63						UCS Peak = 990 psi Tensile Strength = 350 psi Shear Wave = 6879 ft/sec Youngs Modulus = 3763 ksi Poisson's Ratio = 0.03
									Bottom of Hole at 20.1 ft.	
	25									
	30									
	35									



Yeh and Associates, Inc.
Consulting Engineers & Scientists

Project: Idaho Springs Tunnel

Project Number: 211-231

Date:

Boring: **YA-T-02**

Sheet 1 of 2

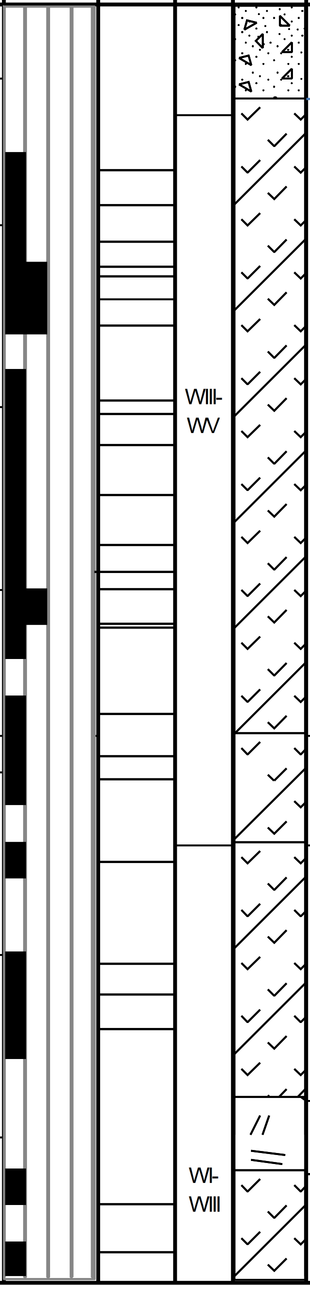
Boring Began:	1/30/12	Completec	1/31/12	Total Depth:	48.4 ft
Drilling Method:	Coring	Drill Bit:	NX	Ground Elevation:	7400.04
Drill:	Integrol Explorer 75	Casing:	Steel	Location:	~ 76 ft W/ Portal, LL
Driller:	Agapito Associates	Weather:		Coordinates:	N:696084.827 E:1006836.097

Ground Water Notes:

Logged By R. Florez/T. Hansen	Depth:	Dry	
Final By: T. Hansen	Date:	1/31/12	
Inclination: 45	Time:	--	--

Elevation (ft)	Depth (ft)	Run/Sample Type	Recovery (%)	RQD
	5		93	7
			96	56
	10			
			100	58
	15			
			100	83
	20			
	25		100	66
			59	59
	30			
			100	100
	35			

Fracture Frequency / Joint Spacing / Weathering / Lithology



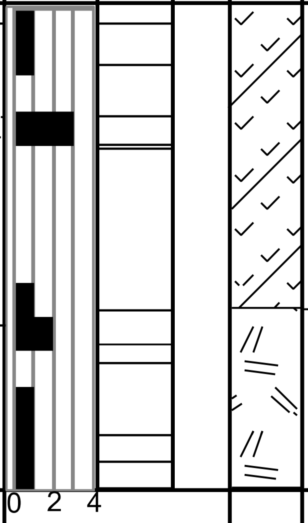
Material Description	Field Notes and Lab Tests
0.0- 2.6ft. Tunnel Liner, 2.6 feet.	
2.7 - 21.0 ft., GNEISS, gray-black, decomposed to moderately weathered, soft to medium hard, joint moderately close, open fractures, clay infilling, smooth surfaces, pyrite clasts, biotite-quartz-plagioclase gneiss.	UCS Peak = 2320 psi Shear Wave = 9481 ft/sec Youngs Modulus =7960 ksi Poisson's Ratio = 0.18
Decomposed biotite, clay infilling	UCS Peak = 2320 psi Shear Wave = 9481 ft/sec Youngs Modulus =7960 ksi Poisson's Ratio = 0.18
	UCS Peak = 990 psi Tensile Strength = 350 psi Shear Wave = 6879 ft/sec Youngs Modulus = 3763 ksi Poisson's Ratio = 0.03
21.0 -23.0 ft. GNEISS, black-gray, predominantly decomposed to moderately weathered, med. hard, fault fractured.	
23.0-31.0 ft. GNEISS, black-gray, moderately weathered to fresh, hard, joint open fractures, clay and gravel infilling, arsenopyrite clasts, biotite-quartz-plagioclase gneiss.	
31-32.6 ft. PEGMATITE, white - gray, fresh, very hard	
32.6-43.0 ft, GNEISS, black-white, slightly weathered to fresh, hard to very hard, micaceous. Extra 0.4 feet of core recovered from previous run	

Yeh and Associates, Inc.
Consulting Engineers & Scientists

Project: Idaho Springs Tunnel
Project Number: 211-231
Date:

Boring: **YA-T-02**
Sheet 2 of 2

Elevation (ft)	Depth (ft)	Run/Sample Type	Recovery (%)	RQD	Fracture Frequency	Joint Spacing	Weathering	Lithology	Material Description	Field Notes and Lab Tests
			100	100						
	40		60	56						UCS Peak = 9490 psi Tensile Strength = 1160 psi Youngs Modulus = 8610 ksi Poisson's Ratio = 0.209
	45		69	65					43.0 - 48.4 ft. PEGMATITE, white - gray, fresh, very hard, biotite phenocrysts, hard drilling.	
									Bottom of Hole at 48.4 ft.	
	50									
	55									
	60									
	65									
	70									
	75									
	80									



Yeh and Associates, Inc.
Consulting Engineers & Scientists

Project: Idaho Springs Tunnel

Boring: **YA-T-03**

Project Number: 211-231

Date:

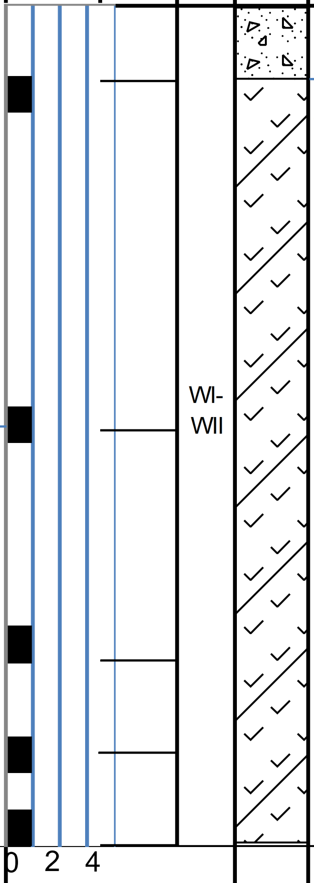
Sheet 1 of 1

Boring Began: 1/31/12
Completec 2/1/12
Total Depth: 22.9 ft
Drilling Method: Coring
Drill Bit: NX
Ground Elevation: 7393.92
Drill: Integrol Explorer 75
Casing: Steel
Location: ~ 52 ft E/ Portal, RL
Driller: Agapito Associates
Weather:
Coordinates: N:696190.61 E:1007392.707

Logged By R. Florez/ T. Hansen
Final By: T. Hansen
Inclination: 45

Ground Water Notes:		
Depth:	Dry	
Date:	2/1/12	
Time:	--	--

Elevation (ft)	Depth (ft)	Run/Sample Type	Recovery (%)	RQD	Fracture Frequency	Joint Spacing	Weathering	Lithology	Material Description	Field Notes and Lab Tests
									0.0- 2.1 ft. Tunnel Liner, 2.1 feet.	
									2.1 - 22.9 ft., GNEISS, gray -w hite, fresh, hard to very hard, joint, moderately close to w ide, closed fractures, no infilling, smooth surfaces, biotite-quartz-plagioclase gneiss.	
	5		100	84						
	10		100	89			WI- WII			UCS Peak= 10600 psi Shear Wave= 8228 ft/sec Young's Modulus=5758 ksi Poisson's Ratio=0.21
			100	100						
	15		100	100						
									19.0 feet to 21.5 feet, secondary joints sets approximately 4 to 6 inches apart, no infilling.	
	20		64	36					Slightly w eathered, hard, encountered a shear or fault zone. Severely fractured rock and rubble infilling.	
					0 2 4				Bottom of Hole at 22.9 ft.	
	25									Drill steel suddenly stopped and casing stuck at 22.9 feet.
	30									
	35									



Yeh and Associates, Inc.
Consulting Engineers & Scientists

Project: Idaho Springs Tunnel

Boring: **YA-T-04**

Project Number: 211-231

Date:

Sheet 1 of 1

Boring Began: 2/13/12

Completec 2/14/12

Total Depth: 19.3 ft

Drilling Method: Coring

Drill Bit: NX

Ground Elevation: 7388.57

Drill: Integrol Explorer 75

Casing: Steel

Location: ~ 350 ft W/ Portal, LL

Driller: Agapito Associates

Weather:

Coordinates: N:696164.341 E:1007091.385

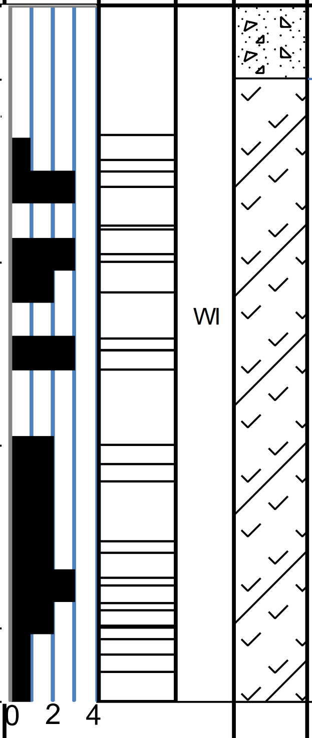
Logged By T. Hansen

Final By: T. Hansen

Inclination: 0

Ground Water Notes:

Depth:	Dry		
Date:	2/13/12		
Time:	--	--	



Elevation (ft)	Depth (ft)	Run/Sample Type	Recovery (%)	RQD	Fracture Frequency	Joint Spacing	Weathering	Lithology	Material Description	Field Notes and Lab Tests
									0.0- 2.0 ft. Tunnel Liner, 2.0 feet.	UCS Peak= 4730 psi Shear Wave=7406 ft/sec Young's Modulus= 3949 ksi Poisson's Ratio= 0.18
	5		100	52					**2.0 - 19.3 ft., GNEISS,** gray -w hite, fresh, hard to very hard, joint, moderately close to w ide, closed fractures, iron oxide infilling, smooth surfaces, biotite-quartz-plagioclase gneiss.	
	10		100	80			WI			UCS Peak= 17960 psi Tensile Strength= 1670 psi Young's Modulus= 8590 ksi Poisson's Ratio= 0.21
	15		100	52					Increased jointing, intrusive pegmatites.	UCS Peak= 9910 psi Tensile Strength= 1330 psi Young's Modulus= 6820 ksi Poisson's Ratio= 0.184
			100	78						
	20 25 30 35								Bottom of Hole at 19.3 ft.	

Yeh and Associates, Inc.
Consulting Engineers & Scientists

Project: Idaho Springs Tunnel

Project Number: 211-231

Date:

Boring: YA-T-05

Sheet 1 of 1

Boring Began: 2/14/12	Completec 2/14/12	Total Depth:	20.0 ft
Drilling Method: Coring	Drill Bit: NX	Ground Elevation:	7384.55
Drill: Integrol Explorer 75	Casing: Steel	Location:	~ 52 ft E/ Portal, LL
Driller: Agapito Associates	Weather:	Coordinates:	N:696221.408 E:1007389.984

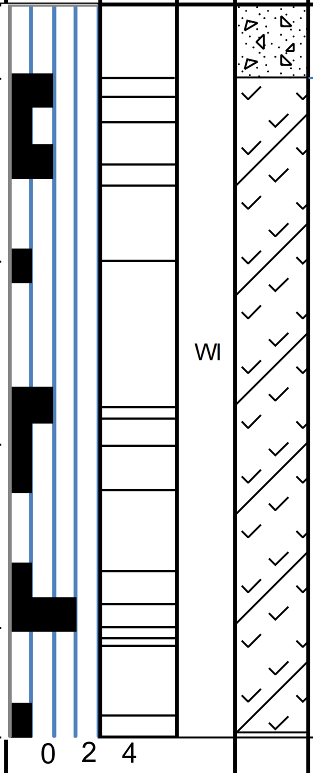
Ground Water Notes:

Depth:	Dry		
Date:	2/14/12		
Time:	--	--	

Logged By R. Florez

Final By: T. Hansen

Inclination: 0



Elevation (ft)	Depth (ft)	Run/Sample Type	Recovery (%)	RQD	Fracture Frequency	Joint Spacing	Weathering	Lithology	Material Description	Field Notes and Lab Tests
									0.0- 2.5 ft. Tunnel Liner, 2.0 feet.	UCS Peak= 7140 psi Shear Wave= 7608 ft/sec Young's Modulus= 3866 ksi Poisson's Ratio= 0.05
	5		100	46					**2.5 - 20.0 ft., GNEISS,** gray -white, fresh, very hard, joint, moderately close to close, high angle, closed fractures, iron oxide stains, smooth surfaces.	
	10		100	100			WI			
									Iron oxide stains, moderate, tight fractures.	UCS Peak= 16110 psi Shear Wave= 8766 ft/sec Young's Modulus= 6670 ksi Poisson's Ratio= 0.21
	15		100	58						
									Small pegmatite intrusions, moderate fractures, clean, tight.	UCS Peak= 15860 psi Shear Wave= 9406 ft/sec Young's Modulus= 7906 ksi Poisson's Ratio= 0.25
	20		100	80						
									Bottom of Hole at 20.0 ft.	
	25									
	30									
	35									

Yeh and Associates, Inc.
Consulting Engineers & Scientists

Project: Idaho Springs Tunnel

Project Number: 211-231

Date:

Boring: **YA-T-06**

Sheet 1 of 2

Boring Began: 2/14/12

Completec 2/15/12

Total Depth: 60 ft

Drilling Method: Coring

Drill Bit: NX

Ground Elevation: 7397.28

Drill: Integrol Explorer 75

Casing: Steel

Location: ~ 350 ft W/ Portal, RL

Driller: Agapito Associates

Weather:

Coordinates: N:696134.471 E:1007097.835

Ground Water Notes:

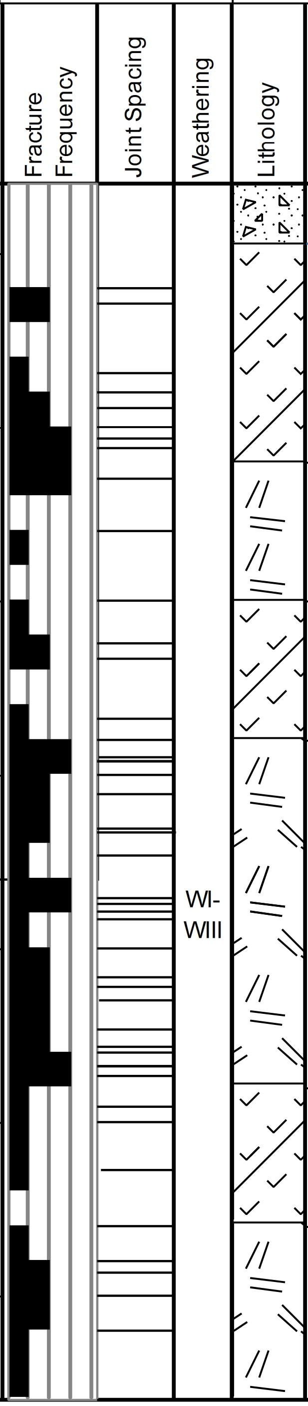
Depth:	Dry	
Date:	2/14/12	
Time:	--	--

Logged By R. Florez/T. Hansen

Final By: T. Hansen

Inclination: 45

Elevation (ft)	Depth (ft)	Run/Sample Type	Recovery (%)	RQD
	5		100	32
	10		100	54
	15		90	60
	20		100	44
	25		100	38
	30		90	60
	35		100	42



Material Description	Field Notes and Lab Tests
0.0- 2.0ft. Tunnel Liner, 2.0 feet.	
2.0 - 8.0 ft., GNEISS, gray-white,slightly weathered to moderately weathered, very hard, joint, close to moderately close, high angle, open fractures, iron oxide infilling, slightly rough surfaces, biotite schist inclusions, fissle. Pegmatite is very hard	UCS Peak= 15310 psi Tensile Strength= 1320 psi Young's Modulus= 5990 ksi Poisson's Ratio= 0.141
8.0 - 12.0 ft., PEGMATITE, white with pink, fresh to slightly weathered, very hard, iron oxide infilling, rough surfaces, highly fractured, crumbly, friable.	
12.0 - 16.0 ft., GNEISS, gray-white,slightly weathered, very hard, joint, high angle, iron oxide stains, fracture zones, crumbly.	
16.0 - 26.0 ft., PEGMATITE, white with gray, fresh, very hard, iron oxide stains, fractured, crumbly, gneiss and biotite intrusions, pyrite crystals. Large biotite book inclusions from 19 feet to 20 feet. Arsenopyrite mineralization.	
26.0 - 30.0 ft., GNEISS, gray-white, fresh, very hard, high angle, minerals: garnet, hematite, arsenopyrite. Highly fractured, crumbly.	
30.0 - 35.5 ft., PEGMATITE, white with yellow, slightly weathered, hard, severely fractured 32 feet to 33.5 feet. Low angle stepped fractures 33.5 feet to 35 feet.	UCS Peak= 11290 psi Tensile Strength= 230 psi Young's Modulus= 4790 ksi Poisson's Ratio= 0.155

Yeh and Associates, Inc.
Consulting Engineers & Scientists

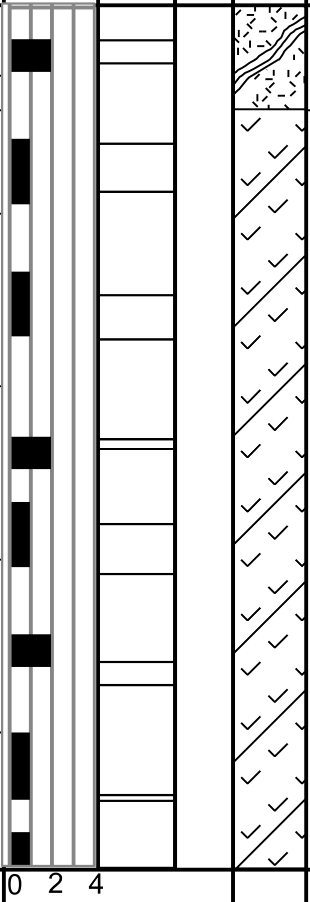
Project: Idaho Springs Tunnel

Boring: **YA-T-06**

Project Number: 211-231

Date:

Sheet 2 of 2

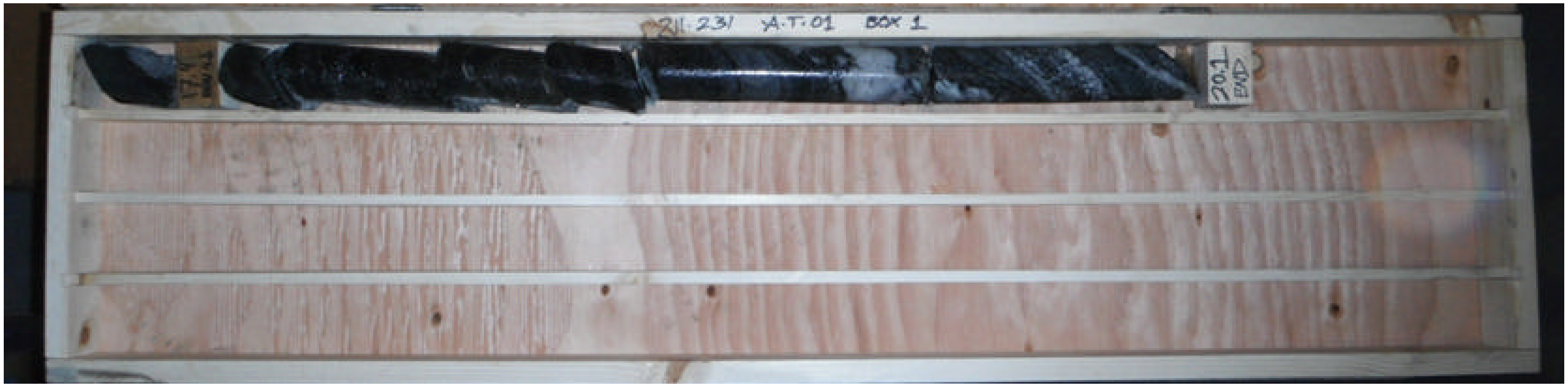


Elevation (ft)	Depth (ft)	Run/Sample Type	Recovery (%)	RQD	Material Description	Field Notes and Lab Tests
					35.5 - 38.5 ft., SCHIST, black-white- grey, slightly weathered, hard, mica, biotite crystals, sparse high angle fractures.	
	40		100	88	**38.5 - 60.0 ft., GNEISS,** white with black, slightly weathered to fresh, very hard, high angle, iron oxide stains, micaeous biotite schist, sparse laminar low angle fractures.	
	45		100	80		
	50		100	66	High angle stepped fractures with biotite, 0.5 inch iron stain infilling fracture.	
	55		100	94	One perpendicular fracture running entire length of core, iron oxide staining, secondary high angle fracture.	
	60		100	90	Low to high angle fractures, sparse iron oxide staining.	UCS Peak= 19440 psi Tensile Strength= 1390 psi Young's Modulus= 10690 ksi Poisson's Ratio= 0.183
					Bottom of Hole at 60.0 ft.	
	65					
	70					
	75					
	80					

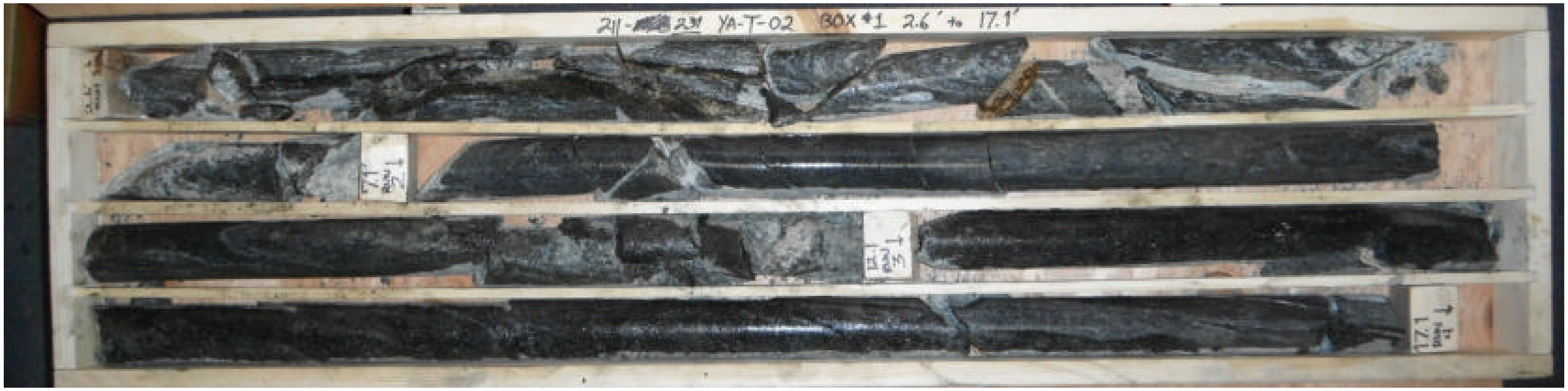
Appendix D

Tunnel Core Photographs

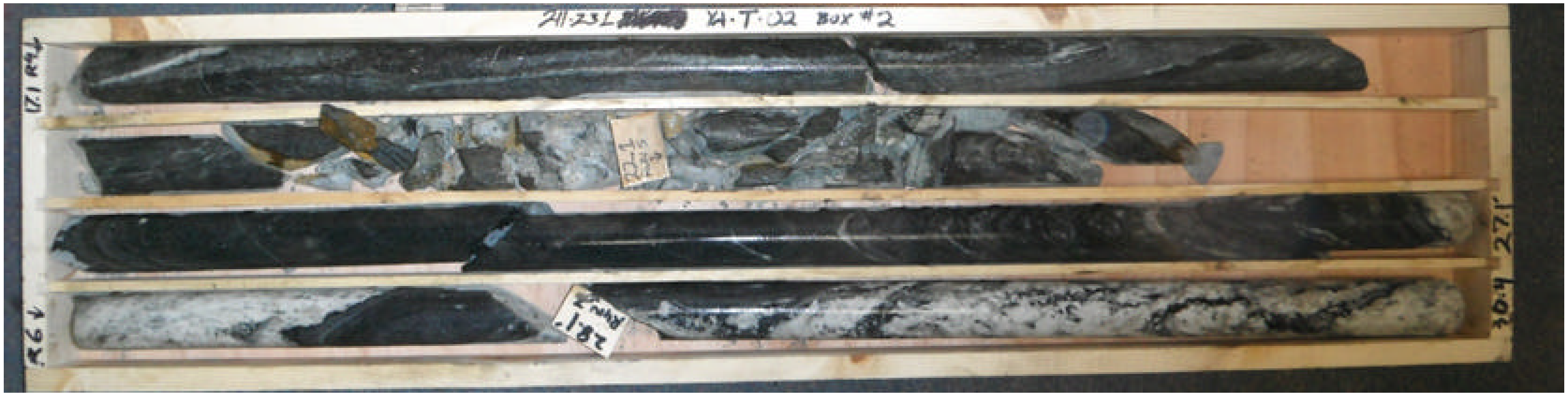
YA-T-01 Box 1 of 2



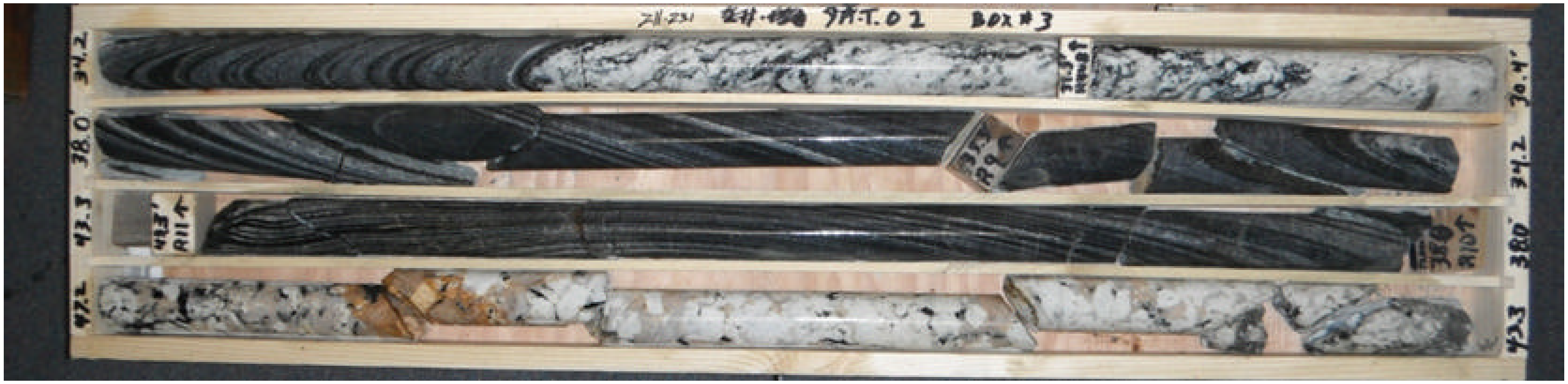
YA-T-01 Box 2 of 2



YA-T-02 Box 1 of 3



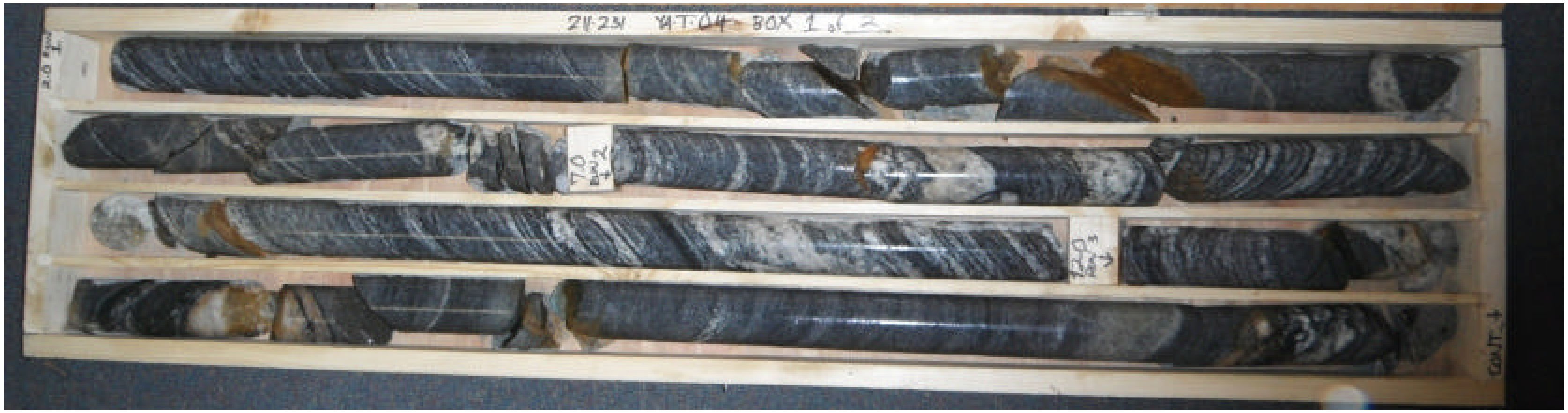
YA-T-02 Box 2 of 3



YA-T-02 Box 3 of 3

YA-T-03 Box 1 of 2

YA-T-03 Box 2 of 2



YA-T-04 Box 1 of 2

YA-T-04 Box 2 of 2

YA-T-05 Box 1 of 2

YA-T-05 Box 2 of 2

YA-T-06 Box 1 of 4

YA-T-06 Box 2 of 4

YA-T-06 Box 3 of 4

YA-T-06 Box 4 of 4

Appendix E

Historical Tunnel Data

A. Zulian

E.G. Swanson

Geology of Pioneer Bore

At your request an inspection of the Pioneer Bore was made December 11th and December 15th, 1959 by our engineering geologist, Stanley Mitchell assisted by Ralph Rhodes, a geologist attached to the Design Section. The purpose of this inspection was to make a geologic log of the Pioneer Bore and to establish limits for the need of concrete lining.

The Pioneer Bore was excavated last summer through a steep sided ridge located two miles east of Idaho Springs. The bore is approximately 800 feet long and 8 by 7 feet in cross section.

The bedrock through which it was cut consists of schist and gneiss of the Idaho Springs Formation. The U.S. Geological Survey has classified the rock as a quartz monzonite gneiss of Pre-Cambrian age. The foliation or bedding of the gneiss parallels closely the alignment of the tunnel and dips 40 to 70 degrees to the north.

At the west portal the formation has been folded and faulted. The rock has been sheared and crushed to some extent and shows considerable alteration by weathering processes. The foliation shows overturning to the south opposite the proposed right lane tunnel. Thin veins of pyrite ($FeSO_4$) were noted along the fault both in the bore and west of the portal. Water follows up along the fault and comes out into the bore in several places. The water was tested by the Chemistry Section and the tests indicate very little acidity or presence of sulfates. However, this does not preclude the possibility that the water may become acid and charged with sulfates at a future date, particularly is its circulation is restricted. The presence of pyrites suggests this possibility.

The effects of faulting are evident in the Pioneer Bore between Stations 173+10 to 174+90. Timber sets have been necessary in several places to help stabilize the roof. Some of the rocks tend to expand and slab off. Several layers of biotite schist, along with fault gouge and seepage, indicate locations of fault zones. The rocks in this area show jointing at approximately right angles to the foliation, and this jointing still further weakens the rock.

East of Station 175+00 the bedrock gneiss is harder, less weathered and appears to be reasonably sound, except for joints which tend to break the formation into disconnected slabs. Most of the joints appear to be tight except near the east portal. Here the formations show the effects of weathering and some open joints back approximately 40 feet from the portal.

The location of the faulted zone, weathering, the strike and dip of the foliation and joints have been plotted on the attached geologic log both in plan and in sections. This information can assist the engineer in determining the probable limits for concrete lining in both the left and right lane tunnels. The suggested limits shown for concrete lining are based upon rock conditions found in the Pioneer Bore. It is possible that the rock structure in the right lane tunnel might not be found to exist exactly as projected on the Geologic Log. However, we feel the rock conditions between Stations 173+20 and 175+20 me be similar to that found in the Pioneer Bore and may need to be concrete lined. The exact limits can be better determined at the time of excavation.

The original determination of the width of the pillar between the left and right lane tunnels was predicted upon the existence of relatively solid rock. However, the excavation made for eh west portals and Pioneer Bore indicates a zone of relatively weak rock between Stations 173 and 175. The structure and character of the rock between these stations suggests the need for a reevaluation of the pillar width, or consideration be given to extra support for the tunnel linings. We suggest that an expert in mining engineering be consulted on this matter before final plans and specifications are finalized.

E.G. Swanson

Staff Materials Engineer

Geologic Conditions at Proposed Highway Tunnel Site
East of Idaho Springs, Colorado

Introduction

This report has been prepared to illustrate and describe geologic conditions between stations 170 and 185 on Colorado Highway Department F.A.P. No. I-70-3(1)250 in Clear Creek County, east of Idaho Springs, where it is proposed to construct twin tunnels approximately 700-800 feet in length. Geologic conditions (rock types, attitude of bedding, overburden, and veins) on the present ground surface are shown on the accompanying plan and profile sheet. Projection of geologic conditions underground are described in the following report and illustrated on the geologic cross section.

General Geology

Bedrock at the tunnel site consists of gray to pink metamorphic quartz monzonite gneiss of Precambrian age. Within the monzonite gneiss are lenses and layers of amphibolite and lime silicate gneiss.

The metamorphic rocks exhibit a layering or foliation which simulates the bedding of sedimentary rocks. In this report this foliation is referred to as bedding. The attitude of the bedding planes is extremely variable due to folding and warping, and ranges from horizontal to nearly vertical. The dip is northward and the strike of the beds is generally east-west.

Talus (overburden) blankets the surface over the western portals of the proposed tunnels, but is thin to absent at the eastern portal. The talus ranges from 5 to 15 feet in thickness.

Geologic structure

The dip and strike of the bedding of the rocks along the centerline of the alignment varies considerably, as shown by the dip and strike symbols on the plan view and in the geologic cross section, but in general average about 45 degrees to the north. Surface observations indicate that similar variations of dip and strike will probably be encountered underground along the grade line of the proposed tunnels.

Prominent joint systems trending N. 70 E., dipping 90°, N. 20 W., dipping 88° NE, and N. 65 W., dipping 85° NE, were observed near the proposed eastern tunnel portals. Spacing between joints varies from 1 to 3 feet. The joints were tight and were not carrying water. It is believed that these joints are probably characteristic of those to be found along the proposed grade line.

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No large faults were observed in the area mapped. Small amounts of displacement may have occurred in the past along some of the bedding planes, joints and veins, but there is no evidence of movement at the present time.

A vein approximately 15-25 feet thick is present about 300 feet south of the centerline. The vein trends generally east-west, dipping 70-80° northward. Projection of the vein underground indicates its position to be about 250 feet south of the centerline at grade line. A smaller mineralized vein 1-3 feet thick crops out near the western end of the left lane tunnel and between stations 170 and 174. Projected down to grade line this vein may be encountered in the left lane tunnel from the portal to station 174.

Masses of pegmatite (coarse-grained granitic rock) are interspersed at random throughout the bedded gneissic rocks along the tunnel alignment. Pegmatite is normally a firm rock and offers little difficulty in excavation.

Overburden

Talus (overburden) covers an area between stations 171 and 174. The talus varies in thickness from 5 to 15 feet and is composed of a heterogenous mixture of soil and rocks up to 3 feet in length. The contact between the overburden and bedrock may carry small amounts of water during wet weather, and may possibly be subject to slipping if cuts are excavated in the lower sections. Provision for protection against talus fall may be needed at the west portal unless talus is completely stripped off.

Water problems

Rocks in the area are believed to contain little water and tunnel excavations should be relatively dry. With the exception of the vein near the western edge of the left tunnel which may carry minor amounts of water and the possibility of water in the overburden, water problems in the tunnels should be negligible during excavation.

I-70-3(2) 251
Idaho Springs to Floyd Hill

COPY

October 20, 1958

A. Zulian

Materials Laboratory

Proposed Tunnel Sta. 171 - 180.

This site was first visited August 7, 1958 by our engineering geologist in company with A. Zulian and L. Olson who requested our opinion as to any adverse geological conditions that might arise during construction of this tunnel. Another visit was made to this site by our geologist who made a geological reconnaissance, the results of which are given herein. This is not to be construed as a thorough geological investigation.

The proposed tunnel will be constructed on tangent through a steep-sided ridge located approximately one mile downstream from Idaho Springs and will extend from Sta. 171 to 180± along proposed improvement.

The bedrock consists of mica schist and gneiss which geologically is termed the Idaho Springs Formation. This formation shows a distinct stratification dipping 30 to 45 degrees to the north. Joint planes intersect this stratification at right angles. This rock structure will produce some overbreak during excavation. Otherwise the bedrock appears quite sound and should need little or no support except possibly

cc: Olson
Miles - Stearns - Adamson
Raukohl
Mitchell
Project file

A tt /1/

near the west portal.

The west portal will be near the contact of loose rock talus and faulted bedrock schist and gneiss. The bedrock shows the effect of faulting along the existing road opposite Sta. 170±. Here the rocks are highly fractured, folded and exhibit fault gouge where they have been completely ground to a clayey mass. The bedrock is covered by talus near the west portal and it will be difficult to predict how much of the tunnel will be affected by this fault. The following observations may throw some light on this matter:

1. There is a fault that runs through the topographic saddle now occupied by a transmission line tower approximately 350 ft southerly of the proposed tunnel.
2. There is a fault exposed in the road cut 200 ft northeasterly of the bridge across Clear Creek. This fault appears to be the easterly continuation of the fault through the saddle described above.
3. There is a fault exposed in the road cut opposite Sta. 170± near the west portal of the tunnel previously described. This fault appears to be the westerly continuation of the fault through the saddle.
4. The above three fault exposures have been plotted as the same fault and the dip and strike of the fault calculated by the three-point method.
5. A geological section has been drawn at right angles to the tunnel through Sta. 177+10. This section follows

closely the top of the ridge and shows the topographic saddle through which the fault runs. The general attitude of the bedding in the schist and gneiss is indicated on this section. Note the abrupt change of this bedding at the fault contact.

Conclusion: If the above interpretation of the three fault exposures is correct then the fault dips steeply to the west as shown in the section. It will dip rapidly below the tunnel grade except for a very short section near the west portal.

C.E. Shumate
Asst. Chief Engineer

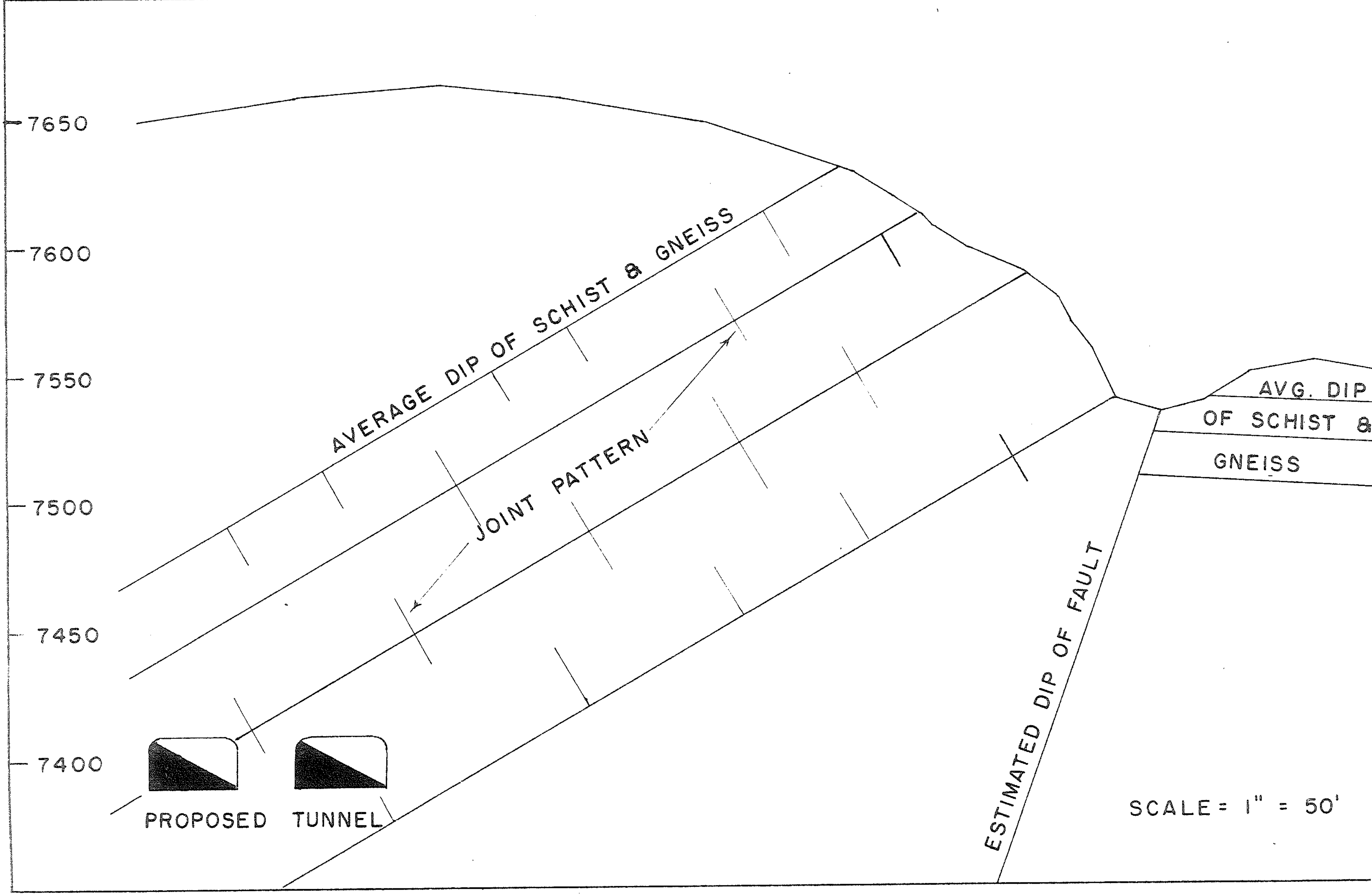
E.G. Swanson
E.G. Swanson
Staff Materials Engineer

SM:lg

GEOLOGICAL SECTION

AT STA. 177 + 10
LOOKING EASTERLY

I 70-3 (2) 251
PROPOSED TUNNEL
APPROX. I MILE EAS
OF IDAHO SPRINGS

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PROPERTY
OF
DEPARTMENT
OF HIGHWAYS
NO
TRESPASSING
N

I-70-3(2)251 Unit 2
Idaho Springs Tunnels

SH

BLASTING
RECOMMENDATIONS

COLORADO DEPARTMENT OF HIGHWAYS
4201 EAST ARKANSAS AVENUE
DENVER 22, COLORADO

December 14, 1959

TO: C. E. SHUMATE

FROM: ADOLPH ZULIAN

SUBJECT: MEETING WITH BUREAU OF MINES

Messrs. Miles, Reseigh and the writer met with the following people on December 10 to discuss plans for our Idaho Springs tunnel:

Bureau of Mines Representatives:

J. H. East, Jr. - Regional Director, Region 3;
R. W. Geehan - Chief, Division of Mineral Resources
A. S. Konselman and S. R. Wilson;
J. Howard Bird - District Supervisor, District H, Health and Safety

Bureau of Public Roads:

A. R. Abelard, M. J. Ennis, A. J. Siccardi, D. C. Harrington and King Burghardt

In accordance with Mr. Rooney's suggestions we have previously conferred with three representatives of the Dupont Powder Company. These men have all advised that the new methods of shooting with millisecond and second delays in the charges have made tunneling with relief holes unnecessary. Representatives at this meeting state this is not true and the timing cannot be depended upon.

The primary discussion centered around the protection of the 25-foot pillar to be left between the tunnels. There seems to be considerable concern that improper blasting might shatter this pillar and make the tunnels unsafe. The following suggestions were made:

(1) Specify maximum length of holes - 8-foot suggested.

(2) Specify maximum 6-inch overbreak on the pillar side of tunnels.

(3) Specify maximum 12-inch overbreak on outsides of tunnels. Permit tunneling of relief holes if the Contractor desires. Bureau of Mines people feel this would be a more economical method of boring the tunnels.

(4) Require that tunnel without pilot bore be advanced at least 25 feet ahead of any blasting to be done in the tunnel with pilot bore. (Some think this should be at least 50 feet ahead.)

(5) Require 5-foot long rock bolts on approximate 4-foot to 4½-foot centers along the pillar areas of the tunnel without pilot bore.

(6) Permit long hole method of tunneling which generally requires a pilot bore ahead of the main tunneling operation.

(7) Require that the Contractor's methods are subject to change during construction if the desired results are not obtained.

(8) Add an estimated quantity of tunnel enlargement excavation to cover possibility of lined section if needed.

(9) Provide requirement for rock bolts throughout the tunnels as required.

My memo of December 10 stated our people would be ready to begin making bolt retention tests in the pioneer bore on December 22 at 9:00 A. M. This should have been December 15 and all parties concerned have been notified.

It is our understanding that recommendations for rock bolt installation will be made by Mr. Rodriguez after the retention tests are completed. We will add this item to the plans.

Many of the suggestions made during the meeting would require that the Department specify how the Contractor is to bore these tunnels. We pointed out that the Department policy is to specify end results rather than methods. It is hoped we can complete these plans in a satisfactory manner and still retain that policy.

A. Zulian

Adolph Zulian
Engineer of Surveys and Plans

AZ:b

cc: G. N. Miles - 4
F. O. Stearns
Chas. Kempf
S. N. Mitchell
T. C. Reseigh
A. Zulian
J. H. East, Jr.
R. W. Geehan
J. Howard Bird
W. J. Walsh
A. R. Abelard - 6

I 70-3(2)251 Unit 2
Idaho Springs Tunnels

[illegible]

December 24, 1959

Info:
Stanley
File

G. N. MILES

A. ZULIAN

TUNNEL LINING AND BOLTING

The following recommendations, for lining and bolting of our proposed tunnels east of Idaho Springs, are an opinion of the writer based on discussions and suggestions involving BPR, Bureau of Mines, Department Geologist and others. Your comments will be appreciated in order that we might proceed with revision of plans.

There is approximately 303 feet of cover above the profile grade of the south tunnel near Sta. 176+ and approximately 309 feet of cover over the profile grade of the north tunnel at Sta. 176+.

1. LINING (ESTIMATED QUANTITIES FOR PLANS)

   a. North Tunnel - Recommend 200 feet of lining at West end (to extend beyond fault) and recommend 40 feet of lining at East end.

   b. South Tunnel - Recommend 150 feet of lining at West end (to extend beyond fault). Portal of South tunnel is approximately 61 feet East of portal for North tunnel. Also recommend 40 feet of lining at East end of South tunnel.

   c. Recommend approximately 50 feet of additional lining in estimate and plans for possible bad areas that may be encountered. A quantity Tunnel Enlargement Excavation is also to be included in plans for bids.

2. ROCK BOLTING AREAS

   a. Sta. 173+ to 173+50 - Shattered Material. Rock bolts in pillar side only. Bureau of Mines will investigate and make recommendations for rock bolting on floor of tunnel at West end to protect against apparent possibility of heave due to bad foliation.

   b. Sta. 173+50 to 174+00 - Estimate scattered rock bolting for temporary support before lining is placed. No mesh required in lined sections. Rock bolts in pillar side.

   c. Sta. 174+00 to 175+ - Fault area. Rock bolts in pillar side. Bolting of Roof not recommended - section to be lined.

   d. Sta. 175+ to 179+80 - Entire tunnel section to be rock bolted (except floor). Chain link fence also to be placed over entire bolted section and secured under rock bolt nuts and washers.

2. ROCK BOLTING AREAS (Cont'd)

   e. Sta. 179+80 to 180+20+ - Lined section. No rock bolting except for pillar side.

   f. Estimate some rock bolting on hillsides at both portals. Bureau of mines states that loose areas can be well protected by bolting.

3. ROCK BOLT DETAILS

   a. Specify 1" diameter slotted wedge type 6 feet long. End to be threaded 8 inches (Std. bolt is threaded 4"). Minimum 60,000 lbs. tensile strength per square inch. Anchor type bolts are not recommended since they require constant tension to keep in place. They are hard to install and if nut becomes loose, they are ineffective especially in hard rock.

   b. Require minimum 200 foot pounds of torque on Bolts. Maximum allowable torque to be 300 foot pounds.

   c. Use 6"x 6" square washer - 3/8" thick. Extra washers and nuts required for every other bolt in full bolted tunnel section. This will permit placement of V mesh fencing.

   d. Require 9 gage chain-link fencing under bolts in fully bolted section. Fencing at bottom can be placed horizontally with balance to be placed circumferentially. Probably a 54 inch wide mesh would be most suitable.

   e. Bolting in tunnel to be on 4 foot centers with first row approximately 2½ feet above floor. Bolting need not be staggered. This requires 17 bolts per ring.

   f. Bolting to progress to face of work after each section of tunnel is blasted.

   g. Where bolting of pillar only is required use 3 rows high on North Tunnel and 4 rows high on South Tunnel.

   h. Chain link fence inside tunnel may be bolted to every other bolt with extra washer and nut. Balance of bolts can then be installed and the single washer and nut will suffice with fencing underneath.

   i. Bolting on hillsides at portals, where required, to be at 7 foot horizontal spacing and 10 foot vertical spacing. Provide 8 foot wide 9 gage chain link fence.

   j. Bolt holes in tunnel to be as near as possible vertical to the face. Bolt holes on hillsides should be a few degrees down to prevent coming out if loosened. This will also keep bolt in shear support in case it should become loose.

   k. Wedge of bolt to be lubricated with grease if necessary. May be required in the softer rock areas.

4. BOLT RETENTION TESTS

   a. Tests conducted by the Bureau of Mines gave resistance results from 3,000 lbs. to 18,000 lbs. The 3,000 lb. areas are not too suitable, but they state bolting is very feasible and highly recommended.

5. REVISION OF PLANS:

   We will proceed to revise plans in accordance with the above outline unless you are not in agreement. Your comments and recommendations will be appreciated. The Bureau of Mines will submit their report sometime after January 15, 1960.

Adolph Zulian
Engineer of Surveys and Plans

AZ:ipi

cc: M. U. Watrous
C. E. Shumate
T. C. Reseight
F. O. Stearns
A. Zulian
E. G. Swanson
BPR
J. Howard Bird - Bureau of Mines

I-70-3(2)251 Unit 2
Idaho Springs - Tunnels

January 14, 1960

T.C. Heseigh

Adolph Zulian

Tunnels

The following additional information is furnished in connection with plans for our tunnels east of Idaho Springs:

1. We should indicate the approximate location of the pioneer bore on the cross-section for the main tunnel.
2. BPH letter of Jan 6, 1960 state that provision should be made for lighting these tunnels. Plans for the portal structure should be revised to show suitable conduit which would receive the power from public service lines and distribute some to a box in each tunnel ceiling.

   The lighting installation could then continue with exposed conduit through the tunnels. It would be very difficult to imbed conduit through the tunnels. It would be very difficult to imbed conduit in the gunite *(shotcrete)* sections of the tunnel due to the irregular surface. An exposed conduit installation would probably never be noticed by the average motorist. This would also permit placement of the conduit in the exact position recommended for the type of lighting to be installed. I understand there was no problem in fastening the conduit to the tunnel which is presently lighted.

   Comments and recommendations as to light intensity are request from District personnel. Mr. Miles has also suggested that outside identification lighting be included in the plan. It appears preferable to have the lighting installed under a separate contract after the tunnels are completed. We might also consider the feasibility of having Public Service Company make the lighting installation. District comments are requested.
3. My memo of December 14th *(1959)* stated we should specify 8-foot maximum length of hole during the tunnel boring operation. Actually our specification should include a maximum length of tunnel to be blasted as 8 feet. It is sometimes necessary that holes be 9 to 10 feet long in order to accomplish this.
4. The end of holes for the wedge-type rock bolts must be 1 3/8" diameter for a minimum distance of 12 inches in order to hold the edge end of the bolt properly. The balance of the hole from the surface may be of larger diameter to facilitate drilling.
5. We have had considerable discussion regarding the chain link fencing to be installed under the rock bolts. You have pointed out that this fence will sag between bolts and protrude beyond the gunite lining in many areas. This would be a very unsightly appearance.

   After considerable discussion with the Bureau of Mines and the Bureau of Public Roads, I believe we can eliminate the chain link fencing inside the tunnel. It might be desirable to include a note stating the Contractor could install chain link fencing at his expense in the sections which are to be lined. This would be in lieu of timber lagging until the concrete lining is placed.

6. Mr. Miles is somewhat in disagreement with the number of rock bolts recommended by the Bureau of Mines. We will probably not have their definite report until after January 16 *(1960)*. A copy of Mr. Miles memo has been forwarded to you.

   A lengthy discussion with BPR indicates that rock bolts at 4-foot spacing in the unlined part of the tunnel would appear excessive. It is suggested that you estimate the bolts on the basis of 8-foot spacing and specify that they are to be placed as determined necessary be field conditions. I believe we should withhold definite decision until the BM report is received.

   It may be necessary, in some cases, to provide support between bolts by fastening a channel section under the bolts. This appears to be common practice and I believe there is some information regarding this in the BPR tunnel specifications which were sent you. It might be well to investigate this. If desirable to include this as a pay item, we should estimate a quantity. It appears advisable to retain the 4-foot bolt spacing on the pillar side of the tunnels. I believe probably two rows high on the north tunnel, and three rows high on the south tunnel would be sufficient if the balance has bolting at approximate 8-foot centers.

   It also appears advisable to include an estimated number of bolts for bolting the flow *(flow or flaw? unknown intention)* on the west end of the tunnel. Mr. Miles is not in agreement with this, but BPR feels it might be very desirable if pressure exists due to the foliation.

   Bolts inside the tunnels normally should be placed at right angles to the general surface. This may vary during construction to meet actual field conditions. Mr. Rodriguez feels that best support will be obtained by the placement at right angles tot eh general surface.
7. BPR still feels we should require a maximum 6-inch overbreak on the pillar side of each tunnel. They feel this can be accomplished by drilling more holes along this area. It is suggested we specify maximum 6-inch overbreak up to 15 feet on the pillar side of the north tunnel and up to 20 feet on the pillar side of the south tunnel. The balance of the tunnels would require a maximum 12-inch overbreak.
8. We should also provide a quantity of drain pipe which would be installed as necessary to drain we areas into the sub-drainage system.

Adolph Zulian

Engineer of Surveys and Plans

PROJECT I- 70-3(2) 251 UNIT 2
IDAHO SPRINGS TUNNELS
GEOLOGIC LOG OF THE PIONEER BORE
STATION 172 + 40 — 180 + 25

SCALE = 1" = 20' HORIZONTAL
" 1" = 20' VERTICAL
F = FOLIATION DIP
J = JOINT DIP

PLAN
NOTE BOOK
NO.
SURVEYED
PLOTTED
ALIGNMENT CHECKED
RT. OF WAY CHECKED
BY
DATE

PROFILE
NOTE BOOK
NO.
SURVEYED
PLOTTED
GRADES CHECKED
B. M.S. NOTED
STRUCTURE NOTAT'NS CH'KD
BY
DATE

Generalized Geologic Cross-section along line A-A'
Note wide variation in dip of bedding
Scale: 1" = 100' (horizontal and vertical)

GEOLOGIC CONDITIONS

Between Stations 170 - 185
F.A.P. No. I - 70 - 3(1)250
Clear Creek County,
Colorado

Prepared by U.S. Geological Survey, Engineering Geology Branch, Denver, Colorado.

Legend

al	Alluvium or artificial fill
t	Talus (overburden on hillside slopes)
p	Pegmatite (coarse-grained granitic rock)
mq	Quartz monzonite gneiss (bedrock in area)
v	Vein
⊥33	Dip and strike of bedding or vein
⊕	Horizontal bedding

OFFICIAL USE ONLY

This report and/or map is preliminary and has not been edited or revised for conformity with Geological Survey standards or nomenclature.

PLATE 1—PLAN—PROFILE O. P. R. & R. E. STANDARD
KEUFFEL & ESSER CO. NEW YORK

Appendix F

Structural Mapping Data

Project: 211-231 Twin Tunnels, Idaho Springs
Outcrop area: #1 W. End/Altered Zone
Date: 12/15/2011

Roughness: Smooth->Rough :1 ->5
Waviness: Straight-> Wavy

Dip Direction	Strike (degrees)	Dip (degrees)	Aperture (mm)	Infilling	Roughness	J/F/X	Waviness	Rock Type	note
124	34	21	0	0	1	F	1	Porphyry intrusive and/or gneiss	Altered zone
128	38	22	0	0	1	F	1		
218	128	22	0	0	1	F	1		
120	30	23	0	0	1	F	1		

Project: 211-231 Twin Tunnels, Idaho Springs
Outcrop area: #2 West side, N to S
Date: 12/13 and 12/15/2011

Roughness: Smooth->Rough :1 ->5
Waviness: Straight-> Wavy

J=Joint F=Foliation
X=Fracture

Dip Direction	Strike (azimuth)	Dip (degrees)	Aperture (mm)	Infilling	Roughness	J/F/X	Waviness	Rock Type	note
17	287	21	0	0	2	F-maj	1	Gneiss	Idaho Springs Formation
139	49	70	0	0	3	J-maj	0	Gneiss	
19	289	29	0	0	1	F-maj	1	Gneiss	
2	272	19	0	0	1	F-min	1	Gneiss	
16	286	25	0	0	2	F-maj	1	Gneiss	
358	268	15	0	0	3	F-min	1	Gneiss	
23	293	22	0	0	0	F-maj	0	Gneiss	
181	91	78	0	0	3	X	2	Gneiss	
344	254	25	0	0	1	F	1	Gneiss	
23	293	25	0	0	2	F	1	Gneiss	
345	255	85	0	0	3	X	1	Gneiss	
347	257	27	0	0	1	F	1	Gneiss	
20	290	38	0	0	2	F	2	Gneiss	
168	78	74	0	0	3	J	2	Gneiss	
263	173	86	0	0	2	J	2	Gneiss	
359	269	26	0	0	2	F	1	Gneiss	
245	155	89	0	0	1	J	1	Gneiss	
184	94	56	0	0	3	J	3	Gneiss	
11	281	78	0	0	2	J-maj	1	Gneiss	
245	155	86	0	0	2	J	2	Gneiss	
321	231	24	0	0	2	F	1	Gneiss	

Project: 211-231 Twin Tunnels, Idaho Springs
Outcrop area: #3 South of tunnels, rock face
Date: 12/15/2011

Roughness: Smooth->Rough :1 ->5
Waviness: Straight-> Wavy

J=Joint F=Foliation
X=Fracture

Dip Direction	Strike (azimuth)	Dip (degrees)	Aperture (mm)	Infilling	Roughness	J/F/X	Waviness	Rock Type	note
233	143	62	0	0	1	J	3	Gneiss	Idaho Springs Formation
260	170	85	0	0	2	J	2	Gneiss	
152	62	83	0	0	1	J	1	Gneiss	
229	139	45	0	0	2	J	3	Gneiss	
229	139	54	0	0	1	J	1	Gneiss	
342	252	85	0	0	1	J	1	Gneiss	
65	335	75	0	0	1	J	1	Gneiss	
248	158	54	0	0	1	J	1	Gneiss	
172	82	90	0	0	2	J	1	Gneiss	No measurements taken in apparent blasting area.
40	310	46	0	0	2	J	1	Gneiss	
260	170	78	0	0	3	J	1	Gneiss	
305	215	45	0	0	3	J	2	Gneiss	
265	175	85	0	0	2	J	1	Gneiss	
295	205	54	0	0	2	J	1	Gneiss	Idaho Springs Formation
307	217	50	0	0	2	J	1	Gneiss	
170	80	90	0	0	1	J	1	Gneiss	
168	78	78	0	0	3	J	1	Gneiss	
259	169	86	0	0	1	J-maj	1	Gneiss	
266	176	82	0	0	1	J-maj	1	Gneiss	
271	181	85	0	0	1	J-maj	1	Gneiss	
191	101	57	0	0	2	J	1	Gneiss	
271	181	83	0	0	2	J-maj	1	Gneiss	
230	140	55	0	0	1	J	1	Gneiss	
209	119	82	0	0	1	J	1	Gneiss	

Project: 211-231 Twin Tunnels, Idaho Springs
Outcrop area: #4 East side
Date: 12/14/2011

Roughness: Smooth->Rough :1 ->5
Waviness: Straight-> Wavy

J=Joint F=Foliation
X=Fracture

Dip Direction	Strike (azimuth)	Dip (degrees)	Aperture (in)	Infilling	Roughness	J/F/X	Waviness	Rock Type	note
64	334	90	0	0	2	J-maj	1	Gneiss	Idaho Springs Formation
6	276	50	0	0	2	J	1	Gneiss	
166	76	55	0	0	3	J	2	Gneiss	
74	344	70	0	0	2	J	2	Gneiss	
110	20	39	0	0	3	J	2	Gneiss	
126	36	72	0	0	2	J	1	Gneiss	
0	270	37	0	0	2	F	1	Gneiss	
343	253	37	3.5	Mica	2	F	1	Gneiss	
221	131	39	0	0	2	J	1	Gneiss	
163	73	72	0	0	2	J	1	Gneiss	
4	274	39	0	0	2	F	1	Gneiss	
11	281	85	0	0	1	J	1	Gneiss	
349	259	33	0	0	2	F	1	Gneiss	
6	276	45	0	0	3	F	2	Gneiss	
193	103	59	0	0	1	J	1	Gneiss	
20	290	40	0	0	1	F	2	Gneiss	
129	39	60	0	0	3	J	2	Gneiss	
211	121	38	0	0	2	J	1	Gneiss	
23	293	54	2	Mica	2	F	2	Gneiss	
266	176	70	0	0	2	J	1	Gneiss	
76	346	83	0	0	1	J	1	Gneiss	
130	40	59	0	0	3	J	2	Gneiss	
13	283	46	0	0	2	F	1	Gneiss	
195	105	47	0	0	2	J	1	Gneiss	
79	349	85	0	0	2	J-maj	1	Gneiss	
246	156	87	0	0	3	J-maj	4	Gneiss	Overturned
220	130	11	0	0	3	F	3	Gneiss	Idaho Springs Formation
346	256	32	0	0	2	F	3	Gneiss	
358	268	41	0	0	3	F	3	Gneiss	
267	177	86	0	0	3	J-maj	2	Gneiss	Overturned
354	264	21	0	0	2	F	3	Gneiss	Idaho Springs Formation
186	96	48	0	0	2	J-min	1	Gneiss	
81	351	82	0	0	1	J-maj	2	Gneiss	
181	91	48	0	0	2	J-min	1	Gneiss	
354	264	31	0	0	1	F	4	Gneiss	
347	257	34	0	0	2	F	4	Gneiss	
205	115	35	0	0	1	J	1	Gneiss	
229	139	63	0	0	1	X	1	Gneiss	

Project: 211-231 Twin Tunnels, Idaho Springs

Outcrop area: #4 East side

Date: 12/14/2011

Roughness: Smooth->Rough :1 ->5

Waviness: Straight-> Wavy

J=Joint F=Foliation

X=Fracture

Dip Direction	Strike (azimuth)	Dip (degrees)	Aperture (in)	Infilling	Roughness	J/F/X	Waviness	Rock Type	note
48	318	35	0	0	1	F	1	Gneiss	Idaho Springs Formation
151	61	54	0	0	3	J	1	Gneiss	
120	30	66	0	0	1	J	3	Gneiss	
263	173	81	0	0	2	J-min	1	Gneiss	
184	94	44	0	0	2	J-maj	1	Gneiss	
351	261	42	0	0	1	F	1	Gneiss	
337	247	54	0	0	2	F	1	Gneiss	
5	275	62	0	0	2	F	2	Gneiss	
280	190	16	0	0	1	J-min	1	Gneiss	
195	105	49	0	0	1	J-maj	1	Gneiss	
350	260	47	0	0	1	F	1	Gneiss	
115	25	86	0	0	2	J	2	Gneiss	
190	100	39	0	0	2	J	1	Gneiss	
14	284	33	0	0	3	F	2	Gneiss	
136	46	35	0	0	2	J-maj	1	Gneiss	
63	333	88	0	0	1	J-maj	1	Gneiss	
9	279	30	0	0	1	F	1	Gneiss	
68	338	85	0	0	2	J	2	Gneiss	

Project: 211-231 Twin Tunnels, Idaho Springs
Outcrop area: #5 East end tunnel, south
Date: 12/15/2011
Roughness: Smooth->Rough :1 ->5
Waviness: Straight-> Wavy
J=Joint F=Foliation
X=Fracture

Dip Direction	Strike (azimuth)	Dip (degrees)	Aperture (in)	Infilling	Roughness	J/F/X	Waviness	Rock Type	note
334	244	57	0	0	1	F	2	Gneiss	Slickensides lineation same as dip direction
336	246	57	0	0	1	F	2	Gneiss	
330	240	61	0	0	1	F	3	Gneiss	
327	237	39	0	0	1	F	3	Gneiss	
306	216	40	0	0	1	F	1	Gneiss	Idaho Springs Formation
353	263	32	0	0	1	F	1	Gneiss	
29	299	36	0	0	0	F	1	Gneiss	
233	143	56	0	0	2	X	1	Gneiss	
345	255	44	0	0	1	F	3	Gneiss	
281	191	33	0	0	2	J?	1	Gneiss	
262	172	76	0	0	1	J	1	Gneiss	
5	275	49	0	0	regional	foliation	east end tunnel	Gneiss	
354	264	48	0	0	regional	foliation	east end tunnel	Gneiss	

Project: 211-231 Twin Tunnels, Idaho Springs   Roughness: Smooth->Rough :1 ->5   J=Joint   F=Foliation
Outcrop area: Area west of tower   Date: 12/15/2011   Waviness: Straight-> Wavy   X=Fracture

Dip Direction	Strike (azimuth)	Dip (degrees)	Aperture (in)	Infilling	Roughness	J/F/X	Waviness	Rock Type	note
0	270	83	0	0	2	J	3	Gneiss	Idaho Springs Formation
3	273	87	0	0	3	J	2	Gneiss	
359	269	90	0	0	1	J	1	Gneiss	
269	179	90	0	0	2	J	2	Gneiss	
271	181	78	0	0	2	J	1	Gneiss	
352	262	17	0	0	3	F	2	Gneiss	
324	234	24	0	0	2	F	3	Gneiss	
334	244	23	0	0	2	F	2	Gneiss	
10	280	86	0	0	1	J	1	Gneiss	
74	344	74	0	0	1	J	1	Gneiss	
349	259	43	0	0	2	F	2	Gneiss	altered
355	265	47	7.9	?	2	F	2	Gneiss	vein
135	45	2	0	0	1	J	3	Gneiss	vein
262	172	5	0	0	1	J	1	Gneiss	slicknsd,vein
185	95	16	0	0	1	J	1	Gneiss	vein

Project: 211-231 Twin Tunnels, Idaho Springs
Outcrop area: Regional joint sets north of I-70 tunnels
Date: 12/15/2011
Roughness: Smooth->Rough :1 ->5
Waviness: Straight-> Wavy
J=Joint F=Foliation
X=Fracture

Dip Direction	Strike (azimuth)	Dip (degrees)	Aperture (mm)	Infilling	Roughness	J/F/X	Waviness	Rock Type	note
70	340	68	n/a	n/a	n/a	J-maj	n/a	Gneiss	Idaho Springs Formation
80	350	82	n/a	n/a	n/a	J-maj	n/a	Gneiss	
75	345	76	n/a	n/a	n/a	J-maj	n/a	Gneiss	
78	348	78	n/a	n/a	n/a	J-maj	n/a	Gneiss	Regional joint sets north of west end of tunnels
74	344	82	n/a	n/a	n/a	J-maj	n/a	Gneiss	
68	338	75	n/a	n/a	n/a	J-maj	n/a	Gneiss	
65	335	77	n/a	n/a	n/a	J-maj	n/a	Gneiss	
76	346	79	n/a	n/a	n/a	J-maj	n/a	Gneiss	
78	348	65	n/a	n/a	n/a	J-maj	n/a	Gneiss	
70	340	75	n/a	n/a	n/a	J-maj	n/a	Gneiss	

Project: 211-231 Twin Tunnels, Idaho Springs

Outcrop area: All outcrops Date: 1/19/2012

Dip Direction (dge)	Dip (dge)	Traverse	Aperture (mm)	Infilling	Roughness	J/F/X	Waviness	Rock Type	note
Foliation									
115	22	Outcrop #1				F			
359	21	Outcrop #2				F			
343	34	Outcrop #4				F			
211	11	Outcrop #4				F			
331	53	Outcrop #5				F			
328	20	Near tower, west side				F			
343	45	Near tower, west side				F			
Joints									
236	87	Outcrop #2				J			
257	83	Outcrop #2				J			
162	90	Outcrop #2				J			
221	54	Outcrop #2				J			
298	50	Outcrop #2				J			
179	47	Outcrop #4				J			
253	76	Outcrop #5				J			
230	2	Near tower, west side				J			
352	87	Near tower, west side				J			
Fractures									
164	86	Outcrop #2				X			
224	56	Outcrop #5				X			

Project: 211-231 Twin Tunnels, Idaho Springs

Outcrop area: YA-T1 Colog   Date: 3/12/12

F=Foliation

X=Fracture

Dip Direction (corrected for magnetic declination)	Strike (azimuth)	Dip (degrees)	Rank Colog	Foliaton or Fracture as defined on Colog	Dip direction from Colog not corrected for magnetic declination	Declination correction = 9 degrees east	Legend
21	291	9	2	X	12	21	Fracture as
166	76	41	1	F	157	166	shown on Colog
178	88	37	1	F	169	178	
173	83	35	1	F	164	173	Fracture determined
173	83	26	0	F	164	173	by Yeh & Associates
189	99	37	1	F	180	189	review of Colog
187	97	45	1	F	178	187	
194	104	46	1	F	185	194	Foliation determined
188	98	45	1	F	179	188	by Yeh & Associates
183	93	46	0	F	174	183	review of Colog
207	117	45	0	F	198	207	
206	116	46	0	F	197	206	
212	122	49	0	F	203	212	
174	84	59	1	F	165	174	
229	139	20	1	F	220	229	
211	121	43	0	F	202	211	
187	97	36	0	F	178	187	
188	98	41	1	F	179	188	
193	103	38	0	F	184	193	
208	118	41	0	F	199	208	
215	125	39	1	F	206	215	
167	77	45	1	F	158	167	
183	93	21	0	F	174	183	
192	102	35	0	F	183	192	
200	110	41	0	F	191	200	
201	111	36	1	F	192	201	
201	111	44	1	F	192	201	
189	99	26	0	F	180	189	
200	110	17	1	F	191	200	
189	99	40	0	F	180	189	
202	112	42	0	F	193	202	
207	117	41	0	F	198	207	
212	122	36	0	F	203	212	
231	141	48	0	F	222	231	
225	135	44	1	F	216	225	
237	147	38	0	F	228	237	

230	140	42	0	F	221	230
178	88	23	0	F	169	178
236	146	41	2	X	227	236
249	159	43	0	F	240	249
260	170	54	0	F	251	260
166	76	45	0	F	157	166
201	111	31	2	X	192	201
204	114	34	1	F	195	204
180	90	47	1	F	171	180
283	193	40	1	F	274	283
238	148	35	0	F	229	238
235	145	40	1	F	226	235
235	145	48	0	F	226	235
224	134	48	0	F	215	224
147	57	54	1	F	138	147
243	153	58	0	F	234	243
194	104	49	0	F	185	194
232	142	47	0	F	223	232
238	148	41	1	F	229	238
258	168	44	0	F	249	258
250	160	39	0	F	241	250
230	140	45	1	F	221	230
233	143	53	1	F	224	233
217	127	46	1	F	208	217
195	105	68	0	F	186	195
232	142	42	0	F	223	232
210	120	62	0	F	201	210
11	281	45	0	F	2	11
202	112	28	0	F	193	202
180	90	44	0	F	171	180
186	96	10	0	F	177	186
18	288	15	0	F	9	18
214	124	33	0	F	205	214
239	149	33	0	F	230	239
203	113	39	1	F	194	203
220	130	32	2	X	211	220
202	112	35	1	F	193	202
234	144	43	1	F	225	234
203	113	38	1	F	194	203
194	104	44	0	F	185	194
201	111	37	1	F	192	201
216	126	41	1	F	207	216
198	108	30	0	F	189	198

Project: 211-231 Twin Tunnels, Idaho Springs
Outcrop area: YA-T2 Colog Date: 3/12/12

F=Foliation
X=Fracture

Dip Direction (corrected for magnetic declination)	Strike (azimuth)	Dip (degrees)	Rank Colog	Foliaton or Fracture as defined on Colog	Dip direction from Colog not corrected for magnetic declination	Declination correction = 9 degrees east	Legend
6	276	22	1	F	357	6	Fracture as
127	37	50	3	X	118	127	shown on Colog
187	97	68	1	F	178	187	
228	138	78	2	X	219	228	Fracture determined
197	107	71	0	F	188	197	by Yeh & Associates
128	38	38	0	F	119	128	review of Colog
132	42	33	0	F	123	132	
143	53	41	0	F	134	143	Foliation determined
335	245	54	0	F	326	335	by Yeh & Associates
217	127	77	0	F	208	217	review of Colog
209	119	80	0	F	200	209	
142	52	45	1	F	133	142	
210	120	79	1	F	201	210	
189	99	82	1	F	180	189	
187	97	82	1	F	178	187	
201	111	54	1	F	192	201	
209	119	82	1	F	200	209	
20	290	80	1	F	11	20	
23	293	84	0	F	14	23	
6	276	75	0	F	357	6	
5	275	77	0	F	356	5	
28	298	85	0	F	19	28	
162	72	66	0	F	153	162	
159	69	32	0	F	150	159	
183	93	47	3	X	174	183	
194	104	63	3	X	185	194	
35	305	70	0	F	26	35	
14	284	81	3	X	5	14	
20	290	70	1	F	11	20	
22	292	68	1	F	13	22	
32	302	71	1	F	23	32	
32	302	71	1	F	23	32	
41	311	67	1	F	32	41	
39	309	64	1	F	30	39	
50	320	62	1	F	41	50	
220	130	12	0	F	211	220	
51	321	64	0	F	42	51	
49	319	62	0	F	40	49	
21	291	71	0	F	12	21	
28	298	70	1	F	19	28	
32	302	53	1	F	23	32	
18	288	48	1	F	9	18	
30	300	46	0	F	21	30	
354	264	54	0	F	345	354	
348	258	61	0	F	339	348	
24	294	67	0	F	15	24	
18	288	65	0	F	9	18	

10	280	62	0	F	1	10
4	274	74	1	F	355	4
1	271	75	1	F	352	1
42	312	20	1	F	33	42
8	278	60	0	F	359	8
9	279	59	0	F	360	9
16	286	62	0	F	7	16
17	287	65	0	F	8	17
18	288	65	0	F	9	18
12	282	69	0	F	3	12
16	286	65	0	F	7	16
10	280	66	0	F	1	10
15	285	68	0	F	6	15
15	285	70	0	F	6	15
13	283	69	0	F	4	13
14	284	72	0	F	5	14
13	283	69	0	F	4	13
16	286	70	0	F	7	16
216	126	28	2	X	207	216
16	286	74	0	F	7	16
210	120	41	3	X	201	210
12	282	74	0	F	3	12
15	285	72	0	F	6	15
15	285	73	0	F	6	15
18	288	72	0	F	9	18
16	286	70	0	F	7	16
14	284	70	0	F	5	14
11	281	70	1	F	2	11
8	278	71	0	F	359	8
12	282	73	0	F	3	12
10	280	73	0	F	1	10
8	278	72	0	F	359	8
8	278	72	0	F	359	8
9	279	73	0	F	360	9
6	276	72	0	F	357	6
5	275	75	0	F	356	5
6	276	74	0	F	357	6
3	273	75	0	F	354	3
359	269	75	0	F	350	359
357	267	78	0	F	348	357
357	267	78	0	F	348	357
359	269	77	0	F	350	359
184	94	84	0	F	175	184
3	273	80	0	F	354	3
292	202	48	2	X	283	292
2	272	81	0	F	353	2
311	221	50	1	F	302	311
4	274	80	0	F	355	4
142	52	31	0	F	133	142
240	150	39	0	F	231	240
236	146	40	2	X	227	236
237	147	65	2	X	228	237
292	202	20	0	F	283	292
343	253	39	0	F	334	343

Project: 211-231 Twin Tunnels, Idaho Springs
Outcrop area: YA-T4 Colog Date: 3/12/12

F=Foliation
X=Fracture

Dip Direction (corrected for magnetic declination)	Strike (azimuth)	Dip (degrees)	Rank Colog	Foliaton or Fracture as defined on Colog	Dip direction from Colog not corrected for magnetic declination	Declination correction = 9 degrees east	Legend
182	92	33	1	F	173	182	Fracture as
235	145	52	0	F	226	235	shown on Colog
148	58	28	1	F	139	148	
337	247	49	0	F	328	337	Fracture determined
339	249	42	0	F	330	339	by Yeh & Associates
265	175	55	0	F	256	265	review of Colog
252	162	56	0	F	243	252	
86	356	49	2	X	77	86	Foliation determined
141	51	64	2	X	132	141	by Yeh & Associates
243	153	53	0	F	234	243	review of Colog
238	148	47	0	F	229	238	
338	248	41	0	F	329	338	
234	144	43	0	F	225	234	
112	22	36	2	X	103	112	
231	141	41	0	F	222	231	
333	243	51	0	F	324	333	
331	241	63	2	X	322	331	
203	113	46	1	F	194	203	
336	246	64	0	F	327	336	
240	150	43	1	F	231	240	
57	327	25	2	X	48	57	
271	181	47	1	F	262	271	
246	156	51	0	F	237	246	
247	157	51	0	F	238	247	
288	198	60	0	F	279	288	
331	241	8	1	F	322	331	
252	162	34	0	F	243	252	
257	167	46	0	F	248	257	
255	165	45	0	F	246	255	
239	149	46	0	F	230	239	
252	162	44	0	F	243	252	
235	145	42	0	F	226	235	
243	153	47	0	F	234	243	
243	153	44	0	F	234	243	
245	155	47	0	F	236	245	
227	137	39	0	F	218	227	
247	157	45	0	F	238	247	
248	158	39	0	F	239	248	
247	157	48	0	F	238	247	
240	150	48	0	F	231	240	
222	132	47	1	F	213	222	
40	310	59	1	F	31	40	
239	149	50	0	F	230	239	
207	117	56	1	F	198	207	
261	171	50	1	F	252	261	
253	163	50	0	F	244	253	
255	165	55	0	F	246	255	
117	27	15	1	F	108	117	
347	257	39	2	X	338	347	
254	164	57	0	F	245	254	
249	159	53	0	F	240	249	
272	182	39	0	F	263	272	

248	158	51	0	F	239	248
246	156	49	0	F	237	246
245	155	48	0	F	236	245
243	153	36	1	F	234	243
259	169	48	0	F	250	259
251	161	47	2	X	242	251
238	148	45	0	F	229	238
241	151	45	0	F	232	241
223	133	47	0	F	214	223
234	144	47	0	F	225	234
163	73	50	0	F	154	163
229	139	37	0	F	220	229
233	143	30	0	F	224	233
194	104	42	0	F	185	194
228	138	48	1	F	219	228
229	139	44	0	F	220	229
233	143	43	0	F	224	233
216	126	43	0	F	207	216
191	101	38	0	F	182	191
247	157	42	0	F	238	247
106	16	59	0	F	97	106
359	269	45	2	X	350	359
239	149	34	0	F	230	239
232	142	48	0	F	223	232
237	147	41	1	F	228	237
342	252	51	1	F	333	342
219	129	40	0	F	210	219
226	136	44	1	F	217	226
220	130	43	1	F	211	220
31	301	50	2	X	22	31
238	148	43	1	F	229	238
240	150	46	0	F	231	240
211	121	43	0	F	202	211
189	99	36	0	F	180	189
191	101	39	0	F	182	191
204	114	47	0	F	195	204
204	114	41	0	F	195	204
213	123	34	0	F	204	213
197	107	41	0	F	188	197
366	276	47	1	F	357	366
213	123	40	0	F	204	213
228	138	47	1	F	219	228
235	145	50	0	F	226	235
211	121	48	0	F	202	211
214	124	45	0	F	205	214
366	276	46	0	F	357	366
39	309	31	0	F	30	39
225	135	42	0	F	216	225
332	242	47	0	F	323	332
199	109	32	0	F	190	199
197	107	29	1	F	188	197
368	278	33	0	F	359	368
224	134	42	0	F	215	224
217	127	40	0	F	208	217
203	113	41	0	F	194	203
210	120	42	0	F	201	210
206	116	44	0	F	197	206
252	162	41	0	F	243	252
240	150	40	0	F	231	240

Project: 211-231 Twin Tunnels, Idaho Springs
Outcrop area: YA-T5 Colog   Date: 3/12/12

F=Foliation
X=Fracture

Dip Direction (corrected for magnetic declination)	Strike (azimuth)	Dip (degrees)	Rank Colog	Foliaton or Fracture as defined on Colog	Dip direction from Colog not corrected for magnetic declination	Declination correction = 9 degrees east	Legend
158	68	13	1	F	149	158	Fracture as
165	75	64	1	F	156	165	shown on Colog
356	266	44	1	F	347	356	
151	61	8	2	X	142	151	Fracture determined
140	50	25	2	X	131	140	by Yeh & Associates
149	59	78	3	X	140	149	review of Colog
136	46	72	2	X	127	136	
145	55	71	2	X	136	145	Foliation determined
212	122	52	0	F	203	212	by Yeh & Associates
147	57	67	1	F	138	147	review of Colog
231	141	53	0	F	222	231	
155	65	70	1	F	146	155	
168	78	57	1	F	159	168	
177	87	54	0	F	168	177	
178	88	53	0	F	169	178	
206	116	56	0	F	197	206	
185	95	50	1	F	176	185	
187	97	44	0	F	178	187	
180	90	48	0	F	171	180	
176	86	42	0	F	167	176	
169	79	51	0	F	160	169	
161	71	53	0	F	152	161	
129	39	66	1	F	120	129	
248	158	64	0	F	239	248	
193	103	50	1	F	184	193	
212	122	49	0	F	203	212	
178	88	32	0	F	169	178	
174	84	48	1	F	165	174	
322	232	61	0	F	313	322	
171	81	52	0	F	162	171	
200	110	52	0	F	191	200	
172	82	51	0	F	163	172	
173	83	52	0	F	164	173	
138	48	82	1	F	129	138	
195	105	52	0	F	186	195	
303	213	81	1	F	294	303	
185	95	53	0	F	176	185	
197	107	47	0	F	188	197	
332	242	64	0	F	323	332	
209	119	43	0	F	200	209	
198	108	45	0	F	189	198	
51	321	78	1	F	42	51	
140	50	77	2	X	131	140	
231	141	42	0	F	222	231	
138	48	76	2	X	129	138	
228	138	47	0	F	219	228	
218	128	42	0	F	209	218	
204	114	50	0	F	195	204	
216	126	53	0	F	207	216	
206	116	53	0	F	197	206	
209	119	53	0	F	200	209	
293	203	42	0	F	284	293	
199	109	53	0	F	190	199	
209	119	55	0	F	200	209	

Project: 211-231 Twin Tunnels, Idaho Springs
Outcrop area: YA-T6 Colog Date: 3/12/12

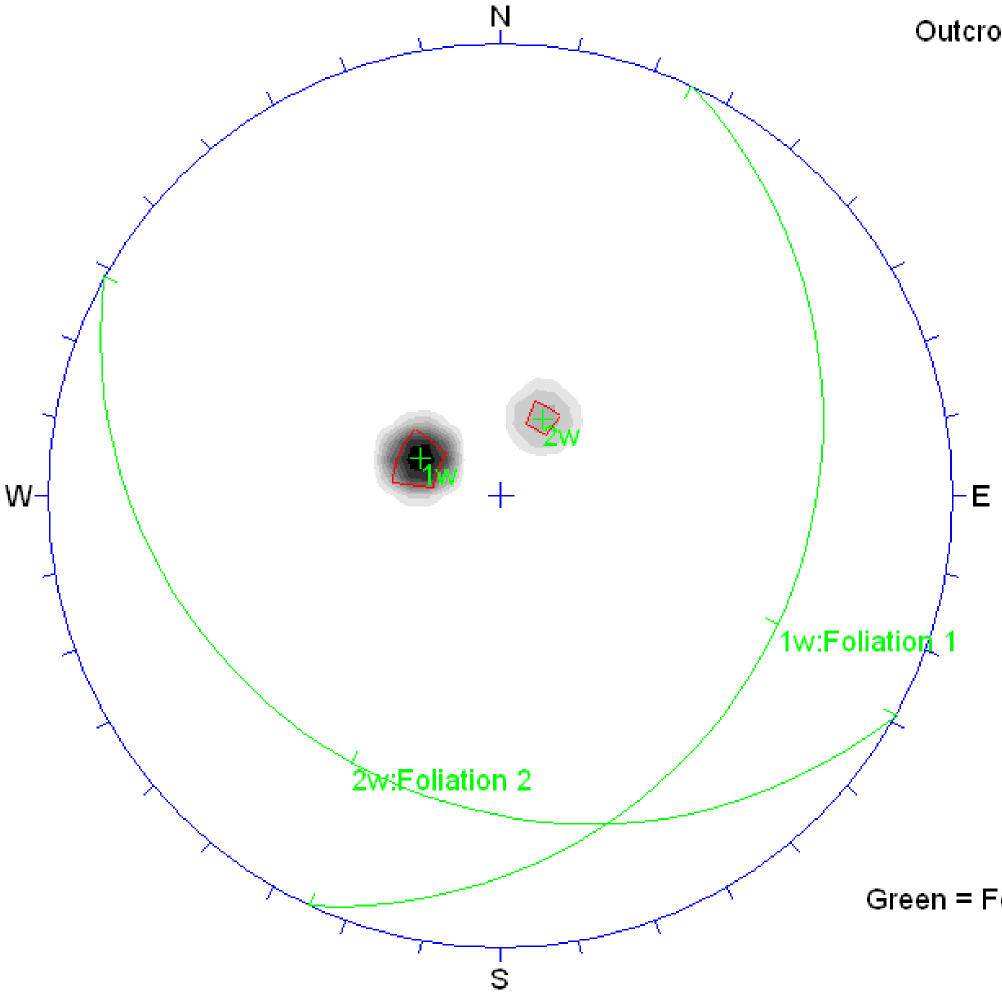
F=Foliation
X=Fracture

Dip Direction (corrected for magnetic declination)	Strike (azimuth)	Dip (degrees)	Rank Colog	Foliation or Fracture as defined on Colog	Dip direction from Colog not corrected for magnetic declination	Declination correction = 9 degrees east	Legend
302	212	43	2	X	293	302	Fracture as
111	21	74	2	X	102	111	shown on Colog
364	274	20	1	F	355	364	
25	295	12	0	F	16	25	Fracture determined
317	227	4	1	F	308	317	by Yeh & Associates
53	323	55	1	F	44	53	review of Colog
35	305	23	2	X	26	35	
44	314	13	0	F	35	44	Foliation determined
37	307	23	0	F	28	37	by Yeh & Associates
25	295	20	2	X	16	25	review of Colog
50	320	29	0	F	41	50	
54	324	21	1	F	45	54	
64	334	20	1	F	55	64	
248	158	37	2	X	239	248	
164	74	35	0	F	155	164	
225	135	37	2	X	216	225	
200	110	27	1	F	191	200	
61	331	41	1	F	52	61	
150	60	24	2	X	141	150	
171	81	28	2	X	162	171	
239	149	20	1	F	230	239	
136	46	15	1	F	127	136	
265	175	18	2	X	256	265	
276	186	14	1	F	267	276	
61	331	24	1	F	52	61	
138	48	53	1	F	129	138	
278	188	41	0	F	269	278	
240	150	20	0	F	231	240	
63	333	25	0	F	54	63	
74	344	11	0	F	65	74	
37	307	12	0	F	28	37	
283	193	20	0	F	274	283	
30	300	70	0	F	21	30	
275	185	28	0	F	266	275	
43	313	54	0	F	34	43	
84	354	8	0	F	75	84	
358	268	16	0	F	349	358	
353	263	58	0	F	344	353	
44	314	24	0	F	35	44	
284	194	24	1	F	275	284	
222	132	64	0	F	213	222	
239	149	57	2	X	230	239	
118	28	45	1	F	109	118	
228	138	62	1	F	219	228	
220	130	48	1	F	211	220	
327	237	10	2	X	318	327	
16	286	37	1	F	7	16	
236	146	61	1	F	227	236	
320	230	26	0	F	311	320	
246	156	58	1	F	237	246	
192	102	41	1	F	183	192	
222	132	45	1	F	213	222	
296	206	53	1	F	287	296	
272	182	33	1	F	263	272	
84	354	76	1	F	75	84	
52	322	59	1	F	43	52	
260	170	47	1	F	251	260	
358	268	50	1	F	349	358	

262	172	62	1	F	253	262
313	223	65	1	F	304	313
42	312	54	1	F	33	42
42	312	59	0	F	33	42
24	294	55	1	F	15	24
223	133	40	1	F	214	223
226	136	28	0	F	217	226
290	200	6	1	F	281	290
317	227	48	0	F	308	317
326	236	31	0	F	317	326
106	16	37	1	F	97	106
226	136	30	1	F	217	226
234	144	60	1	F	225	234
360	270	21	1	F	351	360
302	212	55	1	F	293	302
359	269	68	0	F	350	359
209	119	42	1	F	200	209
230	140	46	1	F	221	230
242	152	52	0	F	233	242
44	314	24	1	F	35	44
368	278	58	0	F	359	368
258	168	4	1	F	249	258
368	278	63	0	F	359	368
37	307	70	1	F	28	37
200	110	35	1	F	191	200
177	87	40	0	F	168	177
162	72	37	0	F	153	162
182	92	42	1	F	173	182
226	136	67	0	F	217	226
226	136	55	0	F	217	226
217	127	56	0	F	208	217
219	129	68	0	F	210	219
39	309	68	0	F	30	39
138	48	40	1	F	129	138
190	100	58	0	F	181	190
7	277	54	1	F	358	7
20	290	50	0	F	11	20
177	87	60	1	F	168	177
315	225	38	1	F	306	315
16	286	35	1	F	7	16
17	287	44	1	F	8	17
192	102	23	1	F	183	192
19	289	55	0	F	10	19
30	300	44	1	F	21	30
186	96	49	0	F	177	186
45	315	48	0	F	36	45
38	308	87	1	F	29	38
357	267	68	1	F	348	357
76	346	86	1	F	67	76
356	266	39	1	F	347	356
357	267	48	1	F	348	357
197	107	62	1	F	188	197
201	111	61	2	X	192	201
191	101	45	1	F	182	191
220	130	56	1	F	211	220
235	145	45	1	F	226	235
215	125	35	0	F	206	215
202	112	42	0	F	193	202
127	37	53	1	F	118	127
66	336	71	0	F	57	66
190	100	58	0	F	181	190
99	9	36	2	X	90	99
247	157	59	3	X	238	247
61	331	51	0	F	52	61
208	118	60	1	F	199	208

221	131	64	0	F	212	221
232	142	38	1	F	223	232
248	158	83	0	F	239	248
9	279	72	1	F	0	9
30	300	49	0	F	21	30
50	320	52	0	F	41	50
15	285	73	1	F	6	15
18	288	71	0	F	9	18
229	139	30	1	F	220	229
13	283	70	0	F	4	13
357	267	65	0	F	348	357
26	296	66	1	F	17	26
108	18	84	1	F	99	108
12	282	65	0	F	3	12
206	116	45	0	F	197	206
13	283	69	0	F	4	13
12	282	70	0	F	3	12
286	196	77	1	F	277	286
26	296	69	0	F	17	26
23	293	69	0	F	14	23
20	290	71	0	F	11	20
10	280	71	0	F	1	10
367	277	72	0	F	358	367
368	278	70	0	F	359	368
368	278	70	0	F	359	368
18	288	69	0	F	9	18
369	279	70	0	F	360	369
231	141	37	1	F	222	231
9	279	68	0	F	0	9
368	278	72	0	F	359	368
10	280	72	1	F	1	10
22	292	73	0	F	13	22
19	289	74	0	F	10	19
16	286	73	1	F	7	16
15	285	70	0	F	6	15
19	289	60	0	F	10	19
212	122	28	1	F	203	212
36	306	67	0	F	27	36
24	294	72	0	F	15	24
9	279	70	2	X	0	9
15	285	71	0	F	6	15
16	286	75	0	F	7	16
21	291	71	0	F	12	21
266	176	40	1	F	257	266
27	297	83	0	F	18	27
18	288	75	0	F	9	18
205	115	86	0	F	196	205
196	106	44	0	F	187	196
16	286	85	3	X	7	16
224	134	68	0	F	215	224
256	166	32	1	F	247	256
220	130	88	3	X	211	220
257	167	67	2	X	248	257
357	267	55	0	F	348	357
301	211	29	1	F	292	301
167	77	44	1	F	158	167
221	131	38	0	F	212	221
270	180	61	0	F	261	270
336	246	69	1	F	327	336
232	142	78	0	F	223	232
225	135	85	1	F	216	225
270	180	49	0	F	261	270

Outcrop #1 Alteration Zone West End Tunnel

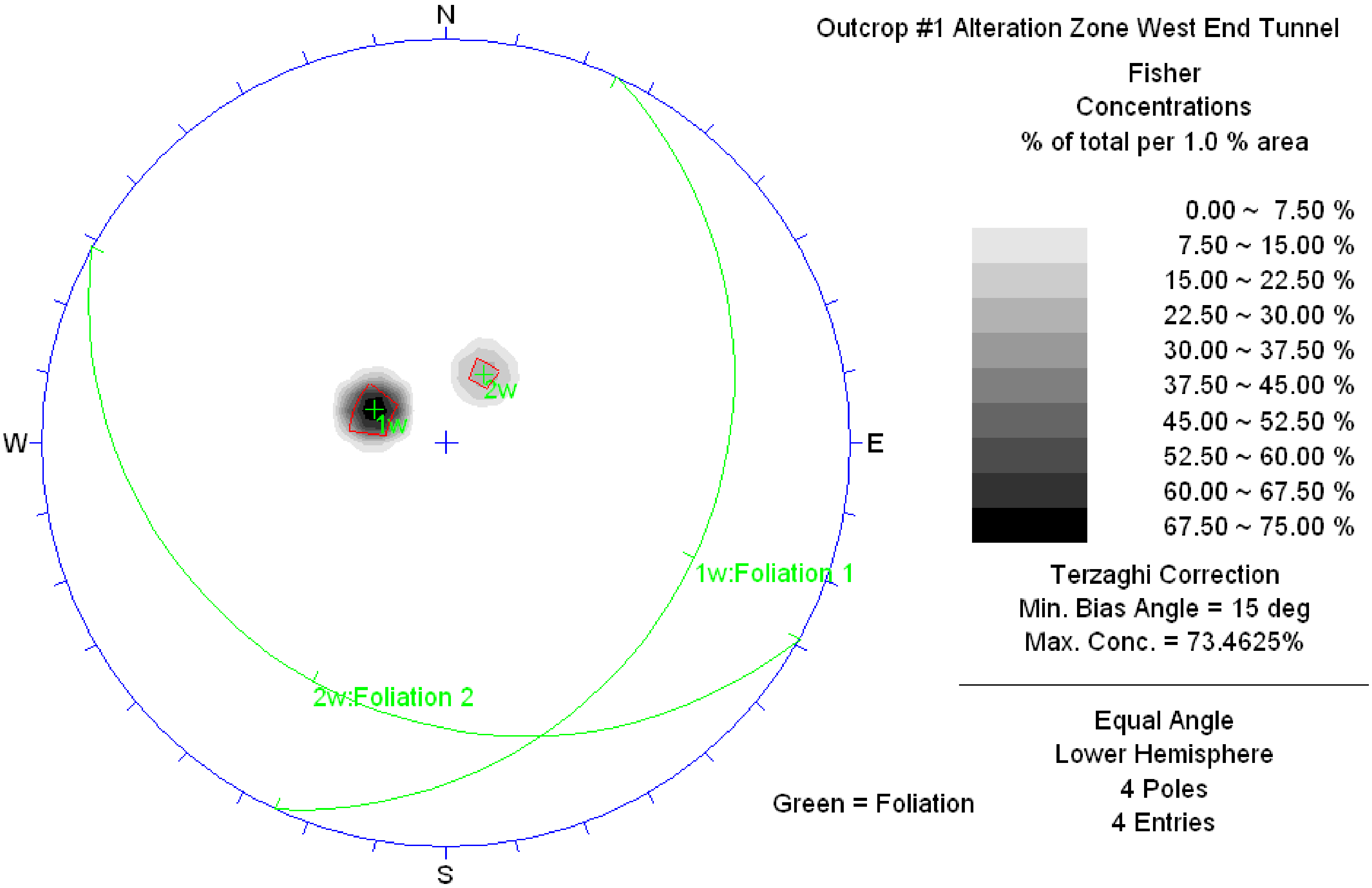


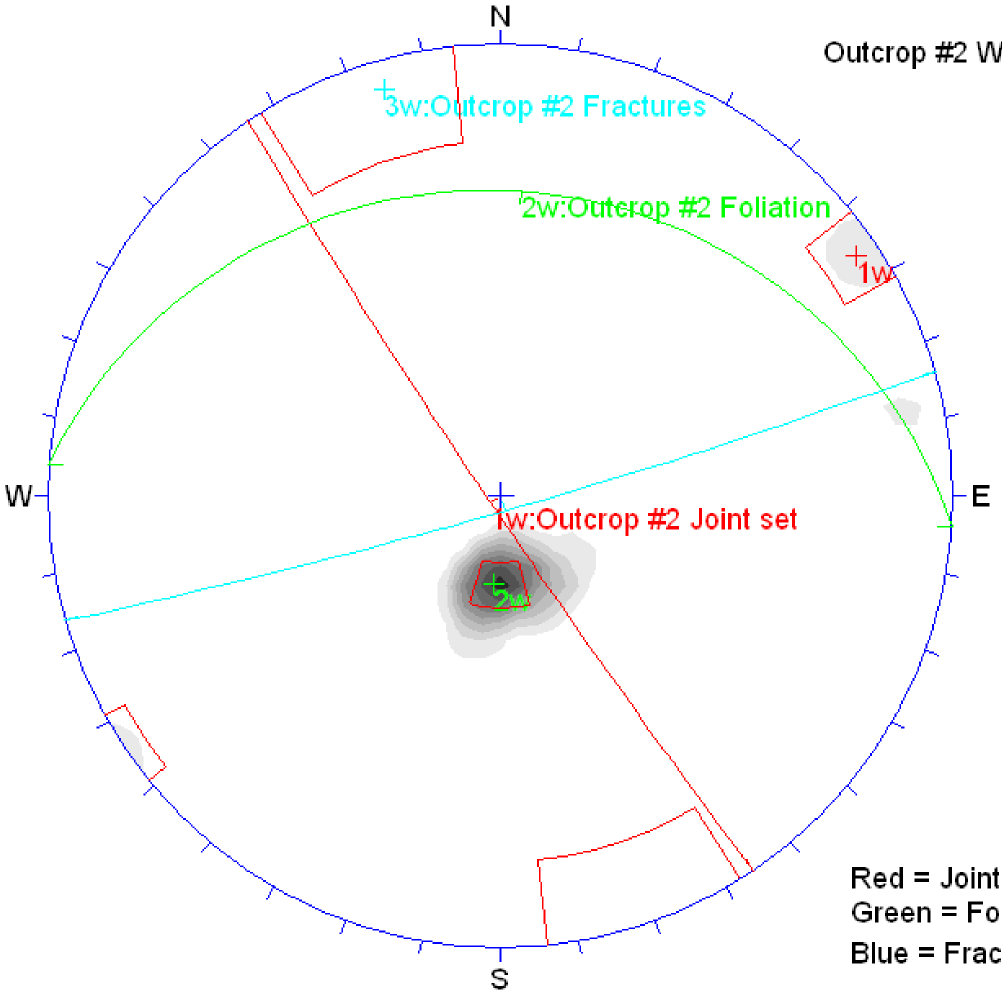
Orientations

ID		Dip / Direction
1	w	22 / 115
2	w	22 / 209

Green = Foliation

Equal Angle
Lower Hemisphere
4 Poles
4 Entries


N
E
S
W
1w
2w
1w:Foliation 1
2w:Foliation 2
Outcrop #1 Alteration Zone West End Tunnel
Fisher
Concentrations
% of total per 1.0 % area
0.00 ~ 7.50 %
7.50 ~ 15.00 %
15.00 ~ 22.50 %
22.50 ~ 30.00 %
30.00 ~ 37.50 %
37.50 ~ 45.00 %
45.00 ~ 52.50 %
52.50 ~ 60.00 %
60.00 ~ 67.50 %
67.50 ~ 75.00 %
Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 73.4625%
Equal Angle
Lower Hemisphere
4 Poles
4 Entries
Green = Foliation



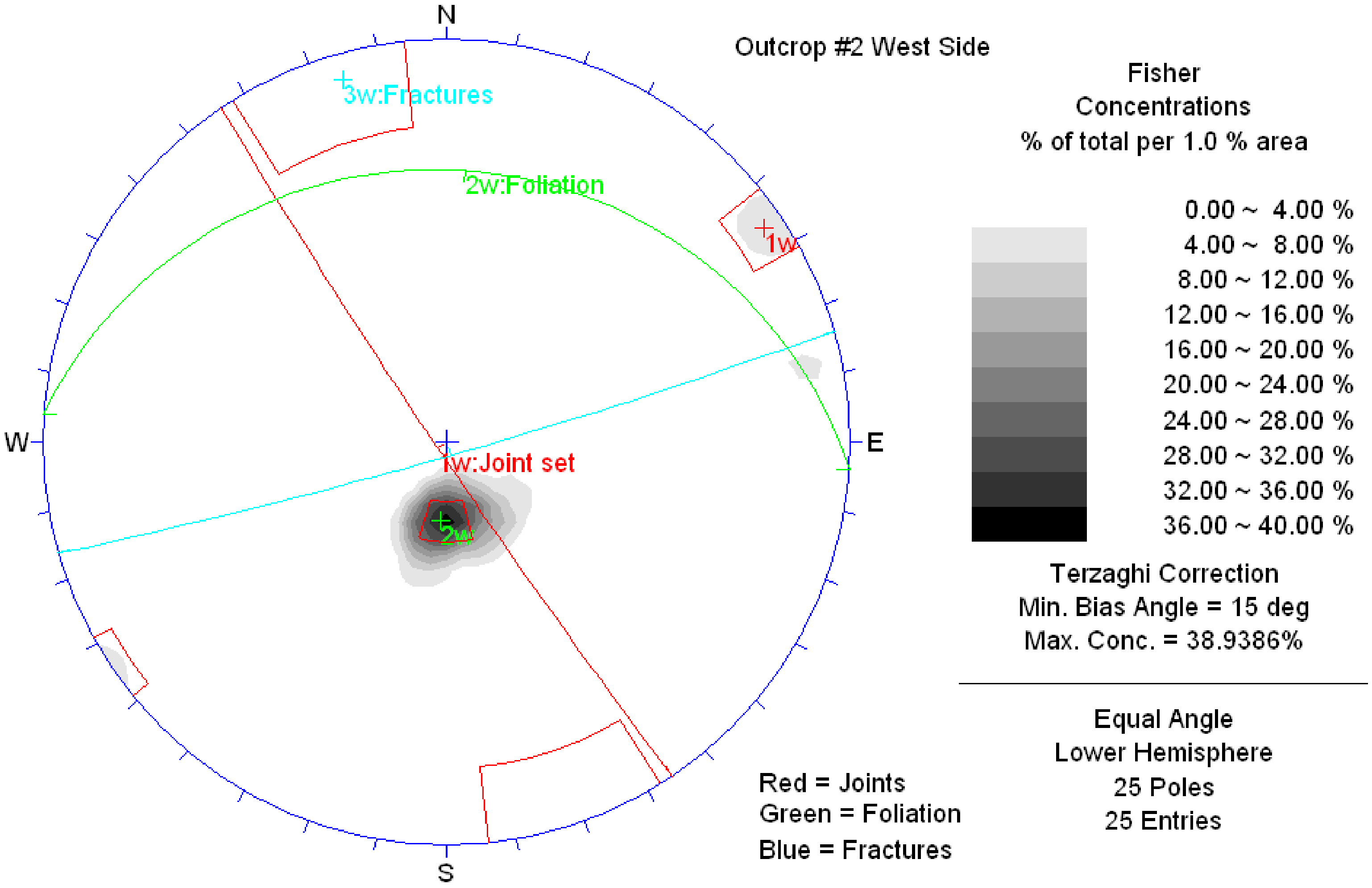
Outcrop #2 West Side

Orientations

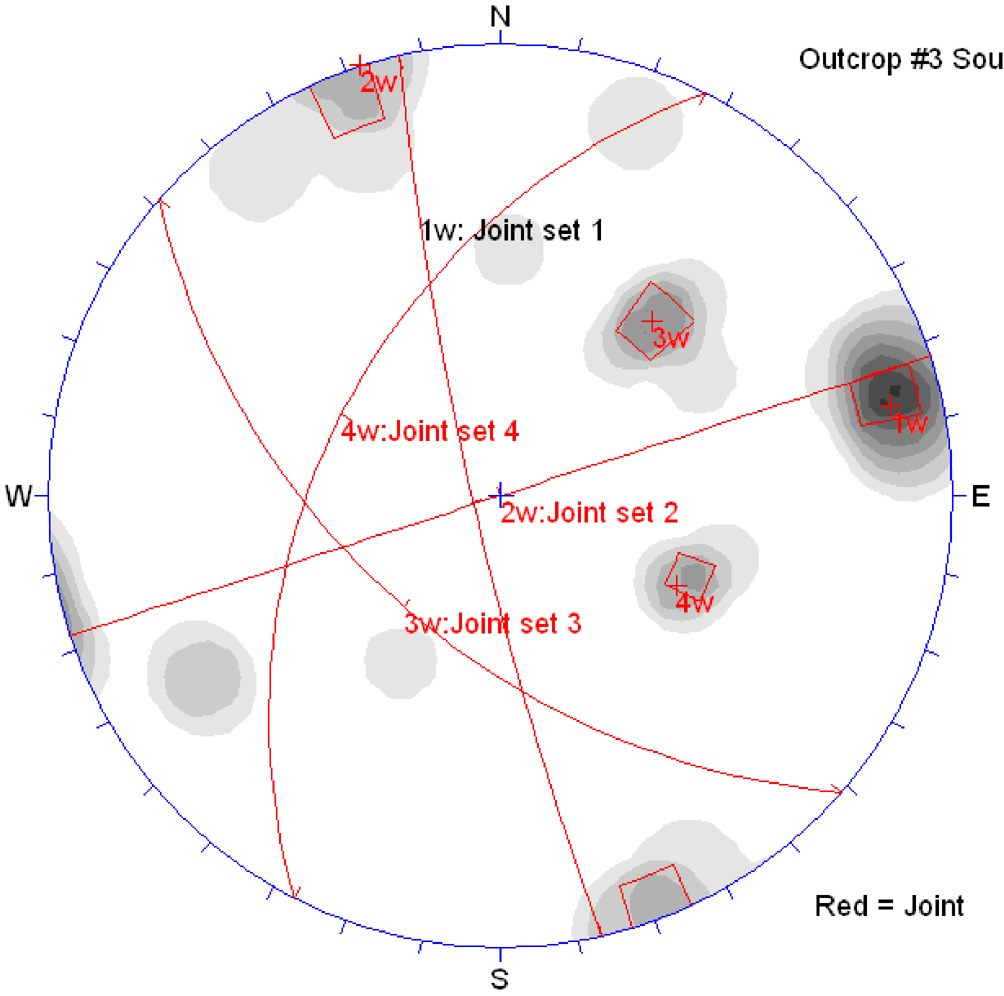
ID		Dip / Direction
1	w	87 / 236
2	w	22 / 004
3	w	86 / 164

Red = Joints
Green = Foliation
Blue = Fractures

Equal Angle
Lower Hemisphere
25 Poles
25 Entries


Outcrop #2 West Side
N
E
S
W
3w:Fractures
2w:Foliation
1w
1w:Joint set
2w
Fisher
Concentrations
% of total per 1.0 % area
0.00 ~ 4.00 %
4.00 ~ 8.00 %
8.00 ~ 12.00 %
12.00 ~ 16.00 %
16.00 ~ 20.00 %
20.00 ~ 24.00 %
24.00 ~ 28.00 %
28.00 ~ 32.00 %
32.00 ~ 36.00 %
36.00 ~ 40.00 %
Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 38.9386%
Equal Angle
Lower Hemisphere
25 Poles
25 Entries
Red = Joints
Green = Foliation
Blue = Fractures

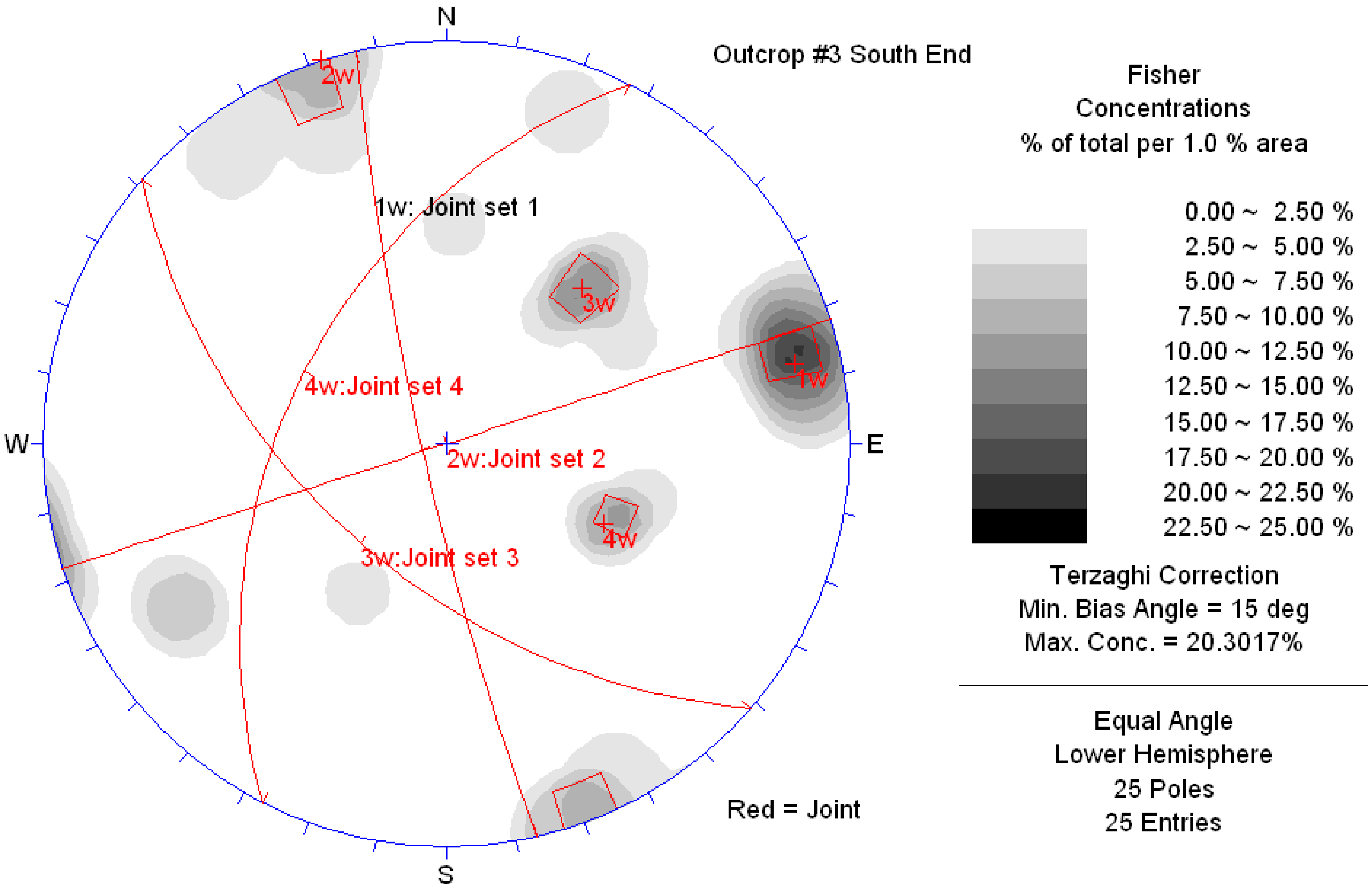
Outcrop #3 South End



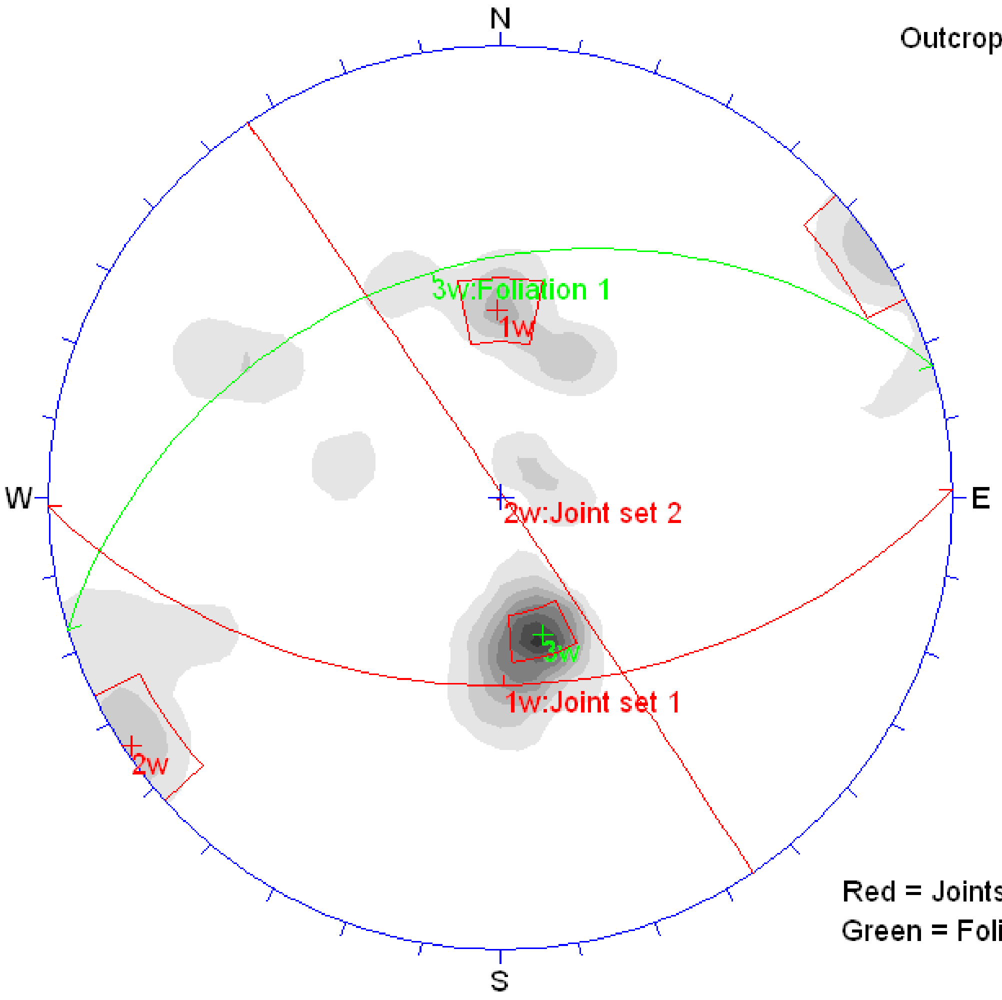
Orientations

ID		Dip / Direction
1	w	83 / 257
2	w	90 / 162
3	w	54 / 221
4	w	47 / 297

Equal Angle
Lower Hemisphere
25 Poles
25 Entries


Outcrop #3 South End
N
E
S
W
1w: Joint set 1
2w:Joint set 2
3w:Joint set 3
4w:Joint set 4
1w
2w
3w
4w
Red = Joint
Fisher
Concentrations
% of total per 1.0 % area
0.00 ~ 2.50 %
2.50 ~ 5.00 %
5.00 ~ 7.50 %
7.50 ~ 10.00 %
10.00 ~ 12.50 %
12.50 ~ 15.00 %
15.00 ~ 17.50 %
17.50 ~ 20.00 %
20.00 ~ 22.50 %
22.50 ~ 25.00 %
Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 20.3017%
Equal Angle
Lower Hemisphere
25 Poles
25 Entries

Outcrop #4 East Side

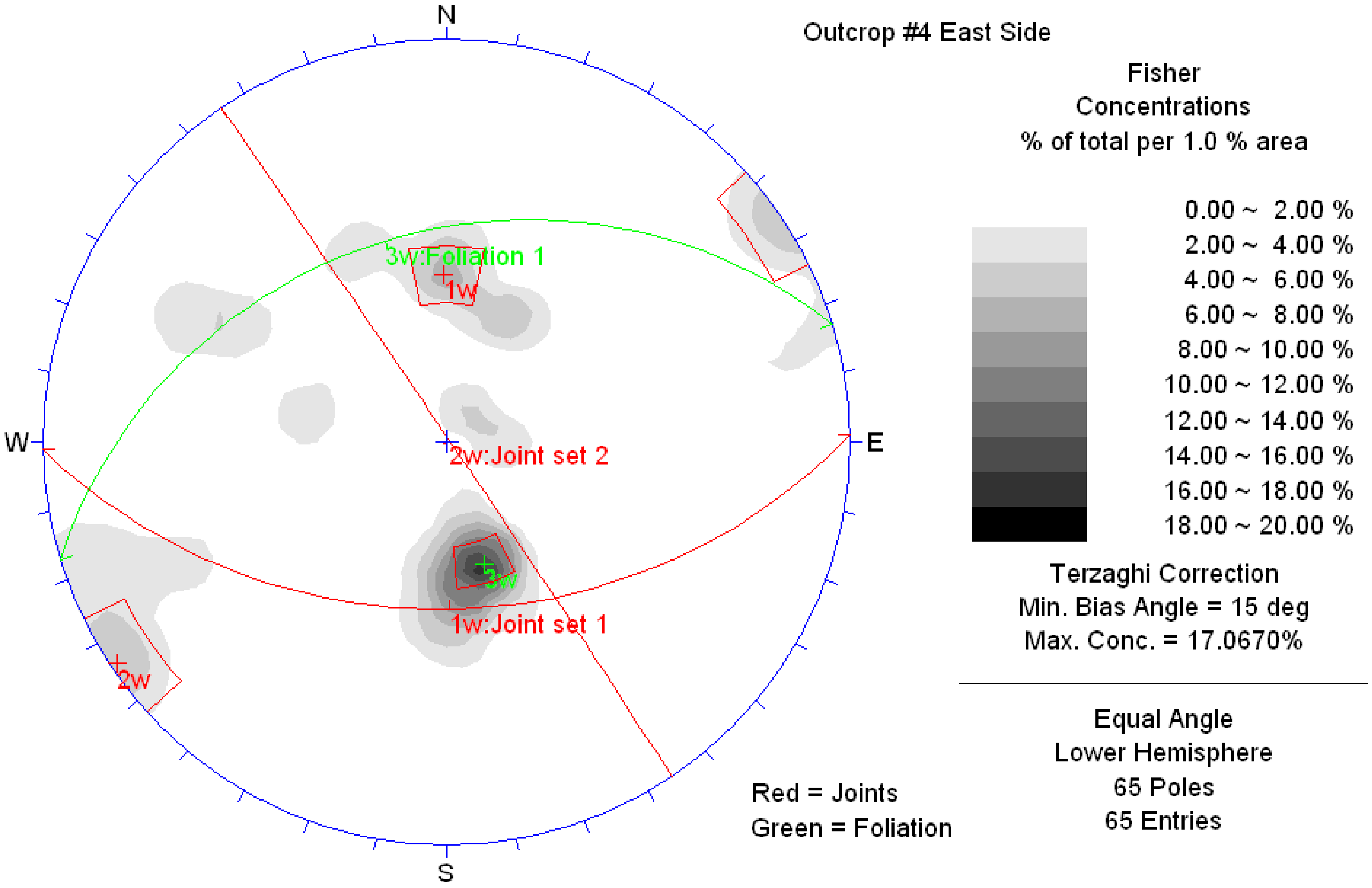


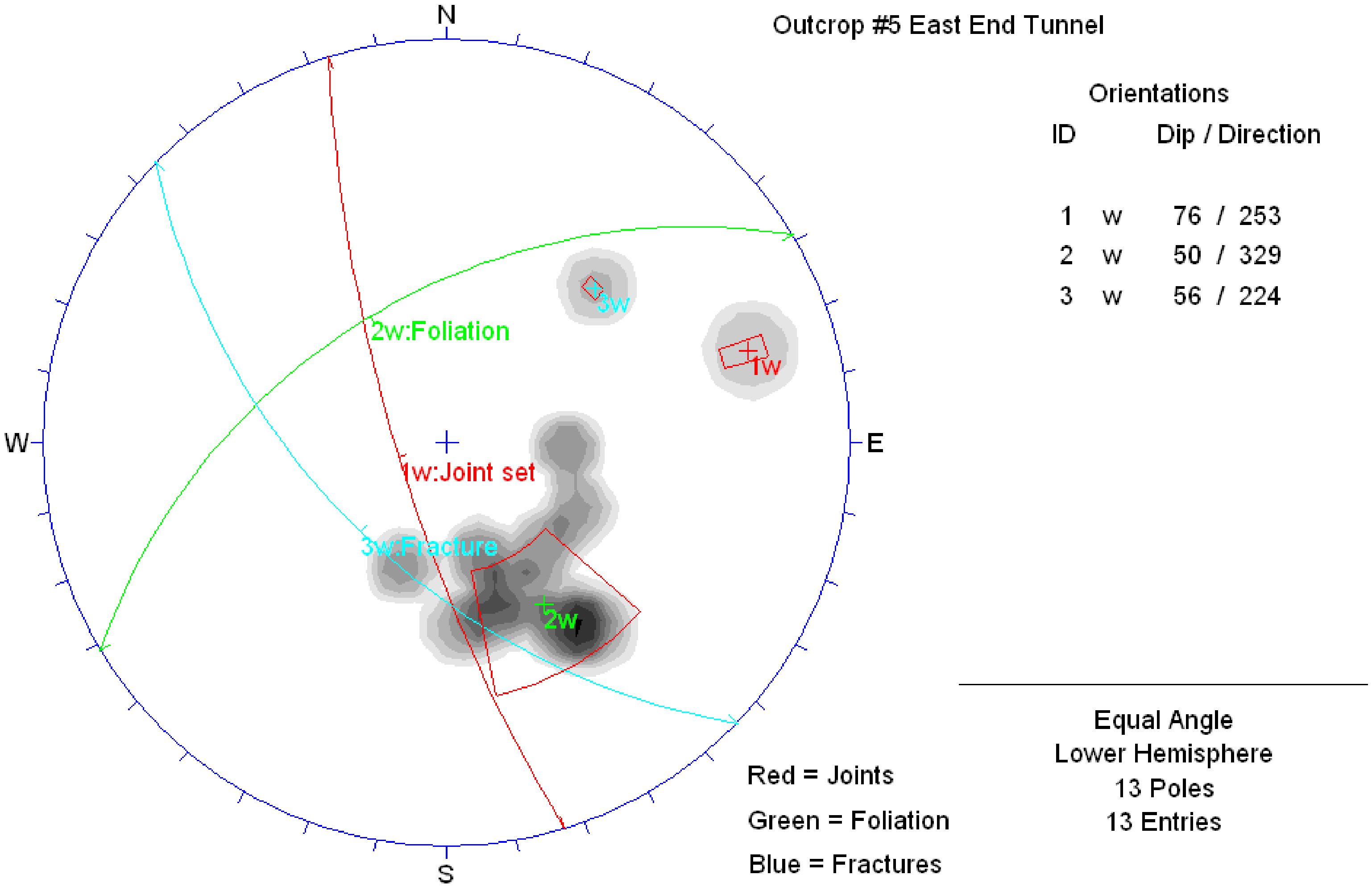
Orientations

ID		Dip / Direction
1	w	45 / 179
2	w	89 / 056
3	w	35 / 343

Equal Angle
Lower Hemisphere
65 Poles
65 Entries

Red = Joints
Green = Foliation


Outcrop #4 East Side
N
E
S
W
3w:Foliation 1
1w
2w:Joint set 2
3w
1w:Joint set 1
2w
Fisher
Concentrations
% of total per 1.0 % area
0.00 ~ 2.00 %
2.00 ~ 4.00 %
4.00 ~ 6.00 %
6.00 ~ 8.00 %
8.00 ~ 10.00 %
10.00 ~ 12.00 %
12.00 ~ 14.00 %
14.00 ~ 16.00 %
16.00 ~ 18.00 %
18.00 ~ 20.00 %
Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 17.0670%
Equal Angle
Lower Hemisphere
65 Poles
65 Entries
Red = Joints
Green = Foliation



Outcrop #5 East End Tunnel

Orientations

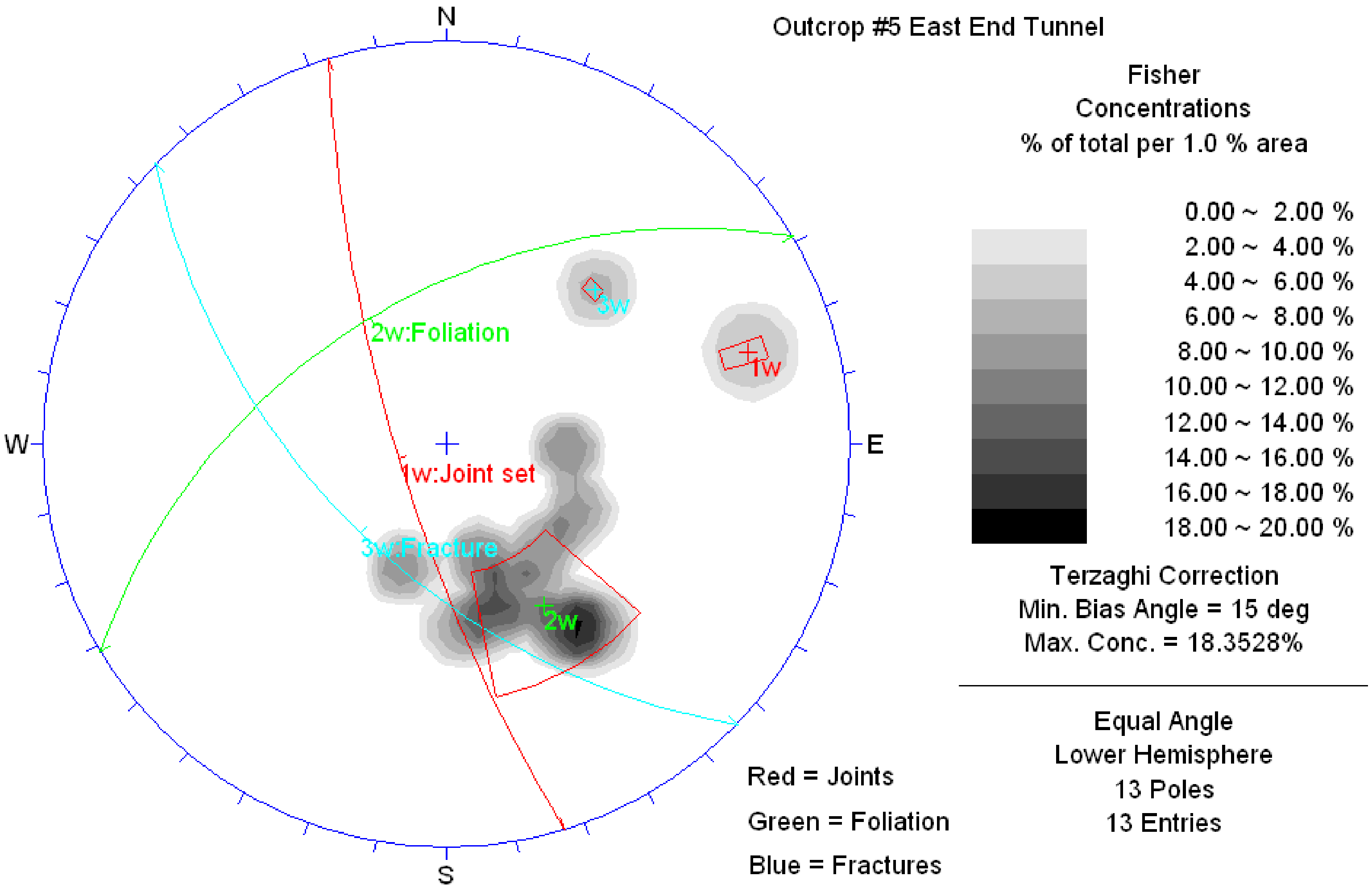
ID		Dip / Direction
1	w	76 / 253
2	w	50 / 329
3	w	56 / 224

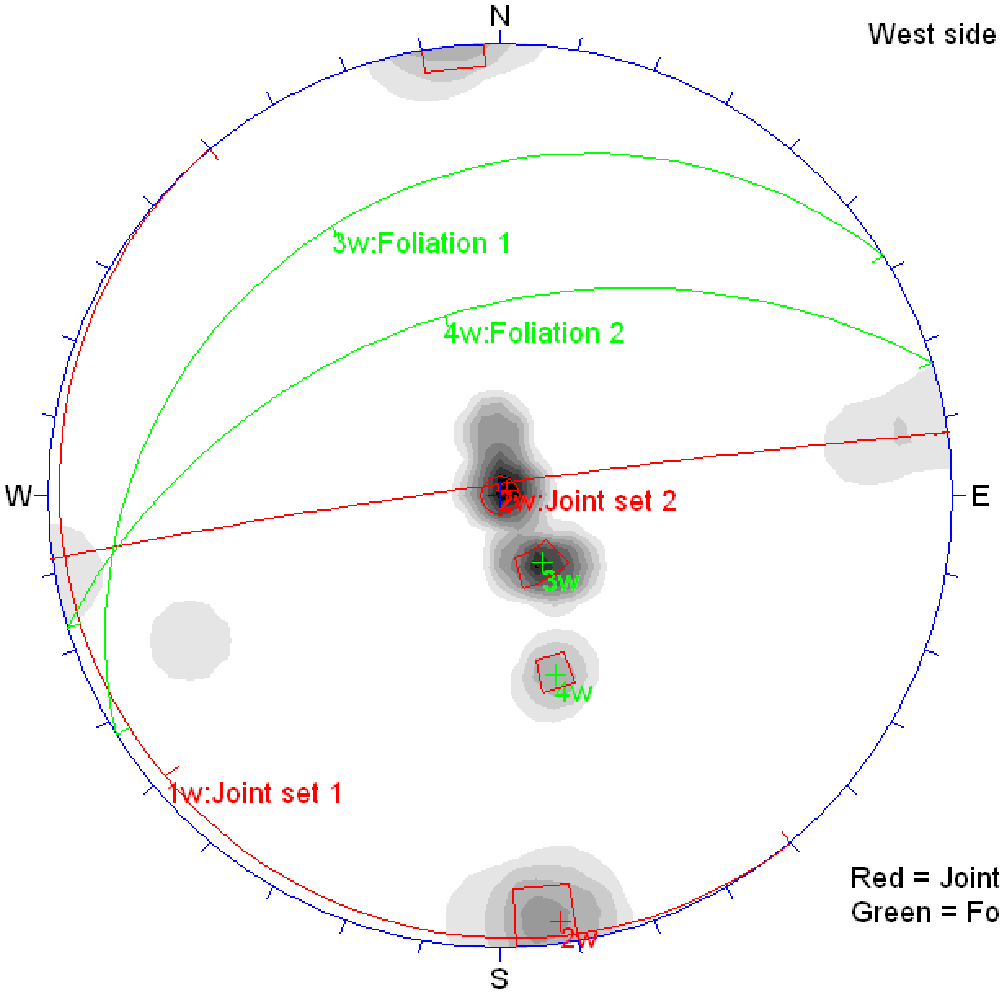
Red = Joints

Green = Foliation

Blue = Fractures

Equal Angle
Lower Hemisphere
13 Poles
13 Entries


Outcrop #5 East End Tunnel
N
E
S
W
1w:Joint set
2w:Foliation
3w:Fracture
1w
2w
3w
Fisher
Concentrations
% of total per 1.0 % area
0.00 ~ 2.00 %
2.00 ~ 4.00 %
4.00 ~ 6.00 %
6.00 ~ 8.00 %
8.00 ~ 10.00 %
10.00 ~ 12.00 %
12.00 ~ 14.00 %
14.00 ~ 16.00 %
16.00 ~ 18.00 %
18.00 ~ 20.00 %
Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 18.3528%
Equal Angle
Lower Hemisphere
13 Poles
13 Entries
Red = Joints
Green = Foliation
Blue = Fractures



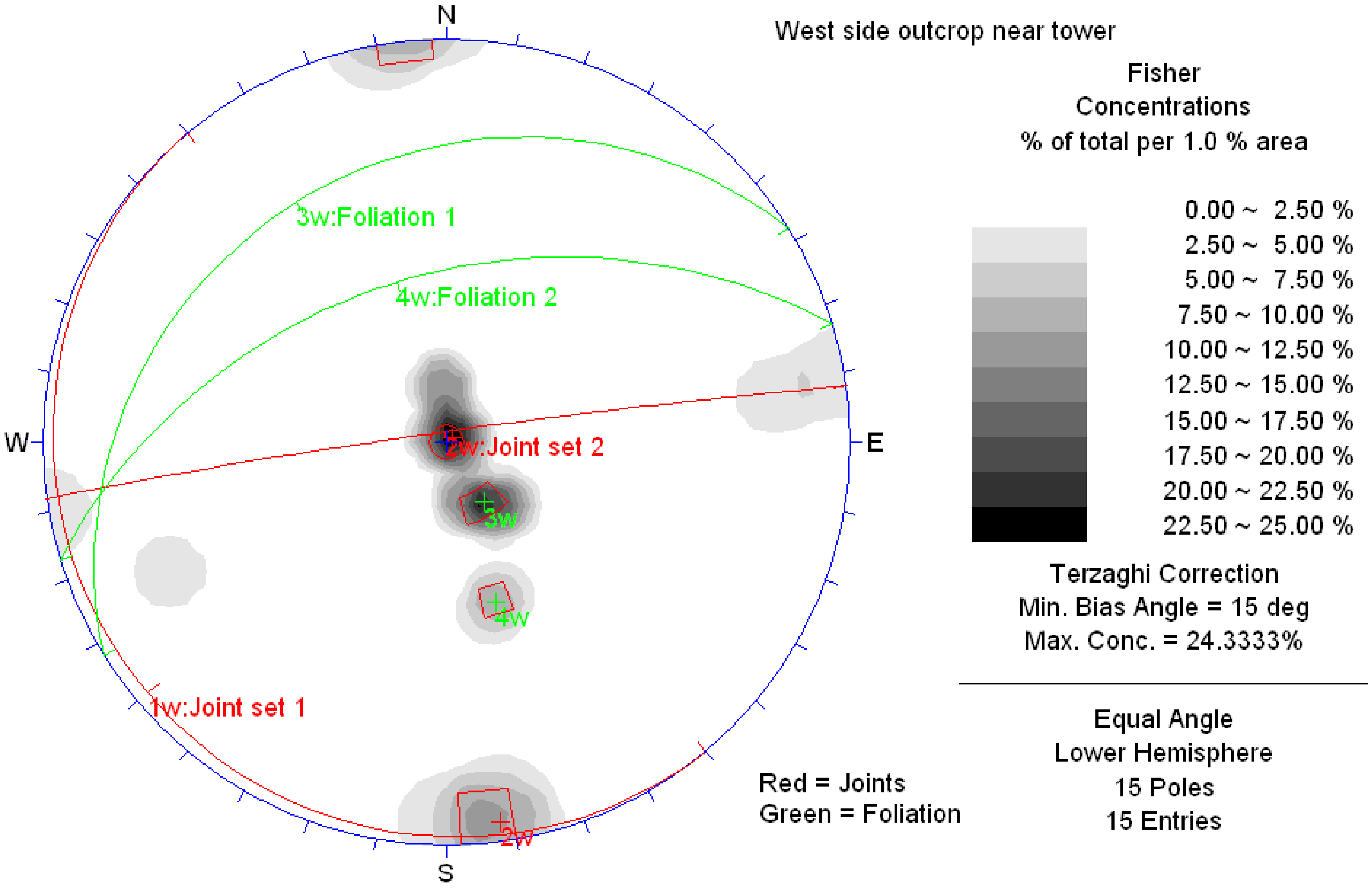
West side outcrop near tower

Orientations

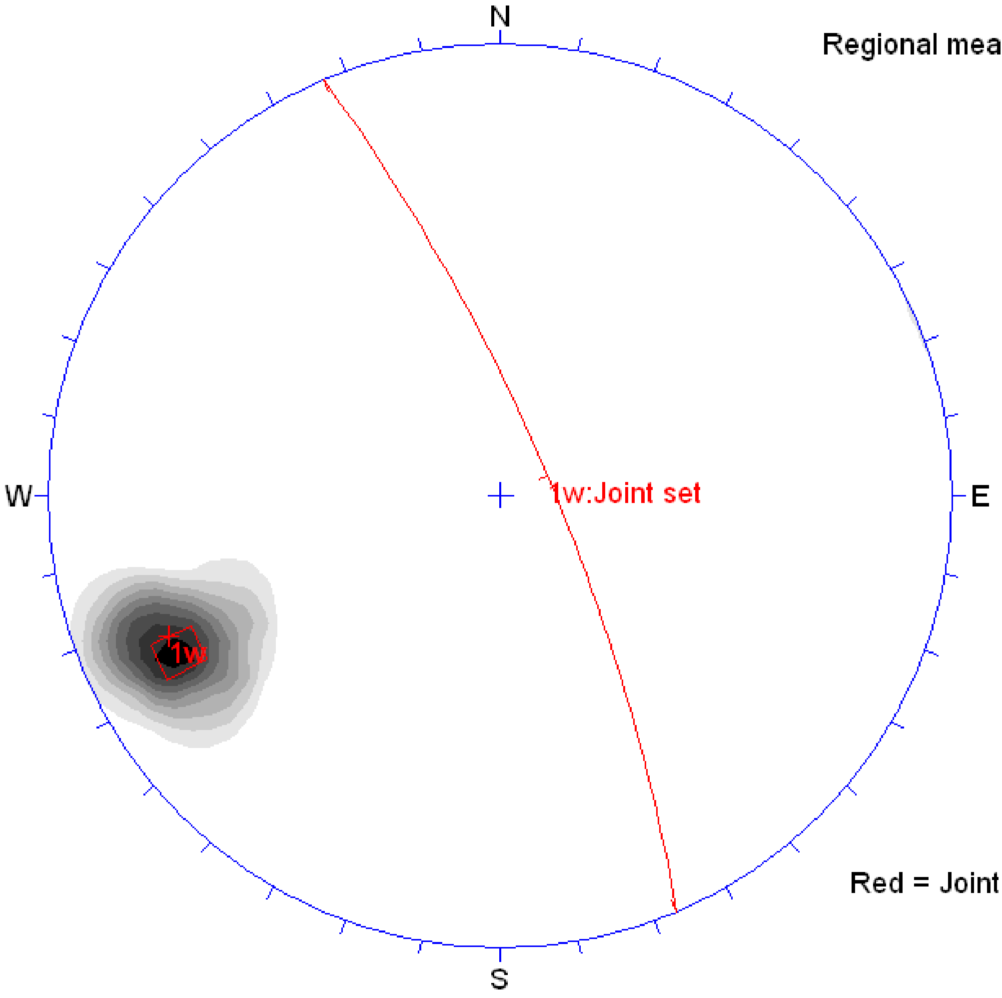
ID		Dip / Direction
1	w	02 / 230
2	w	87 / 352
3	w	20 / 328
4	w	45 / 343

Red = Joints
Green = Foliation

Equal Angle
Lower Hemisphere
15 Poles
15 Entries


West side outcrop near tower
N
E
S
W
3w:Foliation 1
4w:Foliation 2
2w:Joint set 2
1w:Joint set 1
3w
4w
2w
Fisher
Concentrations
% of total per 1.0 % area
0.00 ~ 2.50 %
2.50 ~ 5.00 %
5.00 ~ 7.50 %
7.50 ~ 10.00 %
10.00 ~ 12.50 %
12.50 ~ 15.00 %
15.00 ~ 17.50 %
17.50 ~ 20.00 %
20.00 ~ 22.50 %
22.50 ~ 25.00 %
Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 24.3333%
Equal Angle
Lower Hemisphere
15 Poles
15 Entries
Red = Joints
Green = Foliation

Regional measurements North and West of Tunnel

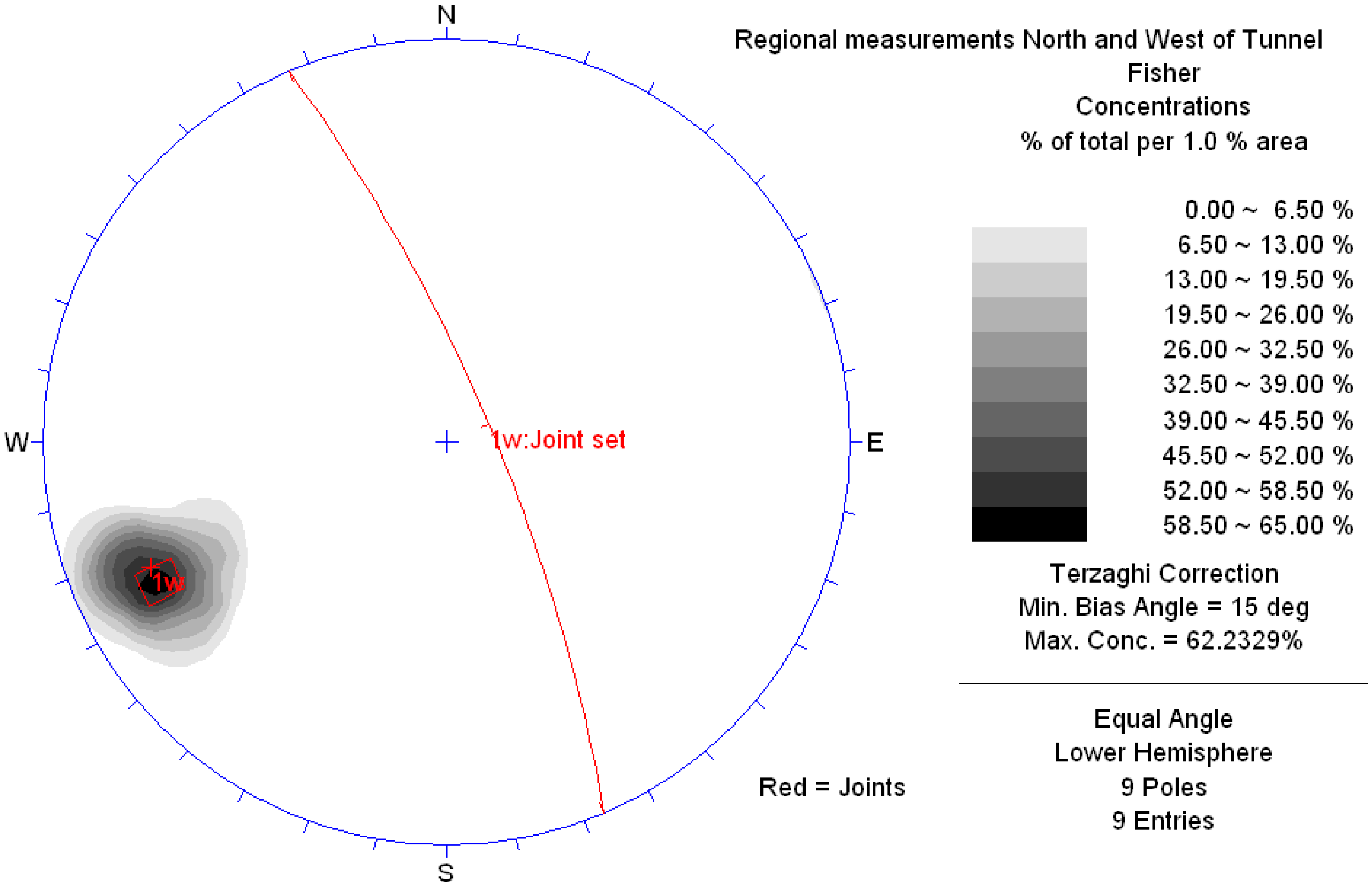


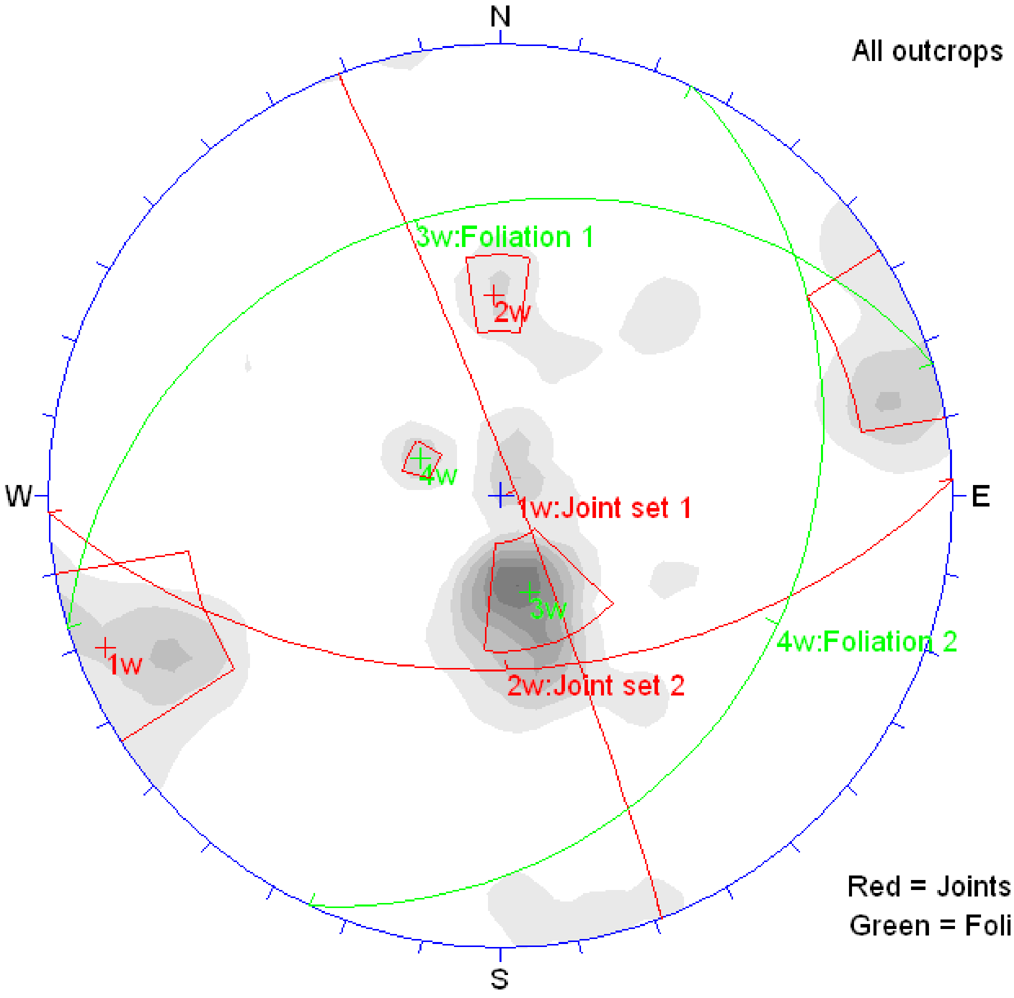
Orientations

ID	Dip / Direction
1 w	77 / 067

Red = Joints

Equal Angle
Lower Hemisphere
9 Poles
9 Entries


Regional measurements North and West of Tunnel
Fisher
Concentrations
% of total per 1.0 % area
0.00 ~ 6.50 %
6.50 ~ 13.00 %
13.00 ~ 19.50 %
19.50 ~ 26.00 %
26.00 ~ 32.50 %
32.50 ~ 39.00 %
39.00 ~ 45.50 %
45.50 ~ 52.00 %
52.00 ~ 58.50 %
58.50 ~ 65.00 %
Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 62.2329%
Equal Angle
Lower Hemisphere
9 Poles
9 Entries
Red = Joints
N
E
S
W
1w:Joint set
1w



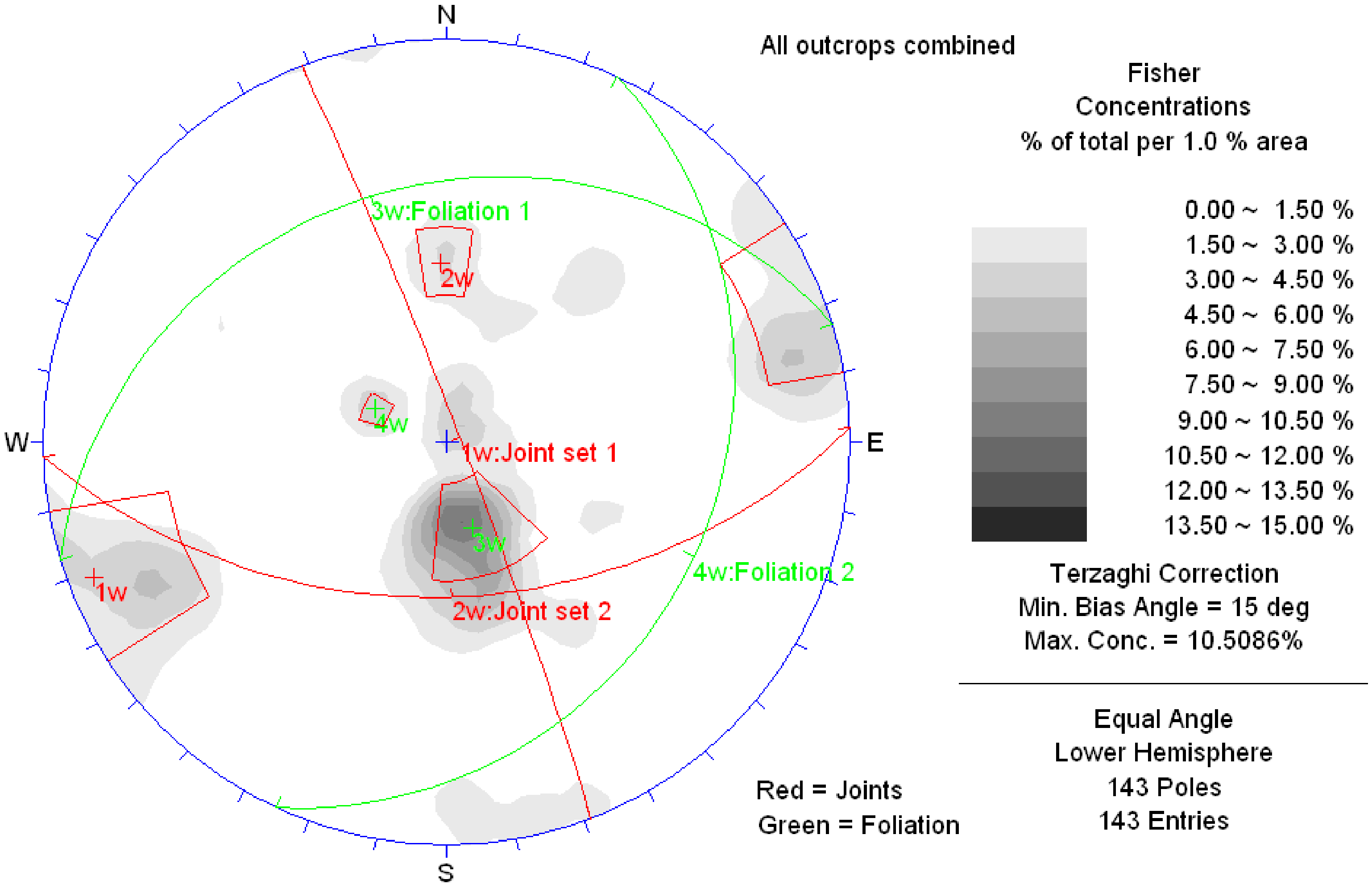
All outcrops combined

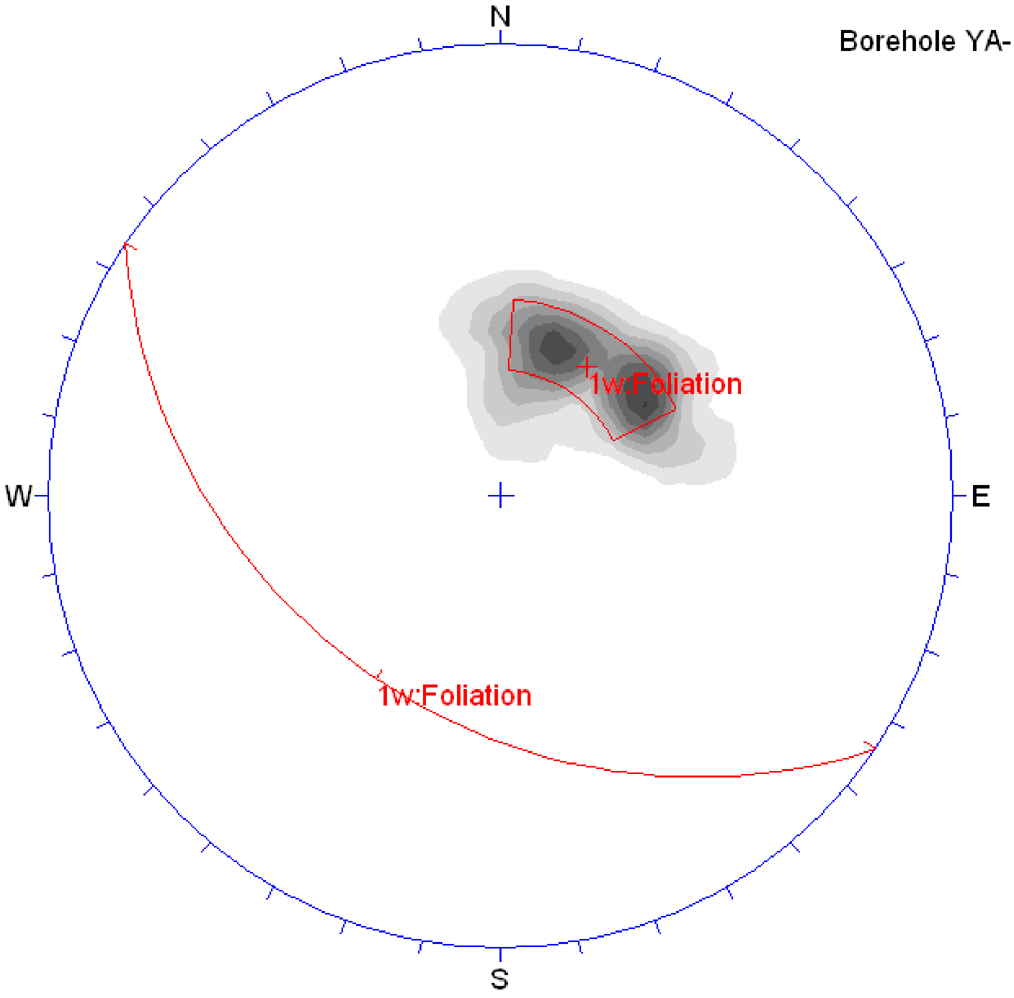
Orientations

ID		Dip / Direction
1	w	86 / 069
2	w	48 / 178
3	w	25 / 343
4	w	22 / 115

Red = Joints
Green = Foliation

Equal Angle
Lower Hemisphere
143 Poles
143 Entries


N
S
W
E
All outcrops combined
3w:Foliation 1
2w
4w
1w:Joint set 1
3w
1w
2w:Joint set 2
4w:Foliation 2
Fisher
Concentrations
% of total per 1.0 % area
0.00 ~ 1.50 %
1.50 ~ 3.00 %
3.00 ~ 4.50 %
4.50 ~ 6.00 %
6.00 ~ 7.50 %
7.50 ~ 9.00 %
9.00 ~ 10.50 %
10.50 ~ 12.00 %
12.00 ~ 13.50 %
13.50 ~ 15.00 %
Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 10.5086%
Equal Angle
Lower Hemisphere
143 Poles
143 Entries
Red = Joints
Green = Foliation

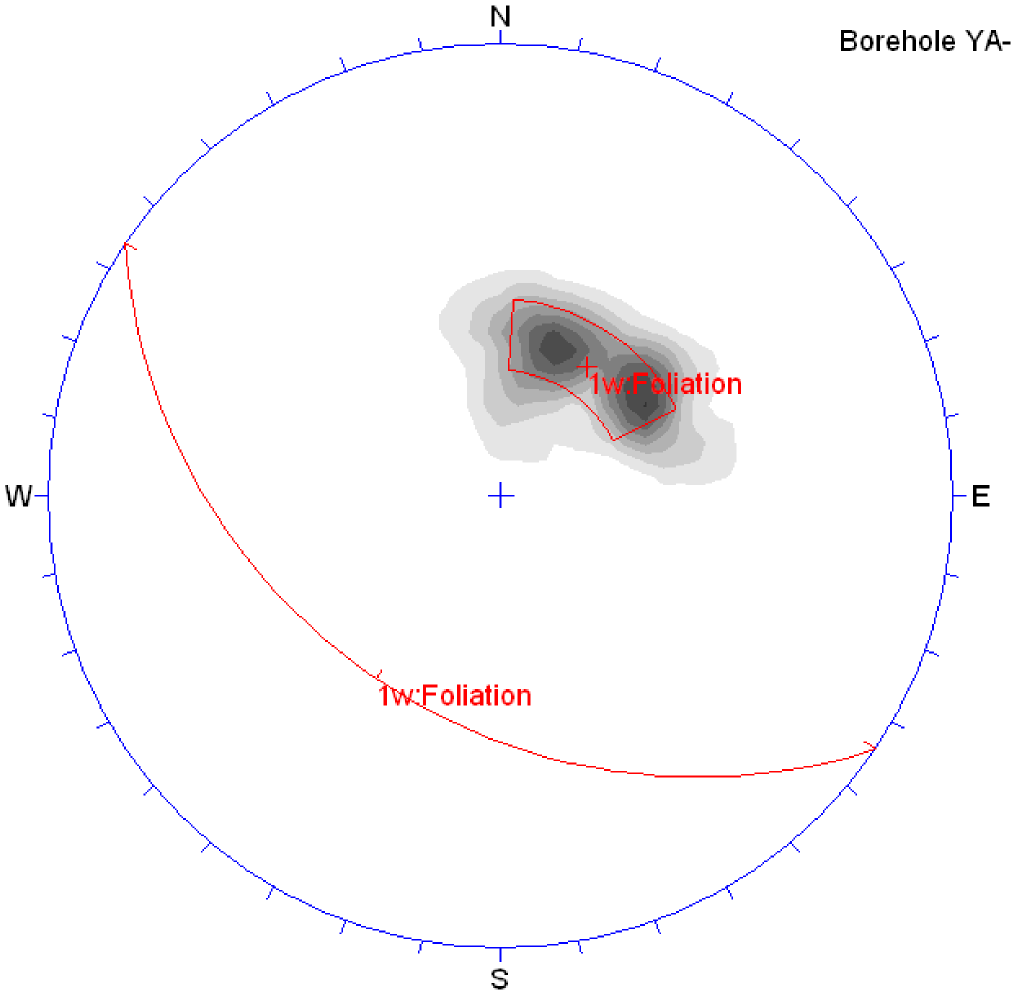


Borehole YA-T1, West end, Eastbound. left lane

Orientations

ID		Dip / Direction
1	w	38 / 214

Equal Angle
Lower Hemisphere
74 Poles
74 Entries



Borehole YA-T1, West end, Eastbound. left lane

Fisher

Concentrations

% of total per 1.0 % area

0.00 ~ 2.50 %

2.50 ~ 5.00 %

5.00 ~ 7.50 %

7.50 ~ 10.00 %

10.00 ~ 12.50 %

12.50 ~ 15.00 %

15.00 ~ 17.50 %

17.50 ~ 20.00 %

20.00 ~ 22.50 %

22.50 ~ 25.00 %

Terzaghi Correction

Min. Bias Angle = 15 deg

Max. Conc. = 20.2425%

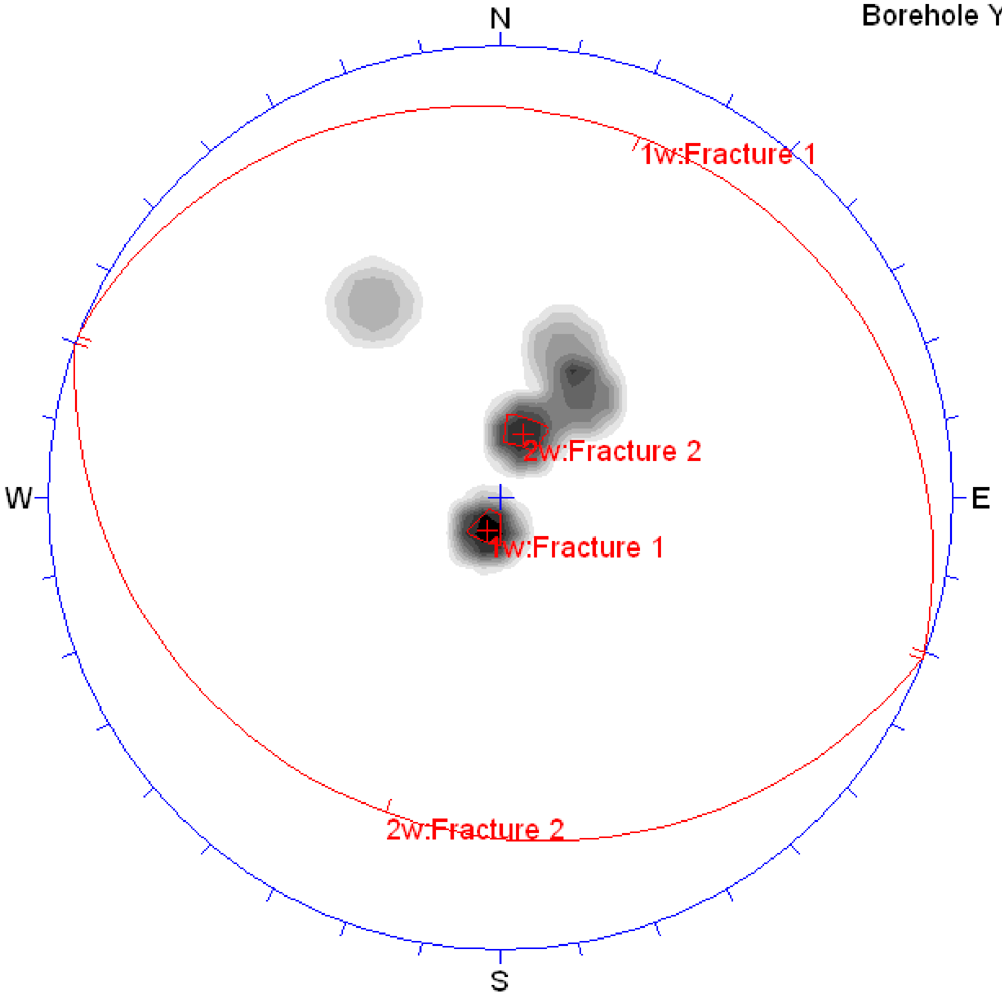
Equal Angle

Lower Hemisphere

74 Poles

74 Entries

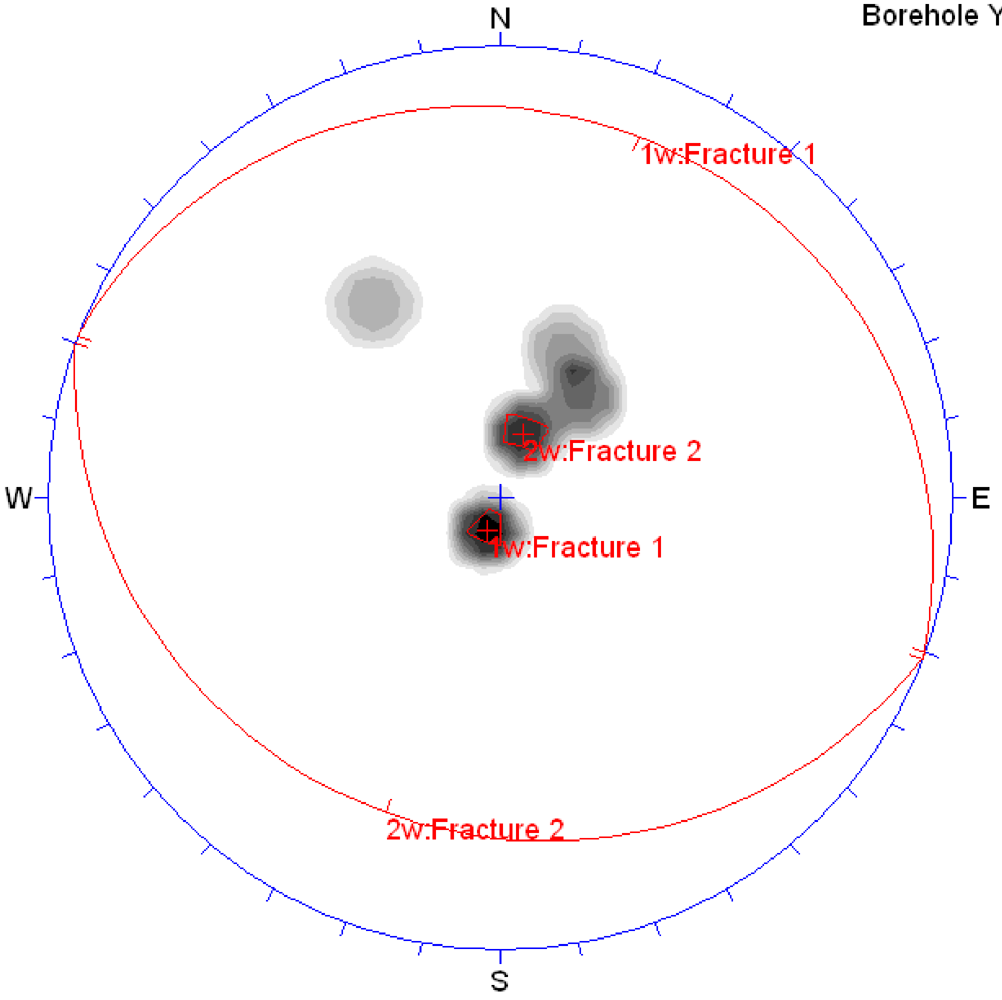
Borehole YA-T1, West end, Eastbound, left lane



Orientations

ID		Dip / Direction
1	w	09 / 021
2	w	17 / 200

Equal Angle
Lower Hemisphere
5 Poles
5 Entries



Borehole YA-T1, West end, Eastbound, left lane

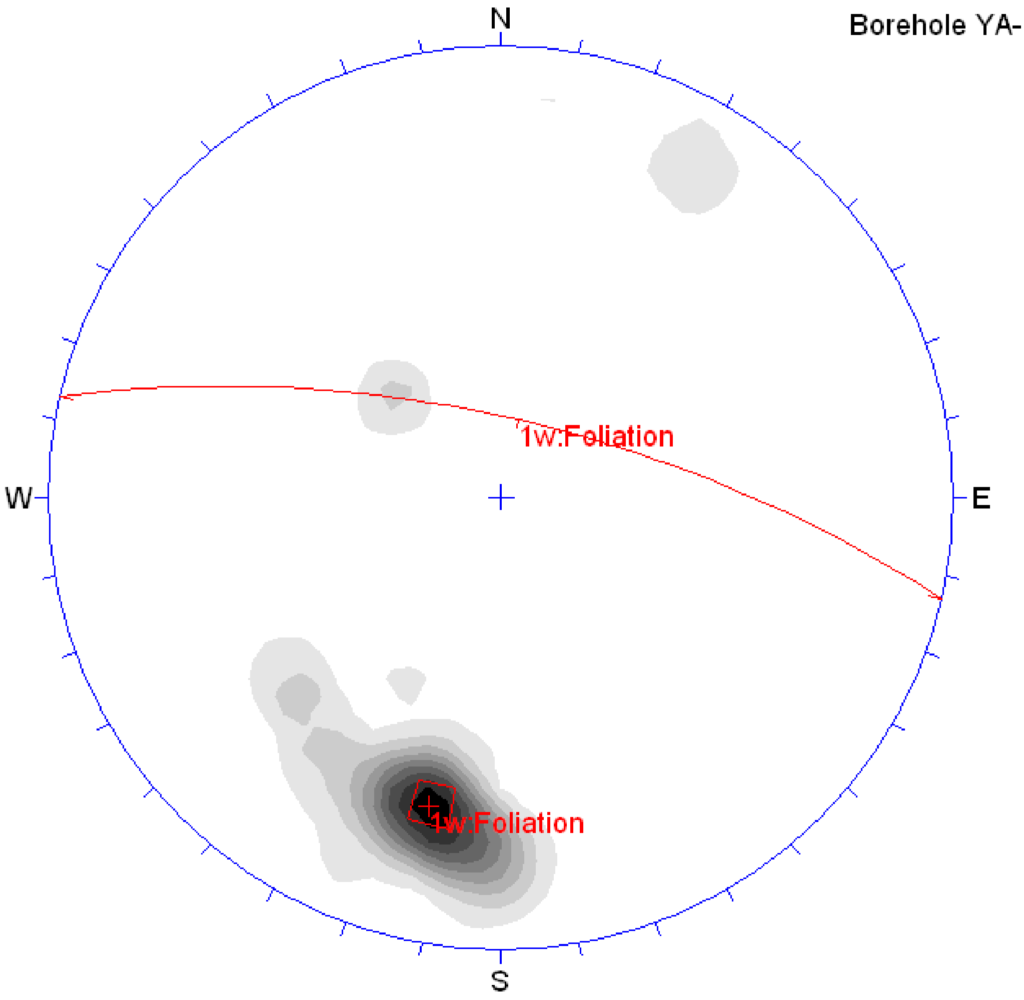
Fisher
Concentrations
% of total per 1.0 % area

0.00 ~ 3.00 %
3.00 ~ 6.00 %
6.00 ~ 9.00 %
9.00 ~ 12.00 %
12.00 ~ 15.00 %
15.00 ~ 18.00 %
18.00 ~ 21.00 %
21.00 ~ 24.00 %
24.00 ~ 27.00 %
27.00 ~ 30.00 %

Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 29.0401%

Equal Angle
Lower Hemisphere
5 Poles
5 Entries

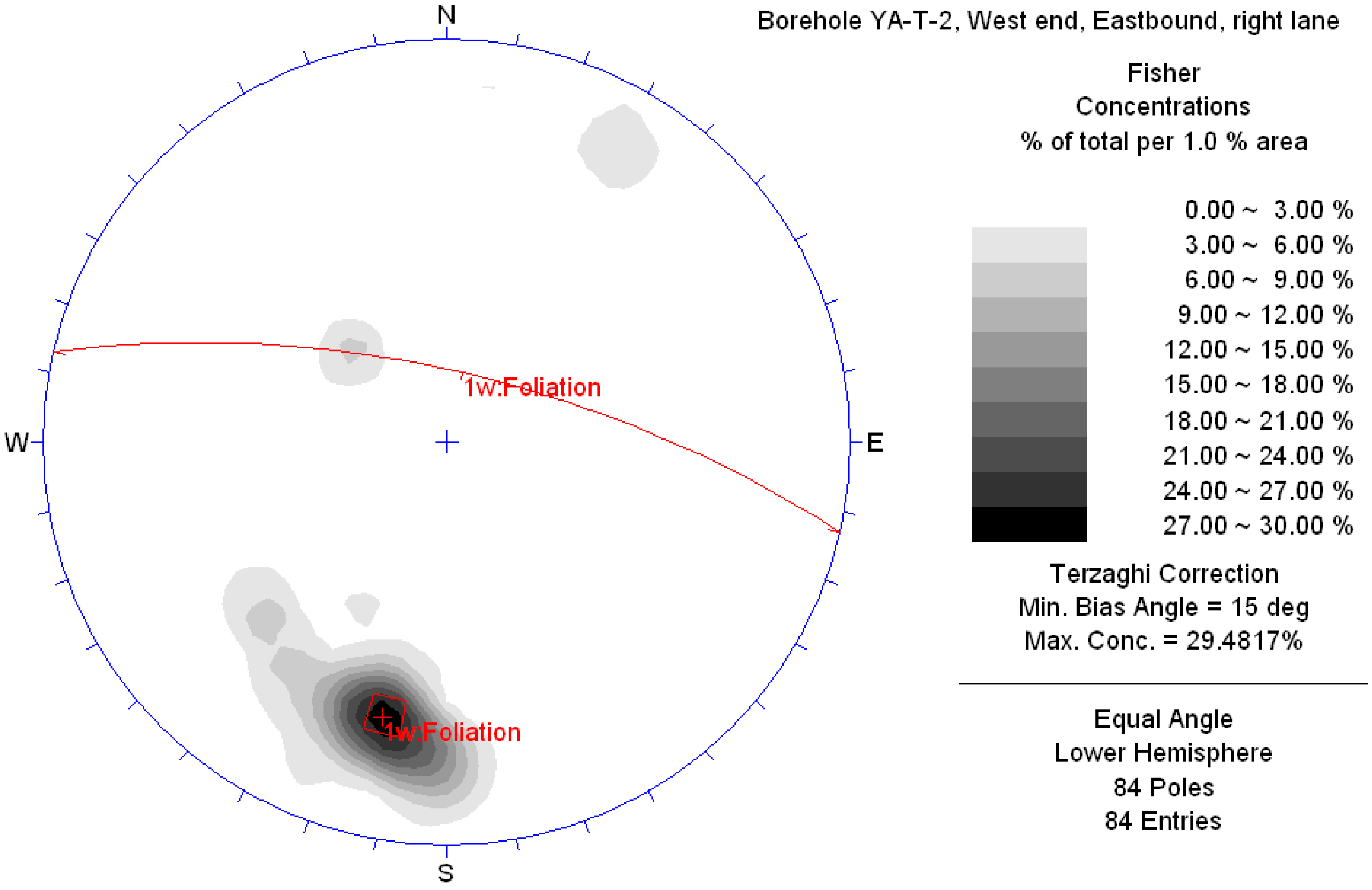
Borehole YA-T-2, West end, Eastbound, right lane



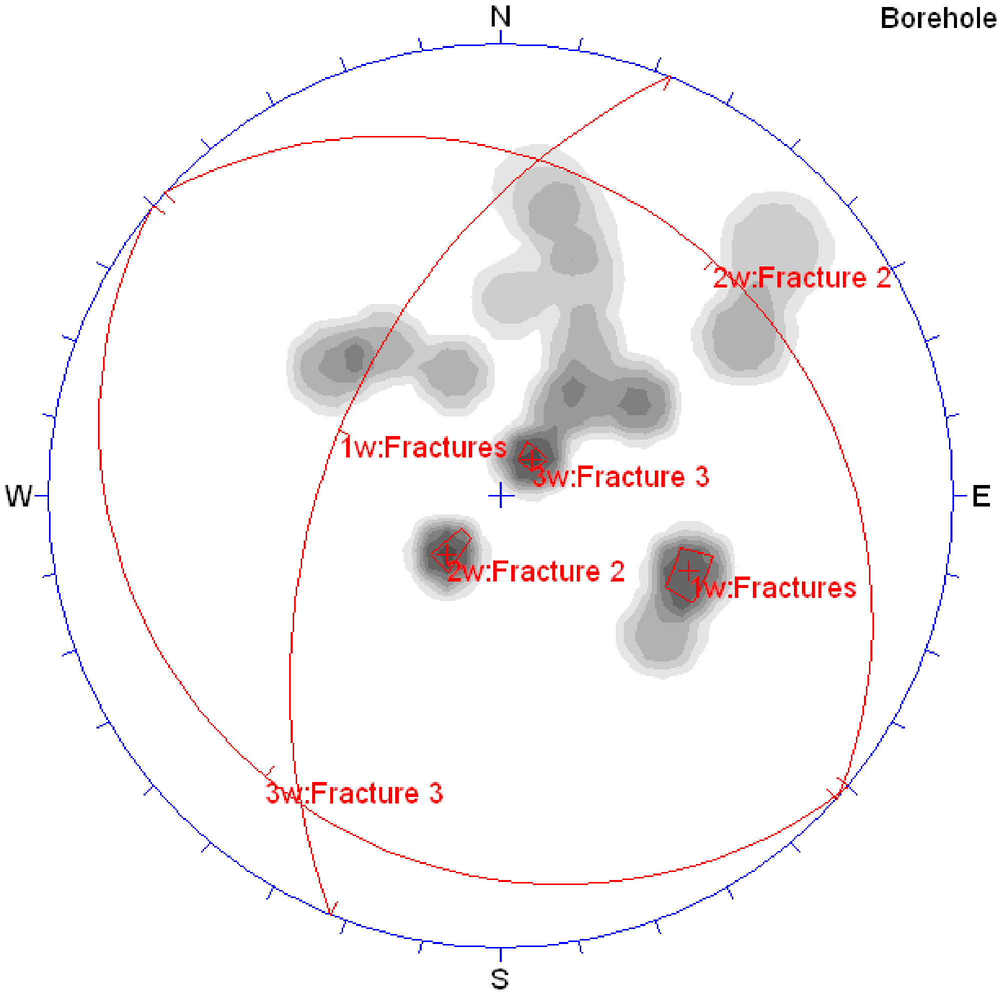
Orientations

ID		Dip / Direction
1	w	70 / 013

Equal Angle
Lower Hemisphere
84 Poles
84 Entries


Borehole YA-T-2, West end, Eastbound, right lane
N
E
S
W
1w:Foliation
1w:Foliation
Fisher
Concentrations
% of total per 1.0 % area
0.00 ~ 3.00 %
3.00 ~ 6.00 %
6.00 ~ 9.00 %
9.00 ~ 12.00 %
12.00 ~ 15.00 %
15.00 ~ 18.00 %
18.00 ~ 21.00 %
21.00 ~ 24.00 %
24.00 ~ 27.00 %
27.00 ~ 30.00 %
Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 29.4817%
Equal Angle
Lower Hemisphere
84 Poles
84 Entries

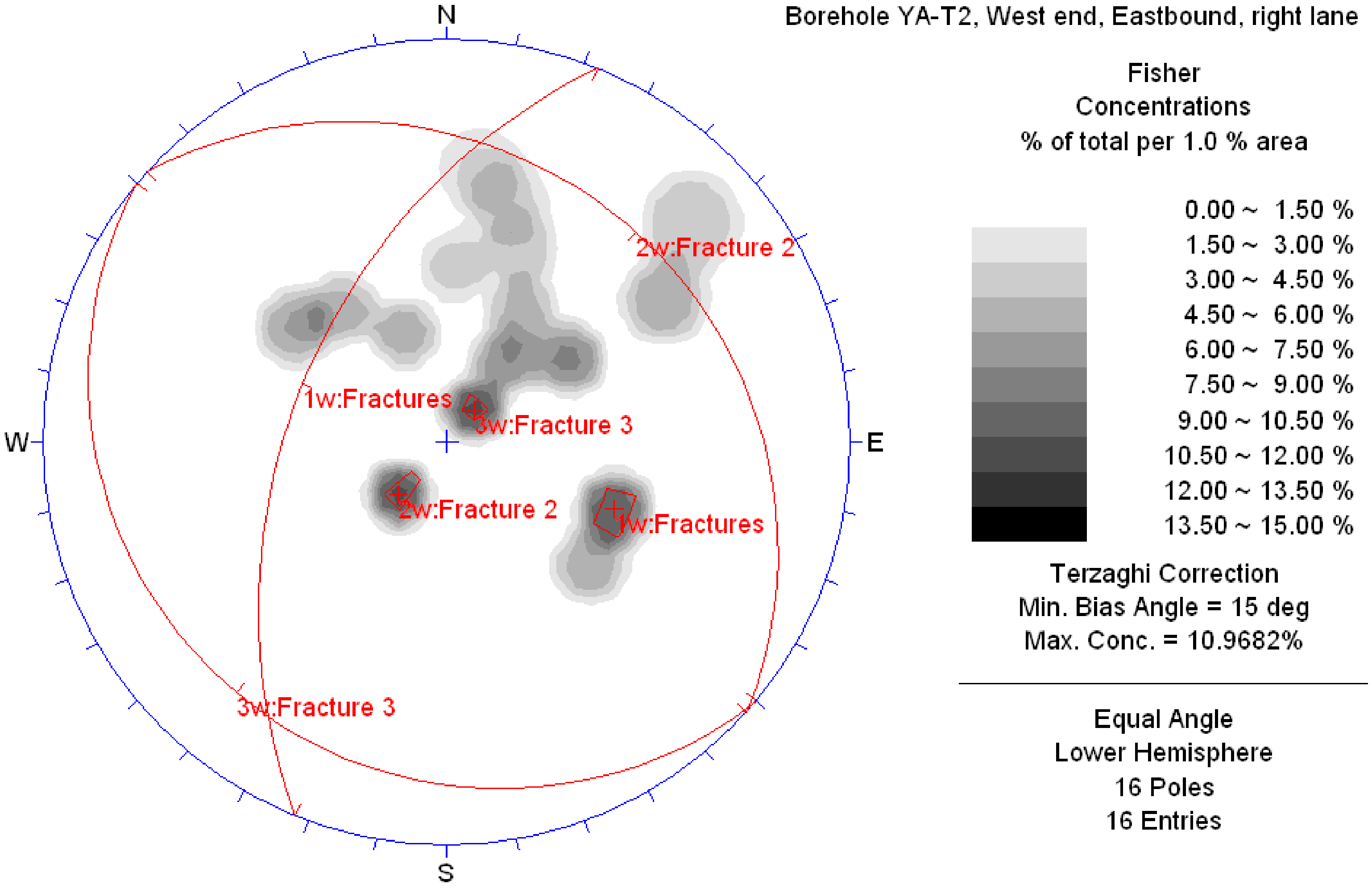
Borehole YA-T2, West end, Eastbound, right lane

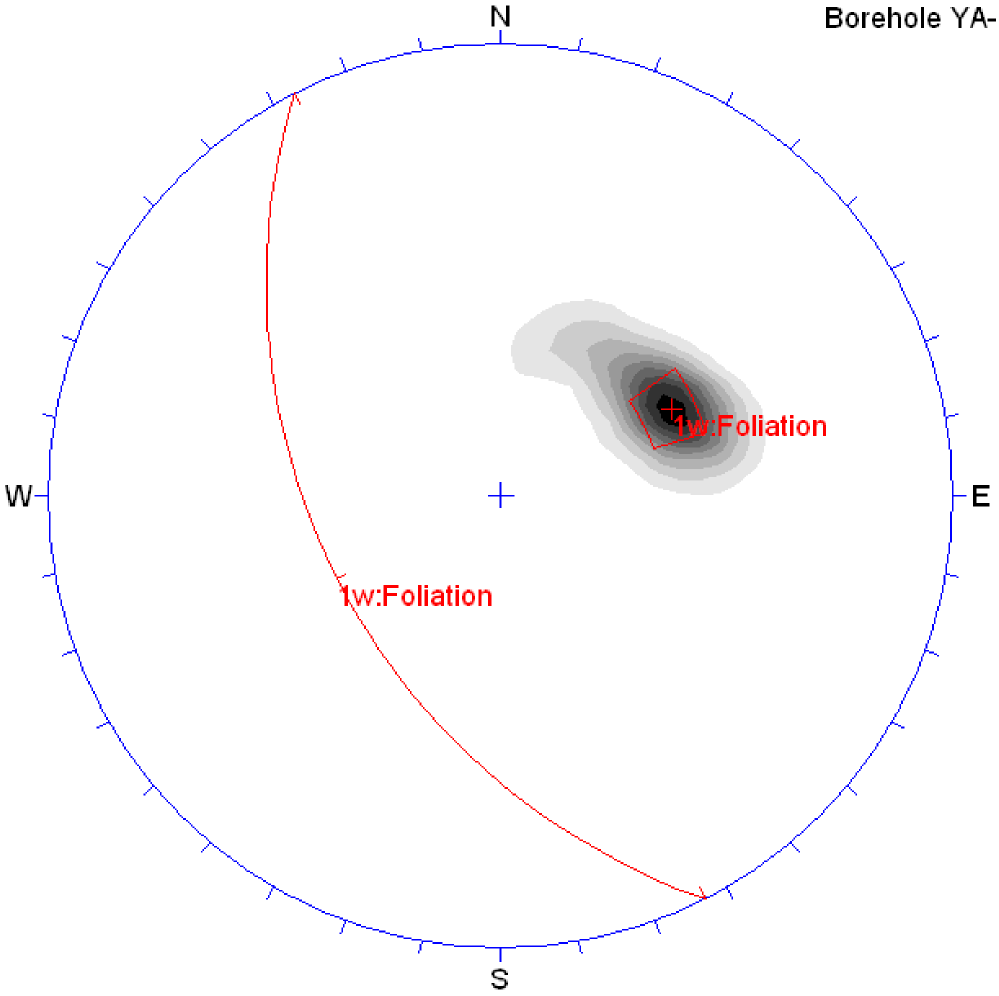


Orientations

ID		Dip / Direction
1	w	48 / 292
2	w	20 / 042
3	w	12 / 220

Equal Angle
Lower Hemisphere
16 Poles
16 Entries


Borehole YA-T2, West end, Eastbound, right lane
N
E
S
W
2w:Fracture 2
1w:Fractures
3w:Fracture 3
2w:Fracture 2
1w:Fractures
3w:Fracture 3
Fisher
Concentrations
% of total per 1.0 % area
0.00 ~ 1.50 %
1.50 ~ 3.00 %
3.00 ~ 4.50 %
4.50 ~ 6.00 %
6.00 ~ 7.50 %
7.50 ~ 9.00 %
9.00 ~ 10.50 %
10.50 ~ 12.00 %
12.00 ~ 13.50 %
13.50 ~ 15.00 %
Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 10.9682%
Equal Angle
Lower Hemisphere
16 Poles
16 Entries

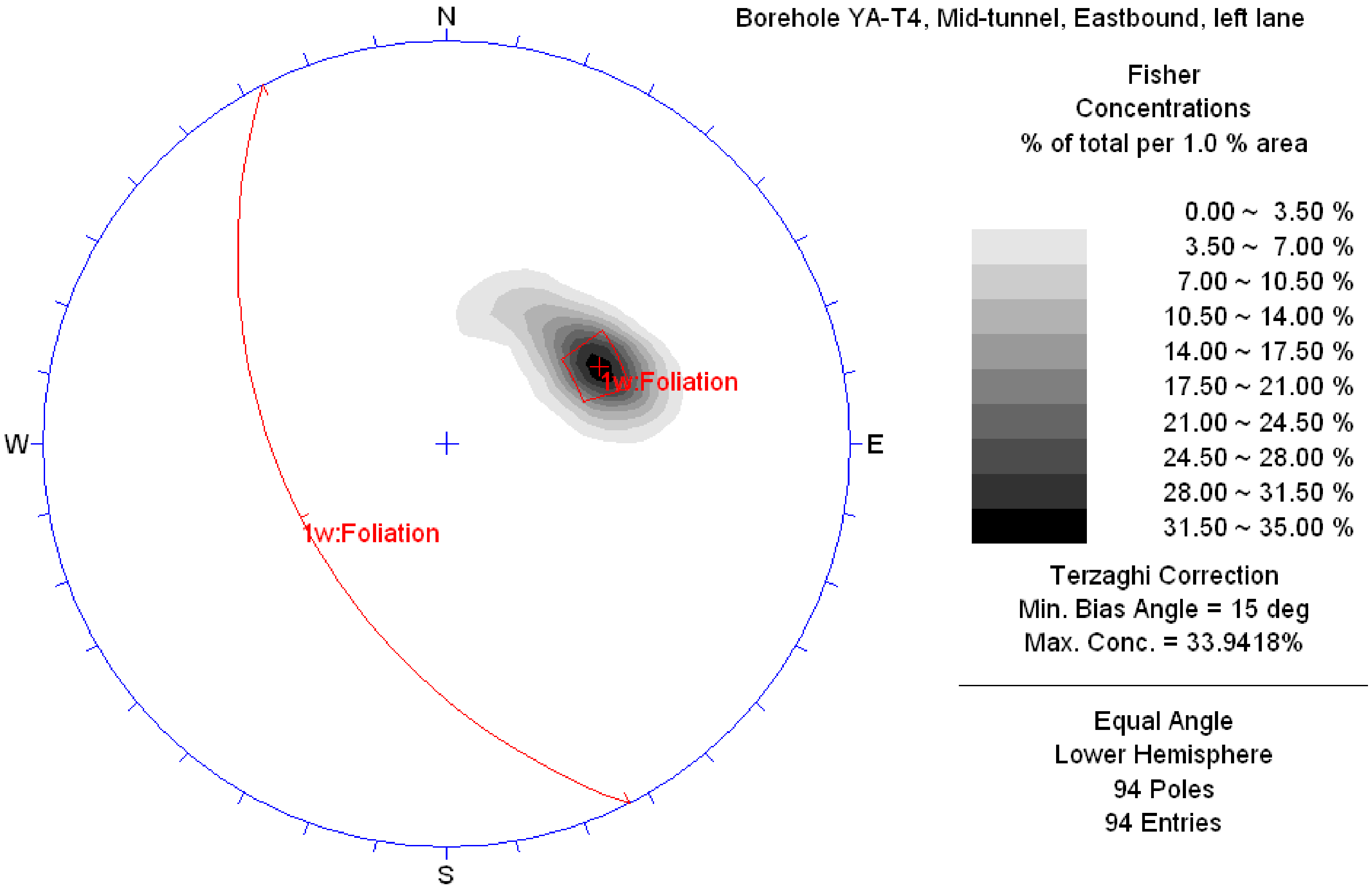


Borehole YA-T4, Mid-tunnel, Eastbound, left lane

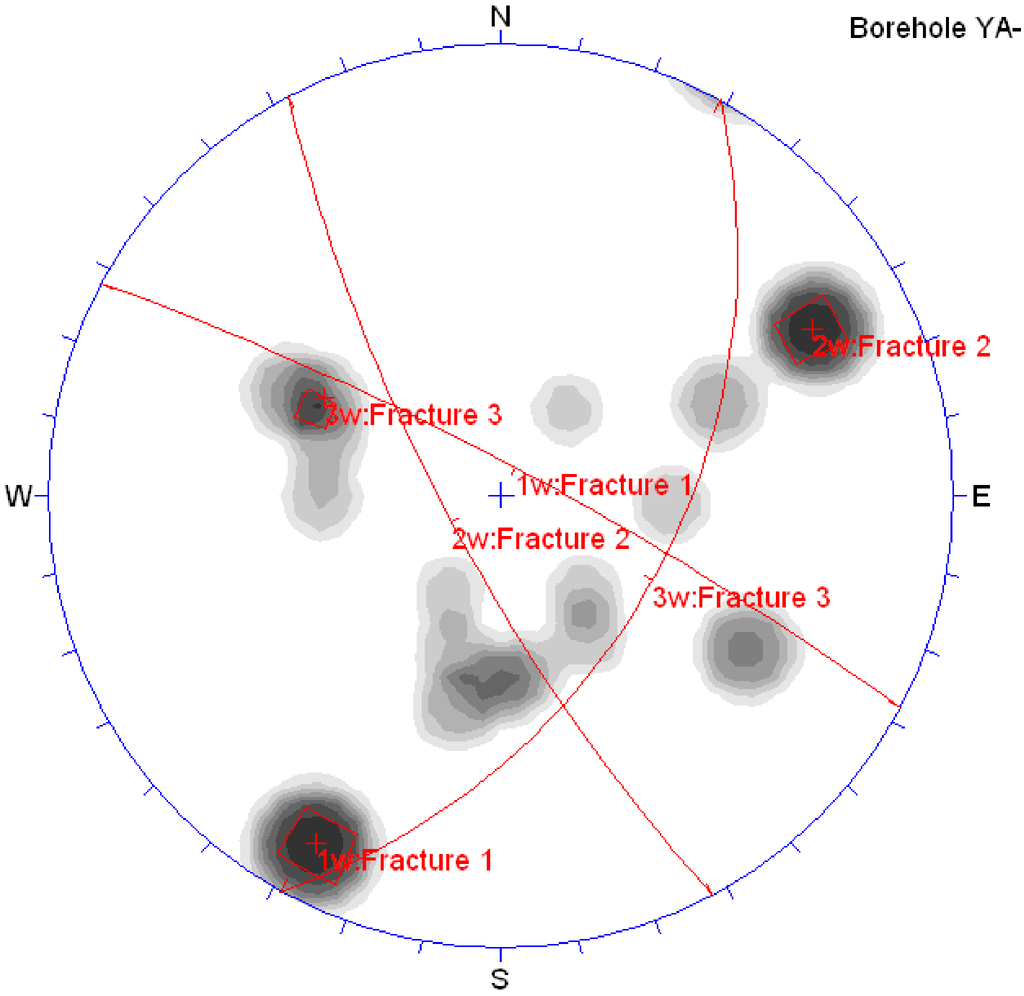
Orientations

ID		Dip / Direction
1	w	46 / 243

Equal Angle
Lower Hemisphere
94 Poles
94 Entries


Borehole YA-T4, Mid-tunnel, Eastbound, left lane
N
E
S
W
1w:Foliation
1w:Foliation
Fisher
Concentrations
% of total per 1.0 % area
0.00 ~ 3.50 %
3.50 ~ 7.00 %
7.00 ~ 10.50 %
10.50 ~ 14.00 %
14.00 ~ 17.50 %
17.50 ~ 21.00 %
21.00 ~ 24.50 %
24.50 ~ 28.00 %
28.00 ~ 31.50 %
31.50 ~ 35.00 %
Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 33.9418%
Equal Angle
Lower Hemisphere
94 Poles
94 Entries

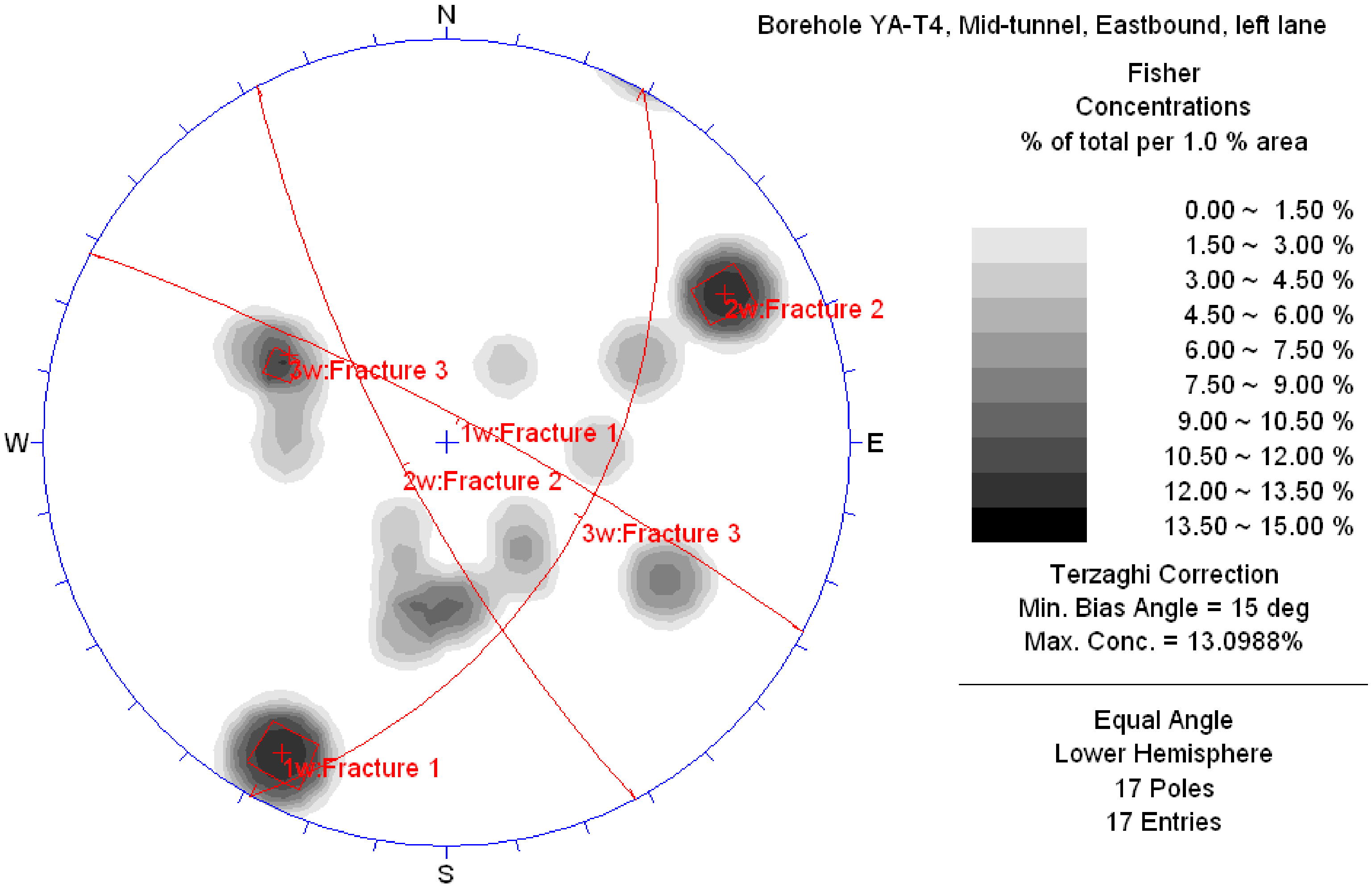
Borehole YA-T4, Mid-tunnel, Eastbound, left lane

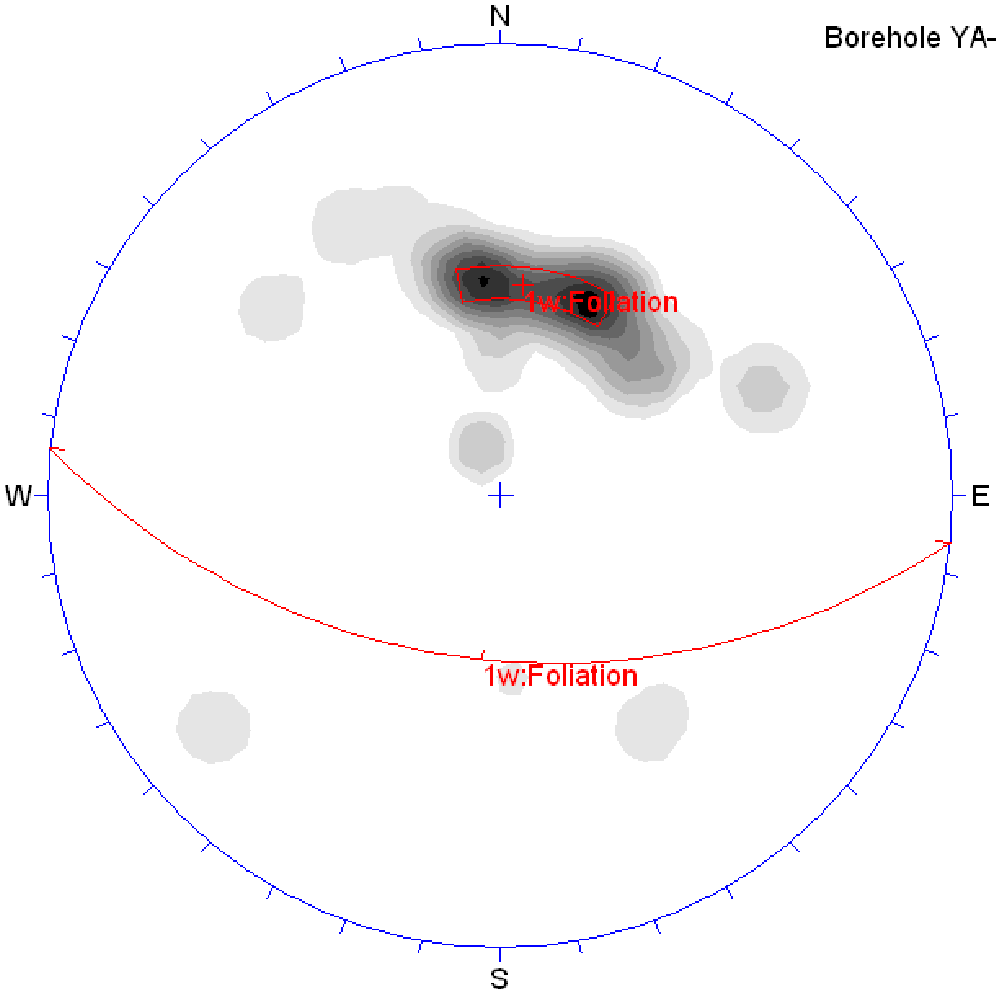


Orientations

ID		Dip / Direction
1	w	82 / 028
2	w	76 / 242
3	w	48 / 119

Equal Angle
Lower Hemisphere
17 Poles
17 Entries


N
E
S
W
1w:Fracture 1
2w:Fracture 2
3w:Fracture 3
2w:Fracture 2
3w:Fracture 3
1w:Fracture 1
Borehole YA-T4, Mid-tunnel, Eastbound, left lane
Fisher
Concentrations
% of total per 1.0 % area
0.00 ~ 1.50 %
1.50 ~ 3.00 %
3.00 ~ 4.50 %
4.50 ~ 6.00 %
6.00 ~ 7.50 %
7.50 ~ 9.00 %
9.00 ~ 10.50 %
10.50 ~ 12.00 %
12.00 ~ 13.50 %
13.50 ~ 15.00 %
Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 13.0988%
Equal Angle
Lower Hemisphere
17 Poles
17 Entries

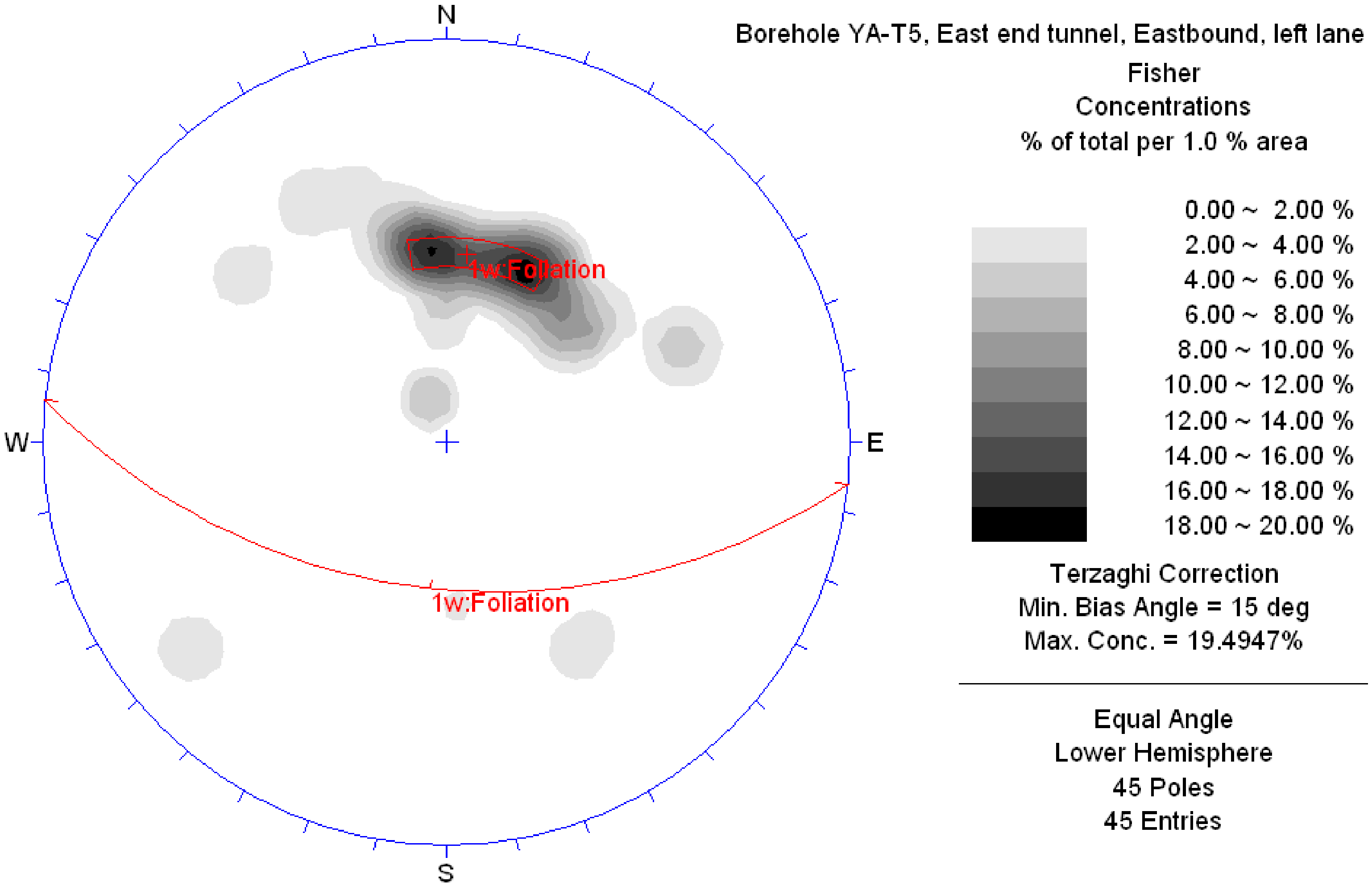


Borehole YA-T5, East end tunnel, Eastbound, left lane

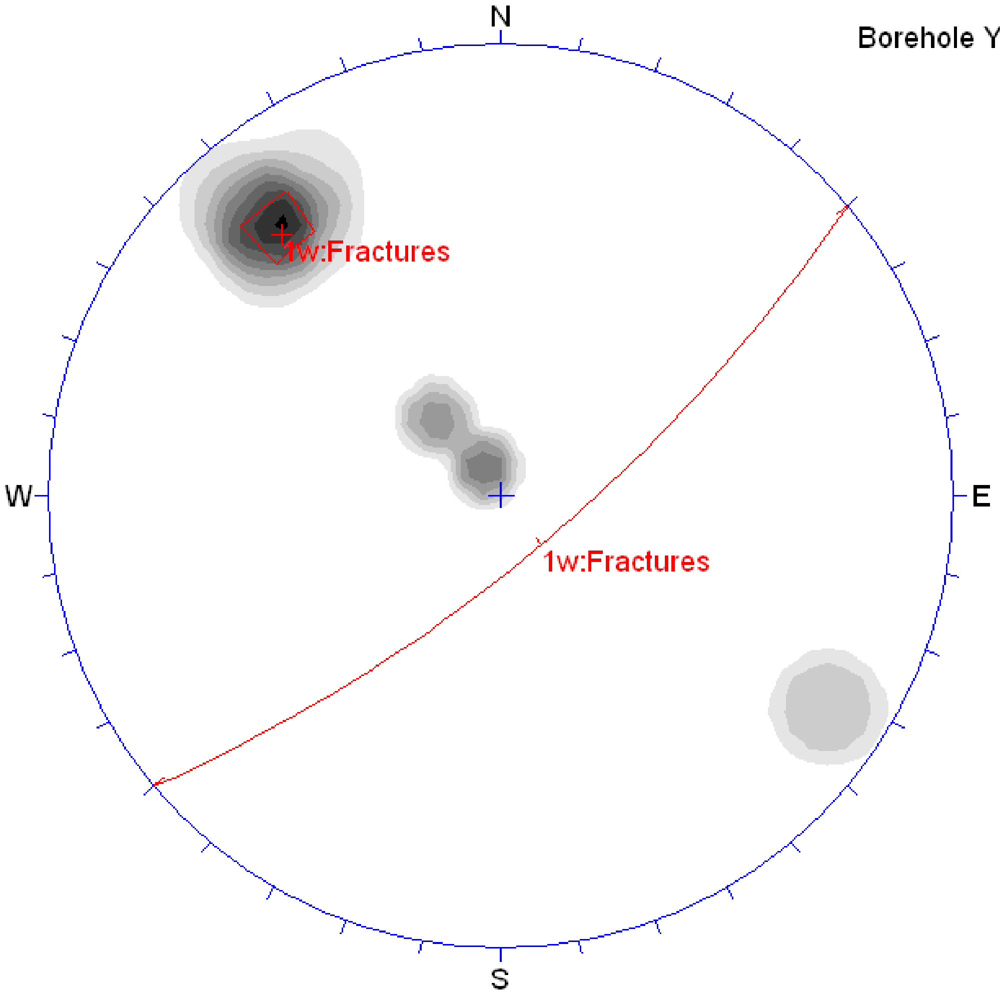
Orientations

ID		Dip / Direction
1	w	50 / 186

Equal Angle
Lower Hemisphere
45 Poles
45 Entries



Borehole YA-T5, East end tunnel, Eastbound, left lane

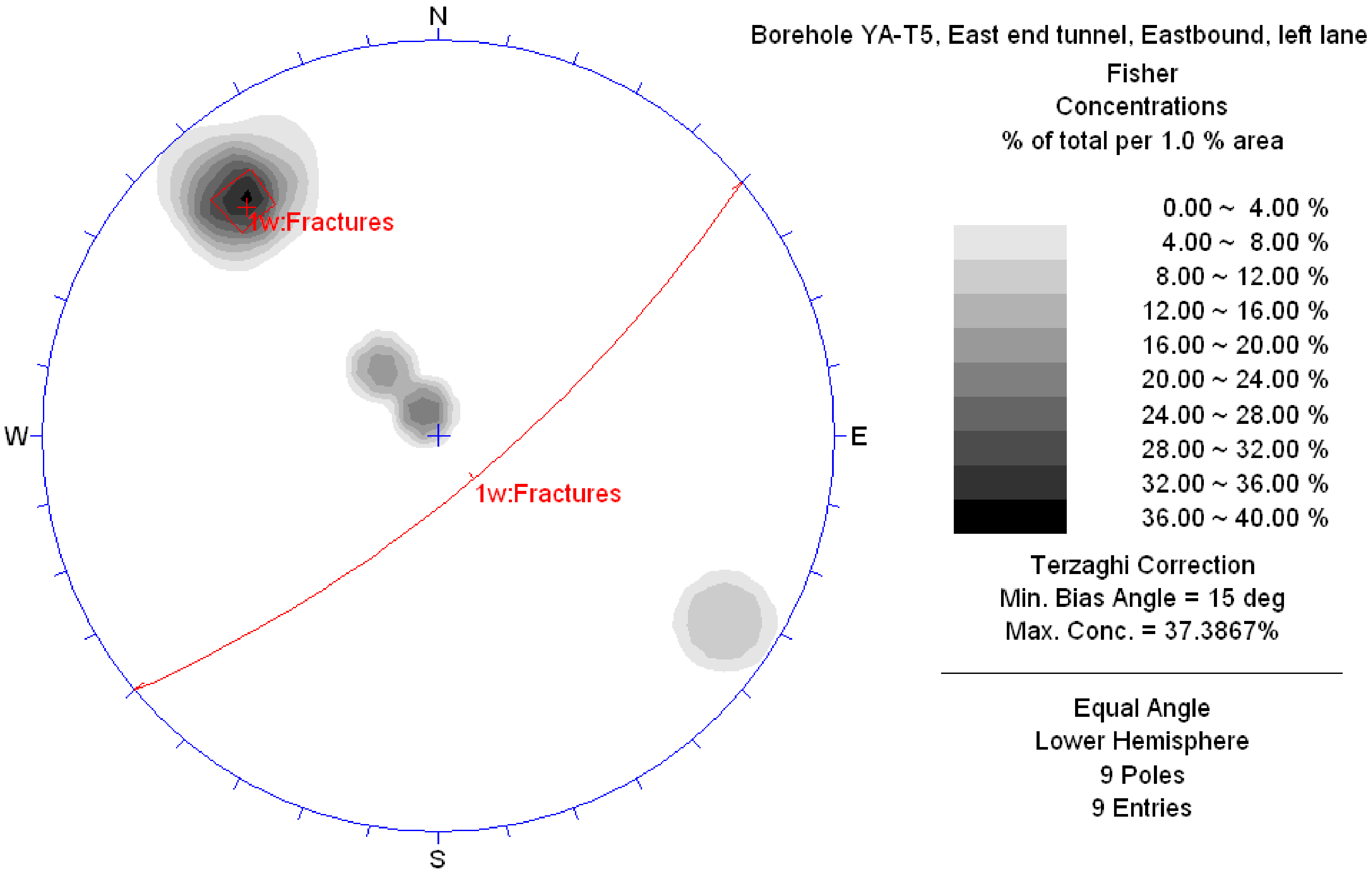


Borehole YA-T5, East end tunnel, Eastbound, left lane

Orientations

ID		Dip / Direction
1	w	74 / 140

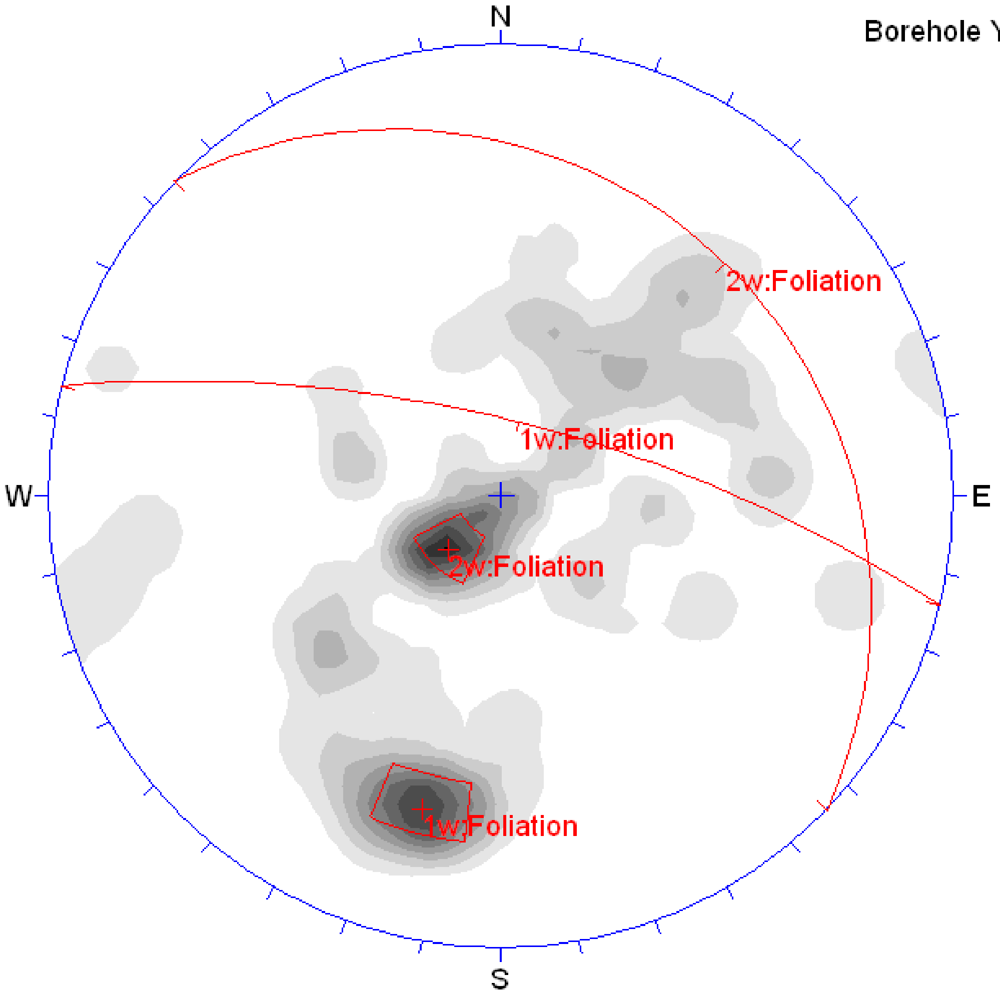
Equal Angle
Lower Hemisphere
9 Poles
9 Entries



Borehole YA-T5, East end tunnel, Eastbound, left lane
Fisher
Concentrations
% of total per 1.0 % area

Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 37.3867%

Equal Angle
Lower Hemisphere
9 Poles
9 Entries

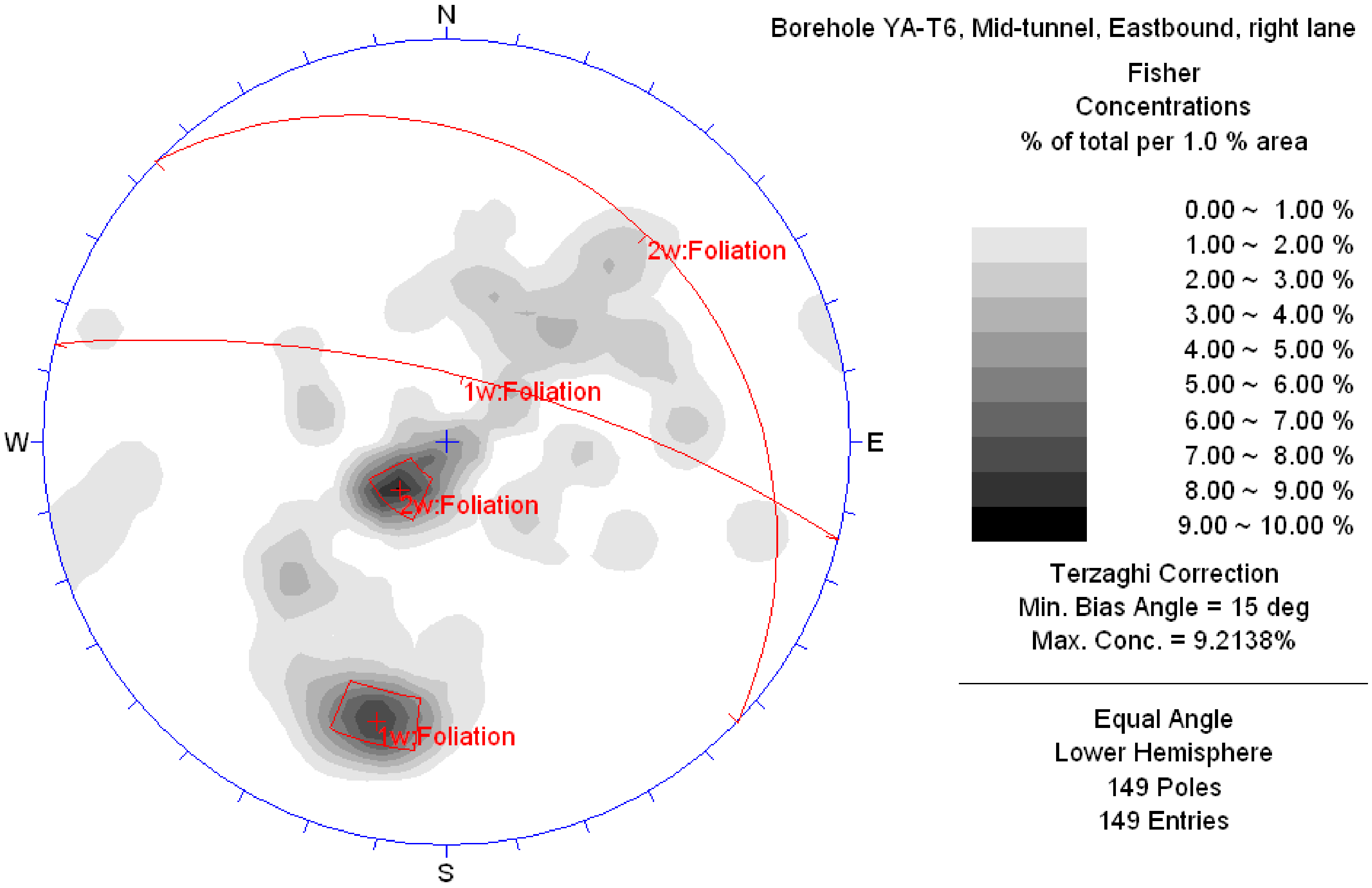


Borehole YA-T6, Mid-tunnel, Eastbound, right lane

Orientations

ID		Dip / Direction
1	w	71 / 014
2	w	19 / 044

Equal Angle
Lower Hemisphere
149 Poles
149 Entries

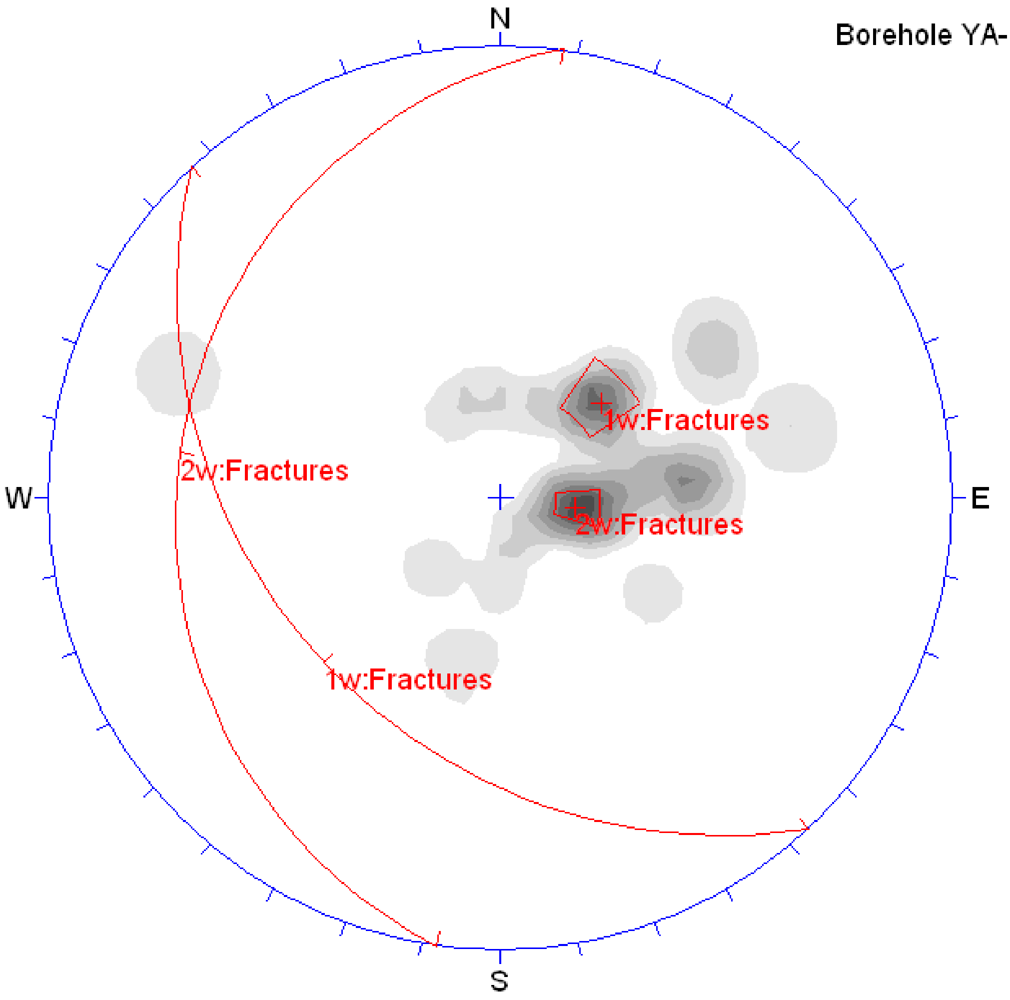


Borehole YA-T6, Mid-tunnel, Eastbound, right lane

Fisher
Concentrations
% of total per 1.0 % area

Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 9.2138%

Equal Angle
Lower Hemisphere
149 Poles
149 Entries

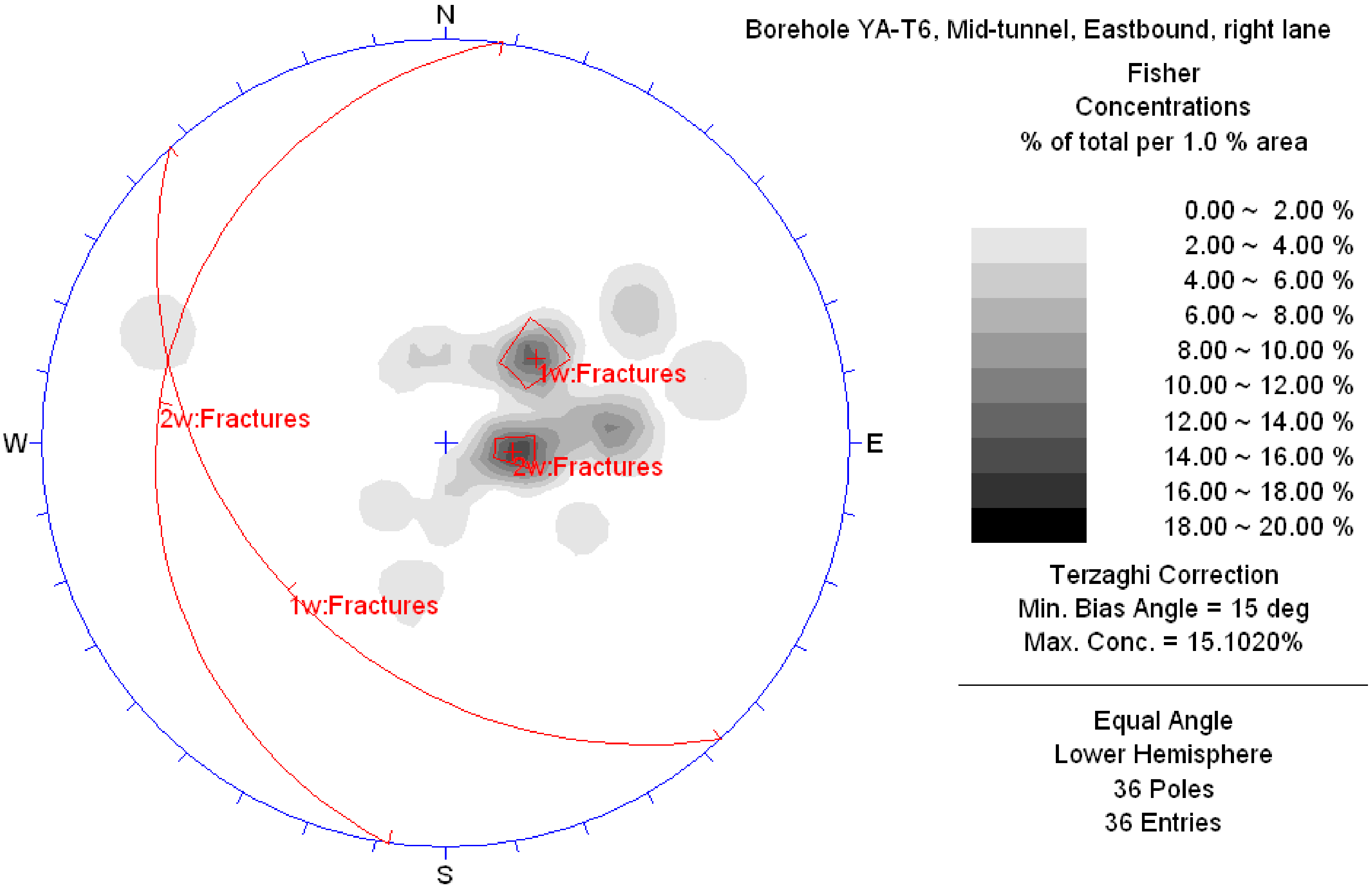


Borehole YA-T6, Mid-tunnel, Eastbound, right lane

Orientations

ID		Dip / Direction
1	w	34 / 227
2	w	19 / 278

Equal Angle
Lower Hemisphere
36 Poles
36 Entries



Borehole YA-T6, Mid-tunnel, Eastbound, right lane

Fisher
Concentrations
% of total per 1.0 % area

0.00 ~ 2.00 %
2.00 ~ 4.00 %
4.00 ~ 6.00 %
6.00 ~ 8.00 %
8.00 ~ 10.00 %
10.00 ~ 12.00 %
12.00 ~ 14.00 %
14.00 ~ 16.00 %
16.00 ~ 18.00 %
18.00 ~ 20.00 %

Terzaghi Correction
Min. Bias Angle = 15 deg
Max. Conc. = 15.1020%

Equal Angle
Lower Hemisphere
36 Poles
36 Entries

Appendix G

Borehole Televiewer Data

Optical Televiewer Image Plot

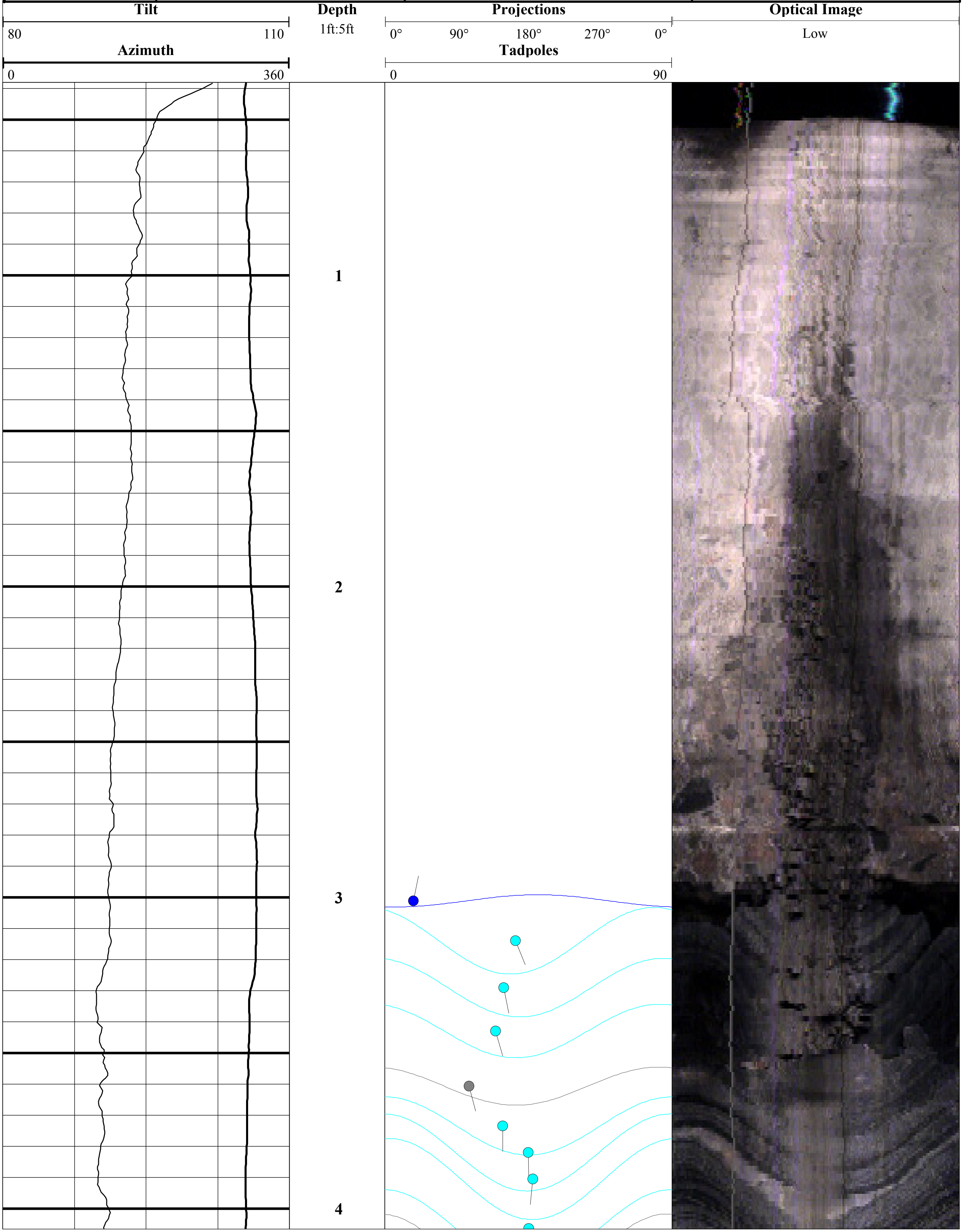
COMPANY: Yeh and Associates

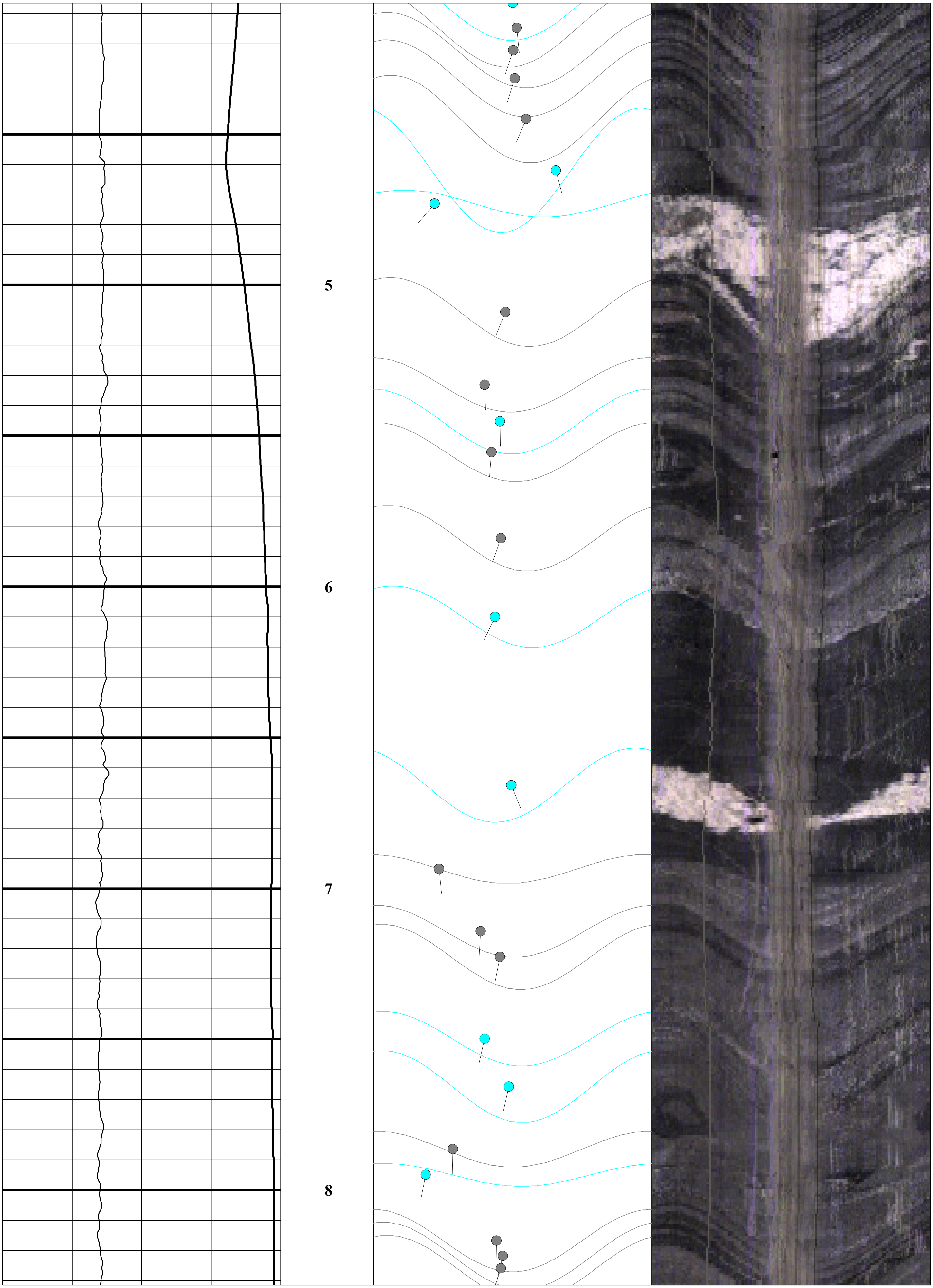
PROJECT: I-70 Tunnel

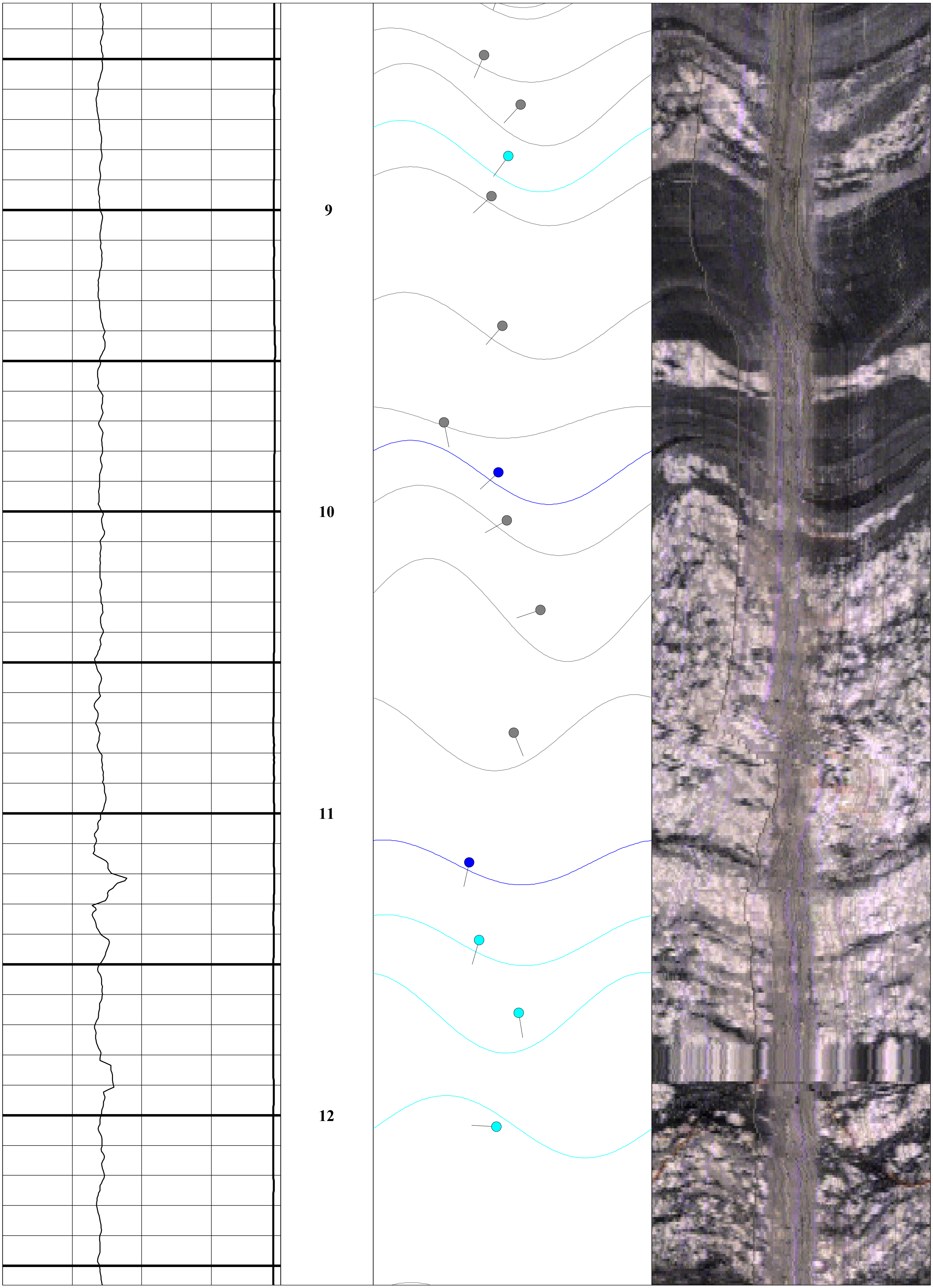
DATE LOGGED: 12 March 2012

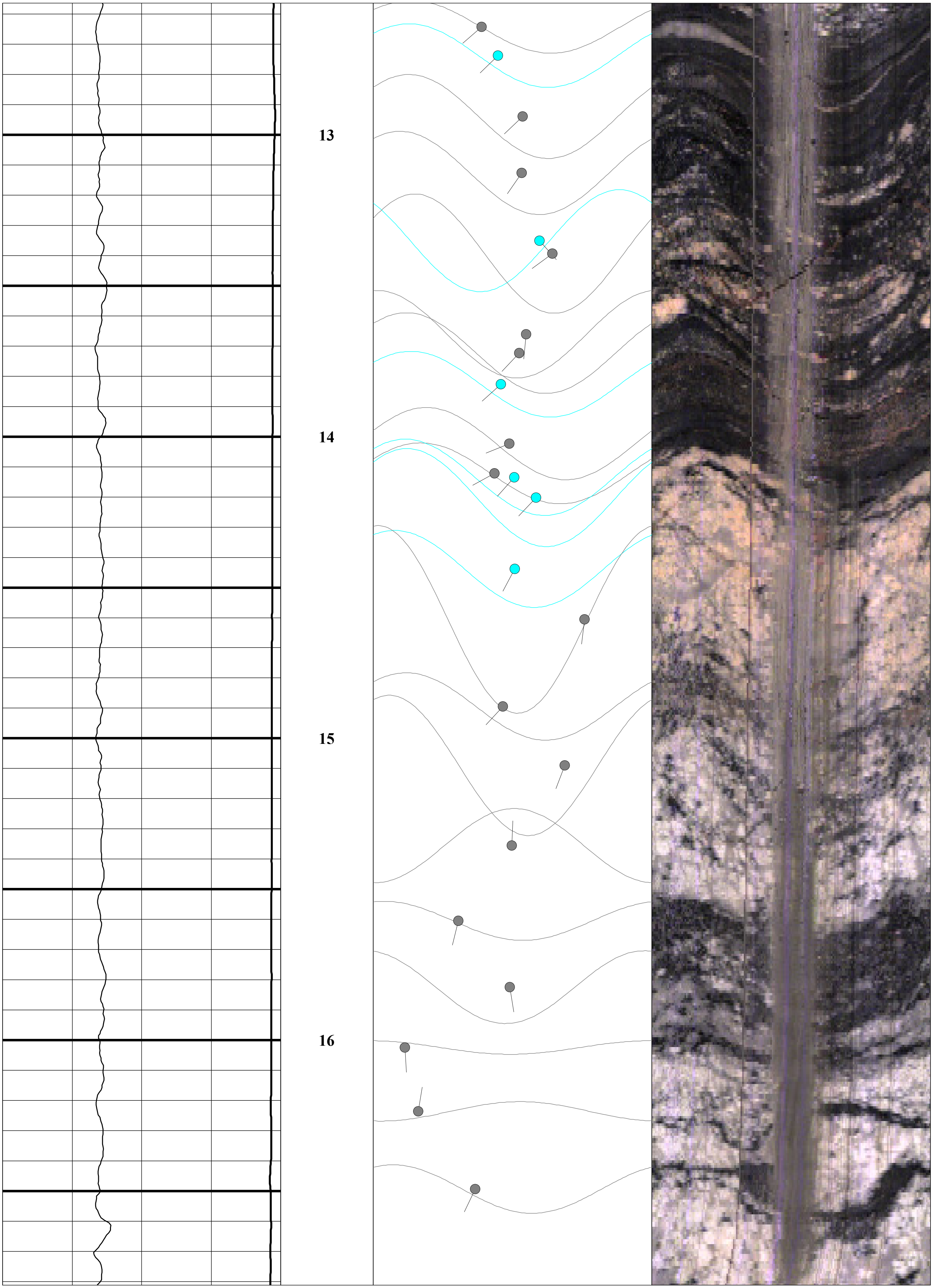
WELL: YA-T1

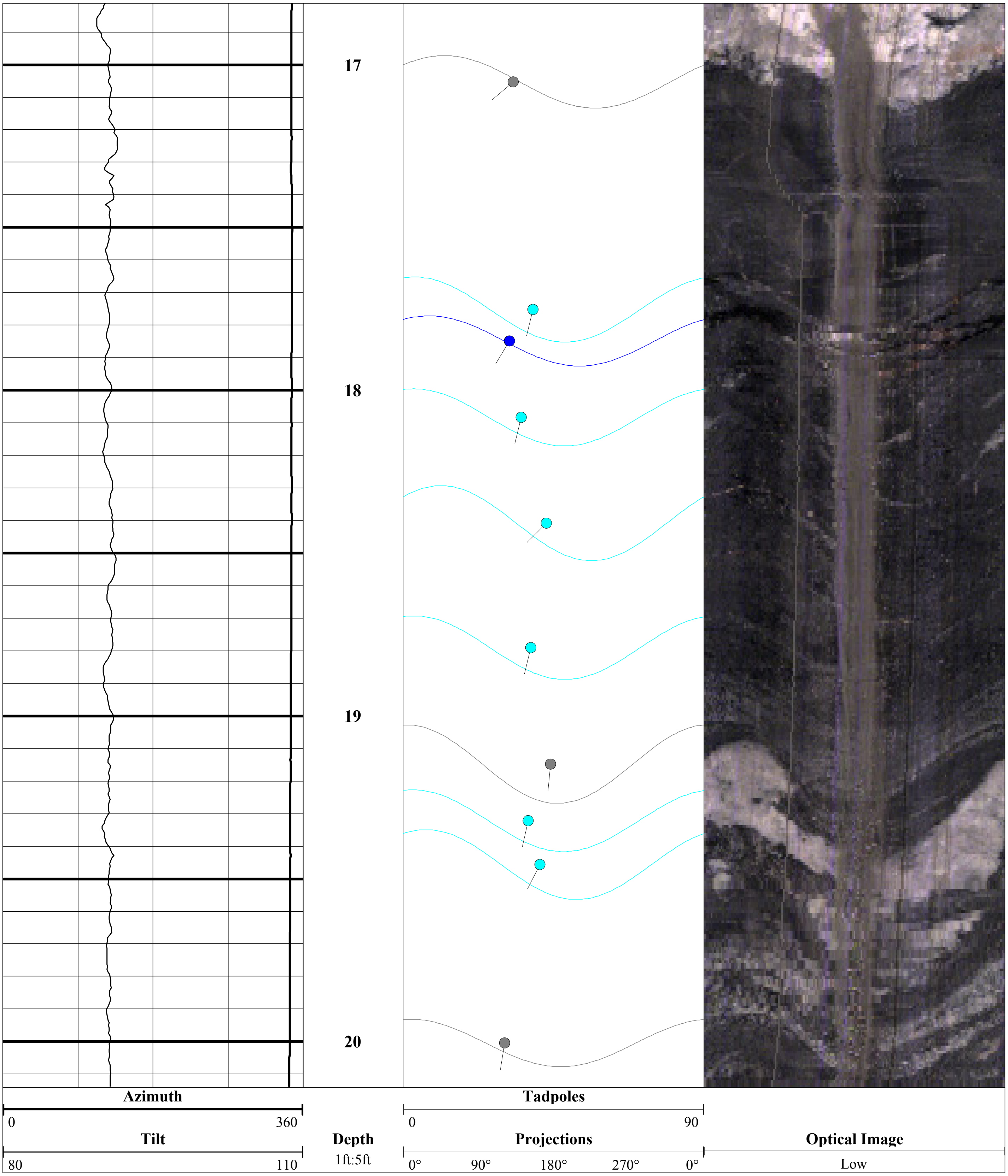
COLOG Main Office
810 Quail Street, Suite E, Lakewood, CO, 80215
Phone: (303) 279-0171, Fax: (303) 278-0135
www.colog.com



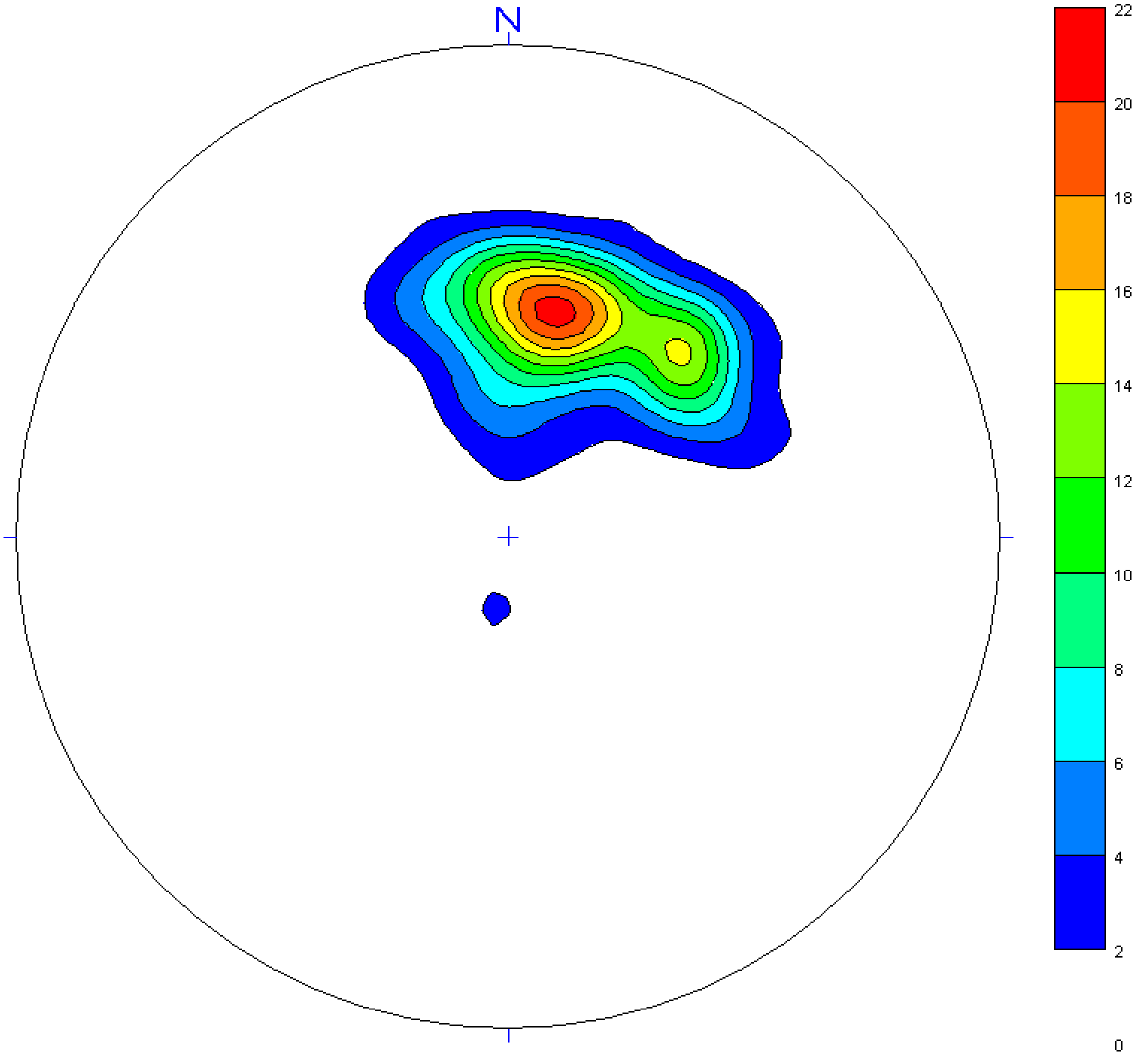

5
6
7
8


9
10
11
12


13
14
15
16

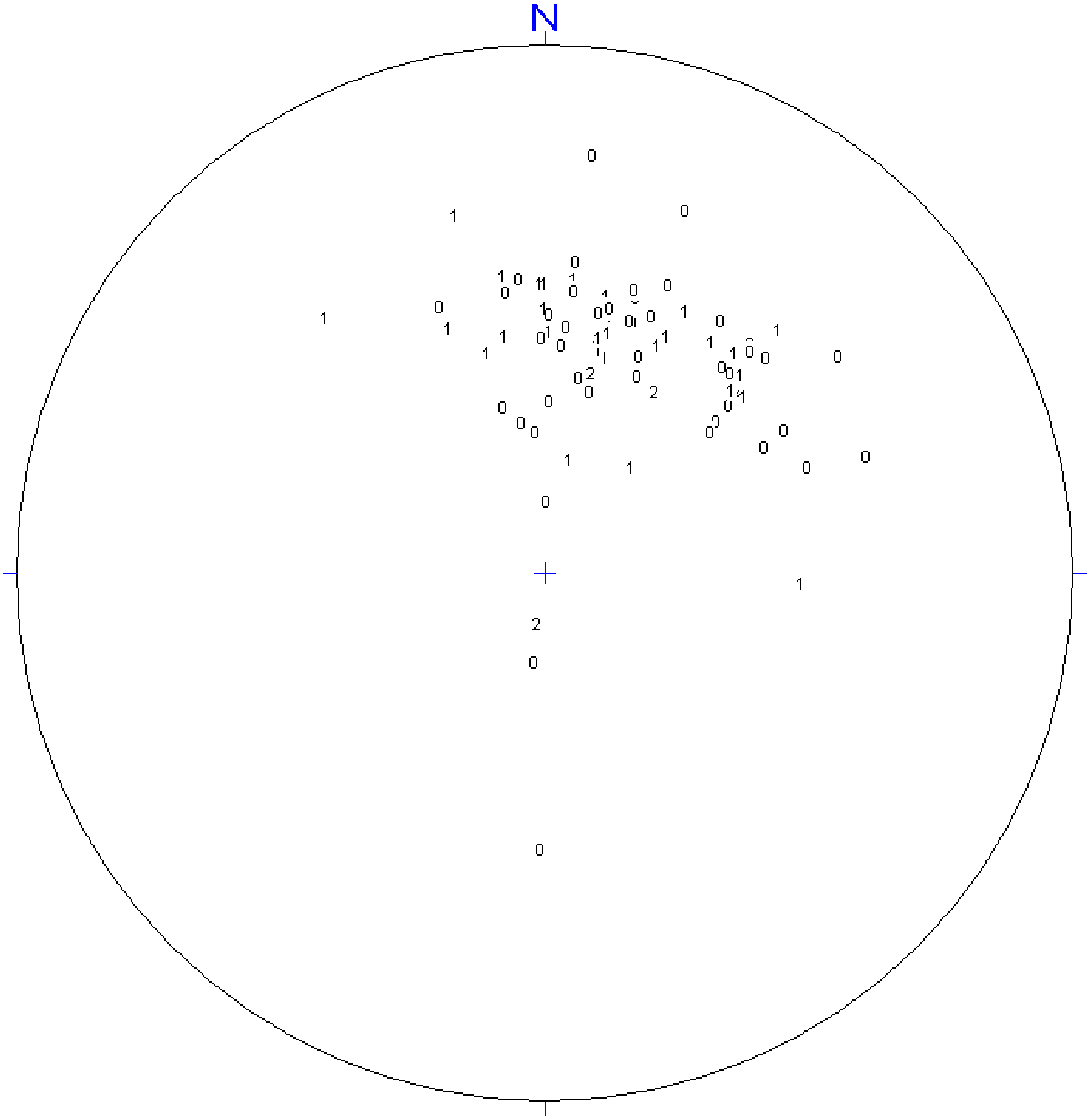

17
18
19
20
Azimuth
0
360
Tilt
80
110
Depth
1ft:5ft
Tadpoles
0
90
Projections
0°
90°
180°
270°
0°
Optical Image
Low

Stereonet Diagram – Schmidt Projection
Optical Televiewer Features
I-70 Tunnel
YA-T1
Yeh and Associates
12 March 2012



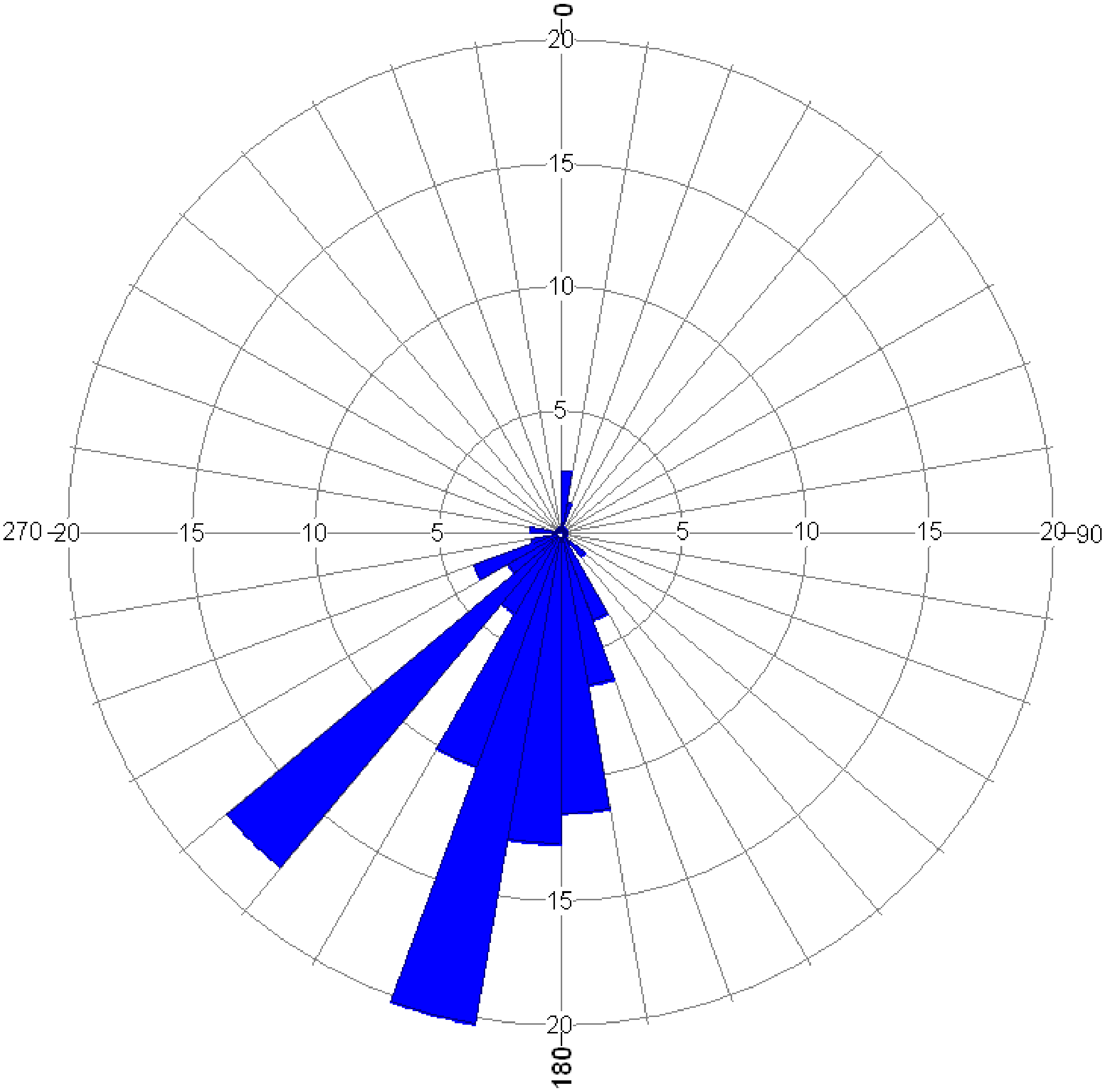
All directions are with respect to Magnetic North.

Stereonet Diagram – Schmidt Projection
Optical Televiewer Features
I-70 Tunnel
YA-T1
Yeh and Associates
12 March 2012



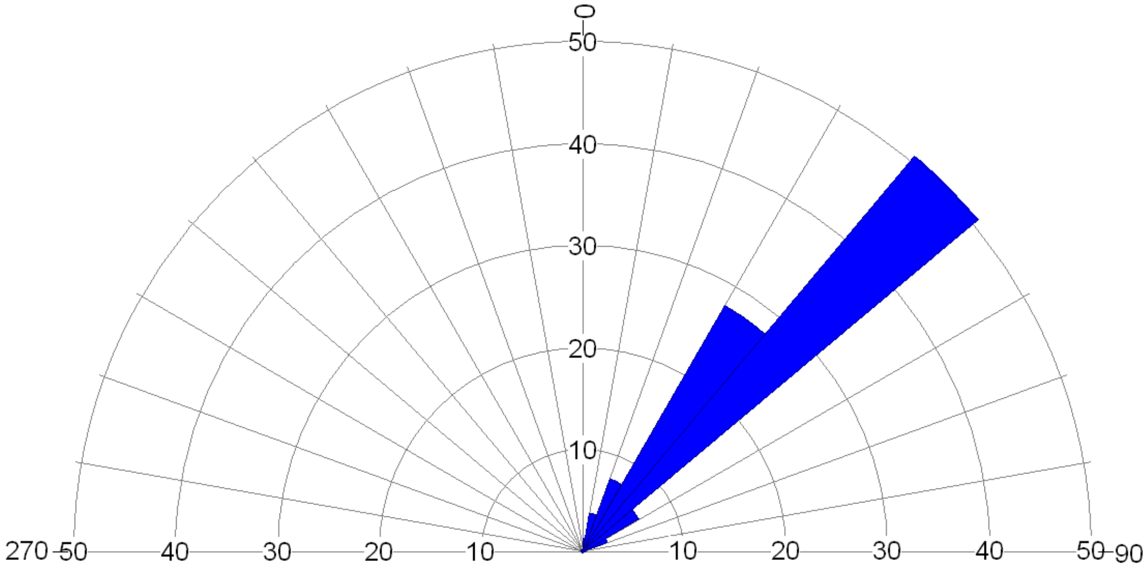
All directions are with respect to Magnetic North.

Rose Diagram – Dip Directions
Optical Televiewer Features
I-70 Tunnel
YA-T1
Yeh and Associates
12 March 2012



All directions are with respect to Magnetic North.

Rose Diagram – Dip Angles
Optical Televiewer Features
I-70 Tunnel
YA-T1
Yeh and Associates
12 March 2012



All directions are with respect to Magnetic North.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T1
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
1	0.92	3.0	12	9	2
2	0.96	3.1	157	41	1
3	1.00	3.3	169	37	1
4	1.05	3.4	164	35	1
5	1.10	3.6	164	26	0
6	1.14	3.7	180	37	1
7	1.16	3.8	178	45	1
8	1.19	3.9	185	46	1
9	1.24	4.1	179	45	1
10	1.26	4.2	174	46	0
11	1.29	4.2	198	45	0
12	1.32	4.3	197	46	0
13	1.36	4.5	203	49	0
14	1.41	4.6	165	59	1
15	1.44	4.7	220	20	1
16	1.55	5.1	202	43	0
17	1.62	5.3	178	36	0
18	1.66	5.5	179	41	1
19	1.69	5.6	184	38	0
20	1.78	5.8	199	41	0
21	1.86	6.1	206	39	1
22	2.03	6.7	158	45	1
23	2.11	6.9	174	21	0
24	2.18	7.1	183	35	0
25	2.20	7.2	191	41	0
26	2.29	7.5	192	36	1
27	2.33	7.7	192	44	1
28	2.40	7.9	180	26	0
29	2.42	8.0	191	17	1
30	2.49	8.2	180	40	0
31	2.51	8.2	193	42	0
32	2.52	8.3	198	41	0
33	2.59	8.5	203	36	0
34	2.64	8.7	222	48	0
35	2.69	8.8	216	44	1
36	2.73	9.0	228	38	0
37	2.86	9.4	221	42	0
38	2.96	9.7	169	23	0
39	3.01	9.9	227	41	2
40	3.06	10.0	240	43	0
41	3.15	10.3	251	54	0
42	3.27	10.7	157	45	0
43	3.40	11.2	192	31	2
44	3.48	11.4	195	34	1
45	3.55	11.7	171	47	1

All directions are with respect to magnetic north.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T1
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
46	3.67	12.0	274	40	1
47	3.85	12.6	229	35	0
48	3.88	12.7	226	40	1
49	3.94	12.9	226	48	0
50	4.00	13.1	215	48	0
51	4.07	13.4	138	54	1
52	4.08	13.4	234	58	0
53	4.16	13.7	185	49	0
54	4.18	13.7	223	47	0
55	4.22	13.8	229	41	1
56	4.27	14.0	249	44	0
57	4.30	14.1	241	39	0
58	4.31	14.1	221	45	1
59	4.33	14.2	224	53	1
60	4.40	14.4	208	46	1
61	4.45	14.6	186	68	0
62	4.54	14.9	223	42	0
63	4.60	15.1	201	62	0
64	4.68	15.4	2	45	0
65	4.75	15.6	193	28	0
66	4.82	15.8	171	44	0
67	4.88	16.0	177	10	0
68	4.95	16.2	9	15	0
69	5.03	16.5	205	33	0
70	5.20	17.1	230	33	0
71	5.41	17.8	194	39	1
72	5.44	17.9	211	32	2
73	5.51	18.1	193	35	1
74	5.61	18.4	225	43	1
75	5.73	18.8	194	38	1
76	5.84	19.2	185	44	0
77	5.89	19.3	192	37	1
78	5.93	19.5	207	41	1
79	6.10	20.0	189	30	0

All directions are with respect to magnetic north.

Optical Televiewer Image Plot

COMPANY: Yeh and Associates

PROJECT: I-70 Tunnel

DATE LOGGED: 12 March 2012

WELL: YA-T2

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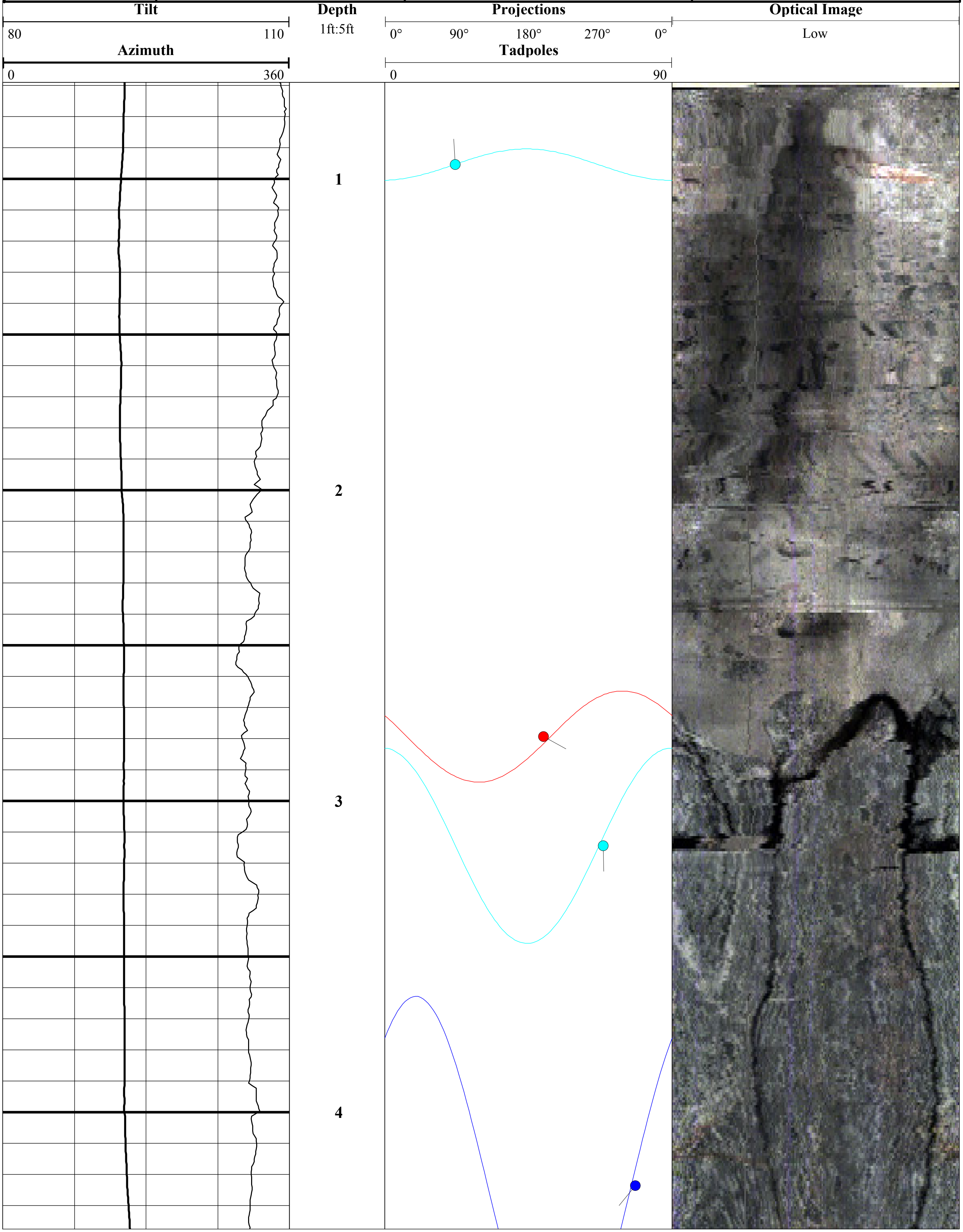

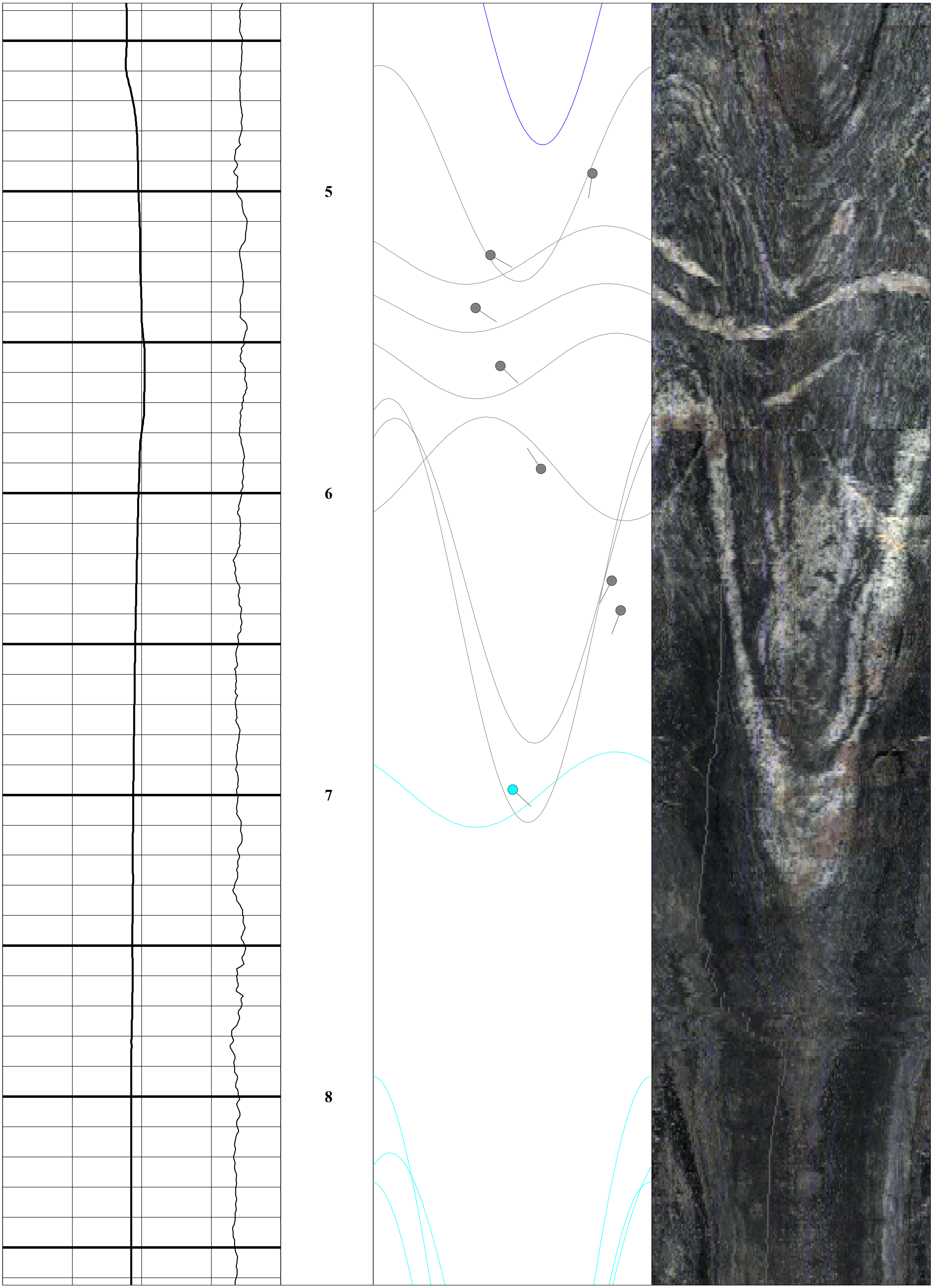
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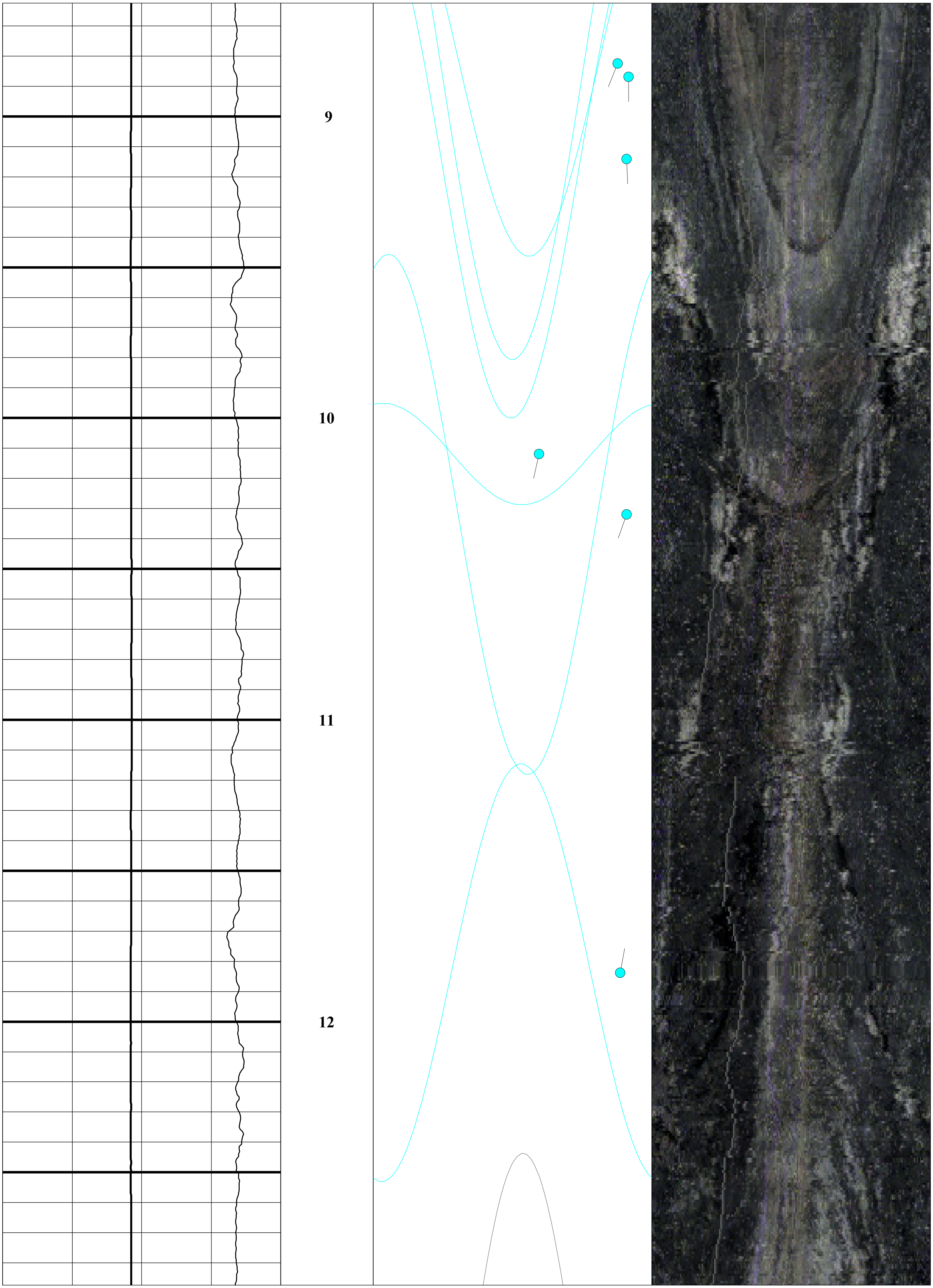
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11
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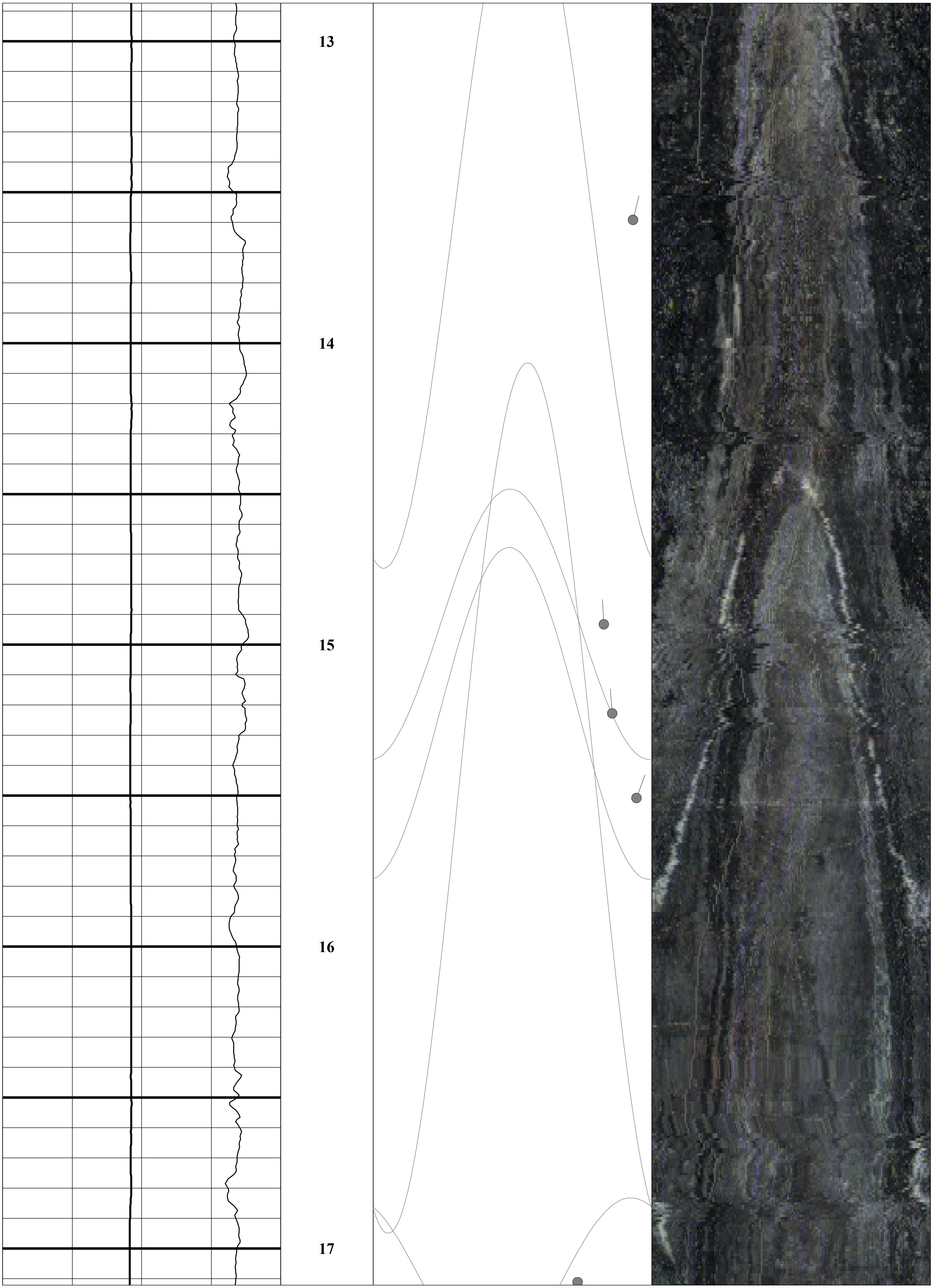
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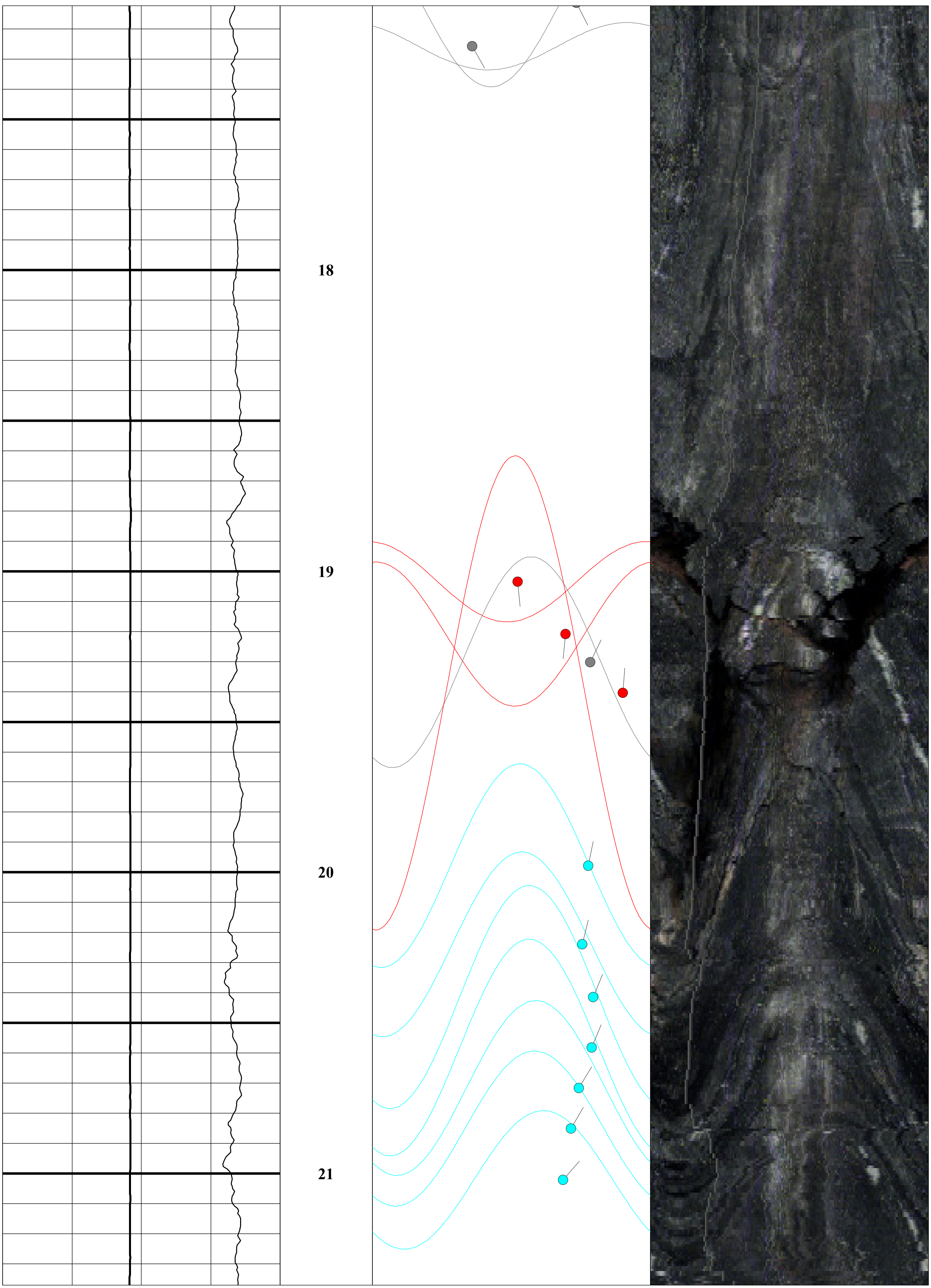
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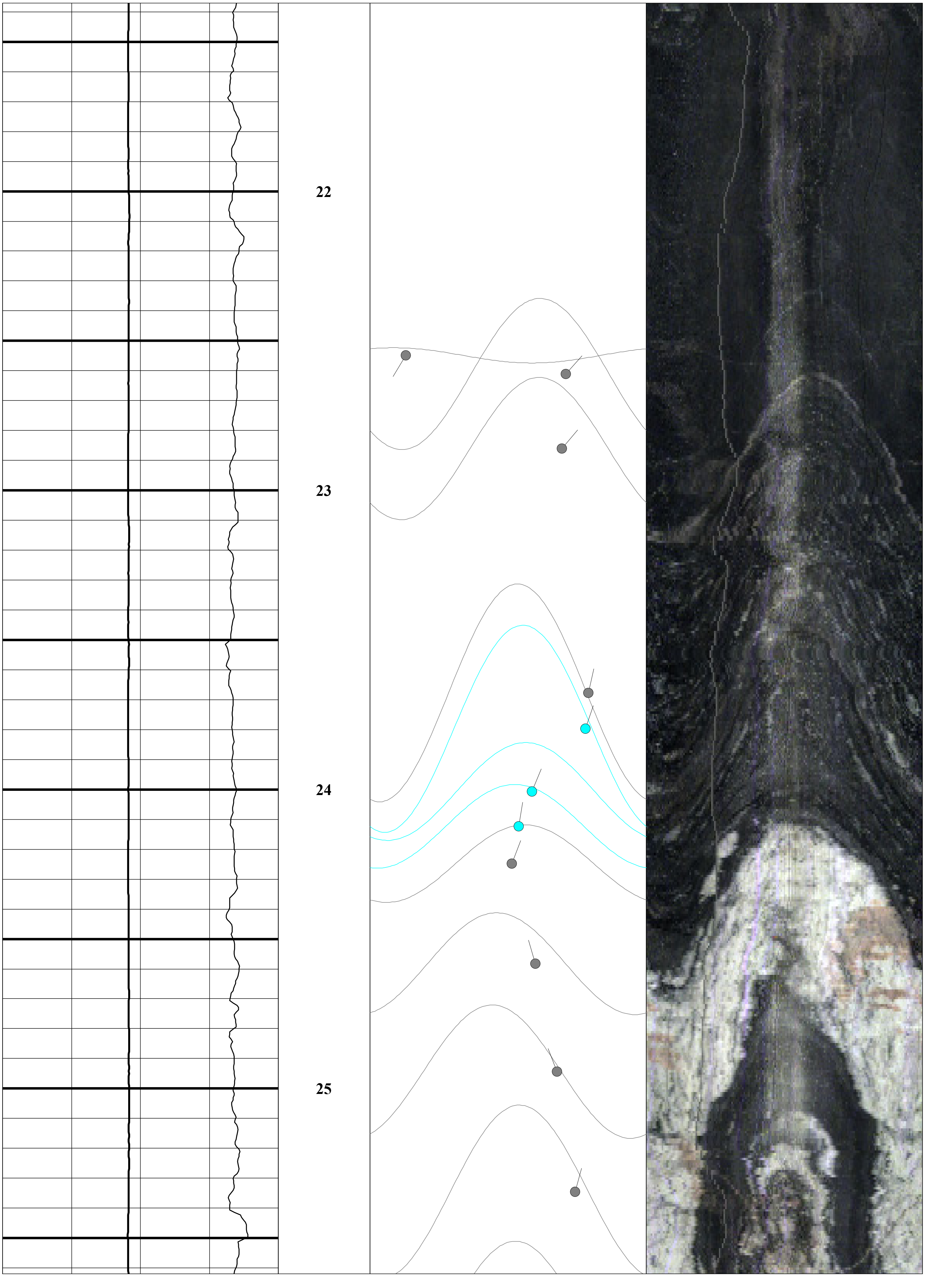
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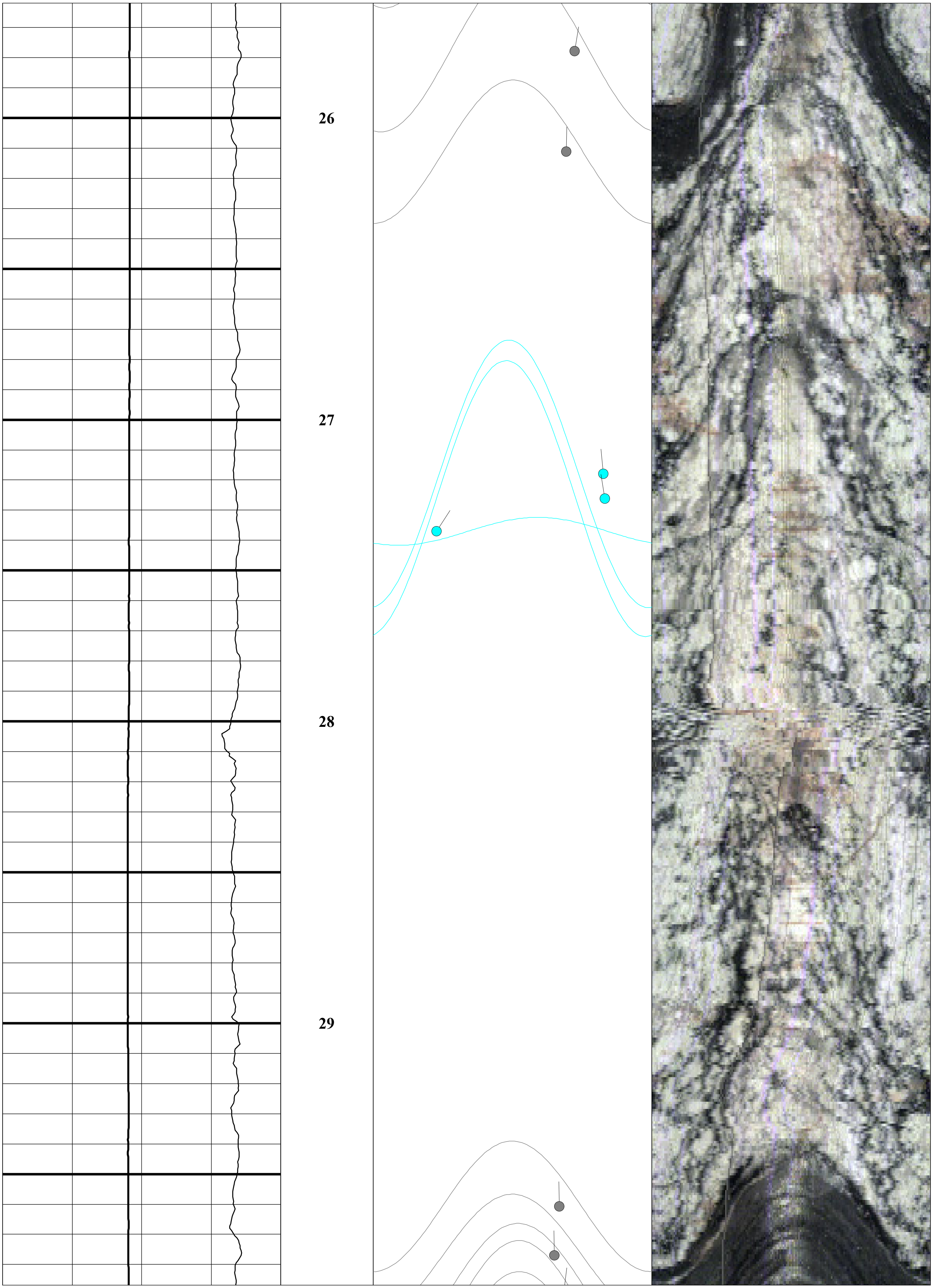
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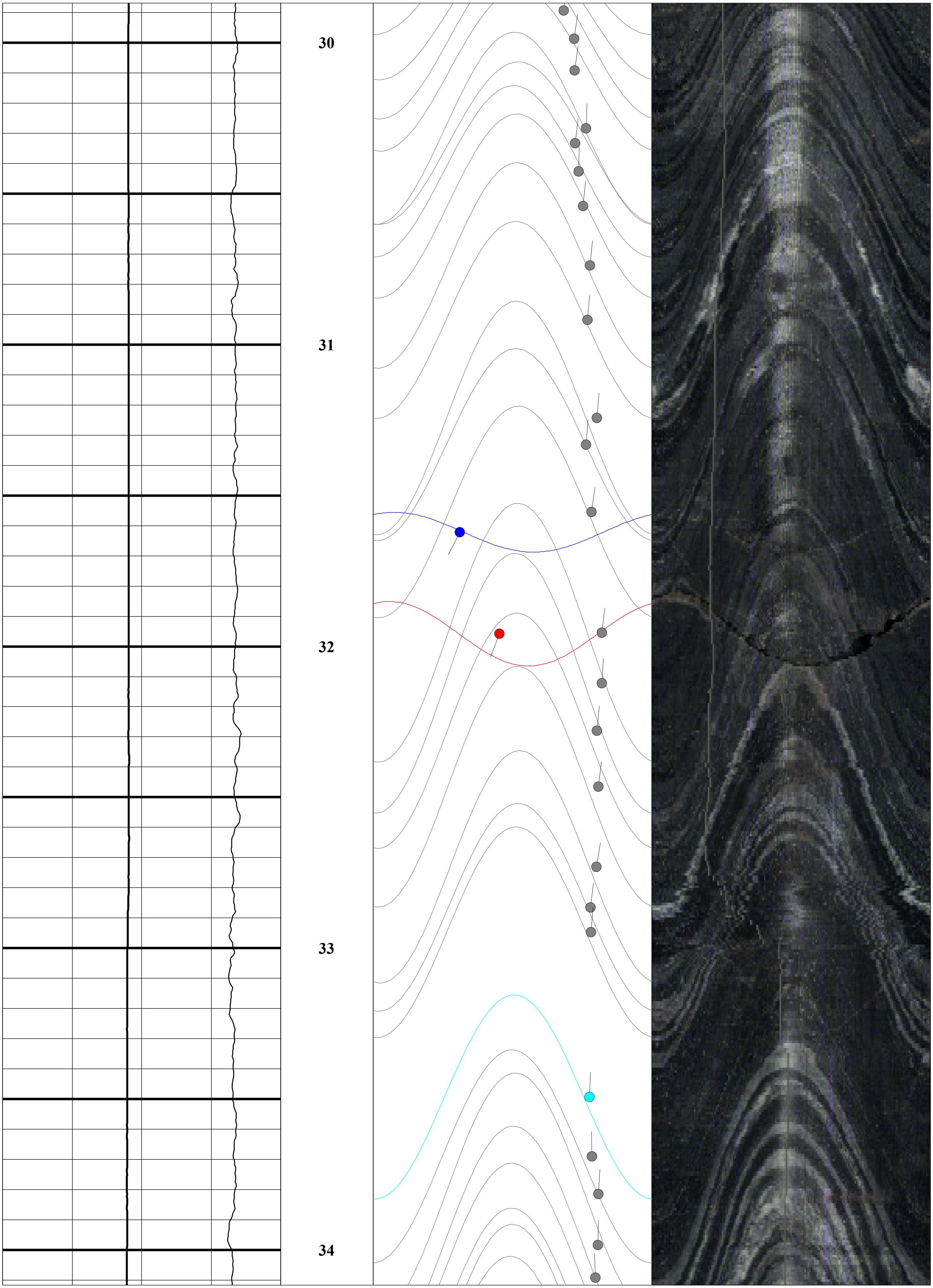
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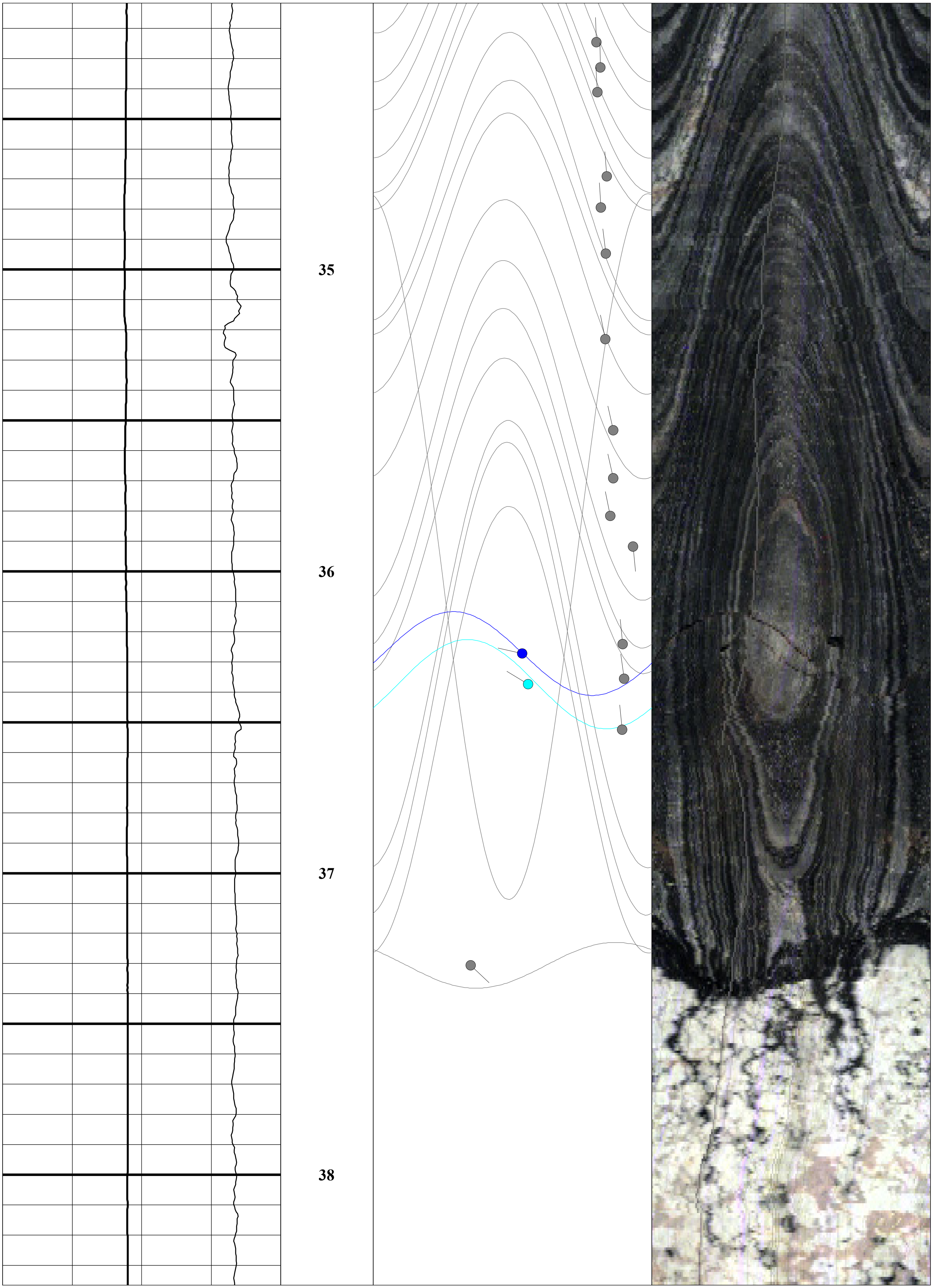
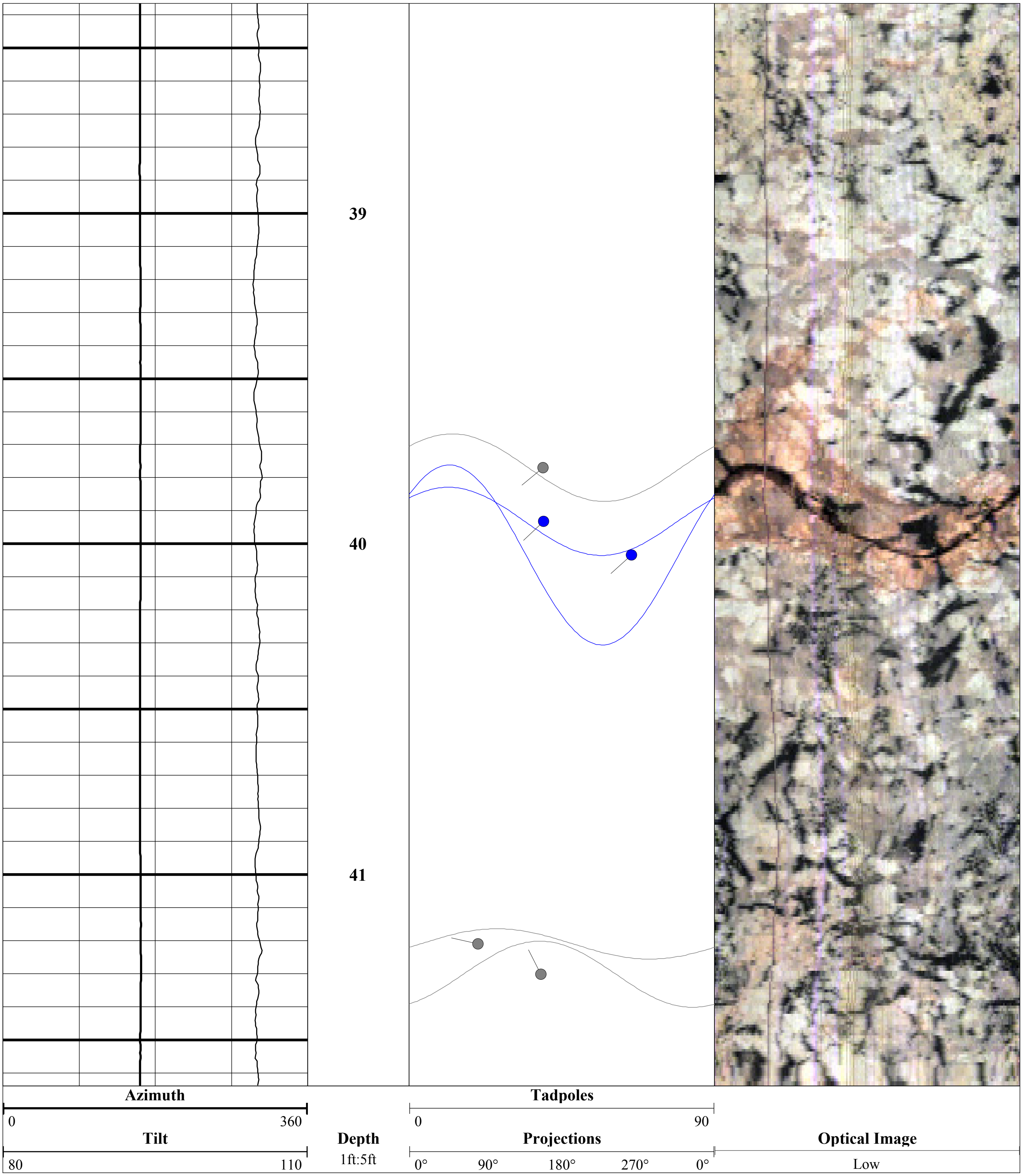
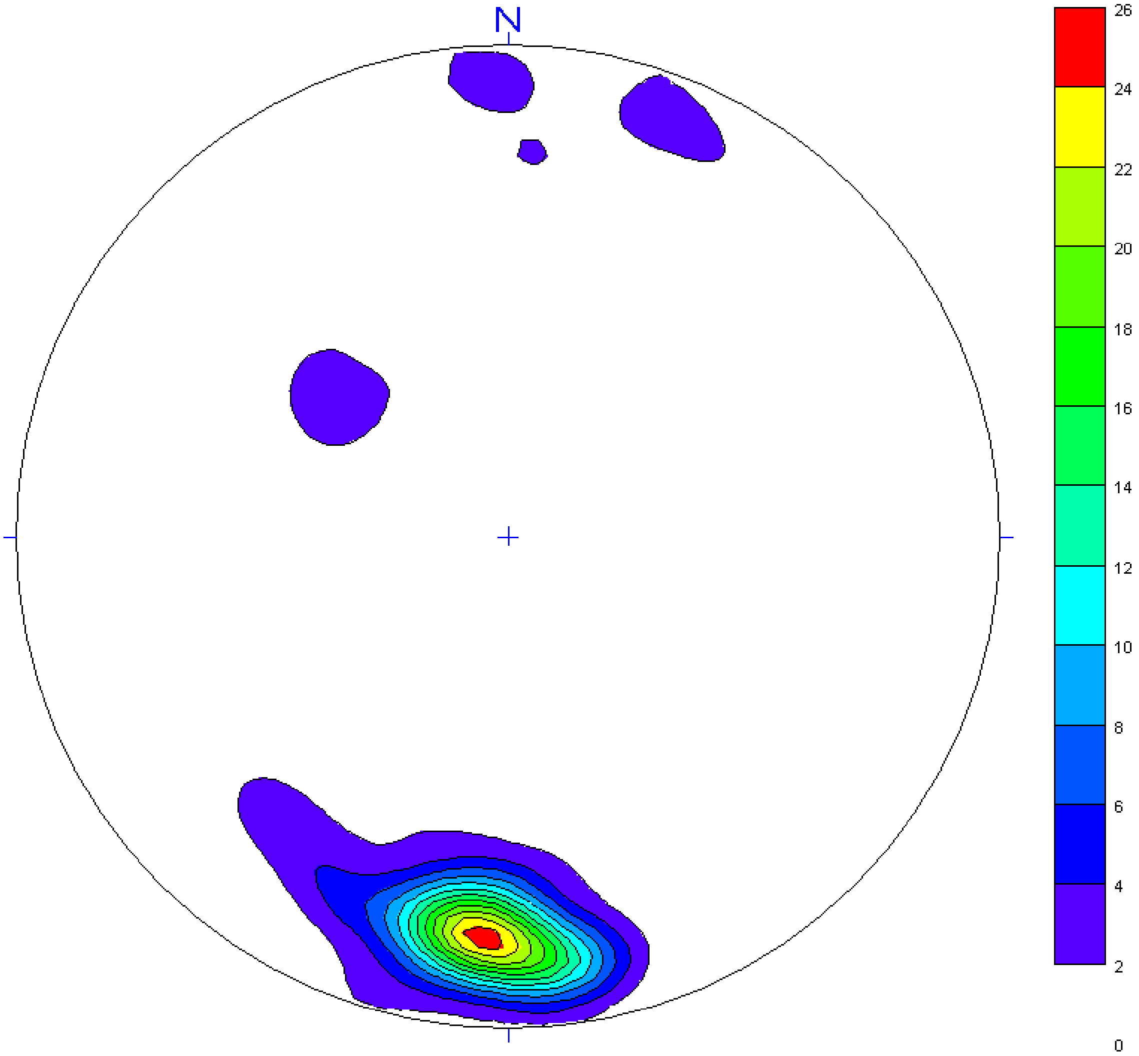
34


35
36
37
38

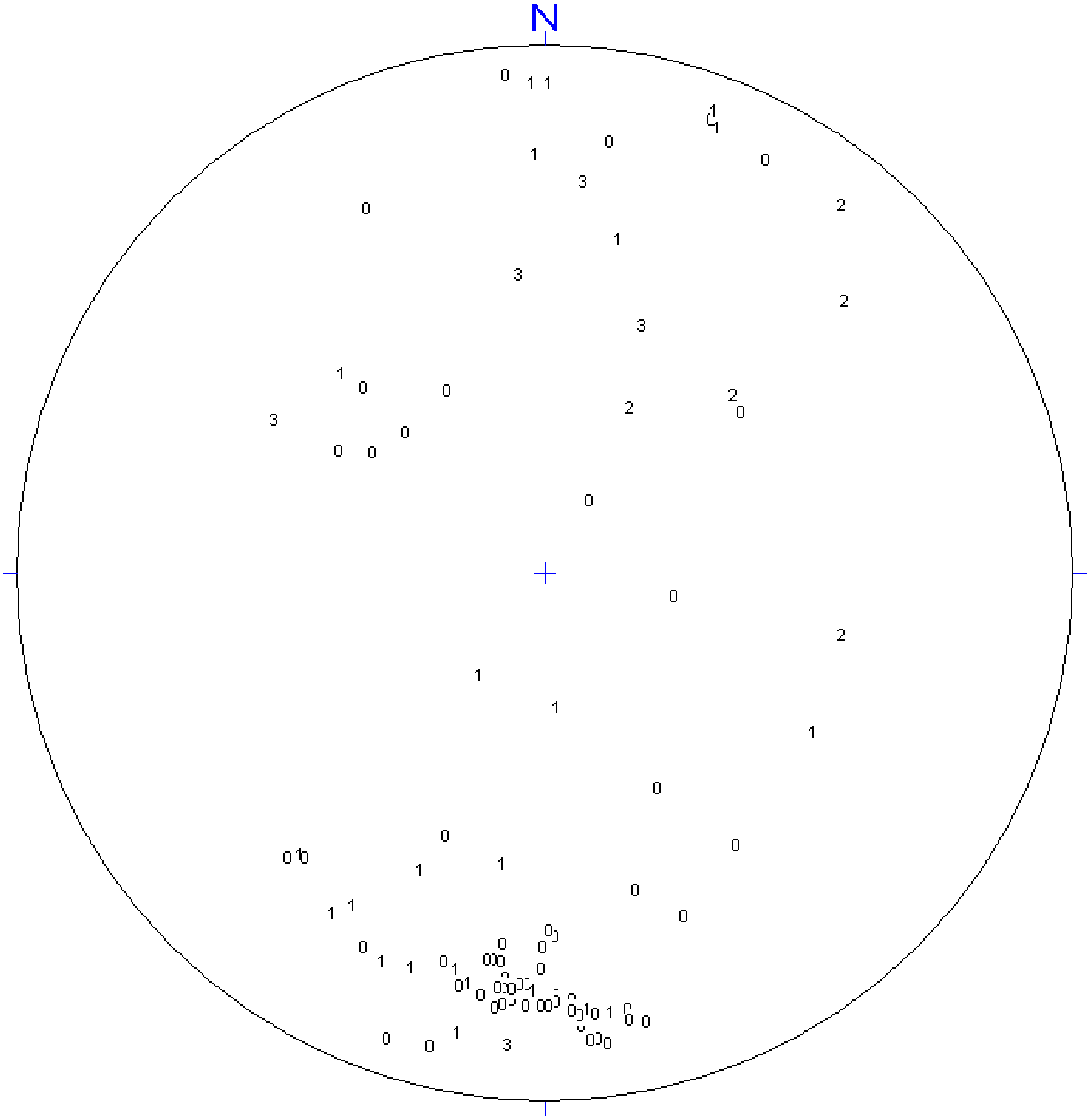

39
40
41
Azimuth
0
360
Tilt
80
110
Depth
1ft:5ft
Tadpoles
0
90
Projections
0°
90°
180°
270°
0°
Optical Image
Low

Stereonet Diagram – Schmidt Projection
Optical Televiewer Features
I-70 Tunnel
YA-T2
Yeh and Associates
12 March 2012



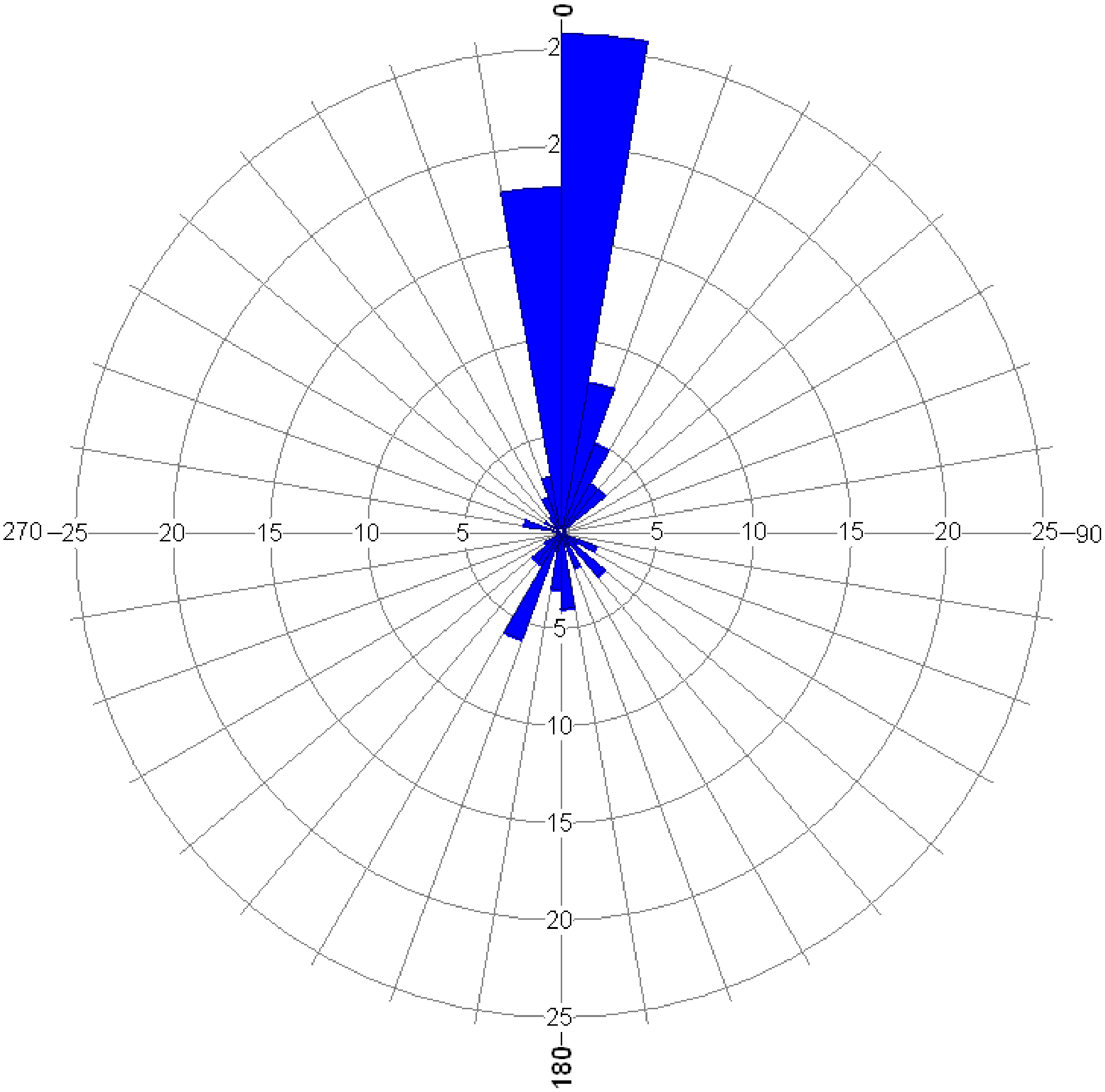
All directions are with respect to Magnetic North.

Stereonet Diagram – Schmidt Projection
Optical Televiewer Features
I-70 Tunnel
YA-T2
Yeh and Associates
12 March 2012



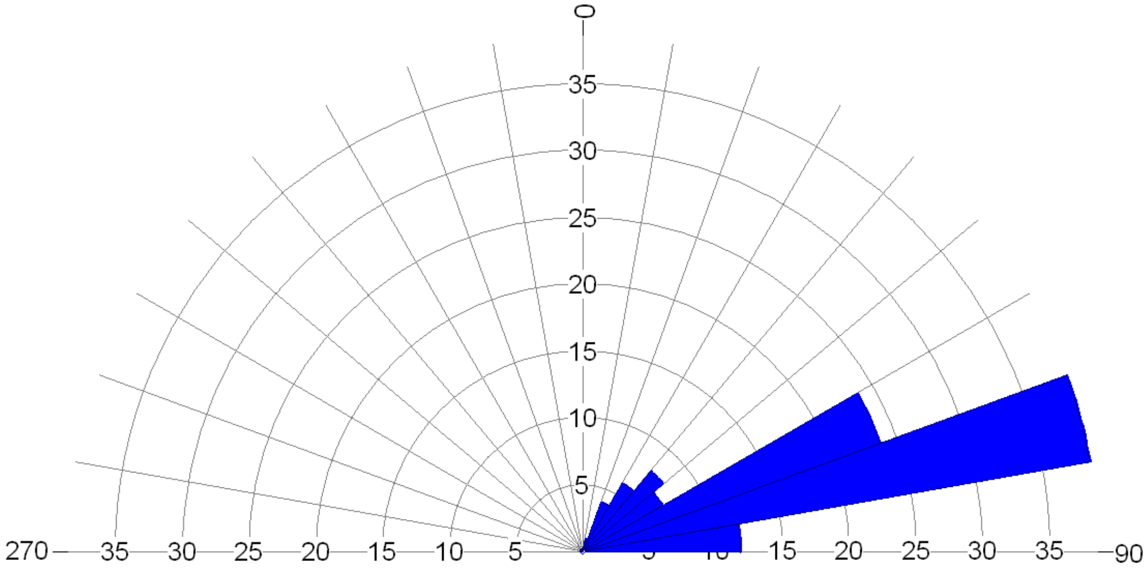
All directions are with respect to Magnetic North.

Rose Diagram – Dip Directions
Optical Televiewer Features
I-70 Tunnel
YA-T2
Yeh and Associates
12 March 2012



All directions are with respect to Magnetic North.

Rose Diagram – Dip Angles
Optical Televiewer Features
I-70 Tunnel
YA-T2
Yeh and Associates
12 March 2012



All directions are with respect to Magnetic North.

Orientation Summary Table

Image Features
I-70 Tunnel
YA-T2
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
1	0.29	1.0	357	22	1
2	0.85	2.8	118	50	3
3	0.96	3.1	178	68	1
4	1.29	4.2	219	78	2
5	1.51	4.9	188	71	0
6	1.59	5.2	119	38	0
7	1.64	5.4	123	33	0
8	1.70	5.6	134	41	0
9	1.80	5.9	326	54	0
10	1.92	6.3	208	77	0
11	1.95	6.4	200	80	0
12	2.13	7.0	133	45	1
13	2.69	8.8	201	79	1
14	2.70	8.9	180	82	1
15	2.79	9.1	178	82	1
16	3.08	10.1	192	54	1
17	3.15	10.3	200	82	1
18	3.61	11.8	11	80	1
19	4.14	13.6	14	84	0
20	4.55	14.9	357	75	0
21	4.64	15.2	356	77	0
22	4.73	15.5	19	85	0
23	5.22	17.1	153	66	0
24	5.26	17.3	150	32	0
25	5.80	19.0	174	47	3
26	5.86	19.2	185	63	3
27	5.88	19.3	26	70	0
28	5.91	19.4	5	81	3
29	6.09	20.0	11	70	1
30	6.17	20.2	13	68	1
31	6.22	20.4	23	71	1
32	6.27	20.6	23	71	1
33	6.32	20.7	32	67	1
34	6.36	20.9	30	64	1
35	6.41	21.0	41	62	1
36	6.87	22.6	211	12	0
37	6.89	22.6	42	64	0
38	6.97	22.9	40	62	0
39	7.22	23.7	12	71	0
40	7.25	23.8	19	70	1
41	7.32	24.0	23	53	1
42	7.35	24.1	9	48	1
43	7.39	24.3	21	46	0
44	7.49	24.6	345	54	0
45	7.60	24.9	339	61	0

All directions are with respect to magnetic north.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T2
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
46	7.73	25.4	15	67	0
47	7.86	25.8	9	65	0
48	7.96	26.1	1	62	0
49	8.28	27.2	355	74	1
50	8.31	27.3	352	75	1
51	8.34	27.4	33	20	1
52	9.03	29.6	359	60	0
53	9.07	29.8	360	59	0
54	9.11	29.9	7	62	0
55	9.14	30.0	8	65	0
56	9.17	30.1	9	65	0
57	9.23	30.3	3	69	0
58	9.24	30.3	7	65	0
59	9.28	30.4	1	66	0
60	9.31	30.5	6	68	0
61	9.37	30.7	6	70	0
62	9.42	30.9	4	69	0
63	9.52	31.2	5	72	0
64	9.55	31.3	4	69	0
65	9.62	31.6	7	70	0
66	9.64	31.6	207	28	2
67	9.74	32.0	7	74	0
68	9.74	32.0	201	41	3
69	9.79	32.1	3	74	0
70	9.84	32.3	6	72	0
71	9.89	32.5	6	73	0
72	9.98	32.7	9	72	0
73	10.02	32.9	7	70	0
74	10.04	33.0	5	70	0
75	10.21	33.5	2	70	1
76	10.27	33.7	359	71	0
77	10.31	33.8	3	73	0
78	10.36	34.0	1	73	0
79	10.39	34.1	359	72	0
80	10.44	34.3	359	72	0
81	10.46	34.3	360	73	0
82	10.49	34.4	357	72	0
83	10.57	34.7	356	75	0
84	10.60	34.8	357	74	0
85	10.65	35.0	354	75	0
86	10.74	35.2	350	75	0
87	10.83	35.5	348	78	0
88	10.88	35.7	348	78	0
89	10.92	35.8	350	77	0
90	10.95	35.9	175	84	0

All directions are with respect to magnetic north.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T2
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
91	11.05	36.2	354	80	0
92	11.06	36.3	283	48	2
93	11.08	36.4	353	81	0
94	11.09	36.4	302	50	1
95	11.13	36.5	355	80	0
96	11.37	37.3	133	31	0
97	12.12	39.8	231	39	0
98	12.17	39.9	227	40	2
99	12.20	40.0	228	65	2
100	12.56	41.2	283	20	0
101	12.59	41.3	334	39	0

Optical Televiewer Image Plot

COMPANY: Yeh and Associates

PROJECT: I-70 Tunnel

DATE LOGGED: 12 March 2012

WELL: YA-T3

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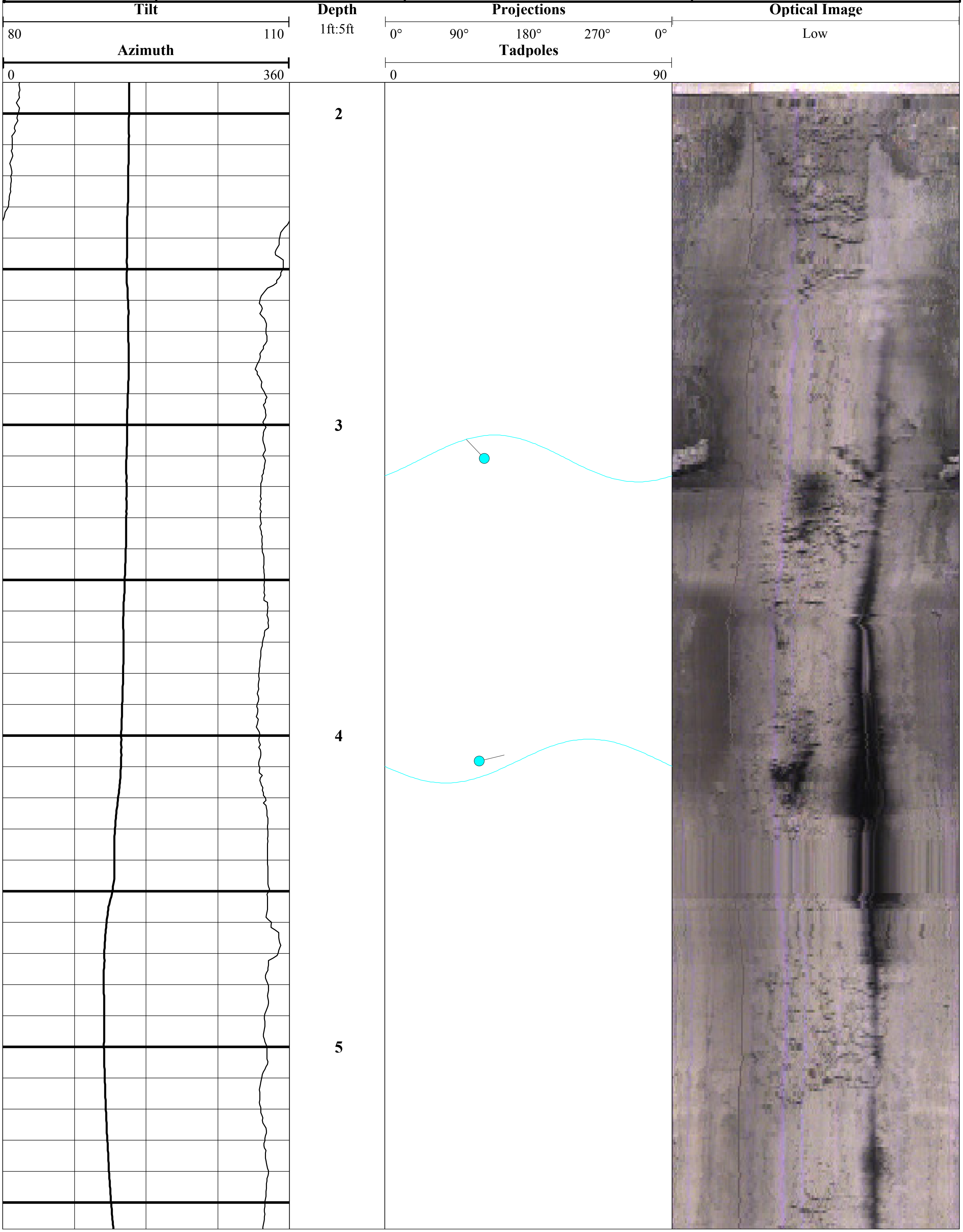

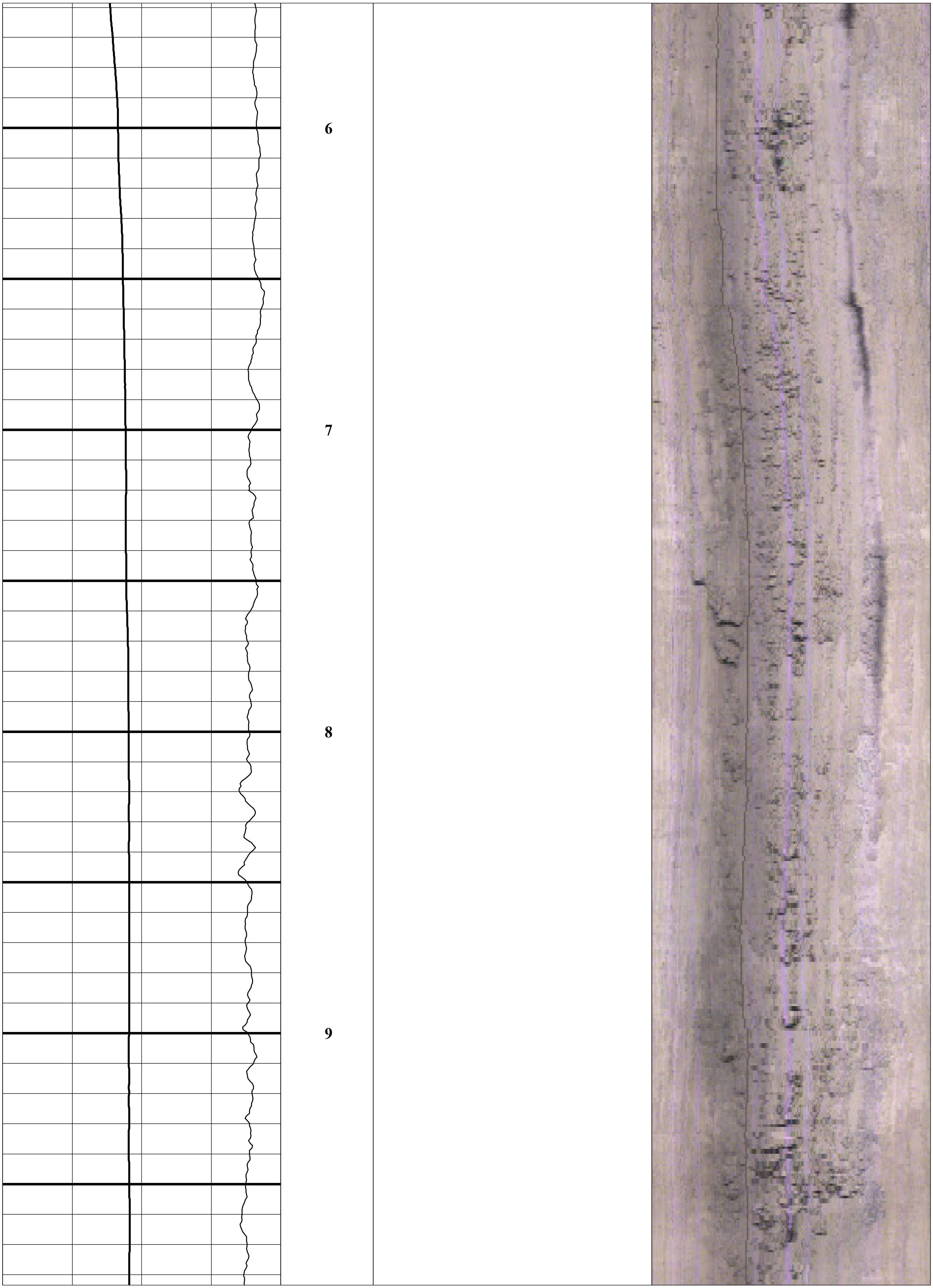
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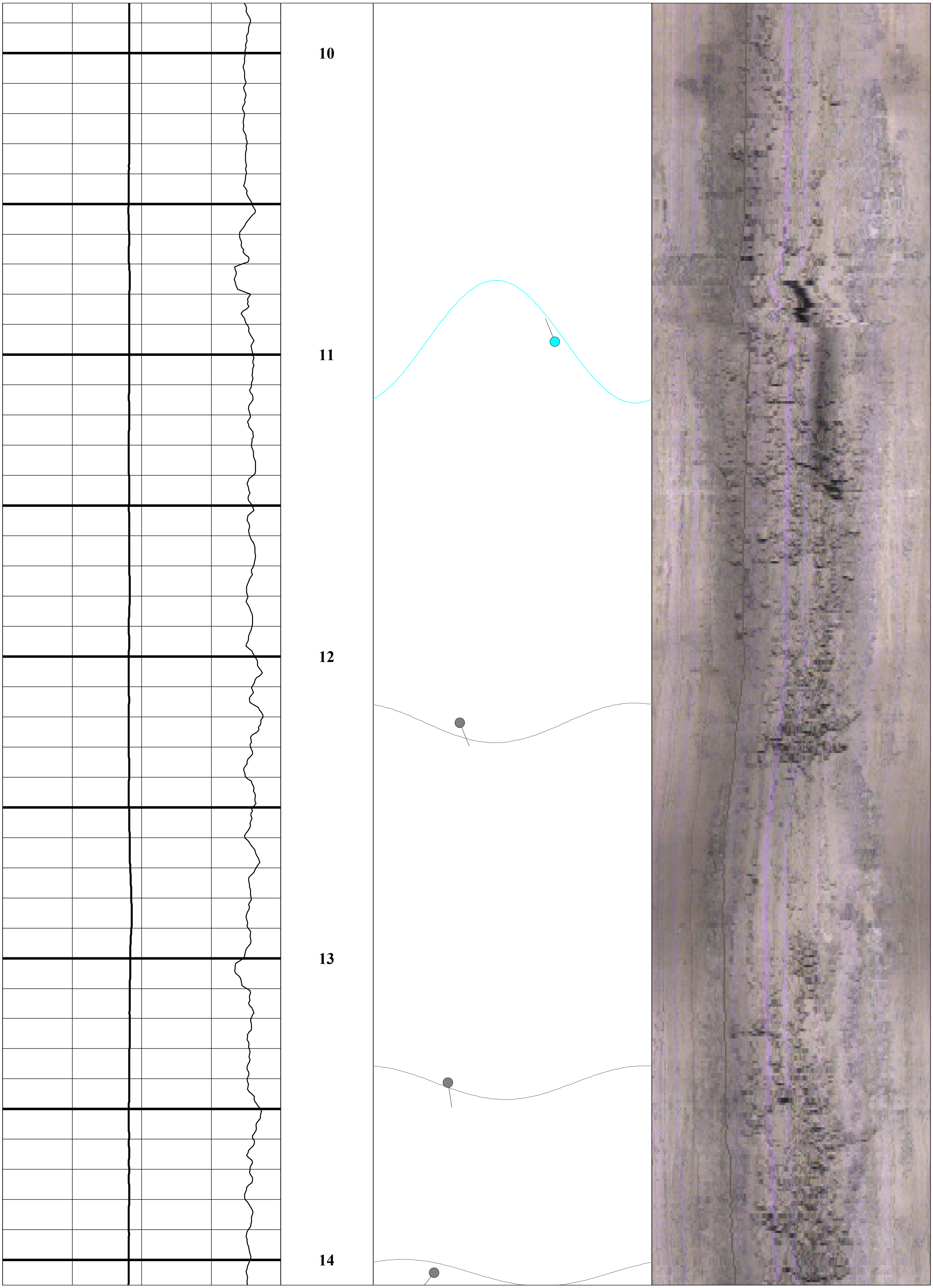
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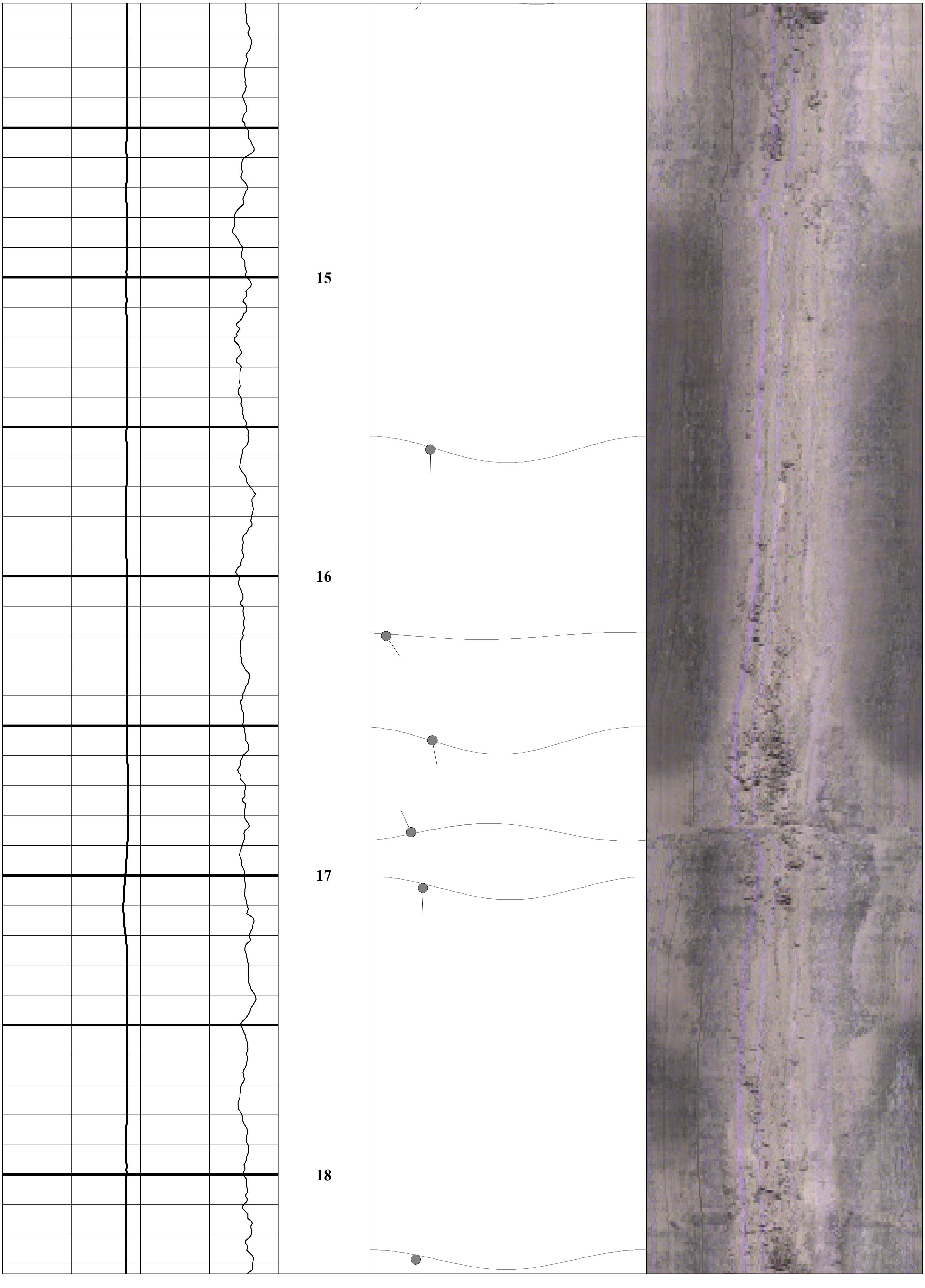
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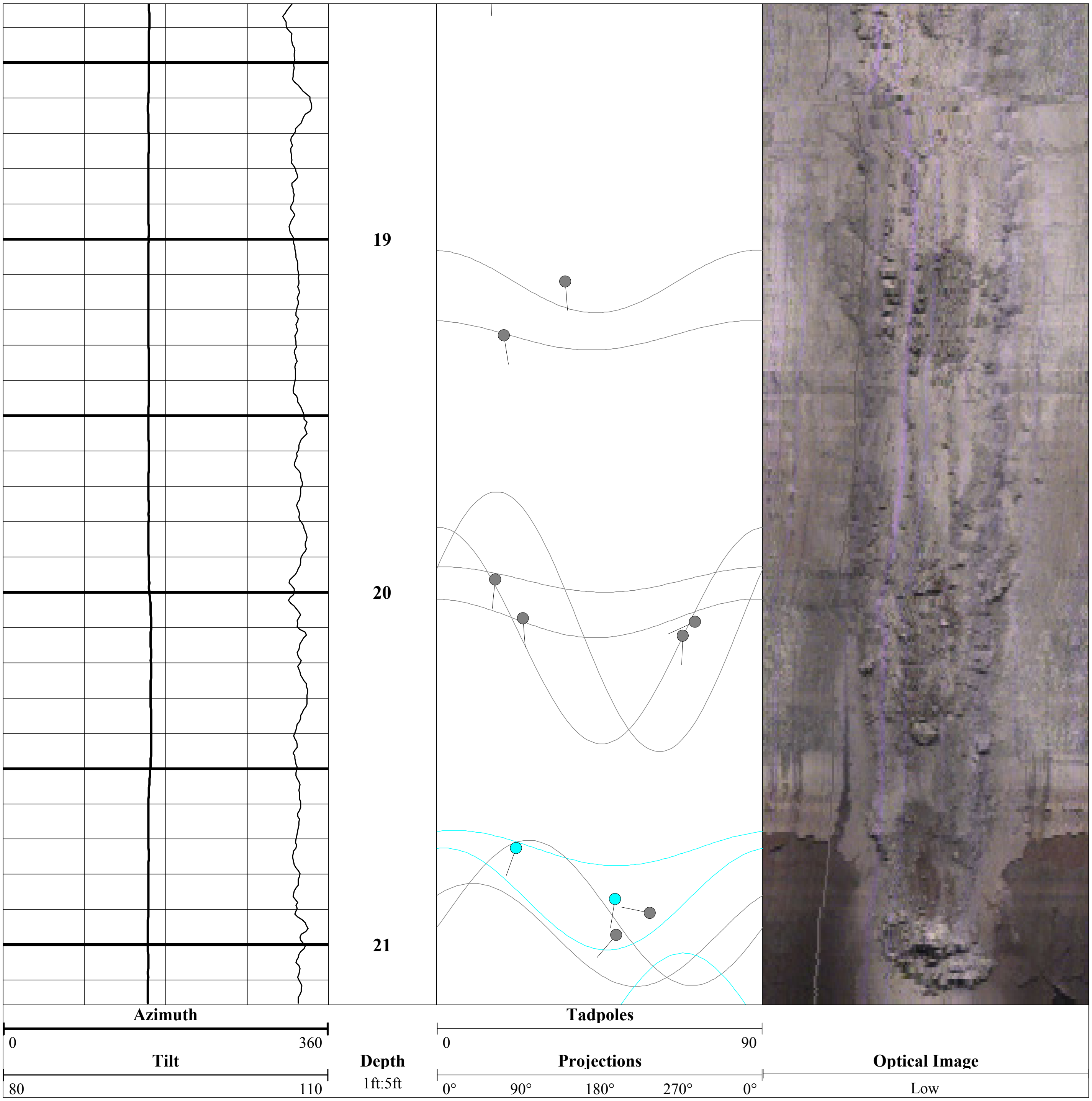
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Tilt
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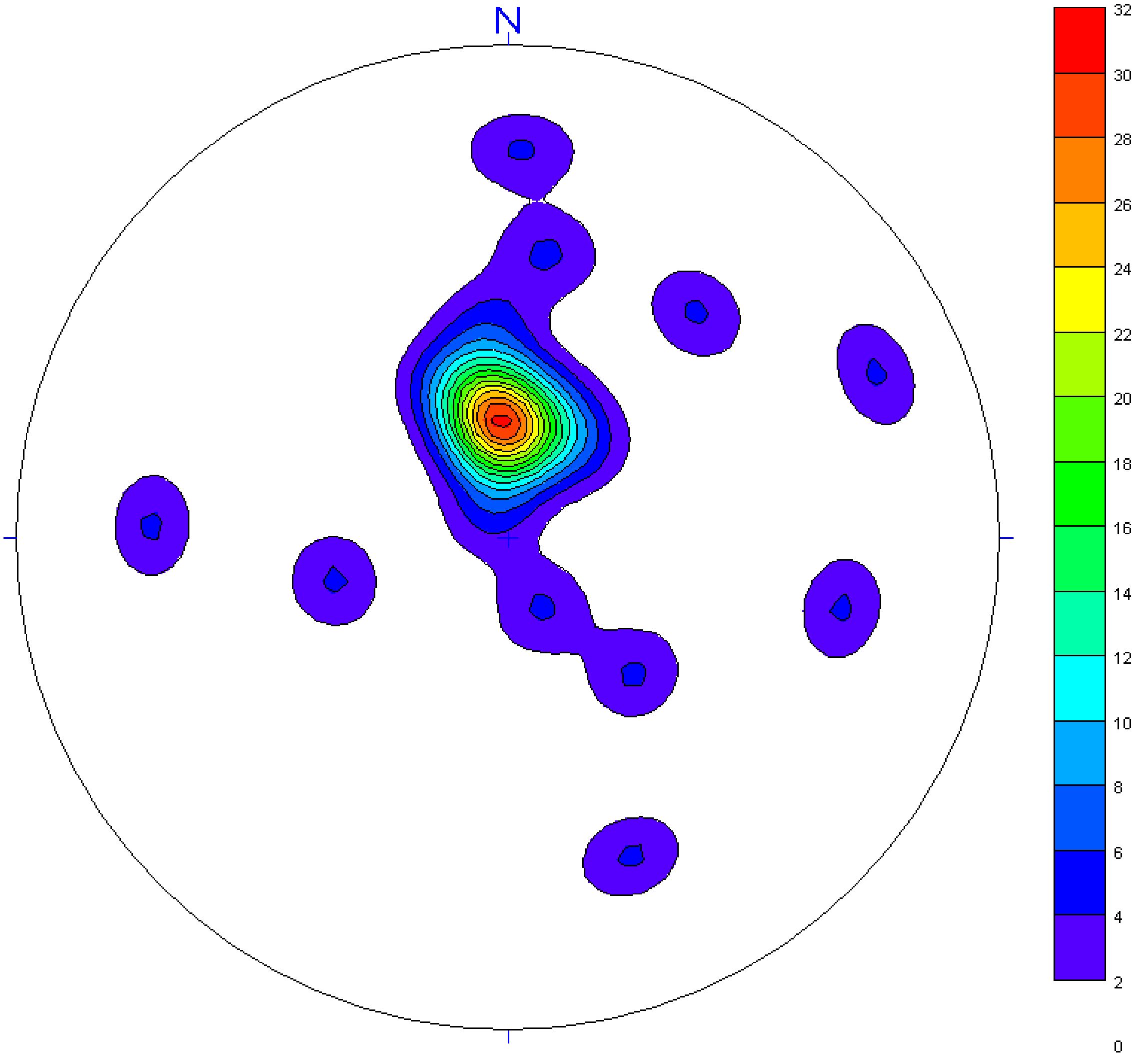
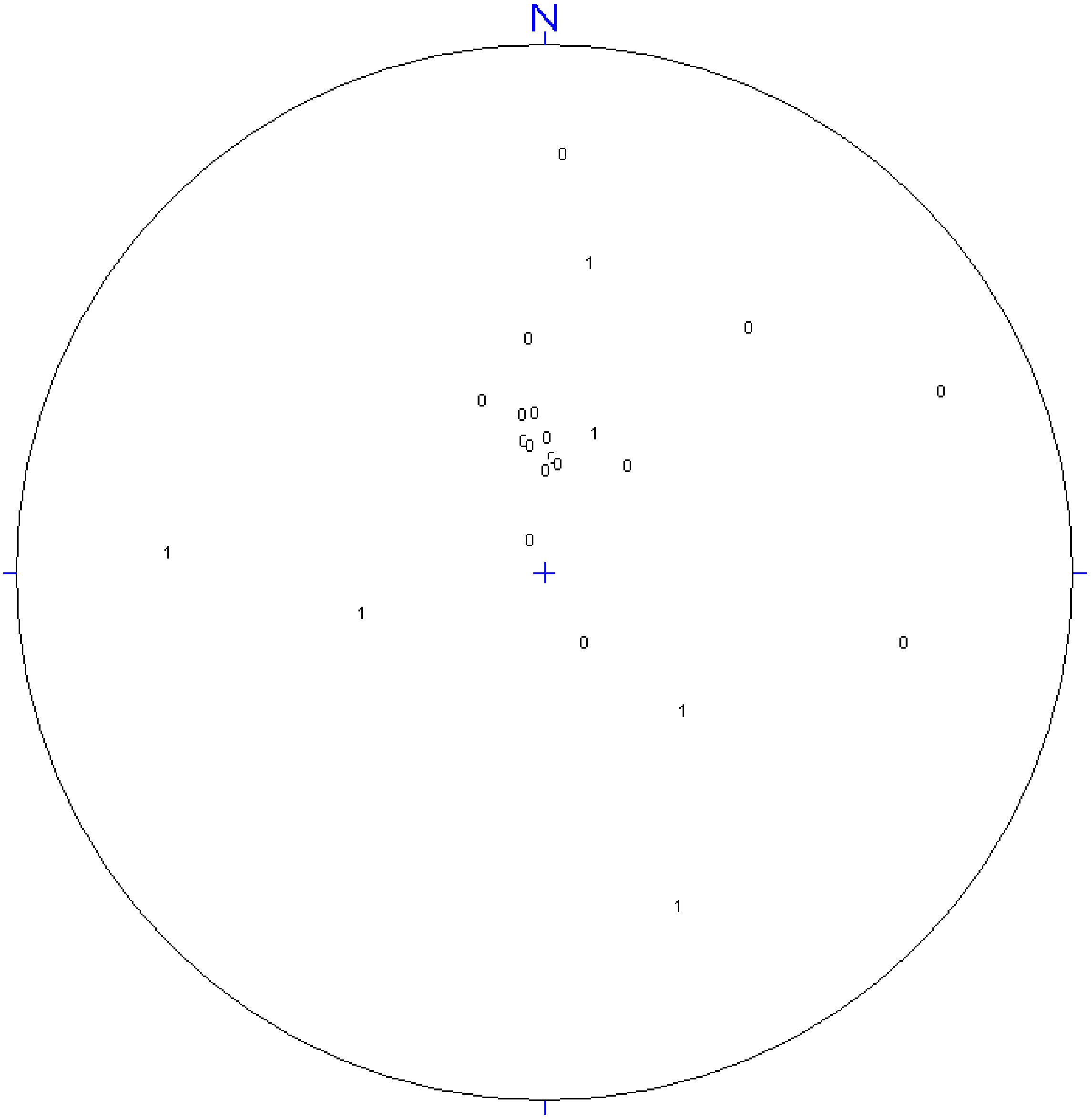
110
Depth
1ft:5ft
Tadpoles
0
90
Projections
0°
90°
180°
270°
0°
Optical Image
Low

Stereonet Diagram – Schmidt Projection
Optical Televiewer Features
I-70 Tunnel
YA-T3
Yeh and Associates
12 March 2012



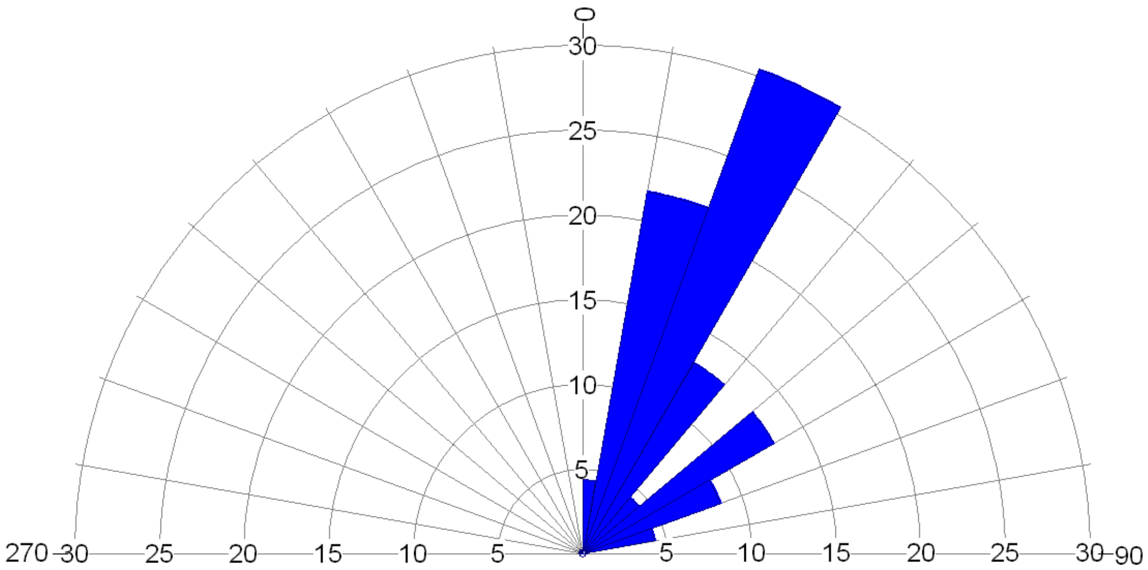
All directions are with respect to Magnetic North.

Stereonet Diagram – Schmidt Projection
Optical Televiewer Features
I-70 Tunnel
YA-T3
Yeh and Associates
12 March 2012



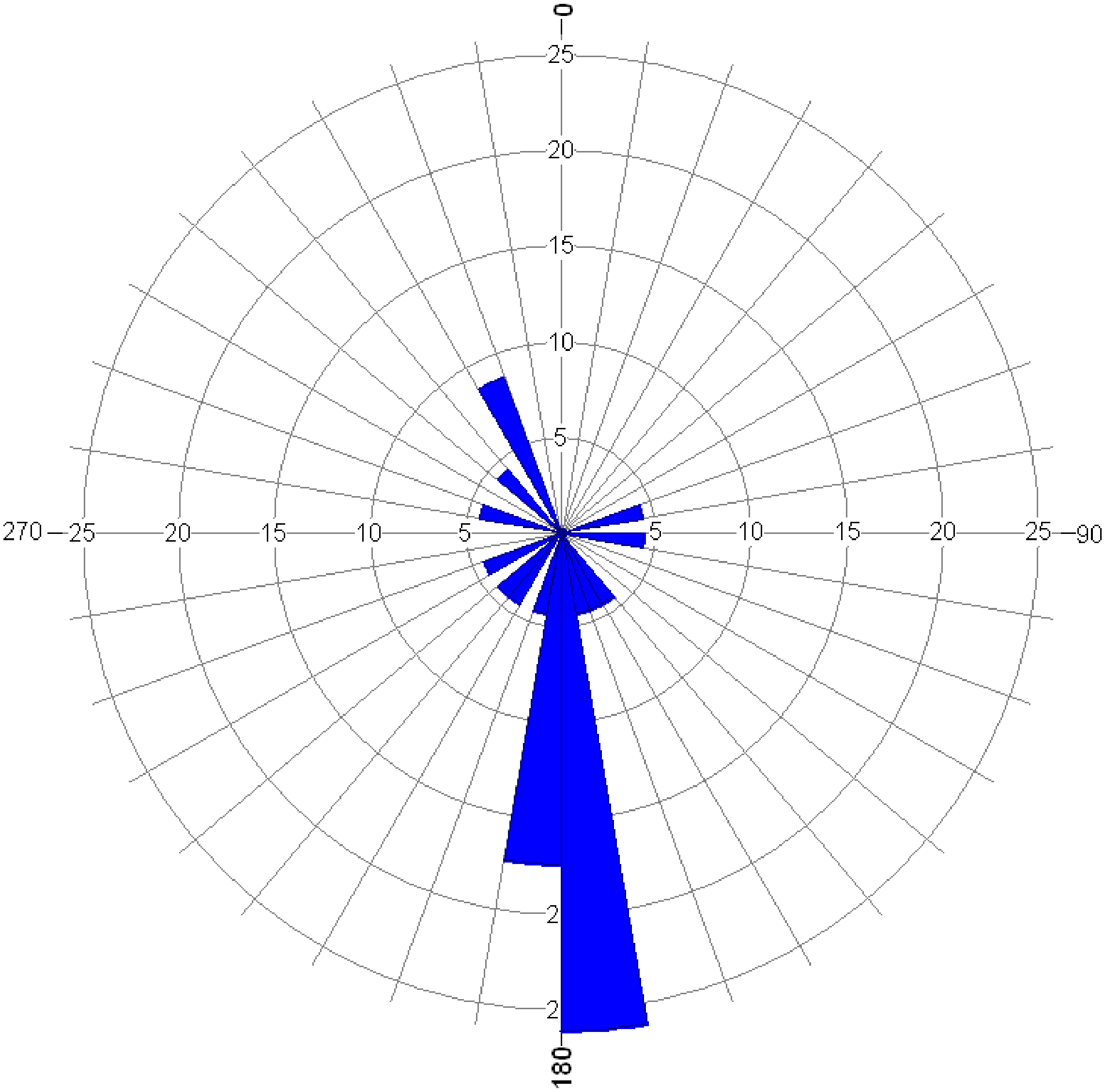
All directions are with respect to Magnetic North.

Rose Diagram – Dip Angles
Optical Televiewer Features
I-70 Tunnel
YA-T3
Yeh and Associates
12 March 2012



All directions are with respect to Magnetic North.

Rose Diagram – Dip Directions
Optical Televiewer Features
I-70 Tunnel
YA-T3
Yeh and Associates
12 March 2012



All directions are with respect to Magnetic North.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T3
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
1	0.95	3.1	317	31	1
2	1.24	4.1	76	30	1
3	3.34	11.0	339	59	1
4	3.72	12.2	158	28	0
5	4.09	13.4	170	24	0
6	4.28	14.0	218	20	0
7	4.75	15.6	179	20	0
8	4.94	16.2	146	5	0
9	5.04	16.6	169	20	0
10	5.14	16.9	335	13	0
11	5.19	17.0	182	17	0
12	5.57	18.3	178	15	0
13	5.83	19.1	175	36	0
14	5.87	19.3	171	19	0
15	6.08	20.0	185	16	0
16	6.12	20.1	175	24	0
17	6.12	20.1	246	71	0
18	6.13	20.1	182	68	0
19	6.32	20.7	199	22	1
20	6.36	20.9	188	49	1
21	6.37	20.9	282	59	0
22	6.39	21.0	220	50	0
23	6.48	21.3	92	62	1

All directions are with respect to magnetic north.

Optical Televiewer Image Plot

COMPANY: Yeh and Associates

PROJECT: I-70 Tunnel

DATE LOGGED: 12 March 2012

WELL: YA-T4

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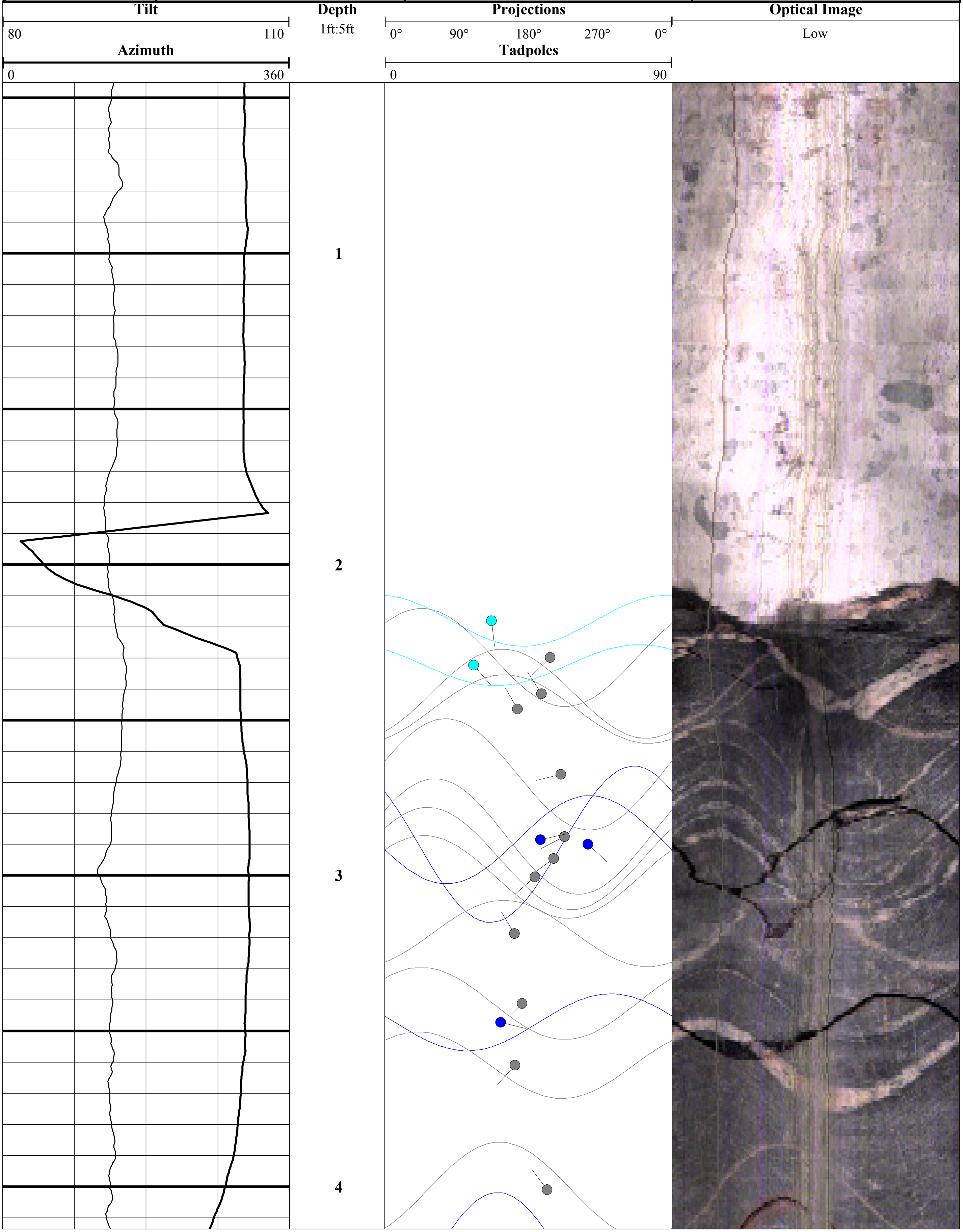

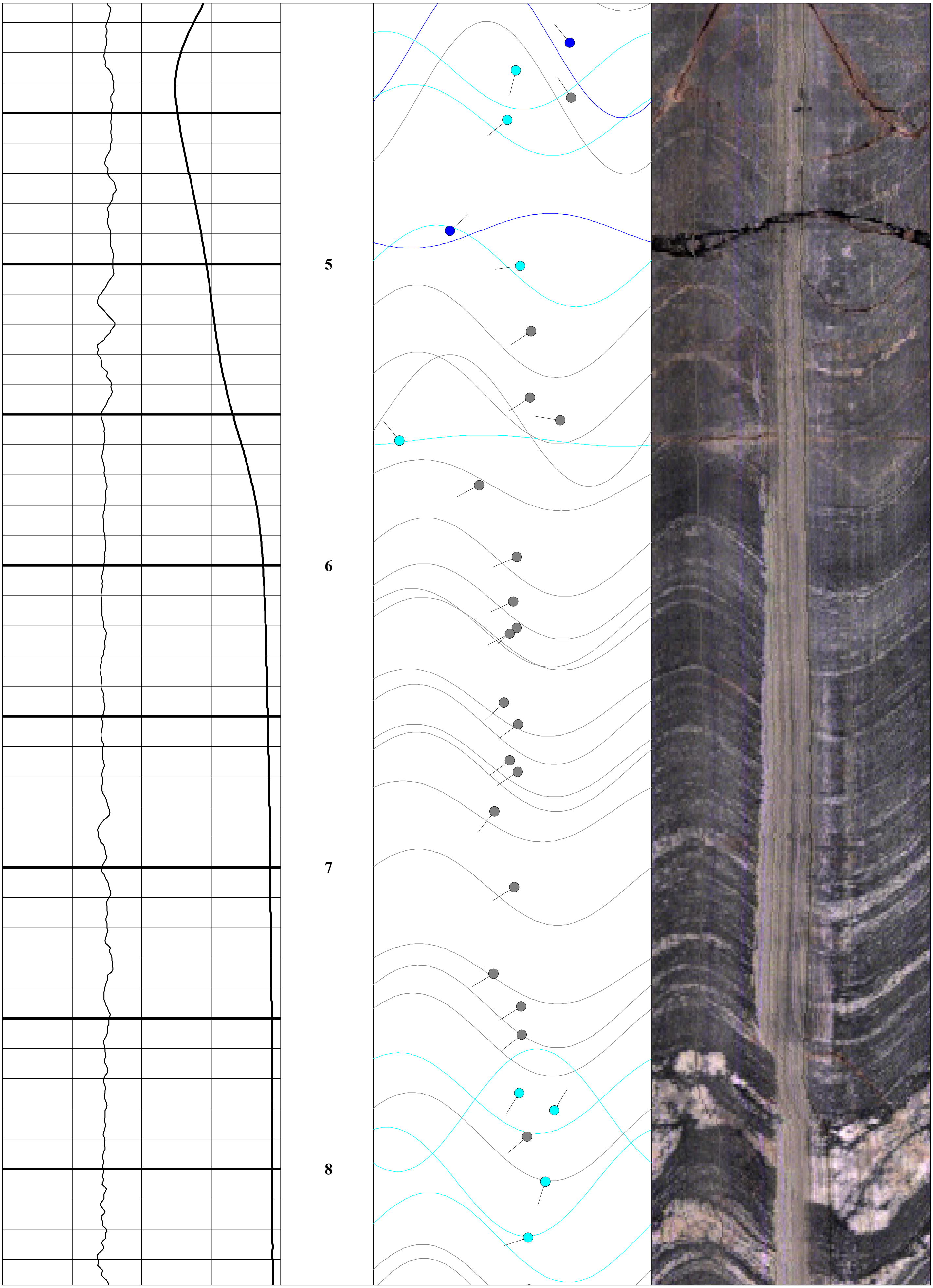
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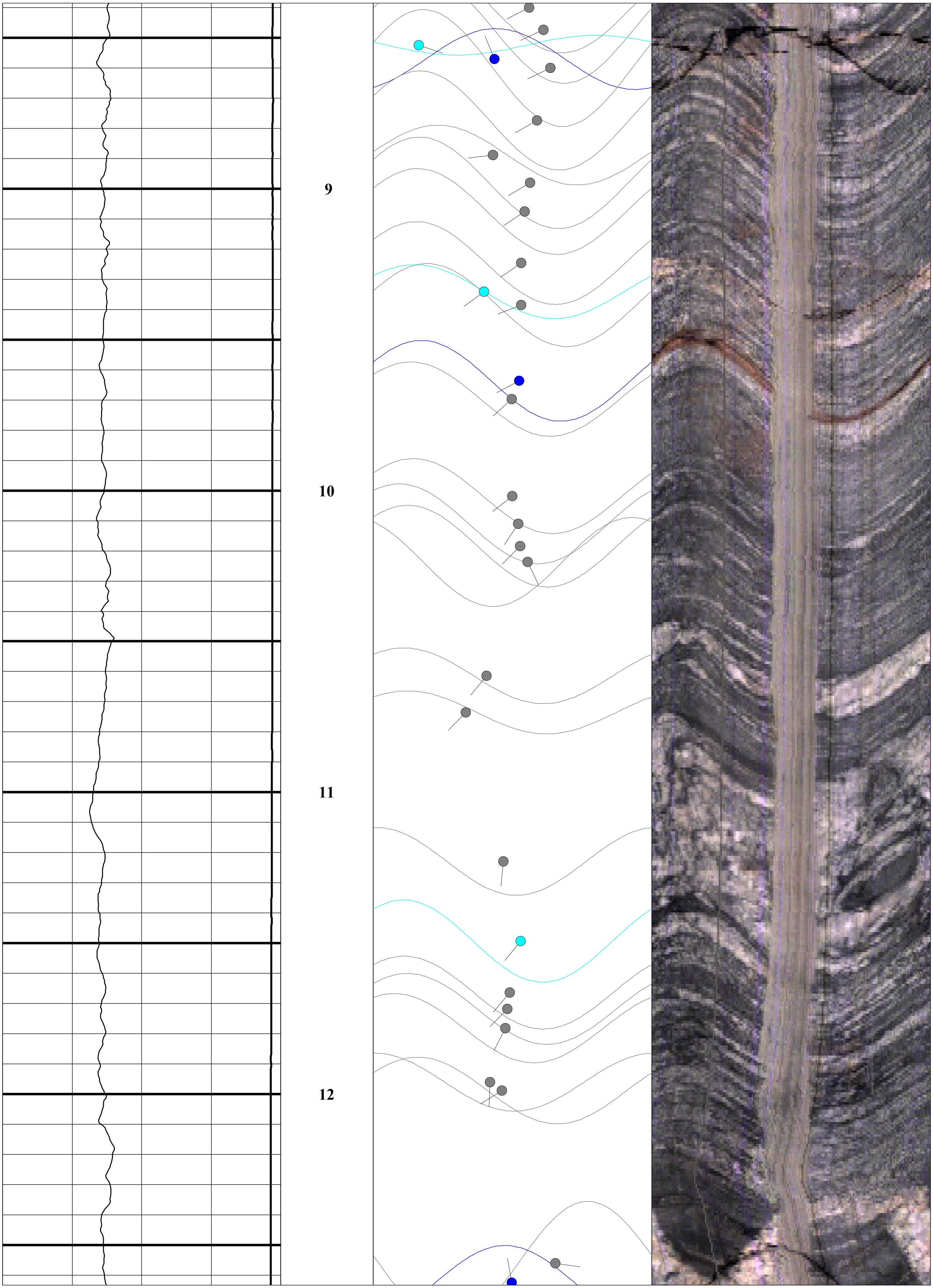
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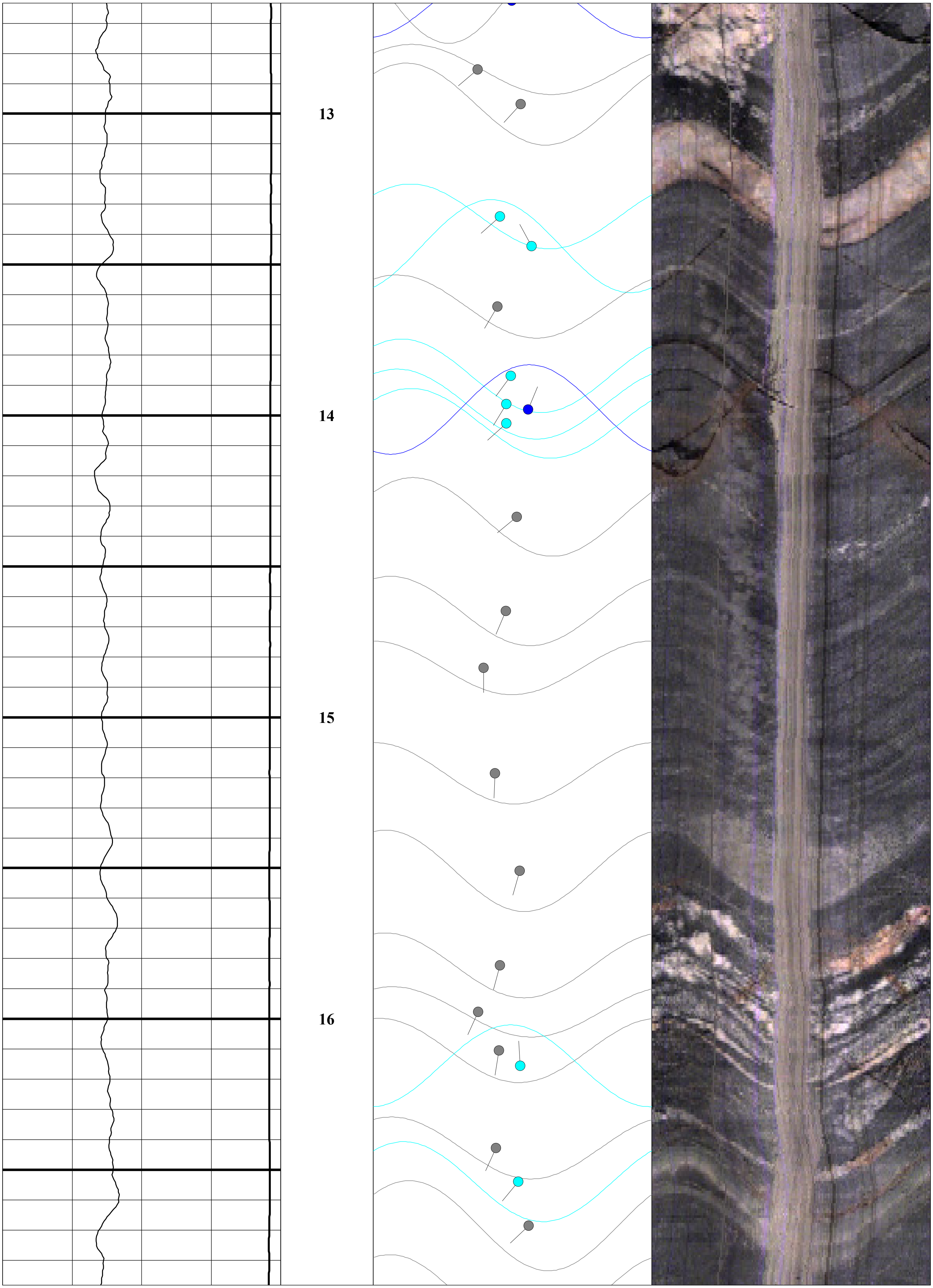
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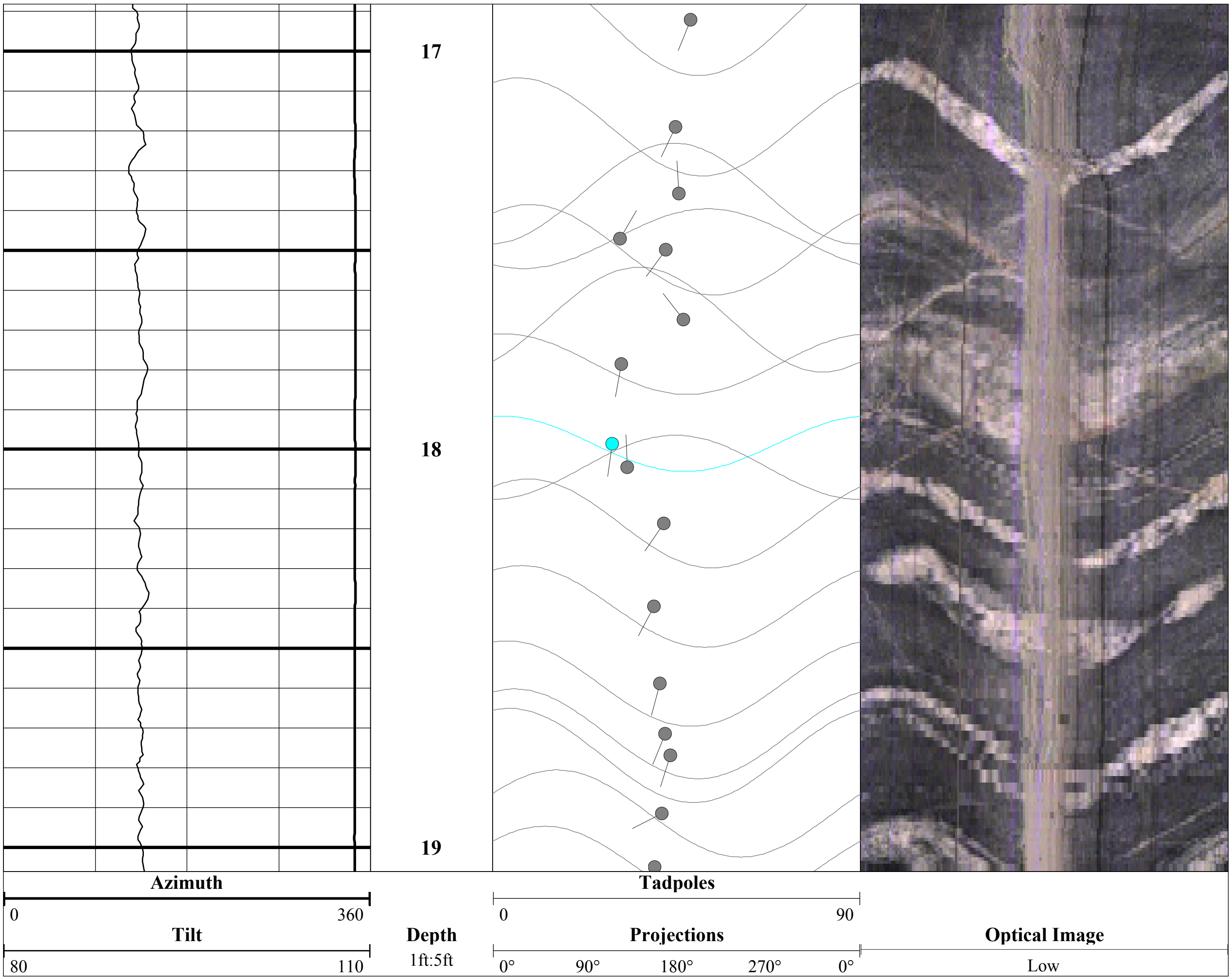
17
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Azimuth
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Tilt
80
110
Depth
1ft:5ft
Tadpoles
0
90
Projections
0°
90°
180°
270°
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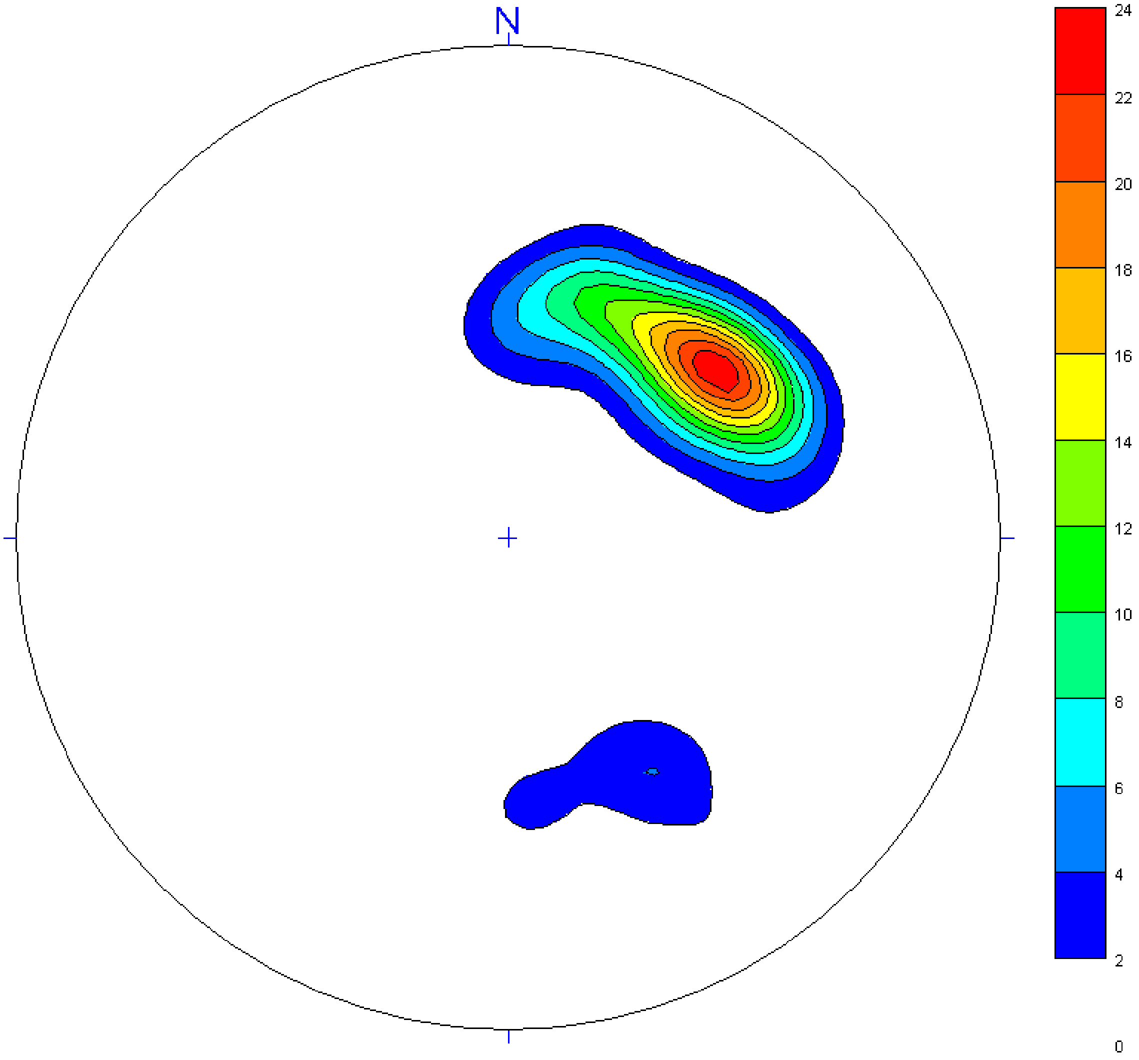
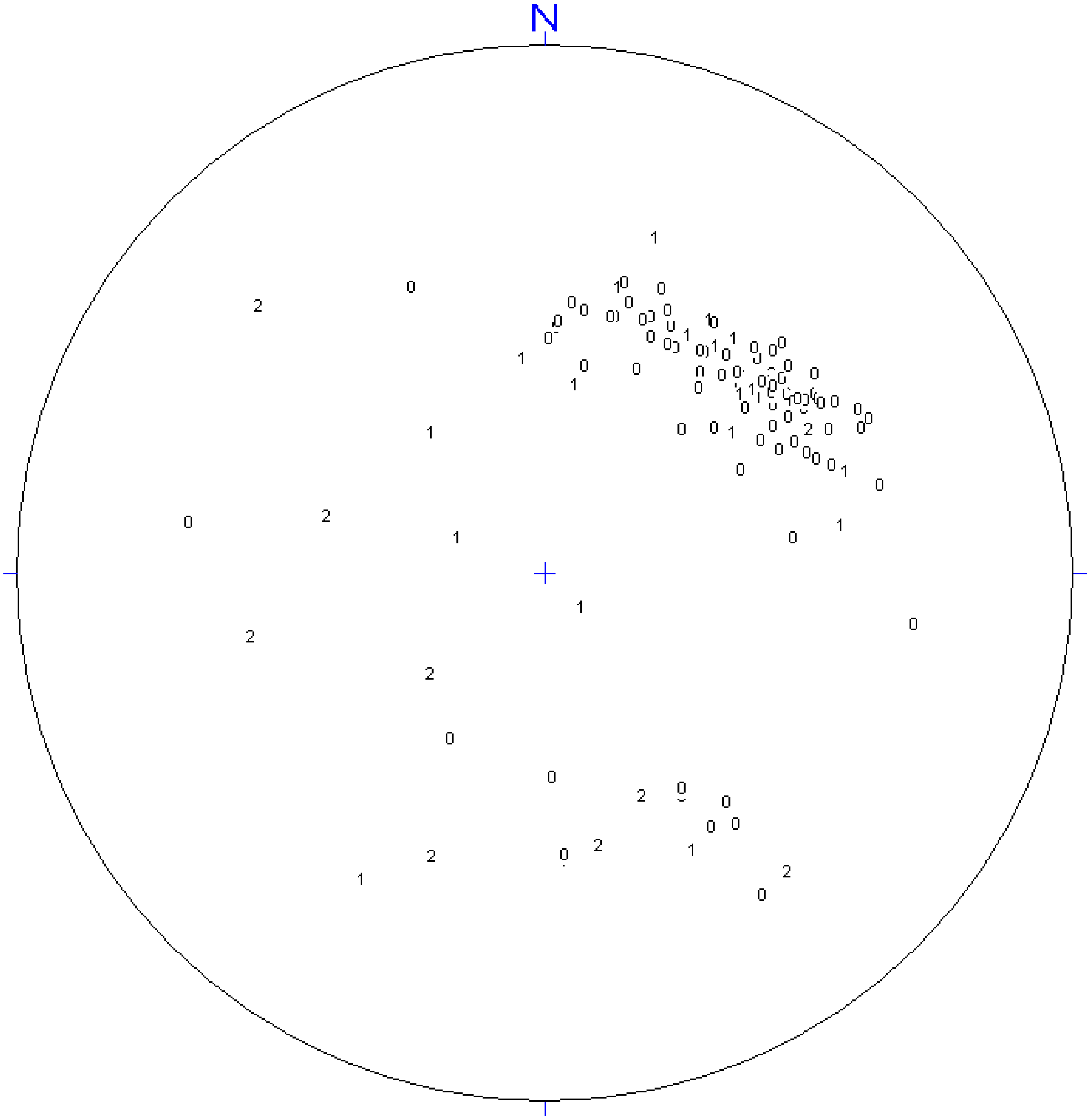
Optical Image
Low

Stereonet Diagram – Schmidt Projection
Optical Televiewer Features
I-70 Tunnel
YA-T4
Yeh and Associates
12 March 2012



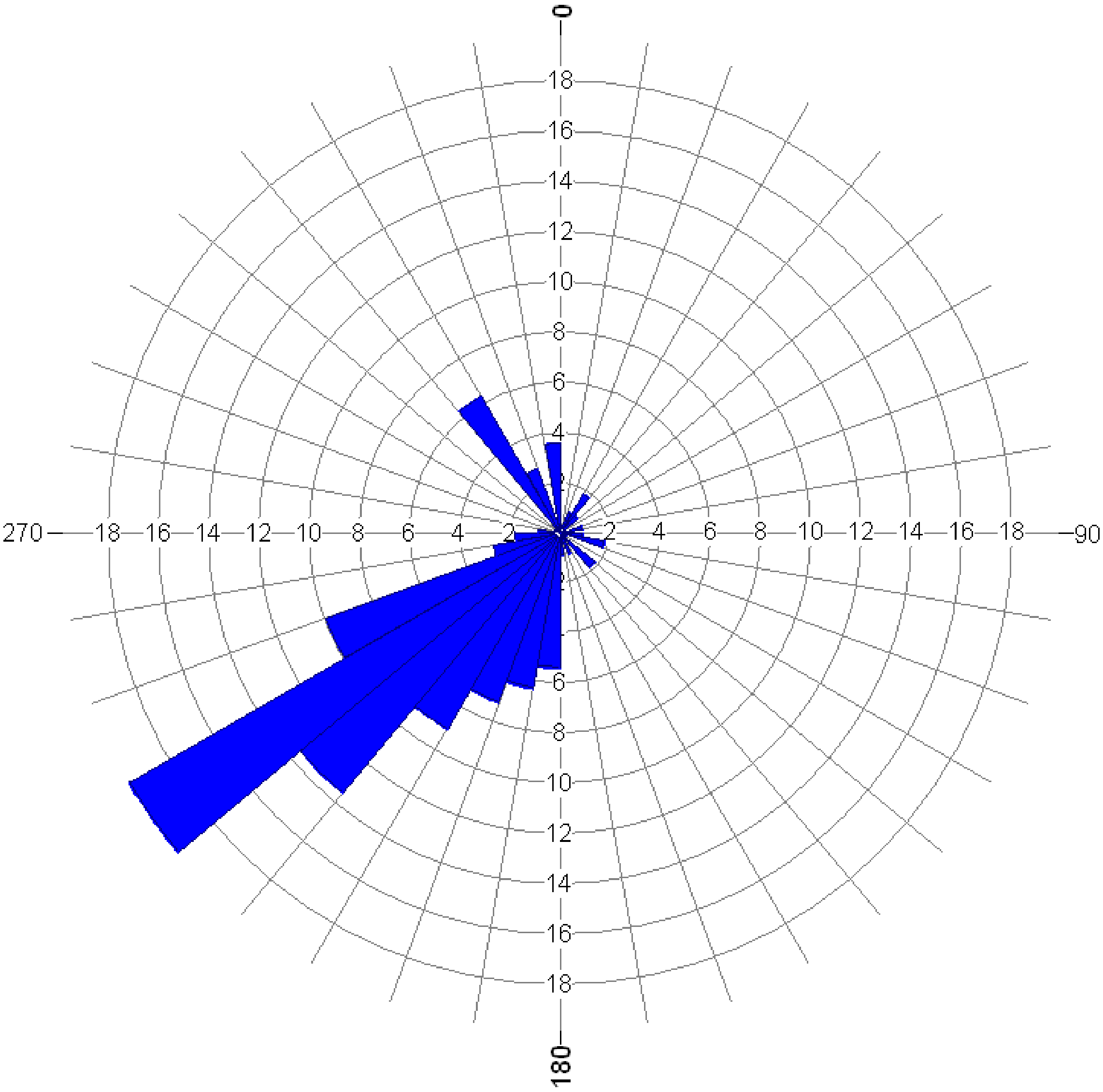
All directions are with respect to Magnetic North.

Stereonet Diagram – Schmidt Projection
Optical Televiewer Features
I-70 Tunnel
YA-T4
Yeh and Associates
12 March 2012



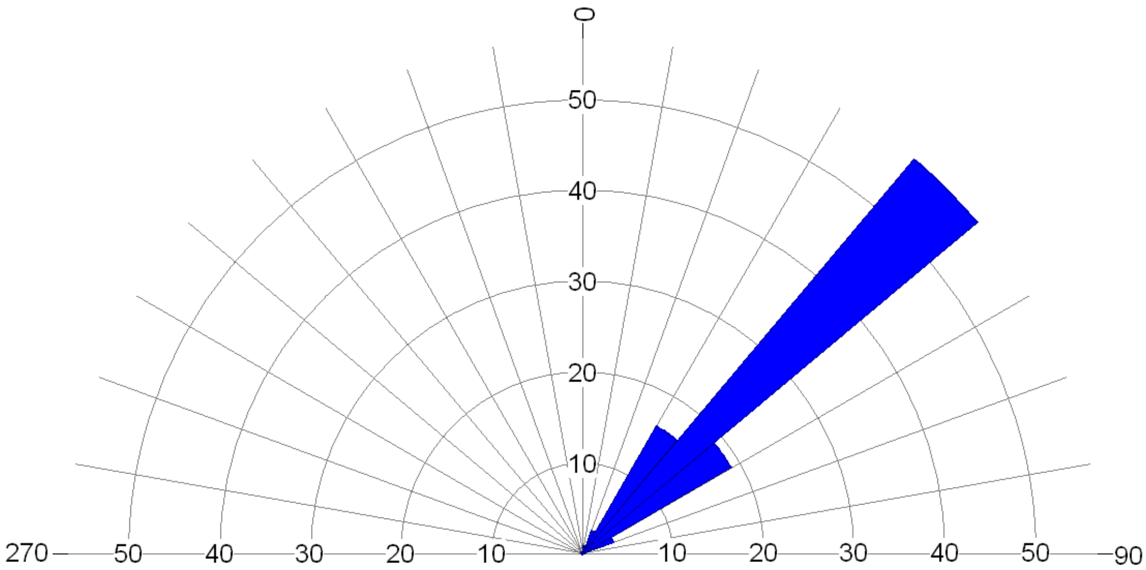
All directions are with respect to Magnetic North.

Rose Diagram – Dip Directions
Optical Televiewer Features
I-70 Tunnel
YA-T4
Yeh and Associates
12 March 2012



All directions are with respect to Magnetic North.

Rose Diagram – Dip Angles
Optical Televiewer Features
I-70 Tunnel
YA-T4
Yeh and Associates
12 March 2012



All directions are with respect to Magnetic North.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T4
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
1	0.66	2.2	173	33	1
2	0.70	2.3	226	52	0
3	0.71	2.3	139	28	1
4	0.73	2.4	328	49	0
5	0.75	2.5	330	42	0
6	0.82	2.7	256	55	0
7	0.88	2.9	243	56	0
8	0.88	2.9	77	49	2
9	0.88	2.9	132	64	2
10	0.90	2.9	234	53	0
11	0.91	3.0	229	47	0
12	0.97	3.2	329	41	0
13	1.04	3.4	225	43	0
14	1.06	3.5	103	36	2
15	1.10	3.6	222	41	0
16	1.22	4.0	324	51	0
17	1.30	4.3	322	63	2
18	1.33	4.4	194	46	1
19	1.36	4.5	327	64	0
20	1.38	4.5	231	43	1
21	1.49	4.9	48	25	2
22	1.53	5.0	262	47	1
23	1.59	5.2	237	51	0
24	1.66	5.4	238	51	0
25	1.68	5.5	279	60	0
26	1.70	5.6	322	8	1
27	1.75	5.7	243	34	0
28	1.82	6.0	248	46	0
29	1.87	6.1	246	45	0
30	1.89	6.2	230	46	0
31	1.90	6.2	243	44	0
32	1.97	6.5	226	42	0
33	1.99	6.5	234	47	0
34	2.03	6.7	234	44	0
35	2.04	6.7	236	47	0
36	2.08	6.8	218	39	0
37	2.15	7.1	238	45	0
38	2.24	7.4	239	39	0
39	2.27	7.5	238	48	0
40	2.30	7.6	231	48	0
41	2.36	7.8	213	47	1
42	2.38	7.8	31	59	1
43	2.40	7.9	230	50	0
44	2.45	8.0	198	56	1
45	2.51	8.2	252	50	1

All directions are with respect to magnetic north.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T4
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
46	2.56	8.4	244	50	0
47	2.58	8.5	246	55	0
48	2.60	8.5	108	15	1
49	2.61	8.6	338	39	2
50	2.62	8.6	245	57	0
51	2.67	8.8	240	53	0
52	2.71	8.9	263	39	0
53	2.74	9.0	239	51	0
54	2.77	9.1	237	49	0
55	2.82	9.3	236	48	0
56	2.85	9.3	234	36	1
57	2.86	9.4	250	48	0
58	2.94	9.6	242	47	2
59	2.96	9.7	229	45	0
60	3.05	10.0	232	45	0
61	3.08	10.1	214	47	0
62	3.10	10.2	225	47	0
63	3.12	10.2	154	50	0
64	3.23	10.6	220	37	0
65	3.27	10.7	224	30	0
66	3.42	11.2	185	42	0
67	3.50	11.5	219	48	1
68	3.55	11.7	220	44	0
69	3.57	11.7	224	43	0
70	3.59	11.8	207	43	0
71	3.65	12.0	182	38	0
72	3.65	12.0	238	42	0
73	3.83	12.6	97	59	0
74	3.85	12.6	350	45	2
75	3.92	12.9	230	34	0
76	3.95	13.0	223	48	0
77	4.07	13.3	228	41	1
78	4.10	13.4	333	51	1
79	4.16	13.6	210	40	0
80	4.23	13.9	217	44	1
81	4.26	14.0	211	43	1
82	4.26	14.0	22	50	2
83	4.28	14.0	229	43	1
84	4.37	14.3	231	46	0
85	4.47	14.7	202	43	0
86	4.52	14.8	180	36	0
87	4.63	15.2	182	39	0
88	4.73	15.5	195	47	0
89	4.82	15.8	195	41	0
90	4.87	16.0	204	34	0

All directions are with respect to magnetic north.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T4
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
91	4.91	16.1	188	41	0
92	4.92	16.2	357	47	1
93	5.01	16.4	204	40	0
94	5.04	16.5	219	47	1
95	5.09	16.7	226	50	0
96	5.16	16.9	202	48	0
97	5.24	17.2	205	45	0
98	5.29	17.4	357	46	0
99	5.32	17.5	30	31	0
100	5.33	17.5	216	42	0
101	5.39	17.7	323	47	0
102	5.42	17.8	190	32	0
103	5.48	18.0	188	29	1
104	5.50	18.1	359	33	0
105	5.54	18.2	215	42	0
106	5.61	18.4	208	40	0
107	5.67	18.6	194	41	0
108	5.70	18.7	201	42	0
109	5.72	18.8	197	44	0
110	5.76	18.9	243	41	0
111	5.81	19.1	231	40	0

All directions are with respect to magnetic north.

Optical Televiewer Image Plot

COMPANY: Yeh and Associates

PROJECT: I-70 Tunnel

DATE LOGGED: 12 March 2012

WELL: YA-T5

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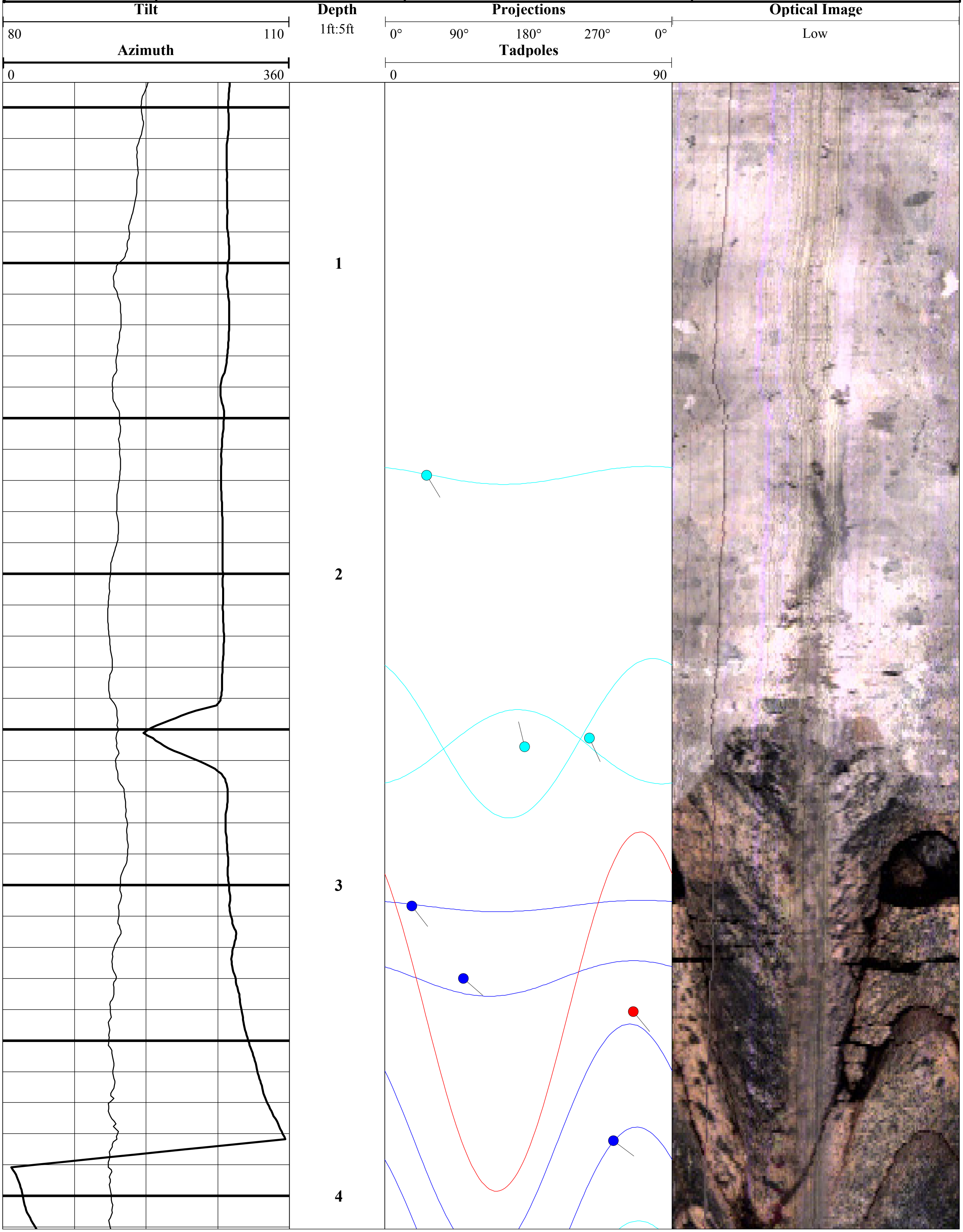

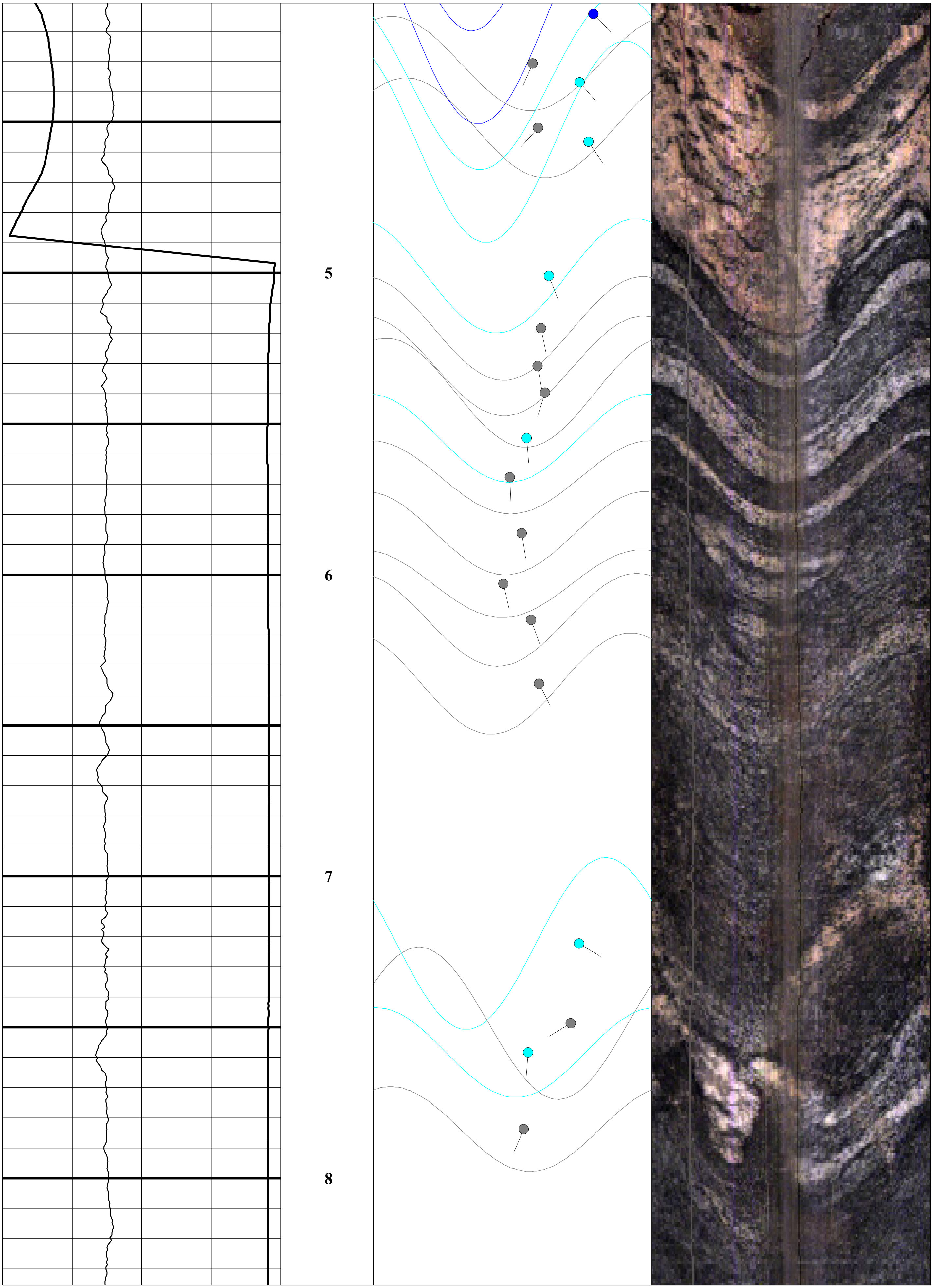
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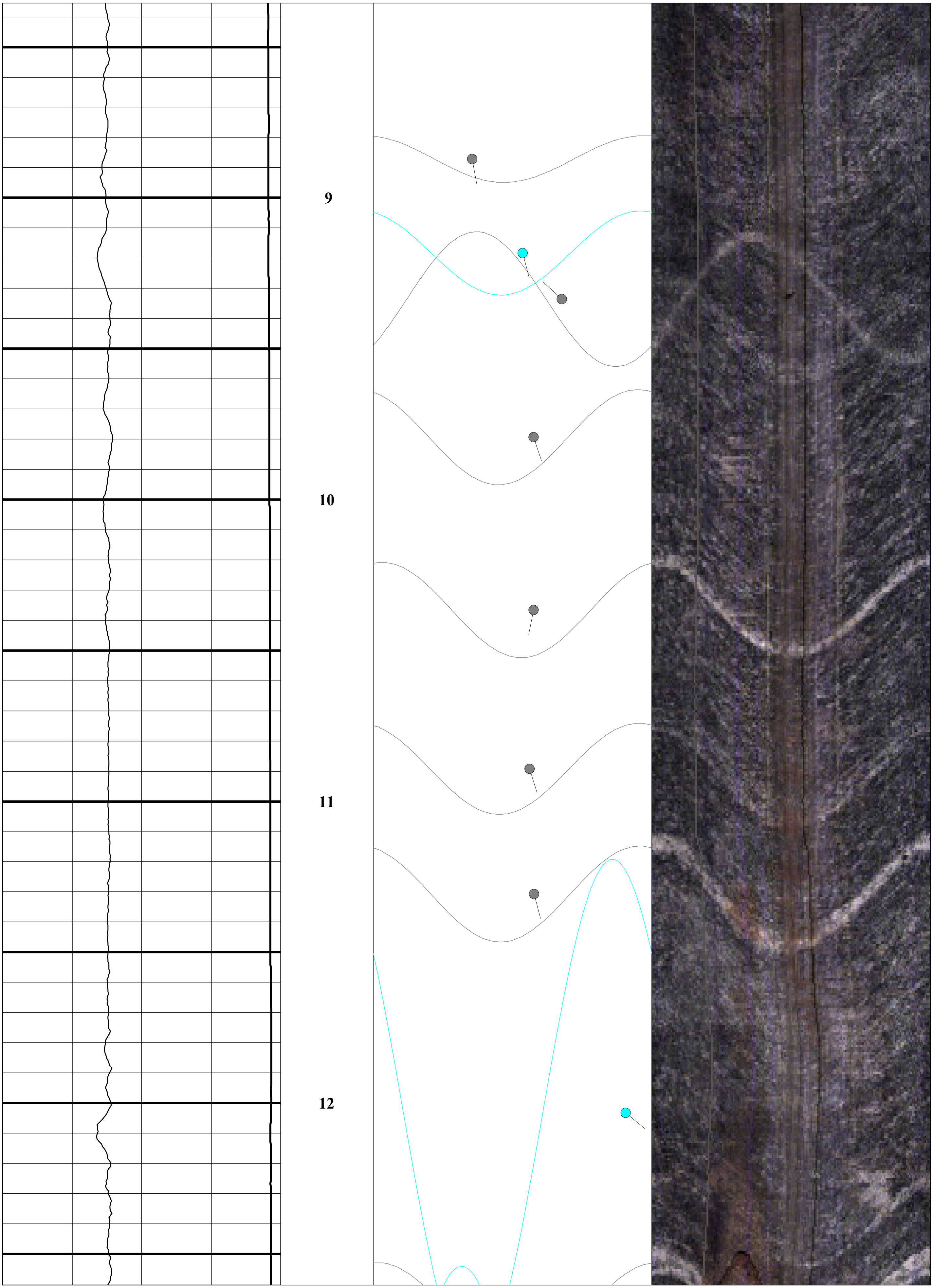
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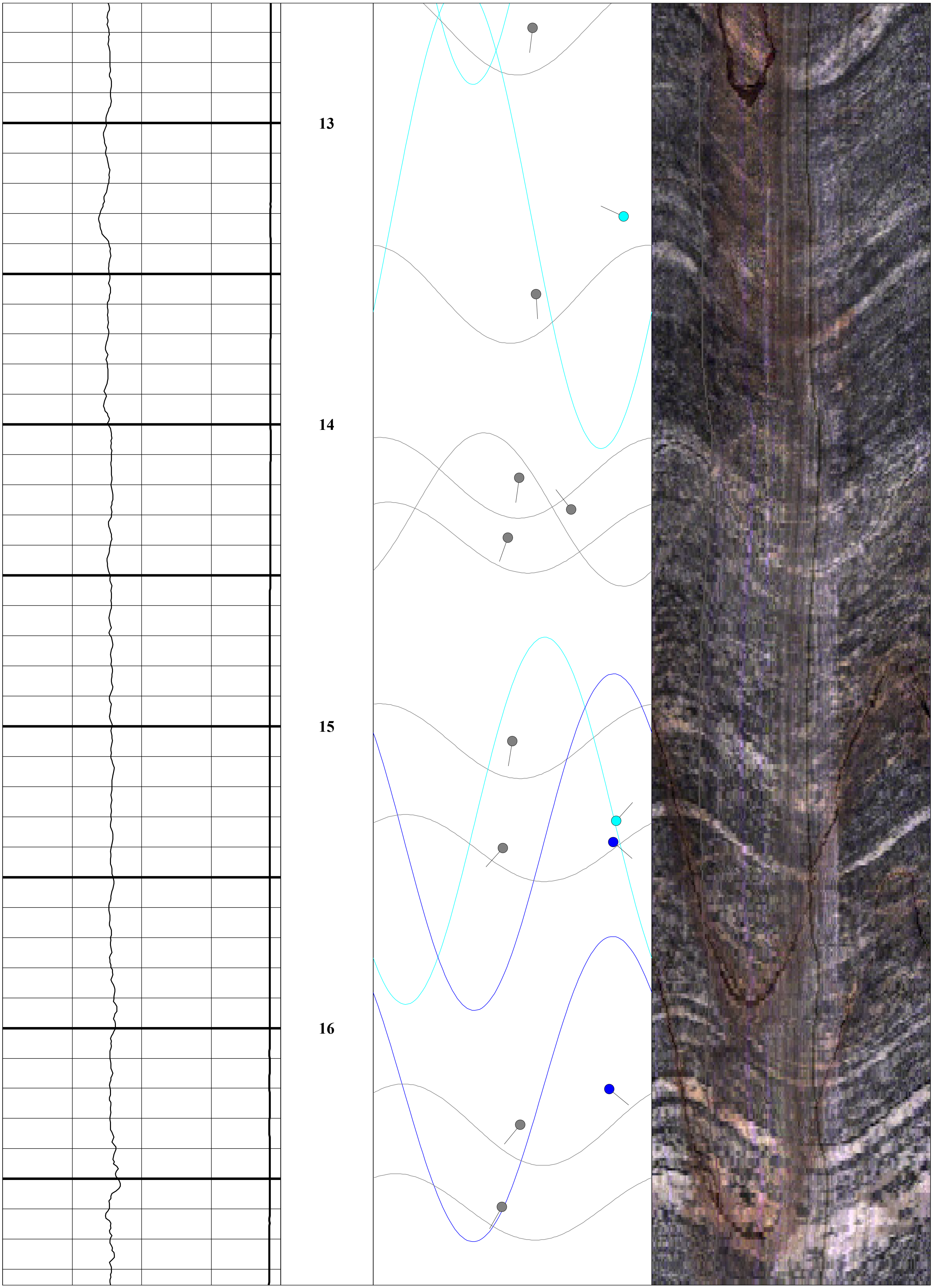
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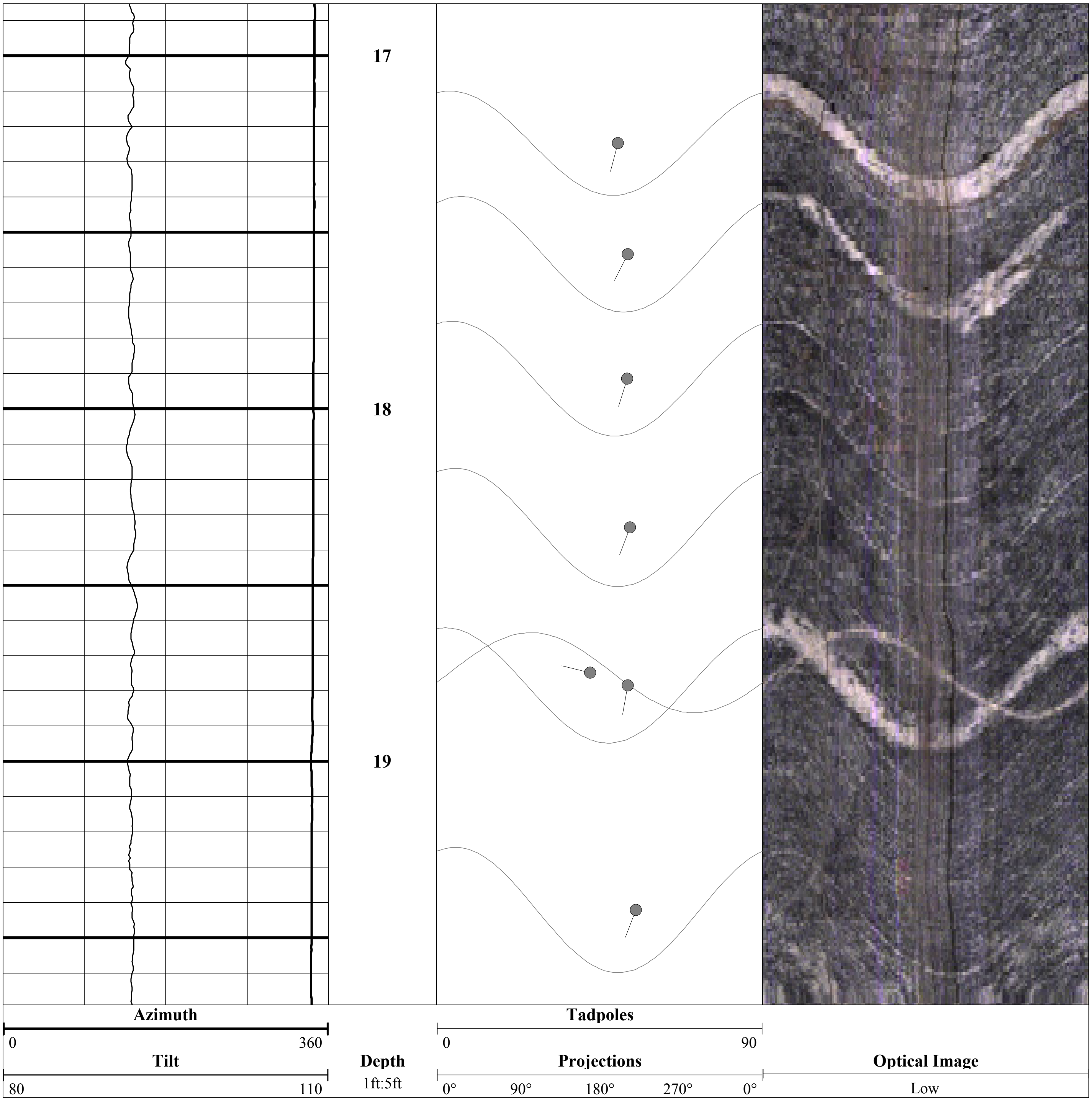
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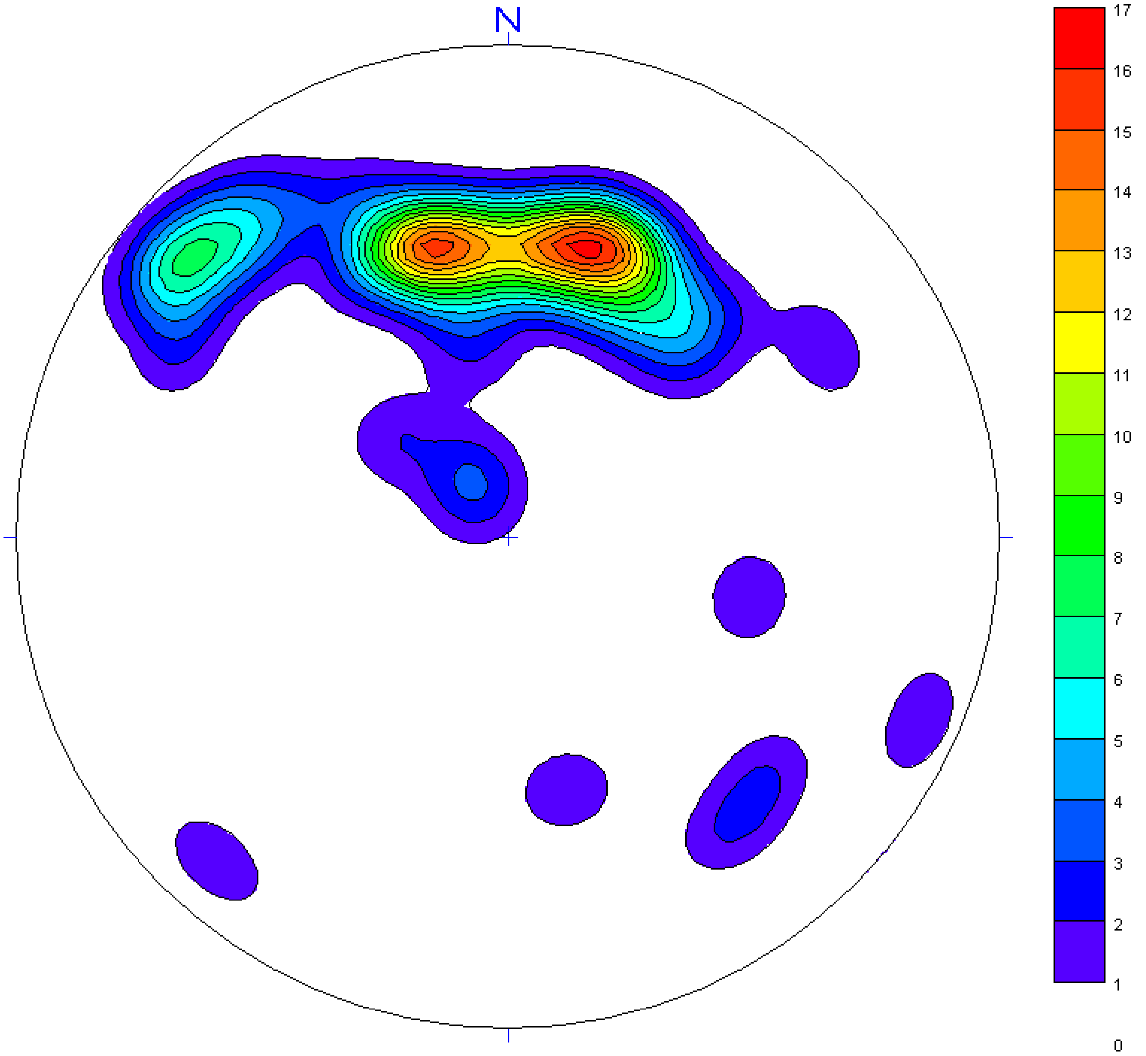
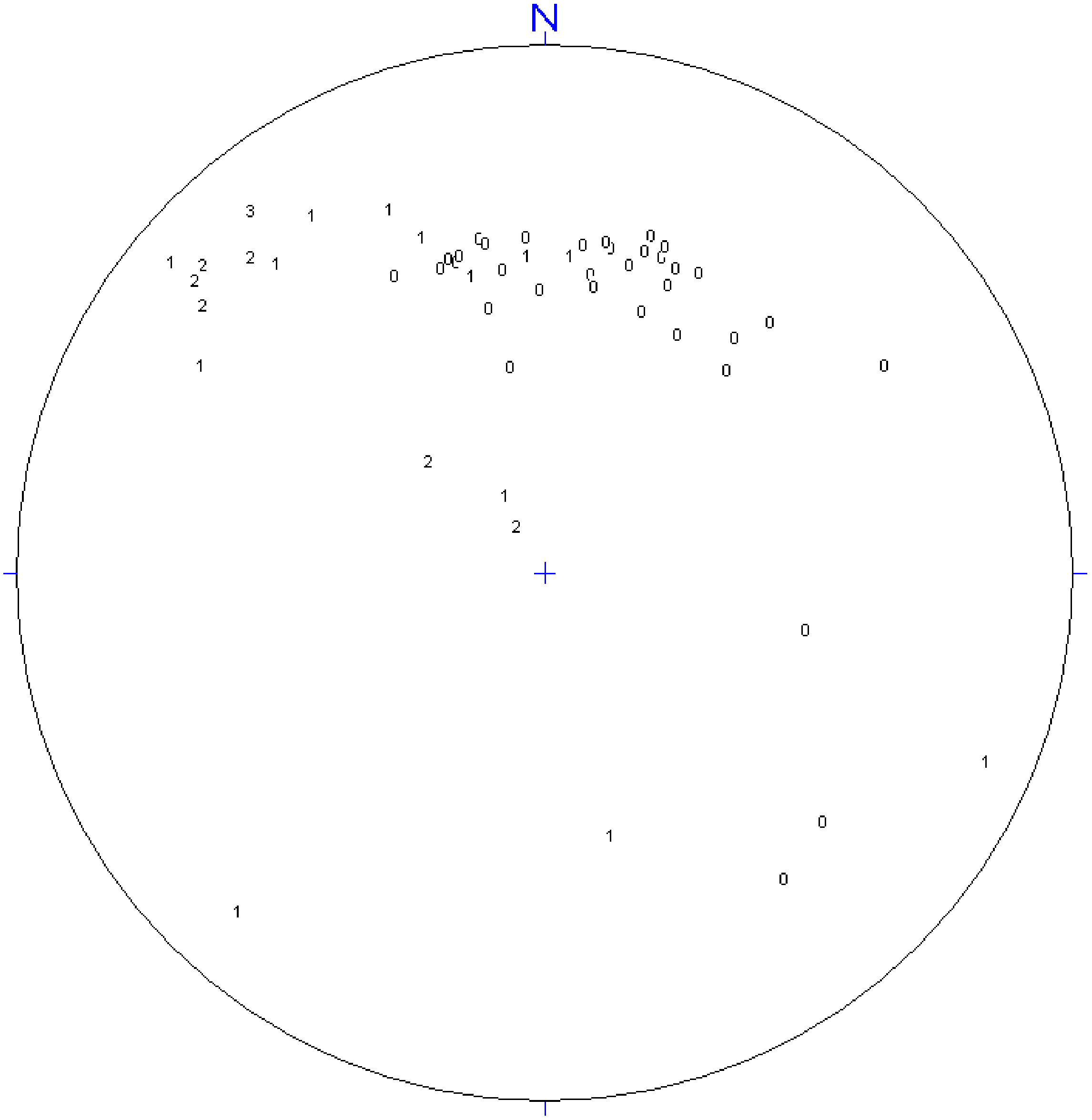
Tilt
80
110
Depth
1ft:5ft
Tadpoles
0
90
Projections
0°
90°
180°
270°
0°
Optical Image
Low

Stereonet Diagram – Schmidt Projection
Optical Televiewer Features
I-70 Tunnel
YA-T5
Yeh and Associates
12 March 2012



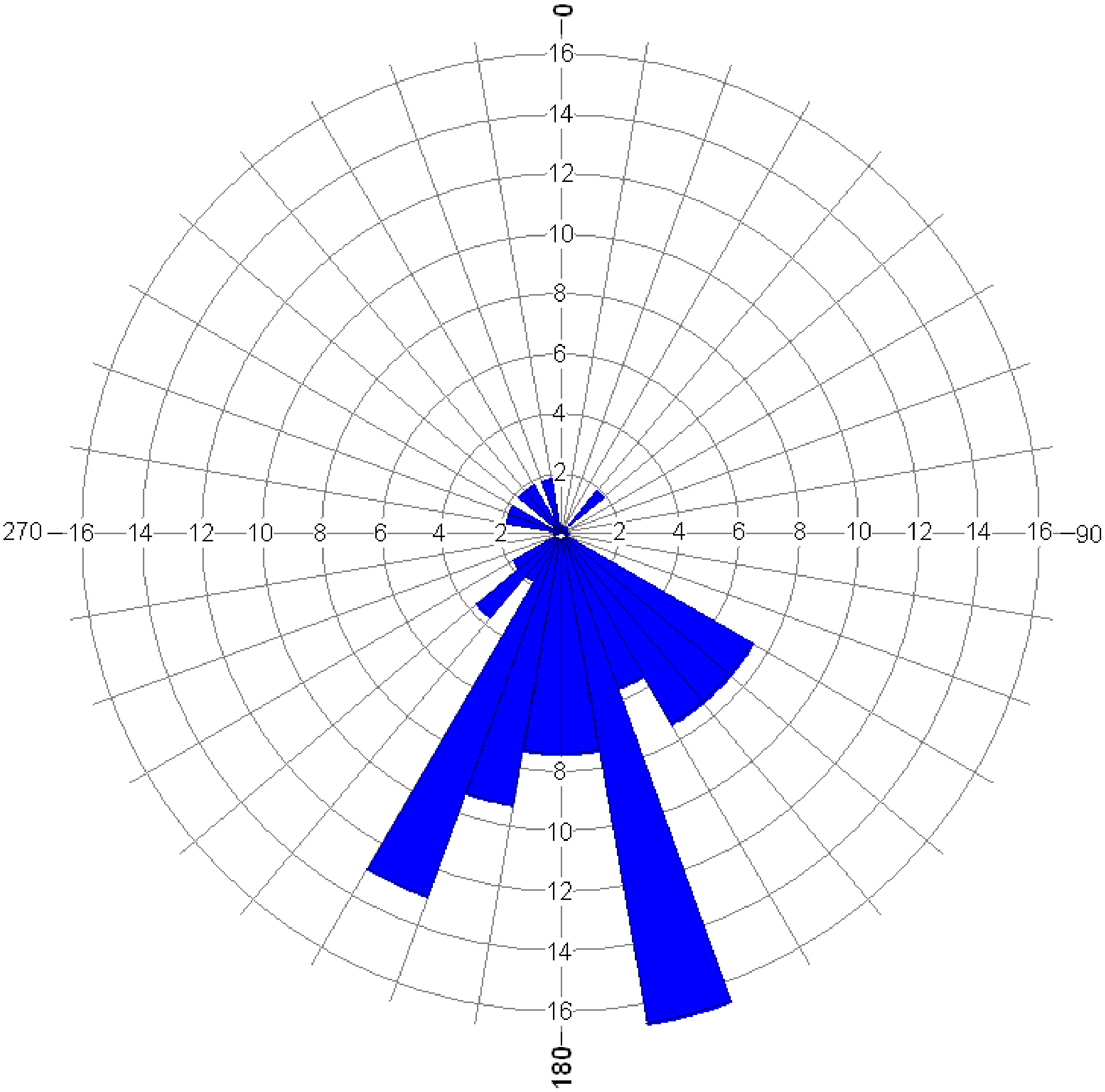
All directions are with respect to Magnetic North.

Stereonet Diagram – Schmidt Projection
Optical Televiewer Features
I-70 Tunnel
YA-T5
Yeh and Associates
12 March 2012



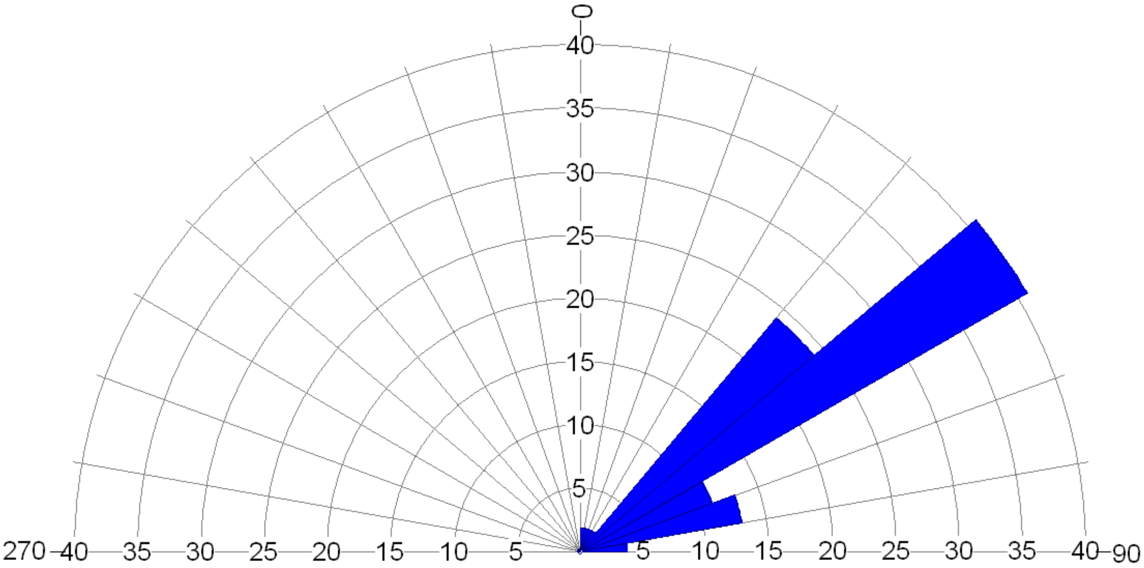
All directions are with respect to Magnetic North.

Rose Diagram – Dip Directions
Optical Televiewer Features
I-70 Tunnel
YA-T5
Yeh and Associates
12 March 2012



All directions are with respect to Magnetic North.

Rose Diagram – Dip Angles
Optical Televiewer Features
I-70 Tunnel
YA-T5
Yeh and Associates
12 March 2012



All directions are with respect to Magnetic North.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T5
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
1	0.51	1.7	149	13	1
2	0.77	2.5	156	64	1
3	0.78	2.6	347	44	1
4	0.94	3.1	142	8	2
5	1.01	3.3	131	25	2
6	1.04	3.4	140	78	3
7	1.16	3.8	127	72	2
8	1.26	4.1	136	71	2
9	1.31	4.3	203	52	0
10	1.33	4.4	138	67	1
11	1.38	4.5	222	53	0
12	1.39	4.6	146	70	1
13	1.53	5.0	159	57	1
14	1.58	5.2	168	54	0
15	1.62	5.3	169	53	0
16	1.65	5.4	197	56	0
17	1.69	5.6	176	50	1
18	1.73	5.7	178	44	0
19	1.79	5.9	171	48	0
20	1.84	6.0	167	42	0
21	1.87	6.2	160	51	0
22	1.94	6.4	152	53	0
23	2.20	7.2	120	66	1
24	2.28	7.5	239	64	0
25	2.31	7.6	184	50	1
26	2.39	7.8	203	49	0
27	2.70	8.9	169	32	0
28	2.80	9.2	165	48	1
29	2.85	9.3	313	61	0
30	2.98	9.8	162	52	0
31	3.16	10.4	191	52	0
32	3.32	10.9	163	51	0
33	3.45	11.3	164	52	0
34	3.67	12.0	129	82	1
35	3.86	12.7	186	52	0
36	4.06	13.3	294	81	1
37	4.14	13.6	176	53	0
38	4.32	14.2	188	47	0
39	4.35	14.3	323	64	0
40	4.38	14.4	200	43	0
41	4.59	15.1	189	45	0
42	4.67	15.3	42	78	1
43	4.69	15.4	131	77	2
44	4.69	15.4	222	42	0
45	4.94	16.2	129	76	2

All directions are with respect to magnetic north.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T5
Yeh and Associates
12 March 2012

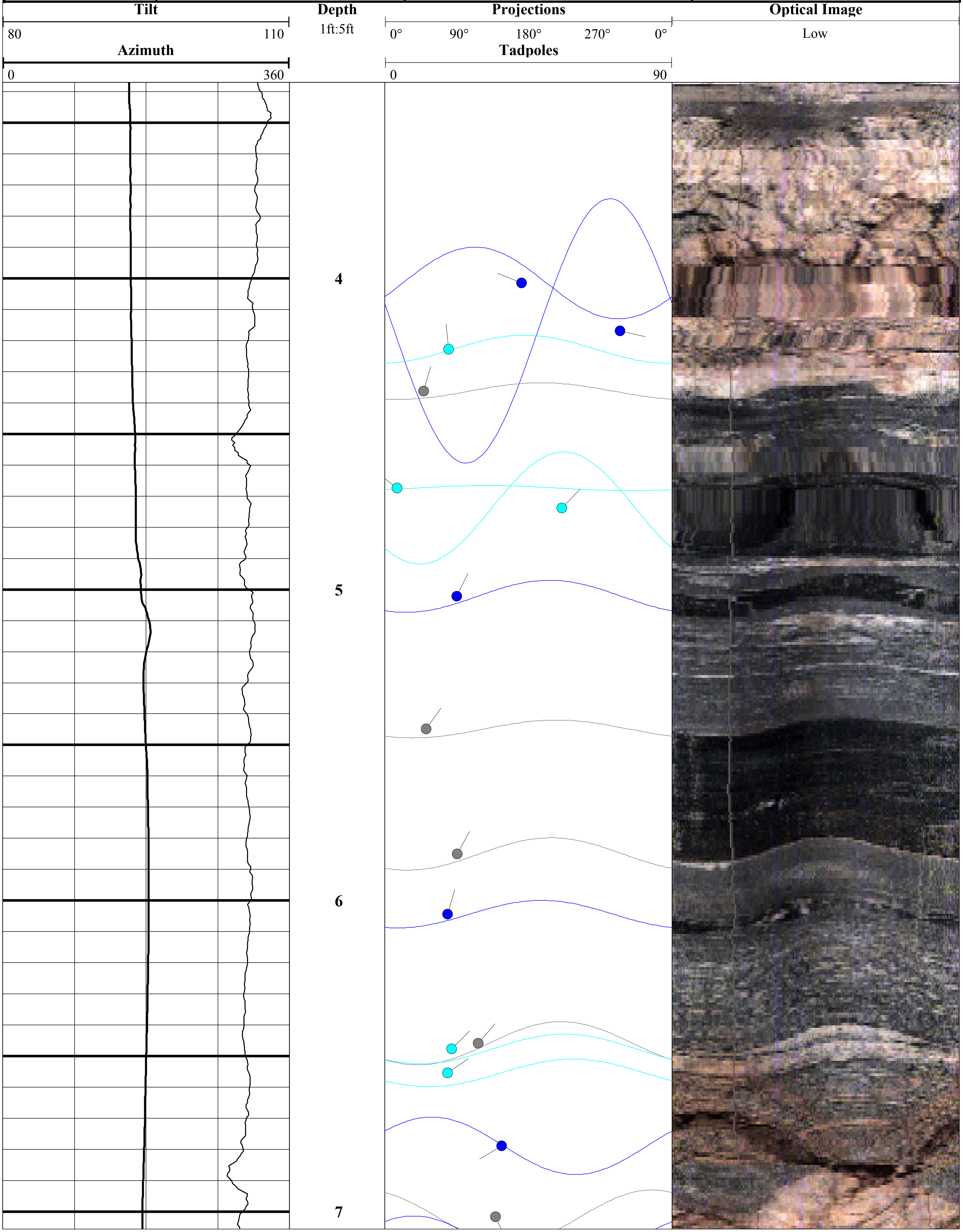
Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
46	4.97	16.3	219	47	0
47	5.06	16.6	209	42	0
48	5.26	17.3	195	50	0
49	5.35	17.6	207	53	0
50	5.46	17.9	197	53	0
51	5.59	18.3	200	53	0
52	5.72	18.8	284	42	0
53	5.72	18.8	190	53	0
54	5.92	19.4	200	55	0

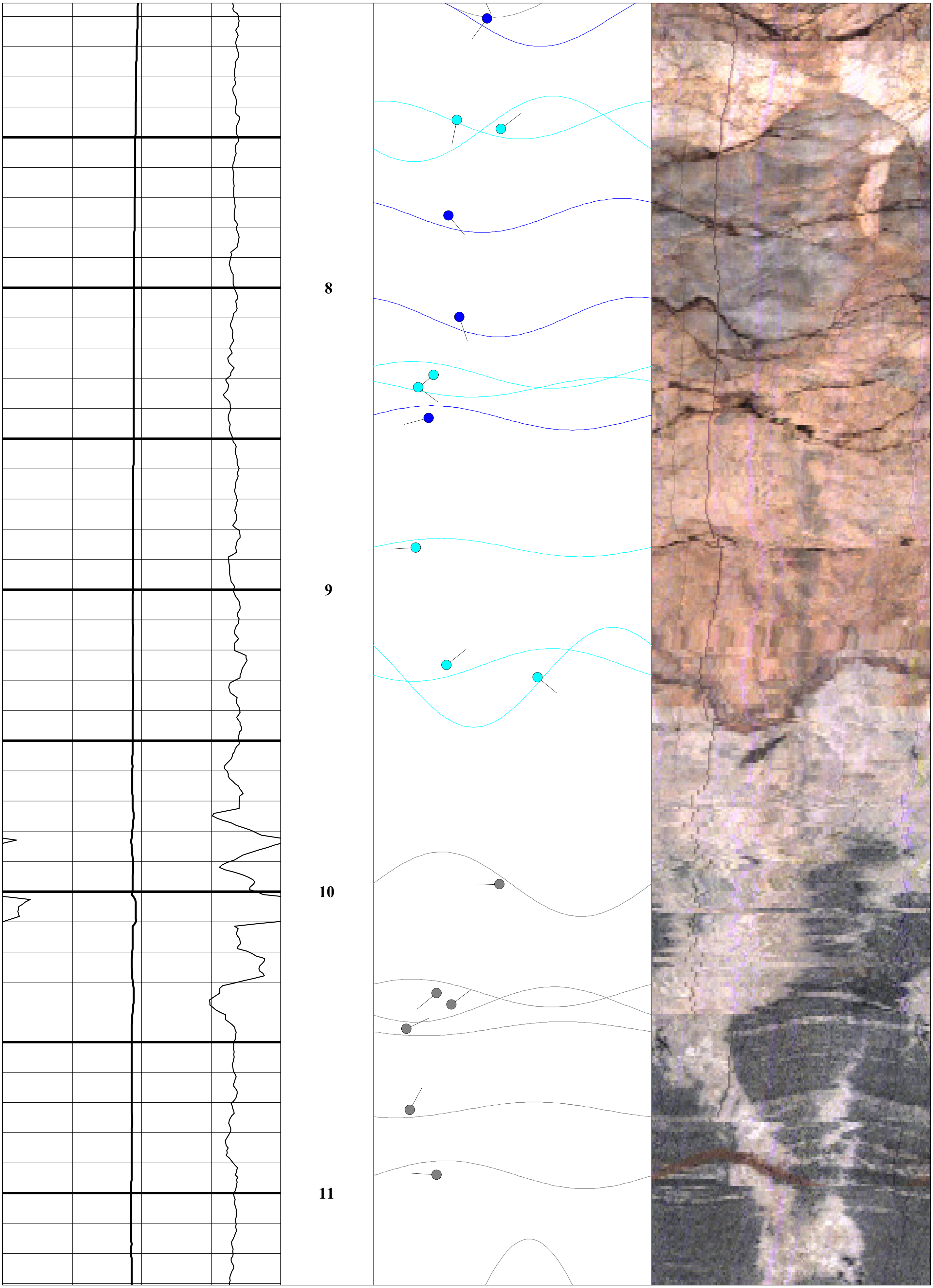
All directions are with respect to magnetic north.

Optical Televiewer Image Plot

COMPANY: Yeh and Associates
PROJECT: I-70 Tunnel
DATE LOGGED: 12 March 2012
WELL: YA-T6

COLOG Main Office
810 Quail Street, Suite E, Lakewood, CO, 80215
Phone: (303) 279-0171, Fax: (303) 278-0135
www.colog.com

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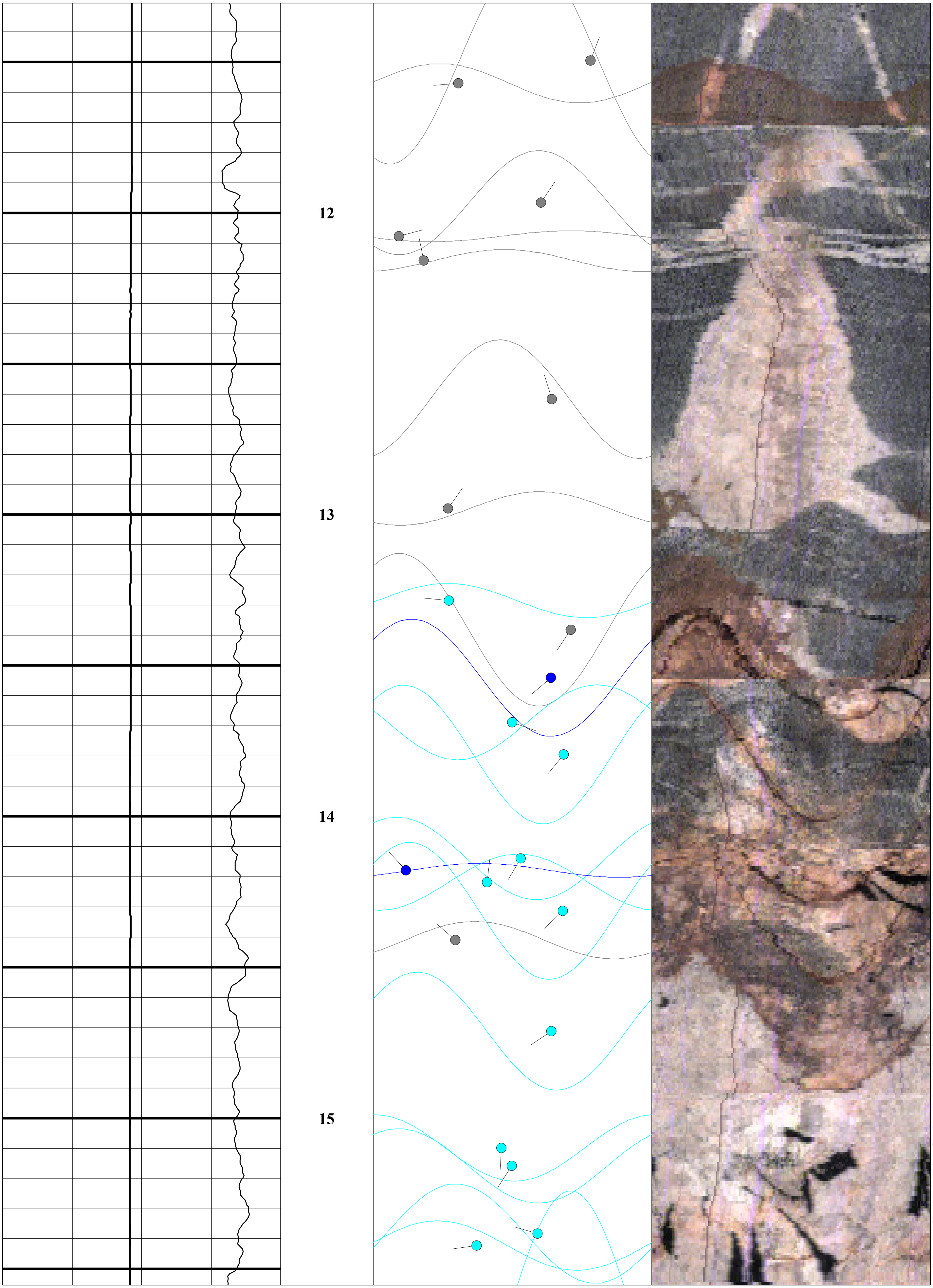
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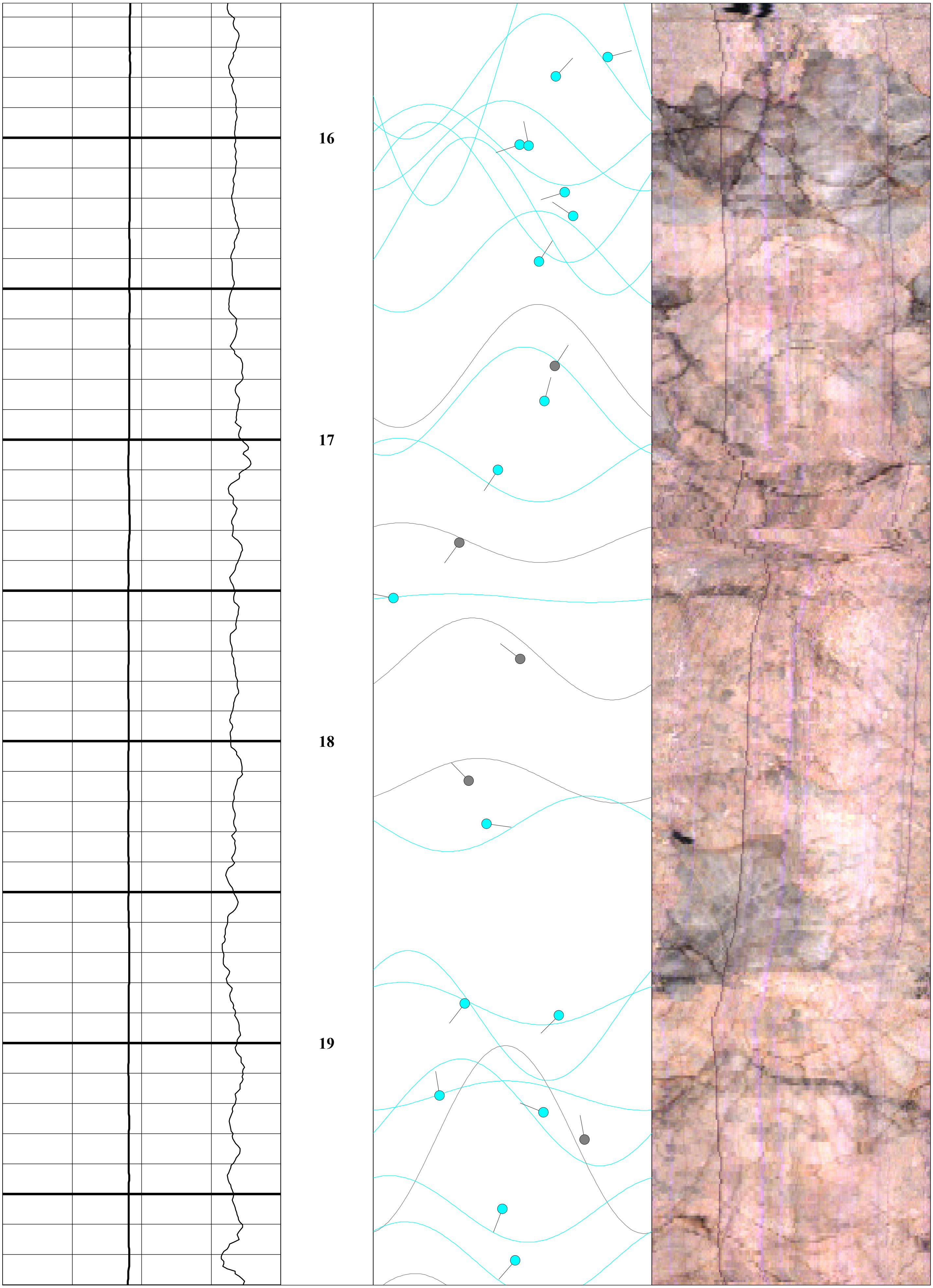
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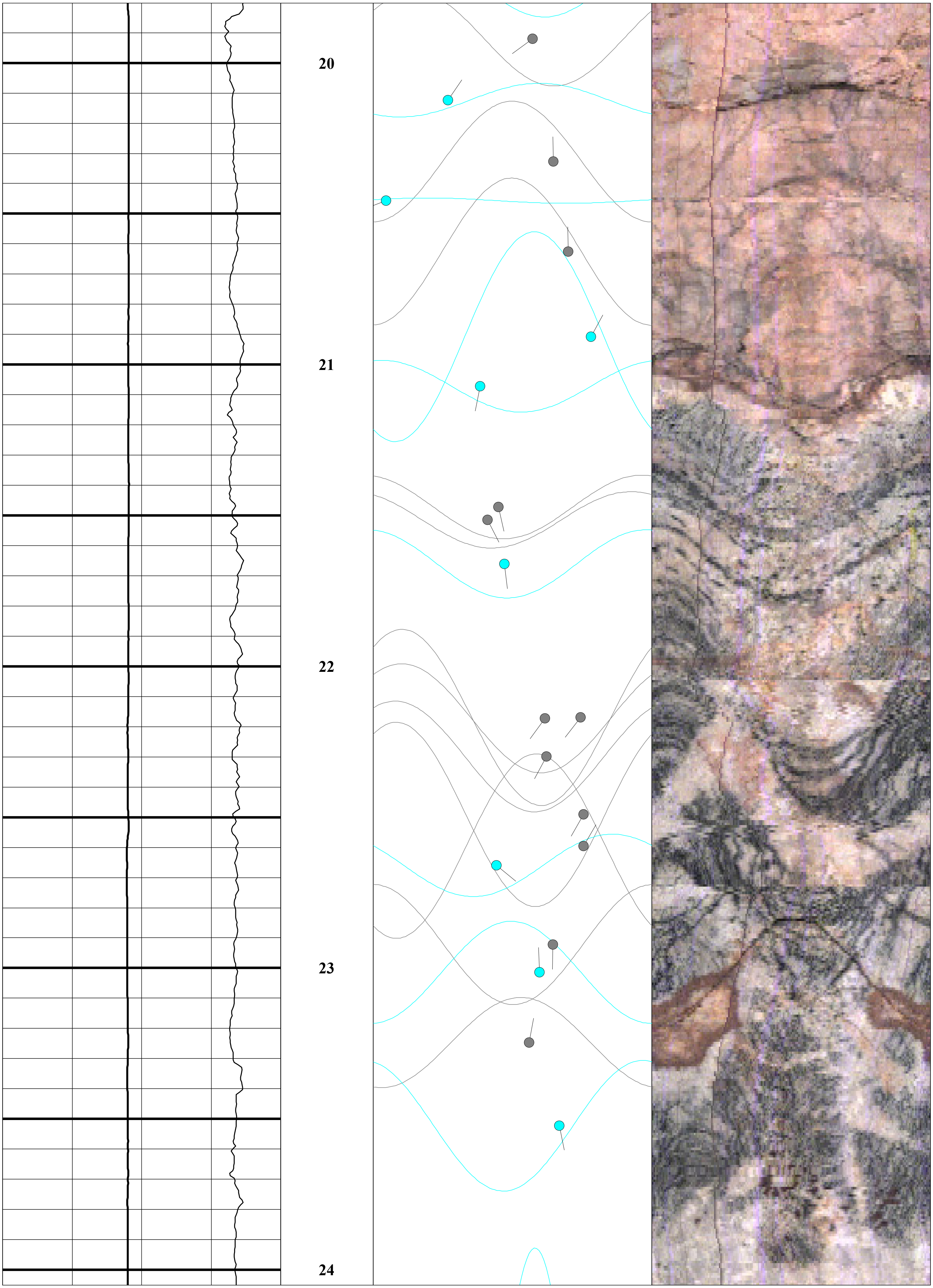
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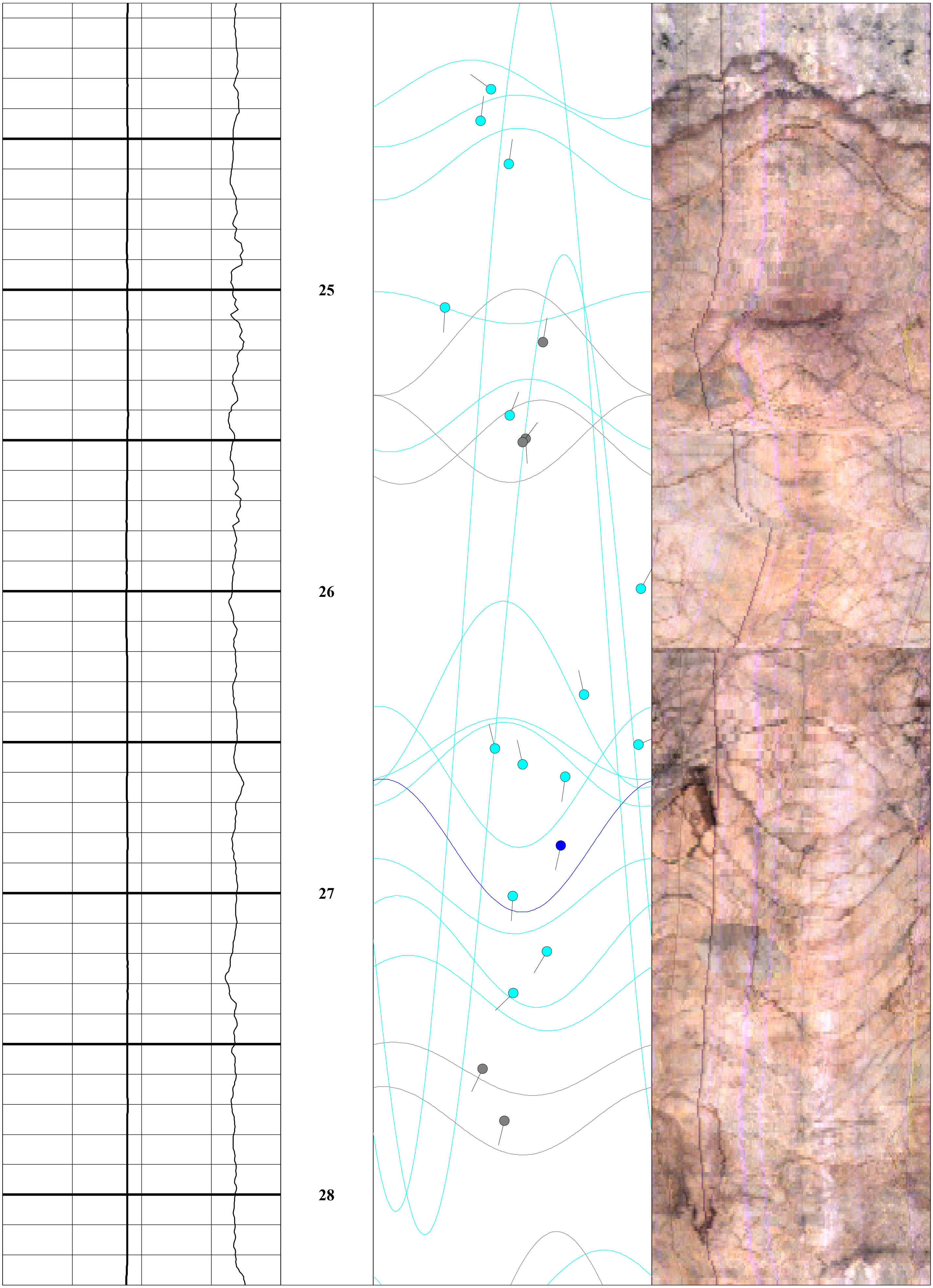
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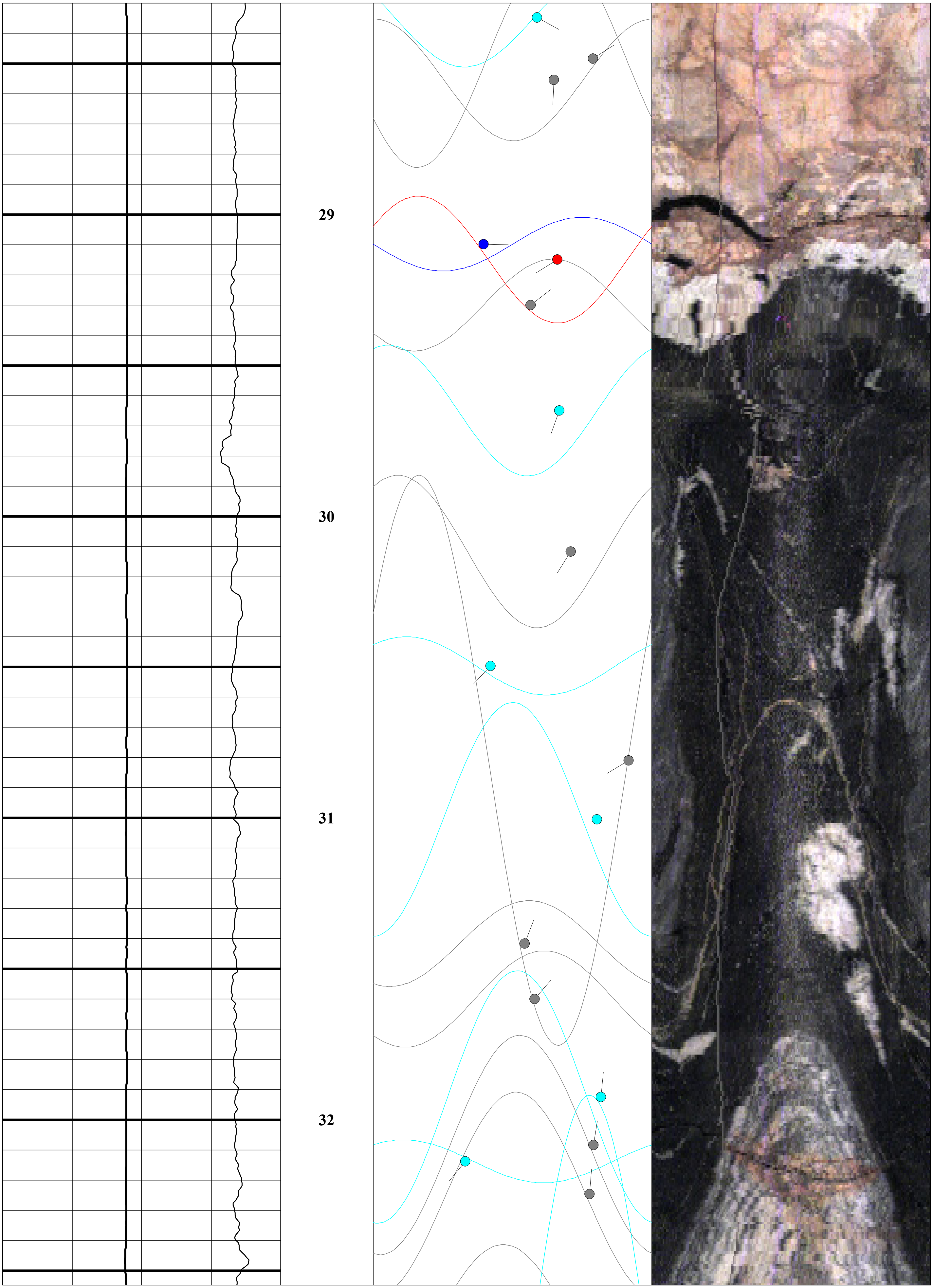
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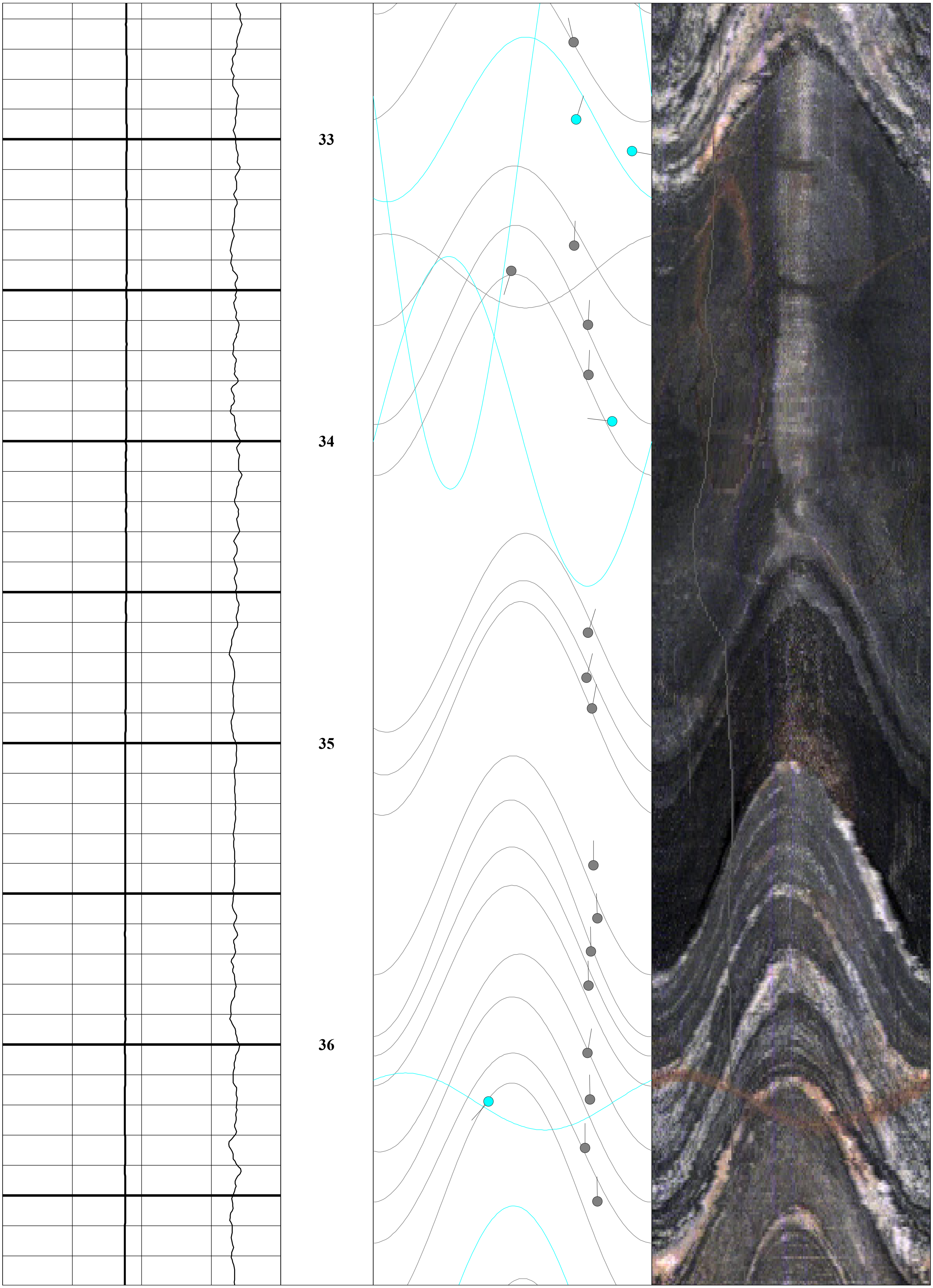
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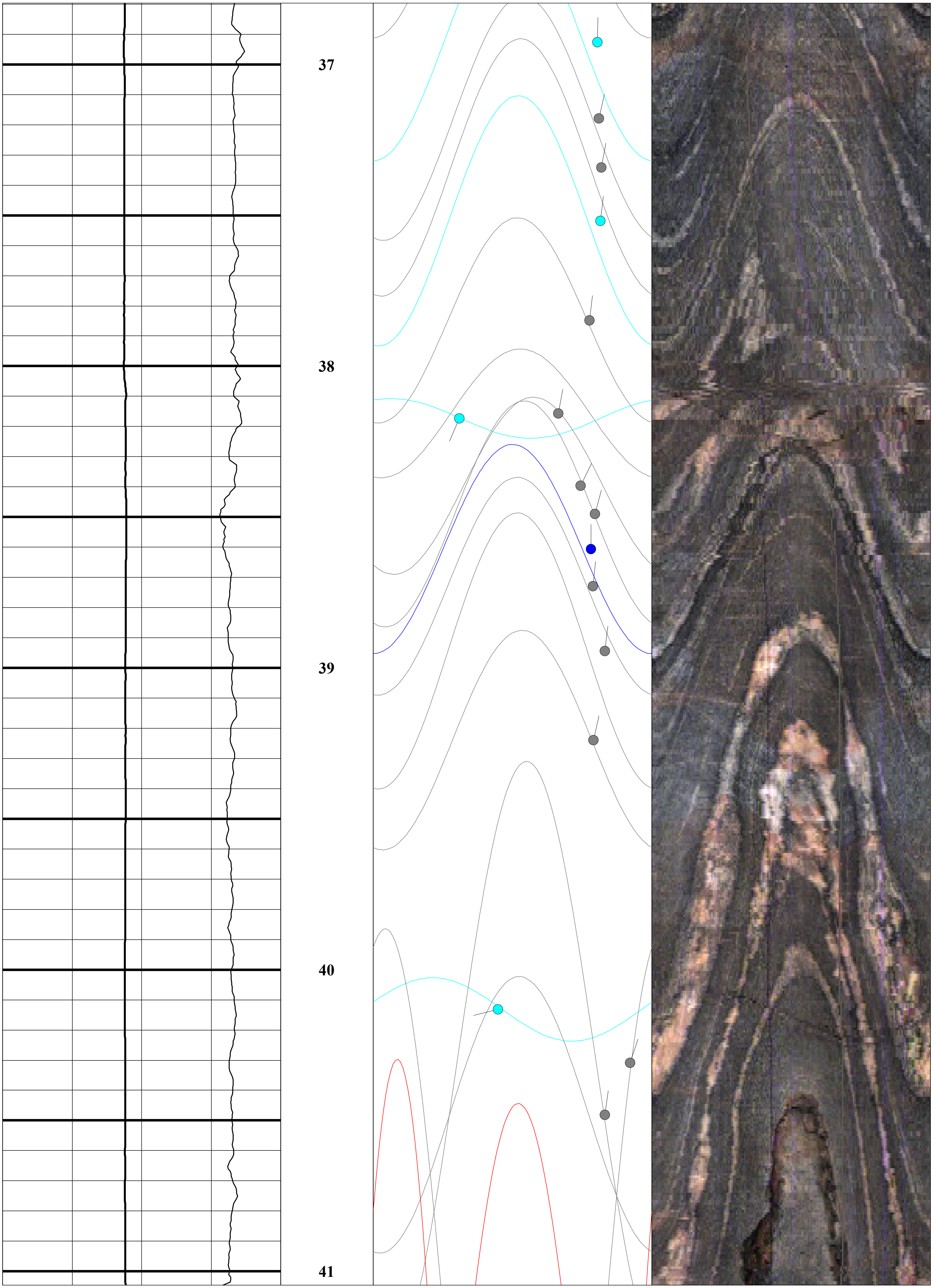
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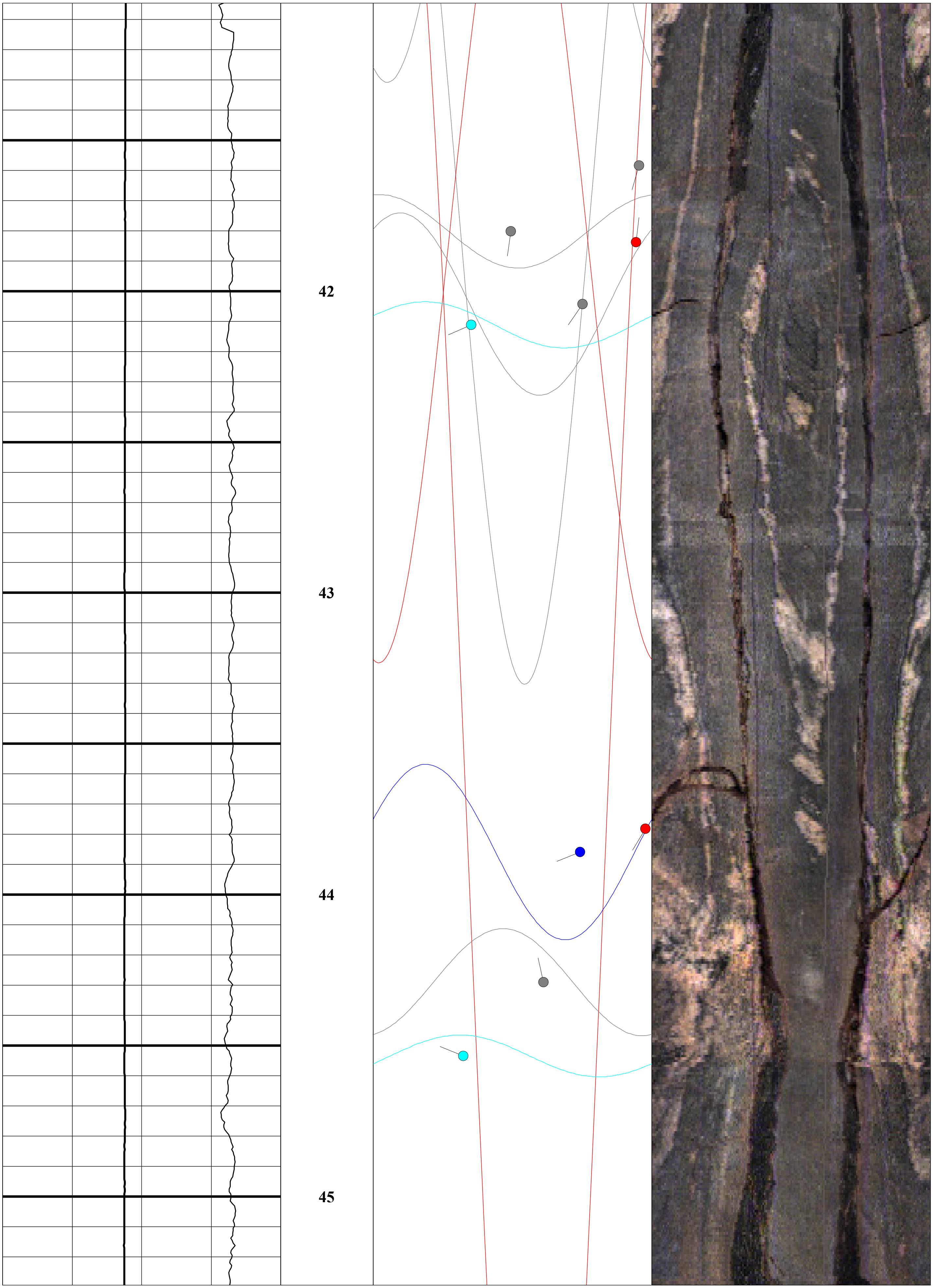
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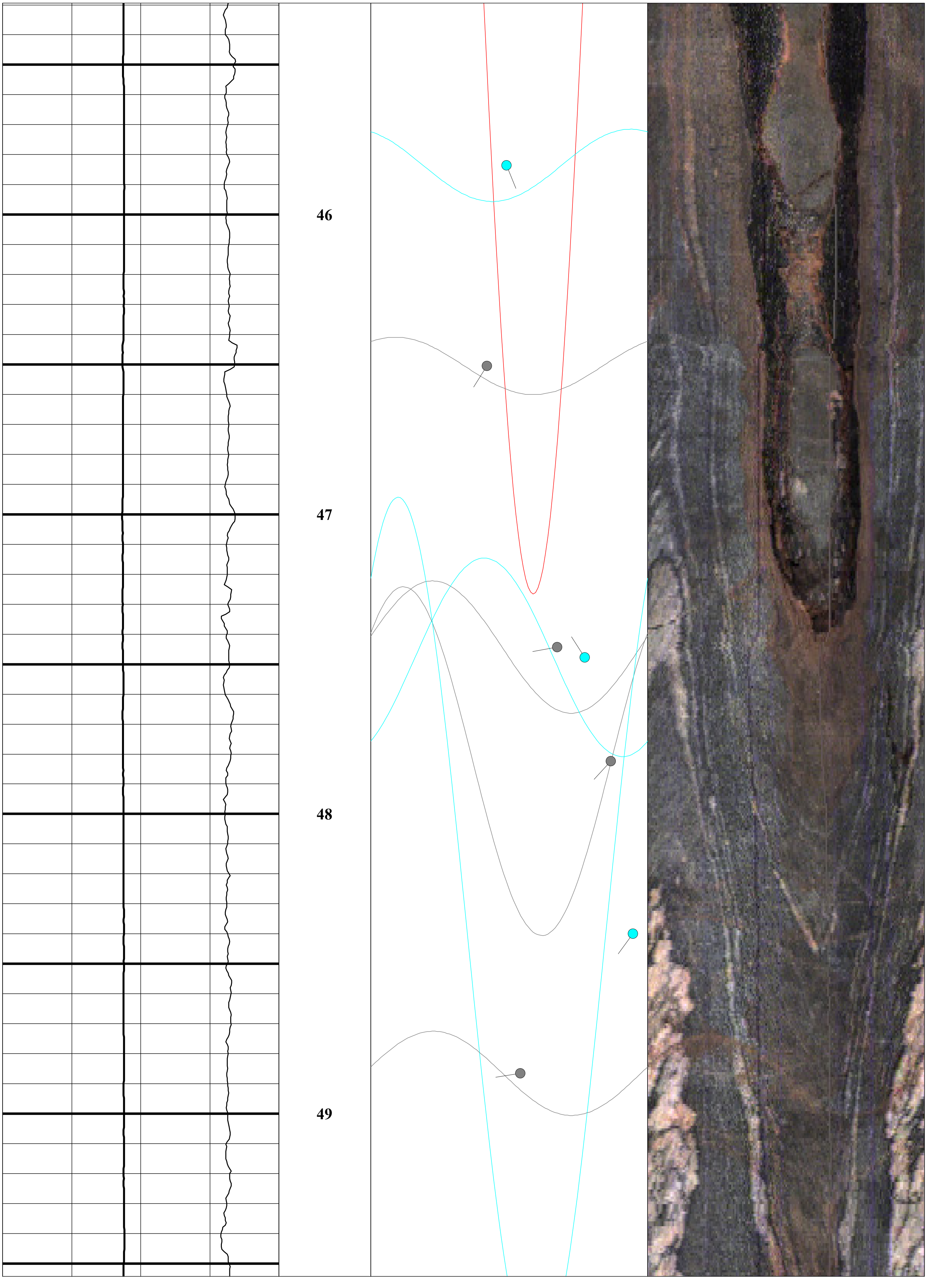
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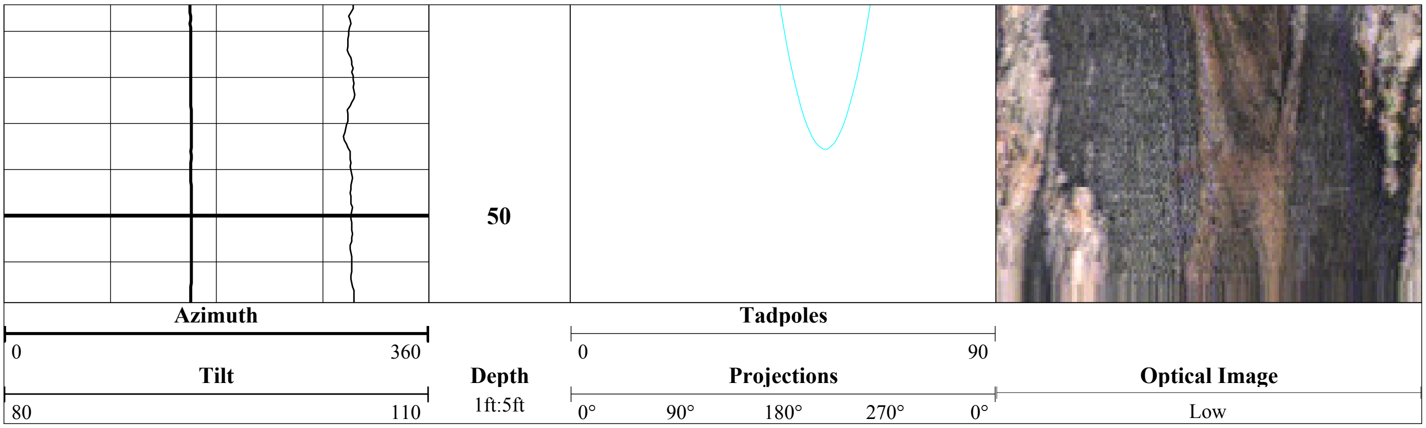
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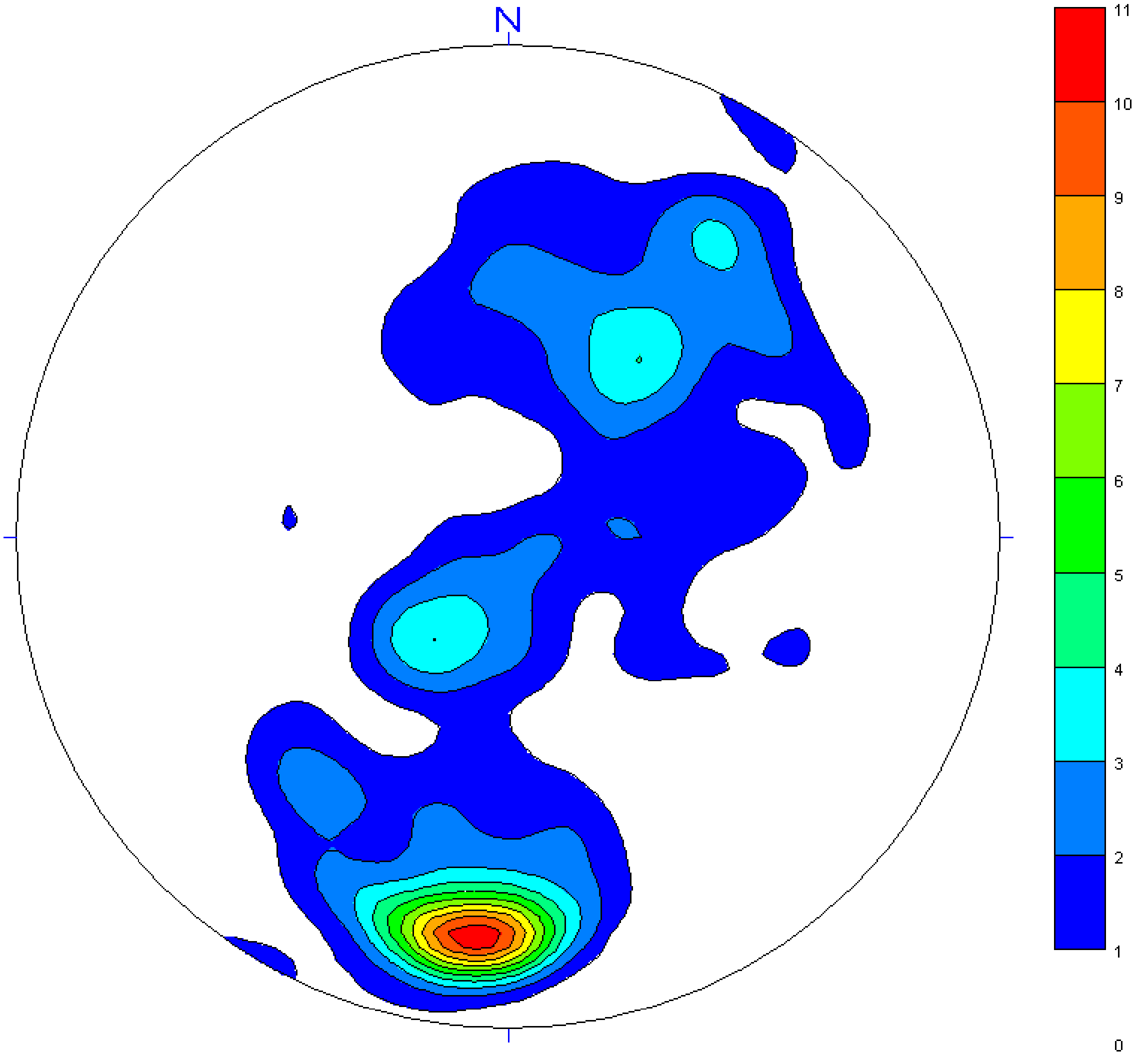
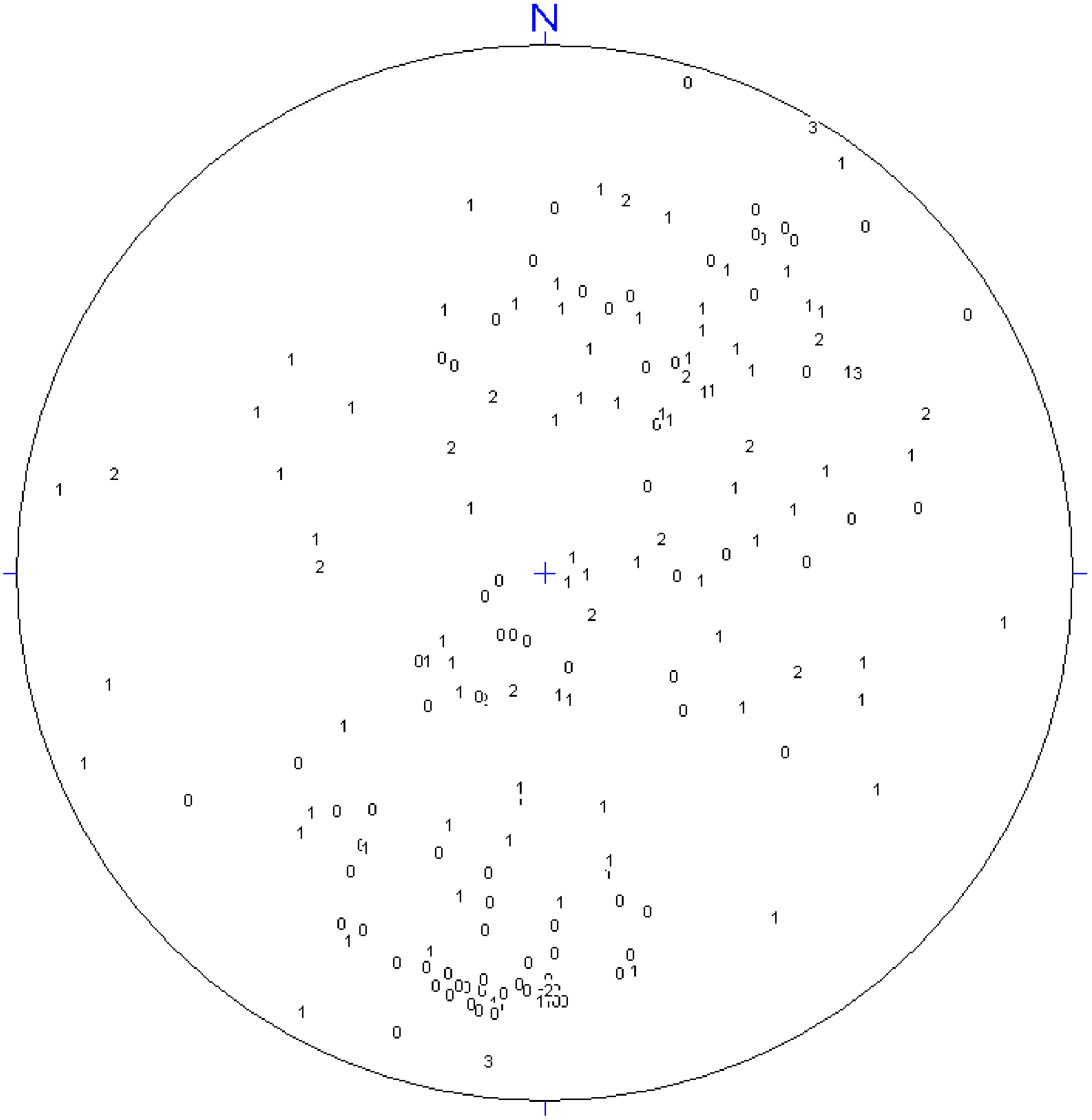
Tilt
80
110
Depth
1ft:5ft
Tadpoles
0
90
Projections
0°
90°
180°
270°
0°
Optical Image
Low

Stereonet Diagram – Schmidt Projection
Optical Televiewer Features
I-70 Tunnel
YA-T6
Yeh and Associates
12 March 2012



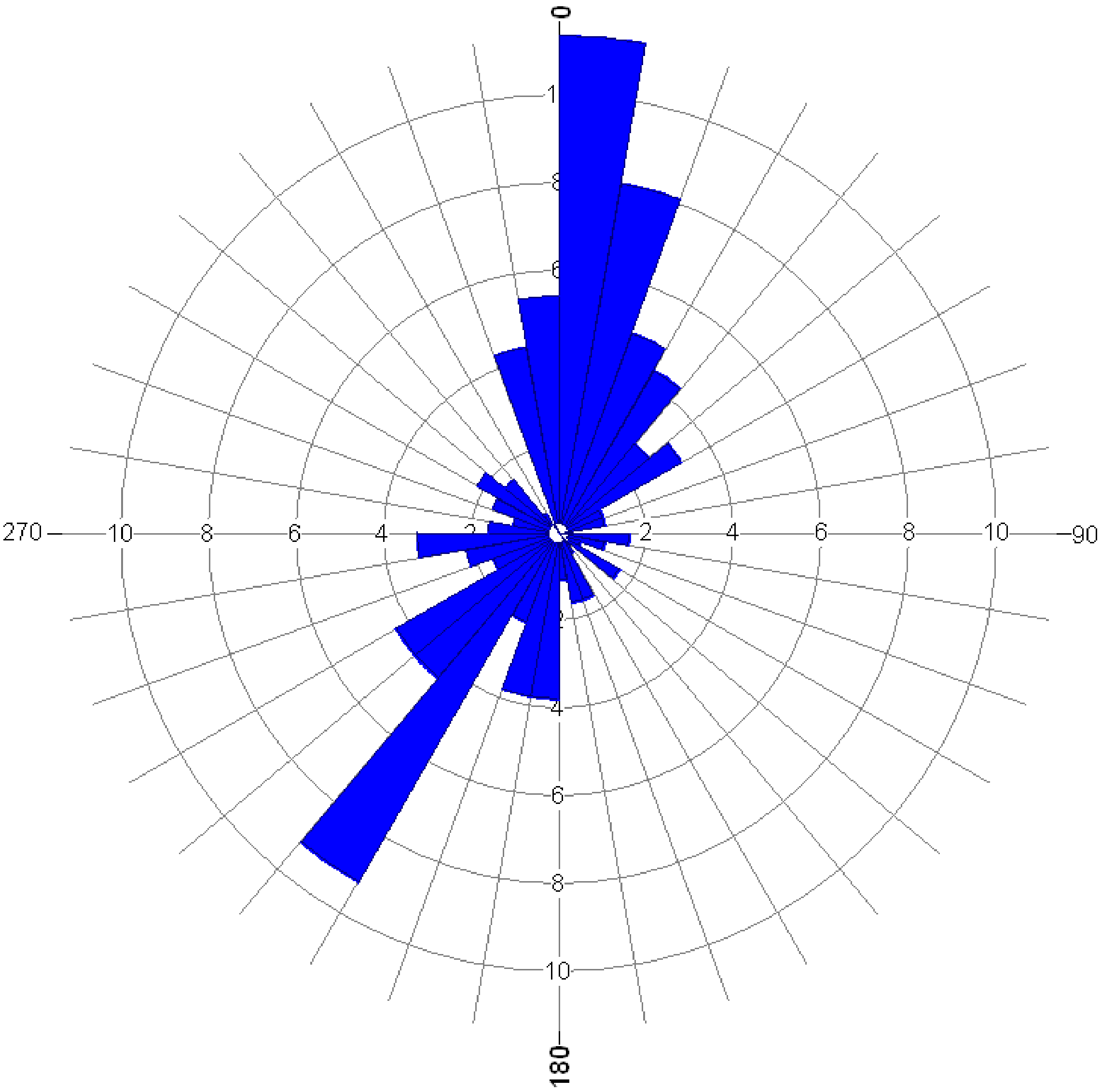
All directions are with respect to Magnetic North.

Stereonet Diagram – Schmidt Projection
Optical Televiewer Features
I-70 Tunnel
YA-T6
Yeh and Associates
12 March 2012



All directions are with respect to Magnetic North.

Rose Diagram – Dip Directions
Optical Televiewer Features
I-70 Tunnel
YA-T6
Yeh and Associates
12 March 2012



All directions are with respect to Magnetic North.

Rose Diagram – Dip Angles
Optical Televiewer Features
I-70 Tunnel
YA-T6
Yeh and Associates
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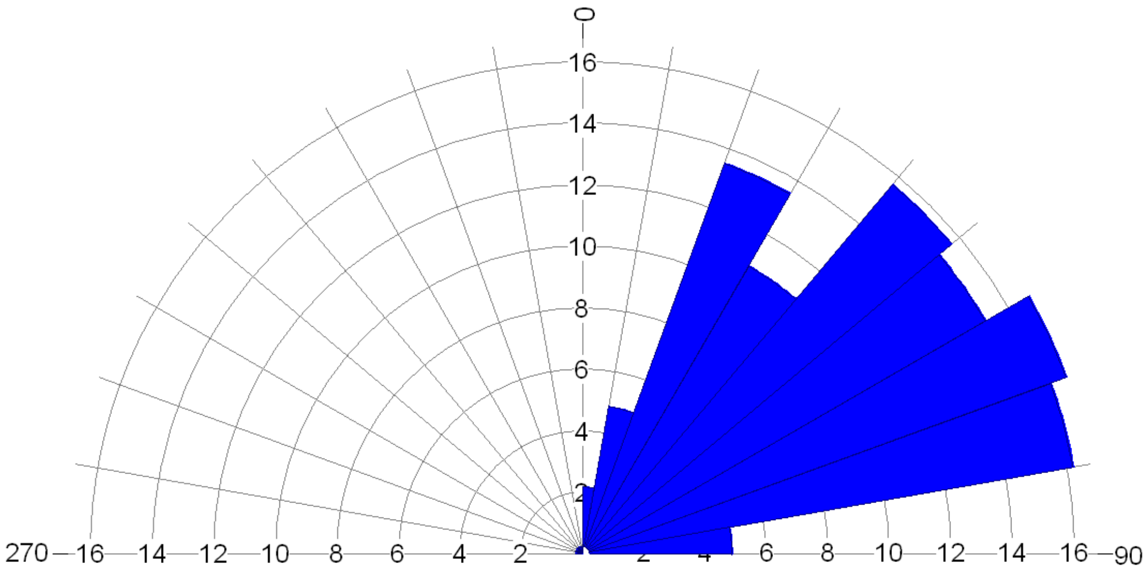


All directions are with respect to Magnetic North.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T6
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
1	1.23	4.0	293	43	2
2	1.27	4.2	102	74	2
3	1.29	4.2	355	20	1
4	1.33	4.4	16	12	0
5	1.42	4.7	308	4	1
6	1.44	4.7	44	55	1
7	1.53	5.0	26	23	2
8	1.66	5.5	35	13	0
9	1.78	5.9	28	23	0
10	1.84	6.0	16	20	2
11	1.97	6.5	41	29	0
12	1.98	6.5	45	21	1
13	2.00	6.6	55	20	1
14	2.07	6.8	239	37	2
15	2.14	7.0	155	35	0
16	2.17	7.1	216	37	2
17	2.27	7.4	191	27	1
18	2.28	7.5	52	41	1
19	2.37	7.8	141	24	2
20	2.47	8.1	162	28	2
21	2.53	8.3	230	20	1
22	2.54	8.3	127	15	1
23	2.57	8.4	256	18	2
24	2.70	8.9	267	14	1
25	2.82	9.3	52	24	1
26	2.83	9.3	129	53	1
27	3.04	10.0	269	41	0
28	3.15	10.3	231	20	0
29	3.16	10.4	54	25	0
30	3.19	10.5	65	11	0
31	3.27	10.7	28	12	0
32	3.33	10.9	274	20	0
33	3.50	11.5	21	70	0
34	3.53	11.6	266	28	0
35	3.65	12.0	34	54	0
36	3.68	12.1	75	8	0
37	3.71	12.2	349	16	0
38	3.85	12.6	344	58	0
39	3.96	13.0	35	24	0
40	4.05	13.3	275	24	1
41	4.08	13.4	213	64	0
42	4.13	13.5	230	57	2
43	4.17	13.7	109	45	1
44	4.21	13.8	219	62	1
45	4.31	14.1	211	48	1

All directions are with respect to magnetic north.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T6
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
46	4.32	14.2	318	10	2
47	4.33	14.2	7	37	1
48	4.36	14.3	227	61	1
49	4.39	14.4	311	26	0
50	4.48	14.7	237	58	1
51	4.60	15.1	183	41	1
52	4.62	15.2	213	45	1
53	4.69	15.4	287	53	1
54	4.70	15.4	263	33	1
55	4.79	15.7	75	76	1
56	4.82	15.8	43	59	1
57	4.88	16.0	251	47	1
58	4.89	16.0	349	50	1
59	4.93	16.2	253	62	1
60	4.96	16.3	304	65	1
61	5.00	16.4	33	54	1
62	5.11	16.8	33	59	0
63	5.14	16.9	15	55	1
64	5.21	17.1	214	40	1
65	5.29	17.3	217	28	0
66	5.34	17.5	281	6	1
67	5.40	17.7	308	48	0
68	5.53	18.1	317	31	0
69	5.57	18.3	97	37	1
70	5.75	18.9	217	30	1
71	5.76	18.9	225	60	1
72	5.84	19.2	351	21	1
73	5.86	19.2	293	55	1
74	5.89	19.3	350	68	0
75	5.96	19.6	200	42	1
76	6.01	19.7	221	46	1
77	6.07	19.9	233	52	0
78	6.13	20.1	35	24	1
79	6.20	20.3	359	58	0
80	6.24	20.5	249	4	1
81	6.29	20.6	359	63	0
82	6.37	20.9	28	70	1
83	6.42	21.1	191	35	1
84	6.54	21.5	168	40	0
85	6.56	21.5	153	37	0
86	6.60	21.7	173	42	1
87	6.76	22.2	217	67	0
88	6.76	22.2	217	55	0
89	6.80	22.3	208	56	0
90	6.85	22.5	210	68	0

All directions are with respect to magnetic north.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T6
Yeh and Associates
12 March 2012

Feature No.	**Depth (meters)**	**Depth (feet)**	**Dip Direction (degrees)**	**Dip Angle (degrees)**	**Feature Rank (0 to 5)**
91	6.89	22.6	30	68	0
92	6.91	22.7	129	40	1
93	6.99	22.9	181	58	0
94	7.01	23.0	358	54	1
95	7.09	23.3	11	50	0
96	7.17	23.5	168	60	1
97	7.42	24.3	306	38	1
98	7.45	24.4	7	35	1
99	7.49	24.6	8	44	1
100	7.64	25.1	183	23	1
101	7.67	25.2	10	55	0
102	7.75	25.4	21	44	1
103	7.77	25.5	177	49	0
104	7.78	25.5	36	48	0
105	7.92	26.0	29	87	1
106	8.03	26.3	348	68	1
107	8.08	26.5	67	86	1
108	8.08	26.5	347	39	1
109	8.10	26.6	348	48	1
110	8.11	26.6	188	62	1
111	8.18	26.8	192	61	2
112	8.23	27.0	182	45	1
113	8.29	27.2	211	56	1
114	8.33	27.3	226	45	1
115	8.41	27.6	206	35	0
116	8.46	27.8	193	42	0
117	8.64	28.4	118	53	1
118	8.68	28.5	57	71	0
119	8.70	28.6	181	58	0
120	8.87	29.1	90	36	2
121	8.88	29.2	238	59	3
122	8.93	29.3	52	51	0
123	9.04	29.7	199	60	1
124	9.18	30.1	212	64	0
125	9.30	30.5	223	38	1
126	9.39	30.8	239	83	0
127	9.45	31.0	0	72	1
128	9.58	31.4	21	49	0
129	9.63	31.6	41	52	0
130	9.73	31.9	6	73	1
131	9.78	32.1	9	71	0
132	9.80	32.1	220	30	1
133	9.83	32.3	4	70	0
134	9.96	32.7	348	65	0
135	10.04	32.9	17	66	1

All directions are with respect to magnetic north.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T6
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
136	10.07	33.0	99	84	1
137	10.17	33.4	3	65	0
138	10.19	33.4	197	45	0
139	10.24	33.6	4	69	0
140	10.30	33.8	3	70	0
141	10.34	33.9	277	77	1
142	10.56	34.6	17	69	0
143	10.60	34.8	14	69	0
144	10.63	34.9	11	71	0
145	10.79	35.4	1	71	0
146	10.84	35.6	358	72	0
147	10.88	35.7	359	70	0
148	10.91	35.8	359	70	0
149	10.98	36.0	9	69	0
150	11.03	36.2	360	70	0
151	11.03	36.2	222	37	1
152	11.08	36.3	0	68	0
153	11.13	36.5	359	72	0
154	11.26	36.9	1	72	1
155	11.33	37.2	13	73	0
156	11.38	37.3	10	74	0
157	11.44	37.5	7	73	1
158	11.54	37.9	6	70	0
159	11.63	38.2	10	60	0
160	11.63	38.2	203	28	1
161	11.70	38.4	27	67	0
162	11.73	38.5	15	72	0
163	11.77	38.6	0	70	2
164	11.80	38.7	6	71	0
165	11.87	38.9	7	75	0
166	11.96	39.2	12	71	0
167	12.23	40.1	257	40	1
168	12.29	40.3	18	83	0
169	12.34	40.5	9	75	0
170	12.67	41.6	196	86	0
171	12.74	41.8	187	44	0
172	12.75	41.8	7	85	3
173	12.81	42.0	215	68	0
174	12.84	42.1	247	32	1
175	13.34	43.8	211	88	3
176	13.37	43.9	248	67	2
177	13.50	44.3	348	55	0
178	13.58	44.5	292	29	1
179	13.97	45.8	158	44	1
180	14.17	46.5	212	38	0

All directions are with respect to magnetic north.

Orientation Summary Table
Image Features
I-70 Tunnel
YA-T6
Yeh and Associates
12 March 2012

Feature No.	Depth (meters)	Depth (feet)	Dip Direction (degrees)	Dip Angle (degrees)	Feature Rank (0 to 5)
181	14.46	47.4	261	61	0
182	14.47	47.5	327	69	1
183	14.58	47.8	223	78	0
184	14.75	48.4	216	85	1
185	14.90	48.9	261	49	0

Optical and Acoustic Televiewers

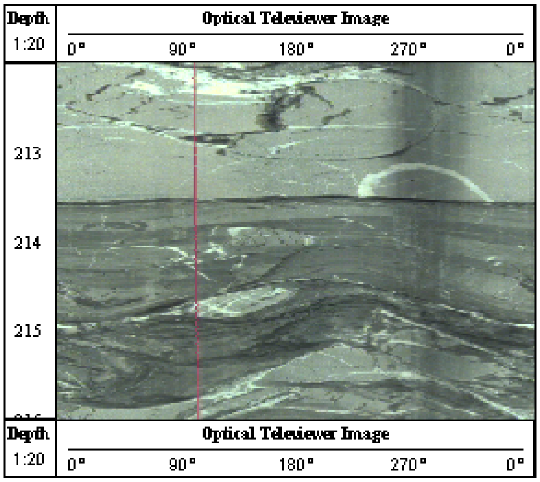
The OBI-40 optical televiewer and the ABI-40 acoustic televiewer (and its predecessor, the FAC40), from Advanced Logic Technologies (ALT), provide the highest resolution available for fracture and feature analysis in boreholes. Precise dip direction and angle measurements of bedding, fractures, and joint planes, along with other geological analyses, are possible.

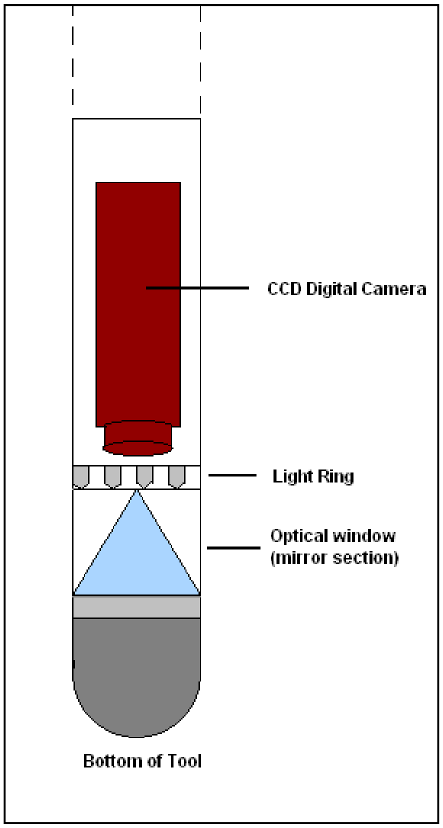
The optical televiewer technology is based on direct optical observation of the borehole wall face and can be utilized in both air and clear fluid filled boreholes. The acoustic televiewer technology is based on the return amplitude and time of an acoustic wave reflected off the borehole wall face; it can be utilized in clear or murky fluid-filled boreholes, but not in air.

Varying borehole conditions often exist which preclude the usage of one or the other tool; therefore, the optical televiewer and acoustic televiewer are often used in conjunction to image the entire borehole. When doing so, it must be kept in mind that optical and acoustic properties are not necessarily yielding the same data set. For example, a transition between two similarly-colored beds may not stand out visually, but it may stand out acoustically if the densities of the two materials are different.

Optical Televiewer – Theory of Operation

The OBI-40 optical televiewer provides a detailed, oriented optical image of the borehole wall. A small ring of lights illuminates the borehole wall allowing a camera to directly image the borehole wall face. A conical mirror housed in a clear cylindrical window focuses a 360° optical "slice" of the borehole wall onto the camera's lens. As the optical televiewer tool is lowered down the hole, the video signal from the camera is transmitted uphole via the wireline to the recording instrumentation.





Figures: Example of OBI40 optical Televiewer data (left) and sketch of OBI40 optical tool head (right).

The signal is digitized in real time by capturing up to 720 pixels from the conical optical image. A digital magnetometer and accelerometer package is used to determine the orientation of the probe, and thus the digital image, for each conical image capture. The conical image rings are stacked and unwrapped to a 2-D, oriented image of the borehole wall.

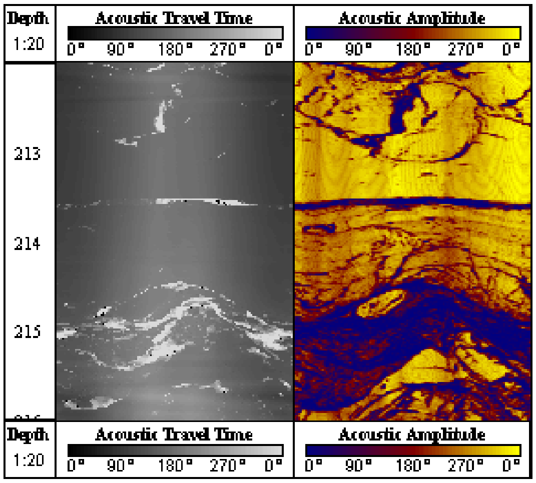
Precise borehole trajectory/deviation and image orientation are achieved using a 3-axis magnetometer and three accelerometers. When the tool is well-centralized, azimuthal accuracy is to ±1.0 degrees and inclination accuracy is to ±0.5 degrees. Deviated or rugous boreholes and outside magnetic interference can contribute to reduced orientation accuracy of the tool, and thus the oriented image. The pink line seen in the example data above represents a fixed point on the tool; it is used in orienting the data with respect to magnetic north.

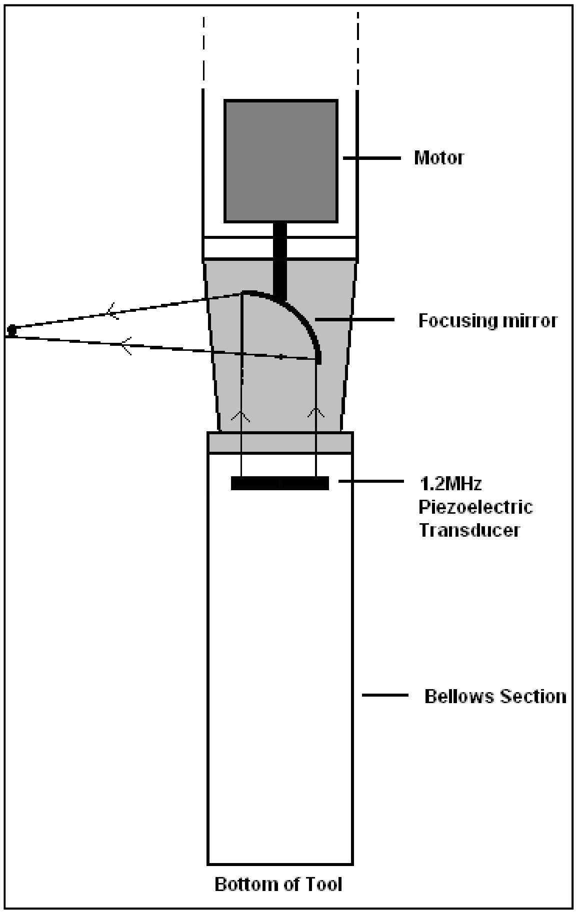
Tool image colors are calibrated in shop to true-color, however, varying light conditions downhole often lead to color images that are somewhat false-colored. This should be taken into account when reviewing images.

Main applications of the optical televiewer include: fracture detection and evaluation, detection of thin beds, determination of bedding dip, lithological characterization, and casing inspection.

Acoustic Televiewer (ATV) – Theory of Operation

The ABI-40 acoustic televiewer, from Advanced Logic Technologies (ALT), provides a detailed, oriented image of acoustic reflections from the borehole wall. A unique focusing system resolves bedding features as small as 2 mm and is capable of detecting fractures with apertures as small as 0.1 mm.





Figures: Example ABI40 acoustic televiewer data (left) and sketch of ABI40 acoustic head (right).

The acoustic televiewer transmits ultrasonic pulses from a rotating sensor (mirror) and records the signals reflected from the interface between the borehole fluid and the borehole wall. The amplitude of these reflections is representative of the hardness of the formation surrounding the borehole, while the travel time represents the borehole shape and diameter. As many as 288 reflections may be recorded per revolution at up to 10 revolutions per second. The conical image rings are stacked and unwrapped to a 2-D, oriented image of the borehole wall. The digital amplitude and travel time data are presented using a variety of color schemes.

Precise borehole trajectory/deviation and acoustic image orientation are achieved using a 3-axis magnetometer and three accelerometers. When the tool is well-centralized, azimuthal accuracy is to ±1.0 degrees and inclination accuracy is to ±0.5 degrees. Deviated or rugous boreholes and outside magnetic interference can contribute to reduced orientation accuracy of the tool, and thus the oriented image.

The high-resolution reflection images and the precise travel time measurements make the ABI-40 acoustic televiewer a versatile tool. Possible applications include: fracture detection and evaluation, detection of thin beds, determination of bedding dip, lithological characterization, casing inspection, and high-resolution caliper measurements.

Acoustic Televiewer Caliper Log

An unconventional caliper log may be generated from the travel time data acquired by the ABI-40 acoustic televiewer. Using WellCAD software, an estimation of the distance from the probe to the borehole wall can be made by incorporating the travel time of the acoustic signal with an estimation of the velocity of the borehole fluid. The time it takes the acoustic signal to travel through a known viscous medium and back to the probe is directly related to the distance between the signal generator and the borehole wall provided the borehole fluid viscosity remains constant and the probe is properly centralized. The distance from the probe to the borehole wall is then corrected for the radius of the probe, producing a borehole diameter value.

Understanding 2-D Televiewer Images

For both the optical and acoustic televiewer, the 2-D picture of the borehole wall is unwrapped from north to north. Planar features that intersect the borehole appear to be sinusoids on the unwrapped image. To calculate the dip angle of a fracture or bedding feature, the amplitude of the sinusoid (h) and the borehole diameter (d) are required. The angle of dip is equal to the arc tangent of h/d, and the dip direction is picked at the trough of the sinusoid.

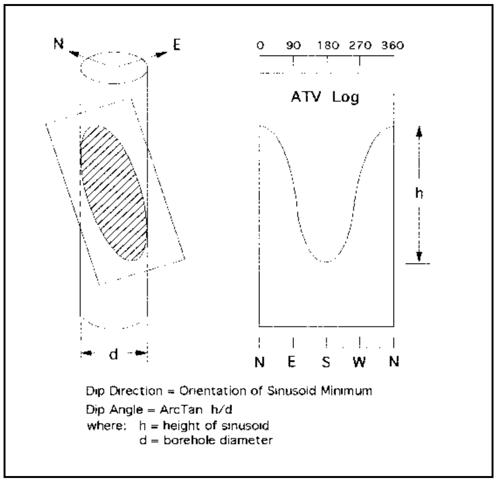


Figure: Geometric representation of a north-dipping fracture plane and corresponding log.

Interpreting Optical and/or Acoustic Televiewer Data

Sinusoidal features are picked throughout the boreholes by visual inspection of the digital optical and acoustic televiewer images using the interactive software WellCAD. These sinusoidal feature *projections* can directly overlay the televiewer images or be plotted alongside the televiewer images.

The features can also be represented by *tadpoles*. The tail of the tadpole points in the azimuthal direction of dip, where north is up, east is 90° to the right, etcetera. The head of the tadpole is located vertically on the plot, at the projection's inflection point, that is, halfway between the peak and the trough depth of the sinusoidal projection. The horizontal head location represents the dip angle, with shallow features near the left side of the plot and steeper features near the right side.

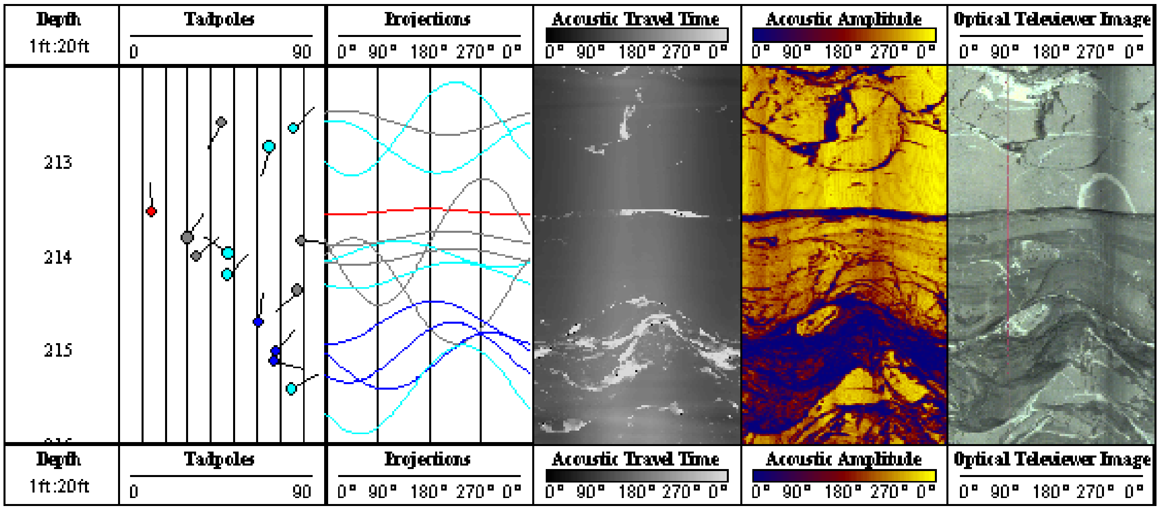


Figure: Example projections and tadpoles for corresponding optical and acoustic televiewer data sets.

The WellCAD software calculates the true feature orientation (dip direction and angle) in either deviated or vertical boreholes. Depths are assigned to the fractures or bedding features at the inflection points (middles) of the sinusoids. Features are subjectively ranked for flow potential using *COLOG's Ranking System for Optical Televiewer Features*, included in this report. The features picked, along with their assigned ranks, orientations and depths are exported and presented in tables for each well. Orientations are based on magnetic north and are not corrected for magnetic declination, unless specified.

From the feature data tables, stereonet plots and rose diagrams are generated, as necessary. Stereonet plots and rose diagrams provide useful information concerning the statistical distribution and possible patterns or trends that may exist from the optical and/or acoustic televiewer feature orientation data set.

Rose Diagrams

A rose diagram is a polar diagram in which radial length of the petals indicates the relative frequency (percentage) of observation of a particular angle or fracture dip direction or range of angles or dip directions. Rose diagrams are used to identify patterns (if any) in the frequency of dip angles or directions for a particular data set. The following rose diagrams and stereonet plots all come from the same data set to help illustrate the relationships between the plot types.

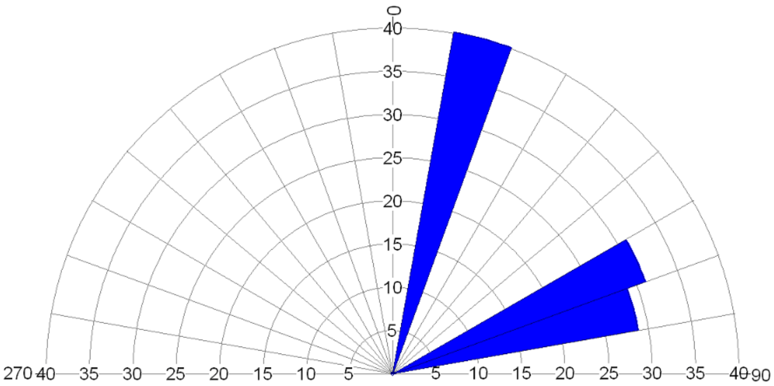


Figure: Example rose diagram from an optical televiewer data set illustrating the frequency (%) of dip angles.

With a quick glance at the above rose diagram of dip angle values, one can see two distinct sets of dip angles; one set with lower dip angles and one set with higher dip angles. Specifically, 40 percent of the features have a dip angle between 10^{o} and $<20^{o}$, and 60 percent of the features have a dip angle between 60^{o} and $<80^{o}$. The left-hand side of the above rose diagram will always be blank by convention of positive dip angle values only.

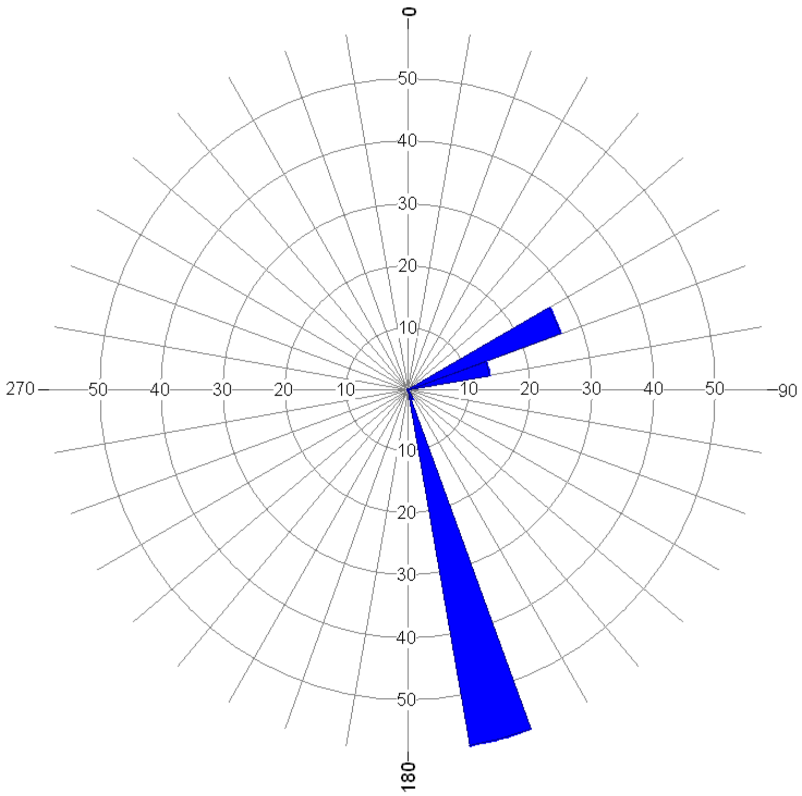


Figure: Example rose diagram from an optical televiewer data set illustrating the frequency (%) of dip direction (azimuth).

With a quick glance at the above rose diagram of dip direction values, one can see that the features (and/or fractures) in this data set have two primary dip directions. Specifically, 40 percent of the features dip to the east-northeast between 60° degrees and <80° in azimuth and 60 percent of the features dip to the south-southeast between 160° and <170° in azimuth.

Stereonets

For stereonets, Colog utilizes a southern-hemisphere projected, equal-area Schmidt net to plot the poles to the feature planes. These plots are often used in plotting geologic data such as the dips and orientations of structural features. Here, the azimuthal angle indicates dip direction of the plane's pole (which dips 180 degrees opposite in azimuth from the plane's dip direction at a complementary angle). The distance from the center indicates the dip magnitude. The further from the center the steeper the dip angle; the closer to the center the more horizontal the feature is.

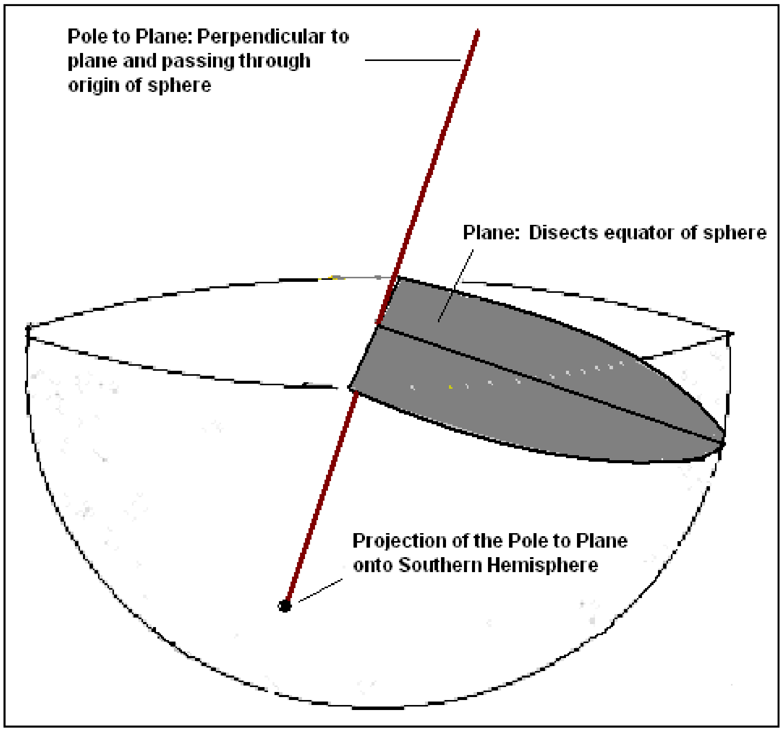


Figure: The above cartoon demonstrates the relationship between a plane and its pole, as projected onto the southern hemisphere of a sphere.

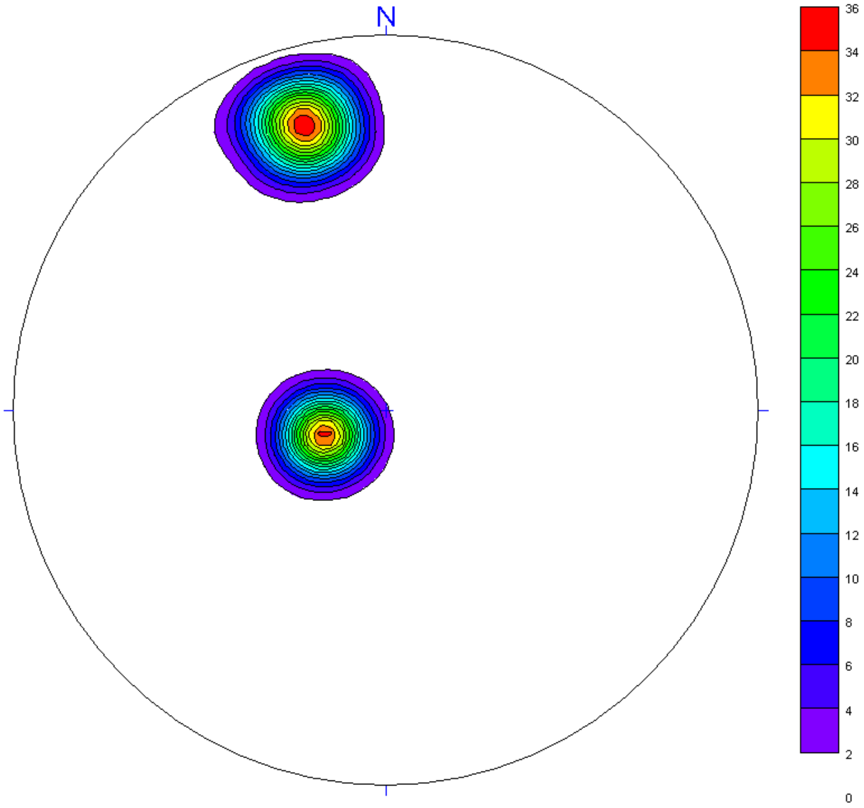
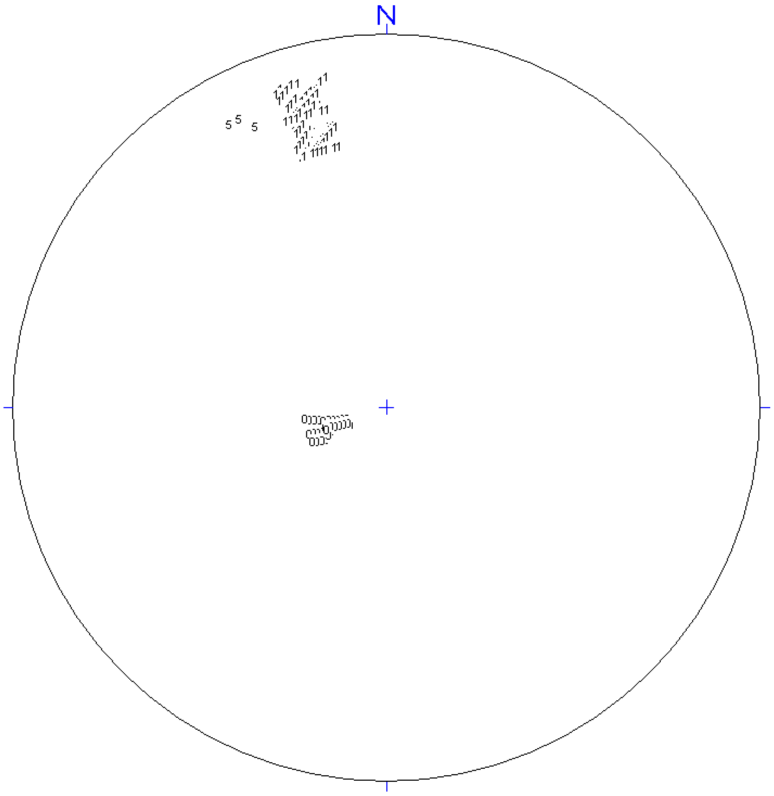


Figure: Example stereonet from an optical televiewer data set illustrating the frequency (%) of dip direction and dip angle.

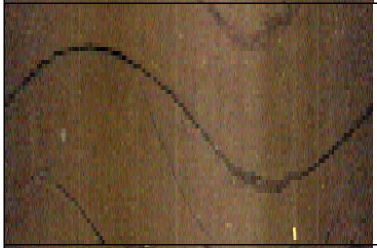
The figure above is an example stereonet diagram from the same televiewer data set of fractures and features as used previously to describe rose diagrams. It was created by binning the density (frequency) of poles per area. The figure below indicates, with a quick glance, that two distinct patterns exist in the example data set. A cluster of fractures/features with similar dip directions of approximately 160-170 degrees with steep dip angles of around 60-80 degrees is apparent. A second cluster is apparent with similar dip directions of approximately 60-80 degrees with moderate dip angles of approximately 10-20 degrees. The white areas indicate low to zero density of poles.



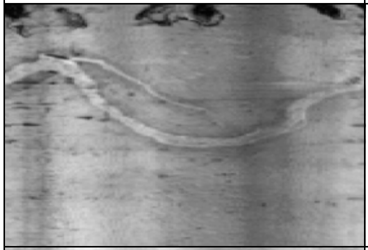
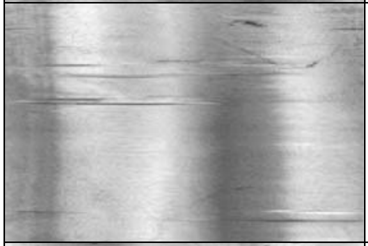
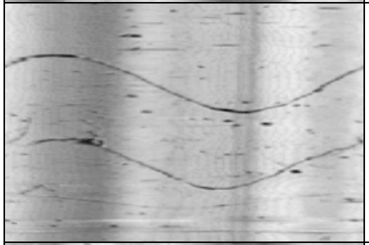
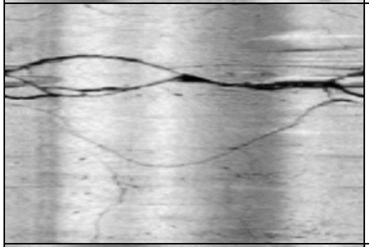
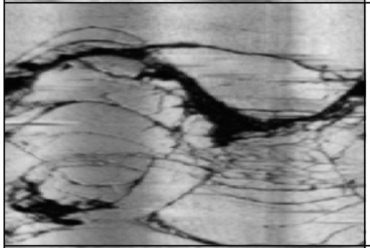
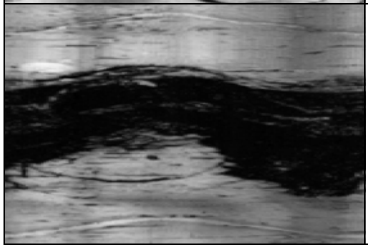
Colog also often provides a Schmidt net with the qualitative rank of each fracture/feature plotted at the location of its planar pole. Please refer to the *Ranking System for Optical/Acoustic Televiewer Features,* included in the report, for an explanation of the qualitative ranks assigned each optical/acoustic televiewer feature identified.

With a quick glance at the above Schmidt net, one can see that the low dip angle features which dip to the east-northeast are bedding features, ranked "0"; the high dip angle features dipping to the south-southeast are primarily weak or partial fractures, ranked "1"; and there are several major fracture zones, ranked "5", with strike/dip very similar to the majority of the partial/weak fractures in the well.

Ranking System for Optical Televiewer Features

	Rank	Color	Observation	Flow Rating System
	0	**Gray** ●	Non-flow feature (bedding, healed fracture, staining, foliation, vein, etc.)	Sealed, No Flow
	1	**Cyan** ●	Weak Feature (not continuous around the borehole)	Partial Open Crack
	2	**Blue** ●	Clear, Distinct Feature	Continuous Open Crack
	3	**Red** ●	Distinct Feature with Apparent Aperture	Wide Open Crack or Cracks
	4	**Magenta** ●	Very Distinct, Wide, Possibly Interconnected Fracture	Very Wide Crack or Multiple Interconnected Fractures
	5	**Green** ●	Major Fracture Zone or Washed out Zone with Large Openings	Major Fracture with Large Openings or Breakouts

Ranking System for Acoustic Televiewer Features

	Rank	Color	Observation	Flow Rating System
	**0**	**Gray** ●	No-Flow Feature (bedding, healed fracture, vein, etc.)	Sealed, No Flow
	**1**	**Cyan** ●	Weak Feature (not continuous around the borehole)	Partial Open Crack
	**2**	**Blue** ●	Clear, Distinct Feature	Continuous Open Crack
	**3**	**Red** ●	Distinct Feature with Apparent Aperture (visible on amplitude and travel-time image)	Wide Open Crack or Cracks
	**4**	**Magenta** ●	Very Distinct, Wide, Possibly Interconnected Fracture (visible on amplitude and travel-time image)	Very Wide Crack or Multiple Interconnected Fractures
	**5**	**Green** ●	Major Fracture Zone or Washed out Zone (visible on amplitude and travel-time image)	Major Fracture with Large Openings or Breakouts

Appendix H

Laboratory Testing Report

Earth Mechanics Institute

Client: ATT

Location: N/A

Project Name: 2546-40

Colorado School of Mines

Mining Engineering Department

Date: 03/19/2012								Dynamic Elastic Constants		
Sample ID	Rock Type	Average Length	Average Diameter	Length to Diameter Ratio	Density	P-Wave Velocity	S-Wave Velocity	Young's Modulus		Poisson's Ratio
		(in)	(in)		(lb/ft3)	(ft/sec)	(ft/sec)	(ksi)	(GPa)	
YA-T1@4	Metamorphic	4.064	1.853	2.19	176	16,127	10,263	9,287	64.0	0.16
YA-T1@10	Metamorphic	4.096	1.869	2.19	174	15,170	9,481	7,960	54.9	0.18
YA-T1@15	Metamorphic	3.557	1.871	1.90	164	16,468	9,410	7,867	54.2	0.26
YA-T1@18	Metamorphic	3.797	1.870	2.03	179	9,888	6,879	3,763	25.9	0.03
YA-T5@12	Metamorphic	4.155	1.867	2.23	167	14,427	8,766	6,670	46.0	0.21
YA-T5@17	Metamorphic	4.007	1.888	2.12	166	16,289	9,406	7,906	54.5	0.25
YA-T3@10	Metamorphic	3.999	1.889	2.12	163	13,602	8,228	5,758	39.7	0.21
YA-T4@LINER	Concrete	6.888	3.216	2.14	142	11,835	7,406	3,949	27.2	0.18
YA-T5@LINER	Concrete	6.847	3.223	2.12	147	11,079	7,608	3,866	26.7	0.05
YA-T6@5	Metamorphic	3.935	1.869	2.11	167	13,384	8,863	6,268	43.2	0.11
YA-T6@30	Metamorphic	3.959	1.870	2.12	164	12,938	7,855	5,285	36.4	0.21
YA-T6@57	Metamorphic	3.847	1.872	2.06	165	16,440	9,715	8,271	57.0	0.23

SPLITTING TENSILE STRENGTH

By Method of Brazilian Disk

ASTM D 3967

SPLITTING TENSILE STRENGTH
By Method of Brazilian Disk
ASTM D 3967

CLIENT: Yeh & Associates

JOB NO.: 2546-40

LOCATION:

DATE TESTED: 3/15/12 HN/BL

PROJECT: 211-231

Page 1 of 1

Specimen ID Boring, Sample No., Depth(ft.)	**Diameter (in.)**	**Length (in.)**	**Mass (gms)**	**Wet Density (pcf)**	**Failure Load (lb)**	**Failure Type ***	**Splitting Tensile Strength (psi)**
YA-T6, 5'	1.865	0.914	108.7	165.9	3,534	S	1,320
YA-T6, 30'	1.868	0.743	93.5	174.9	503	S	230
YA-T6, 57'	1.868	0.908	108.3	165.8	3,709	S	1,390
YA-T4, 7'	1.865	0.774	91.9	165.6	3,790	S	1,670
YA-T4, 15'	1.865	0.812	97.9	168.1	3,171	S	1,330
YA-T2, 12'	1.871	0.728	92.2	175.5	853	S	400
YA-T2, 27'	1.865	0.793	93.4	164.3	2,946	S	1,270
YA-T2, 38'	1.851	0.825	102.8	176.4	2,784	S	1,160
YA-T1, 18'	1.856	0.976	125.0	180.3	1,003	M	350
YA-T1, 15'	1.871	0.892	105.6	164.0	3,234	S	1,230

Notes and Comments:

Splitting Tensile Strength=2P/piLD.
P=Failure Load
pi = 3.1415926....
D = Sample Diameter
L = Sample Length

* Failure Type: S: Single Failure Plane, M: Multiple Failure Planes

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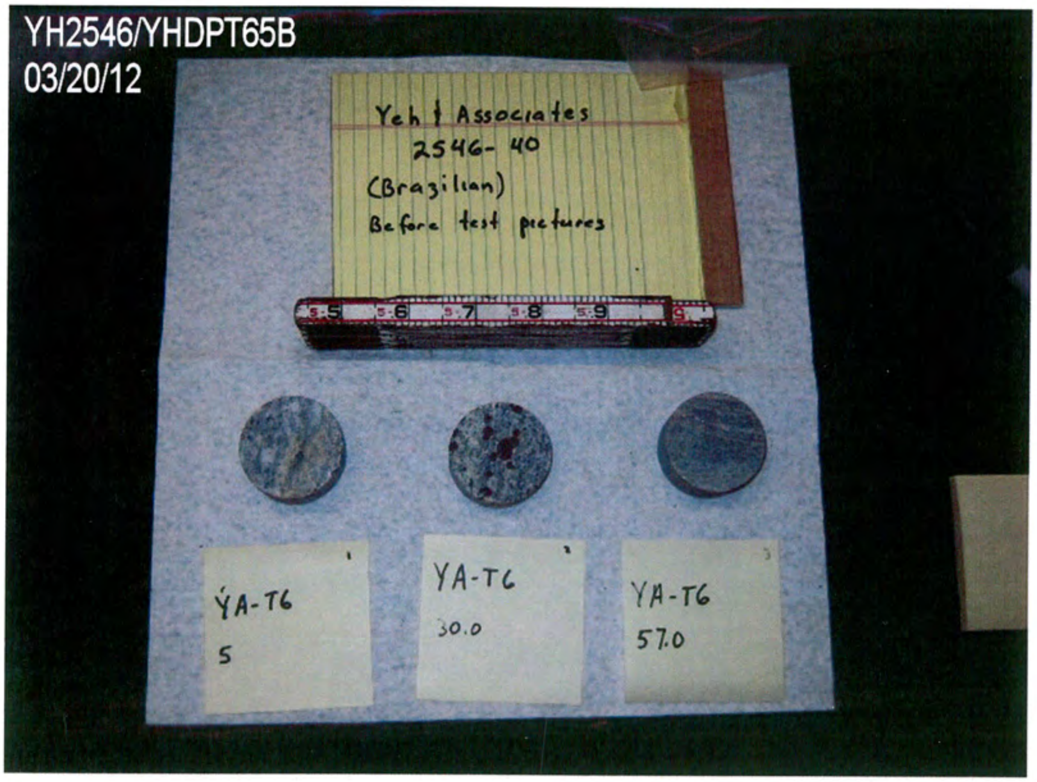
Data Checked By: HN Date: 03/22 2012
Filename: YHBD40BZ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03/20/12
Yeh & Associates
2546- 40
(Brazilian)
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YA-T6
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YA-T6
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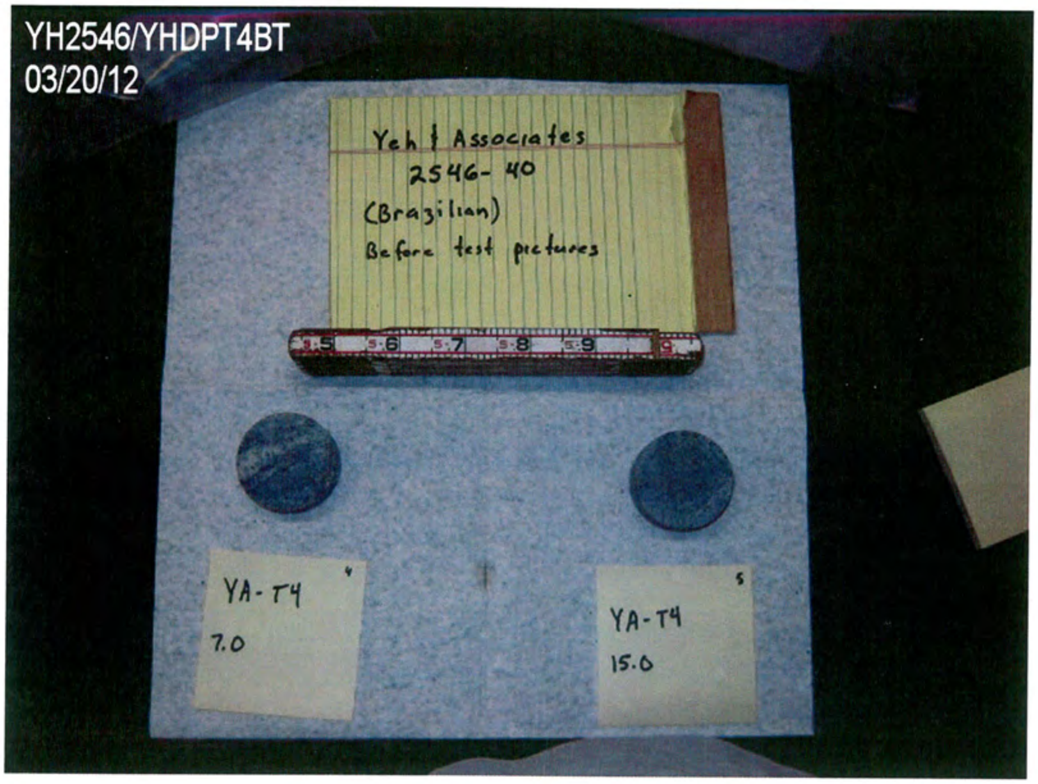
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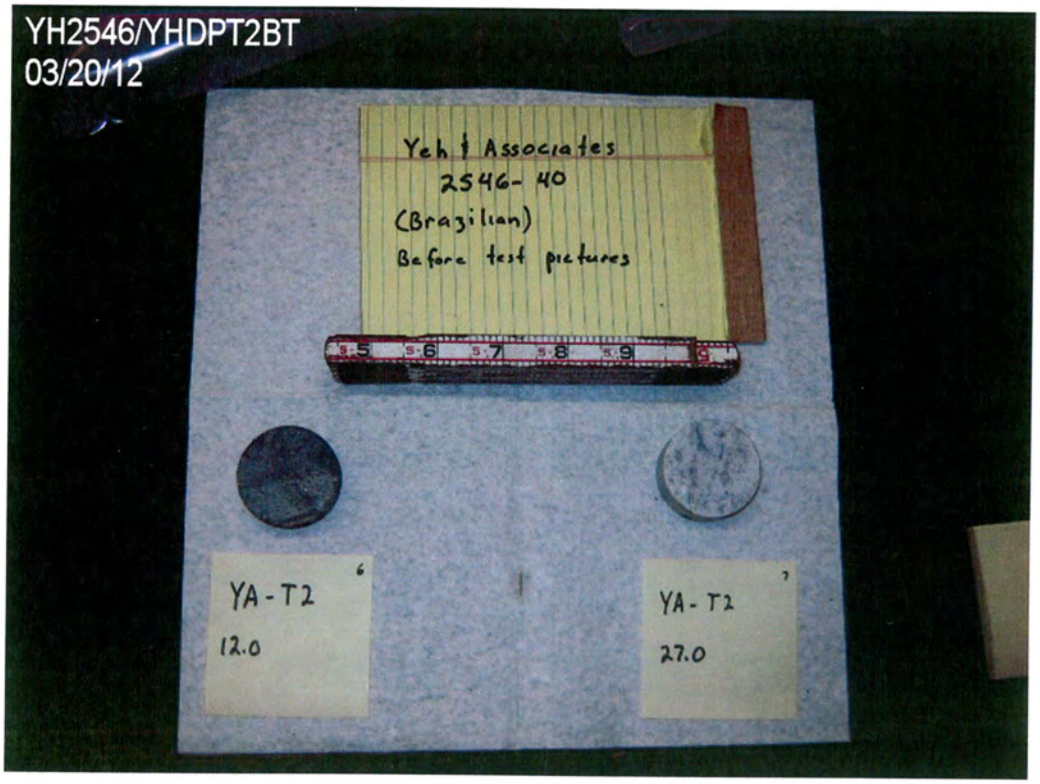
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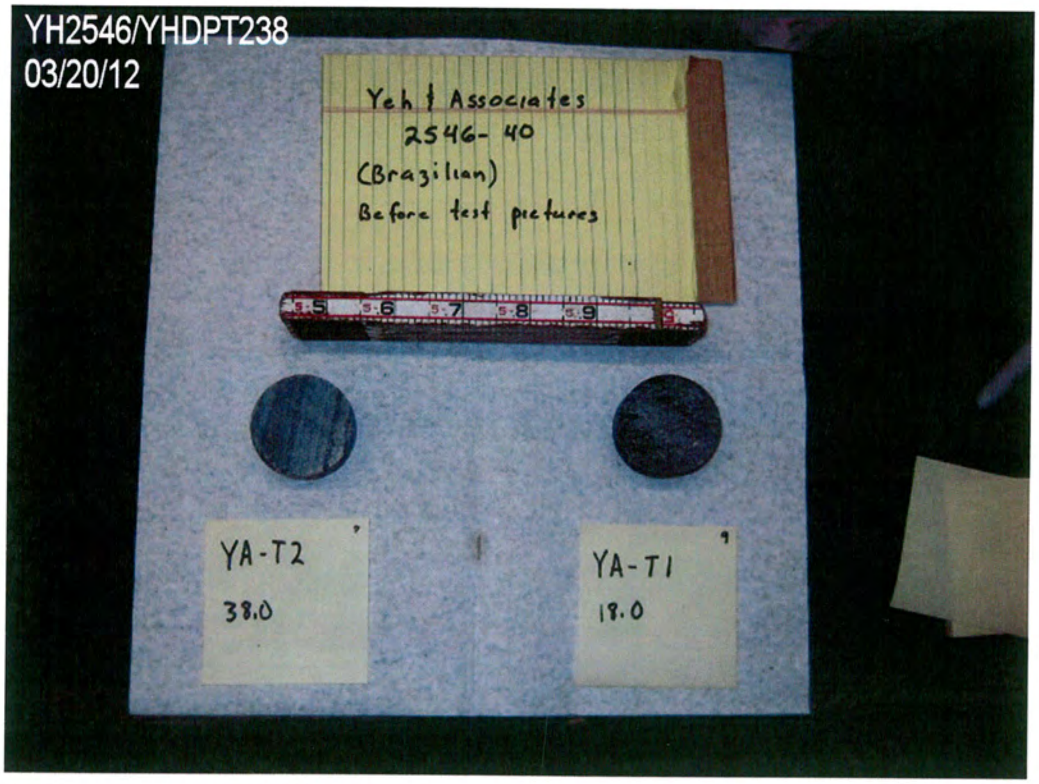
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YA-T1
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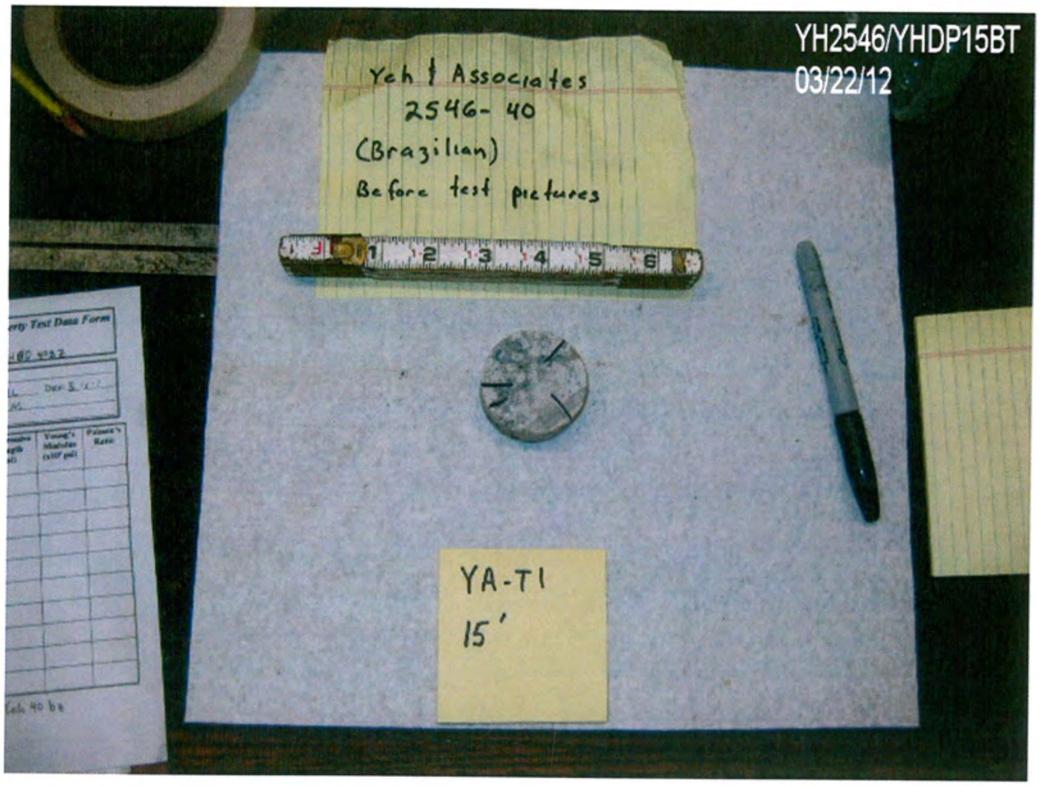
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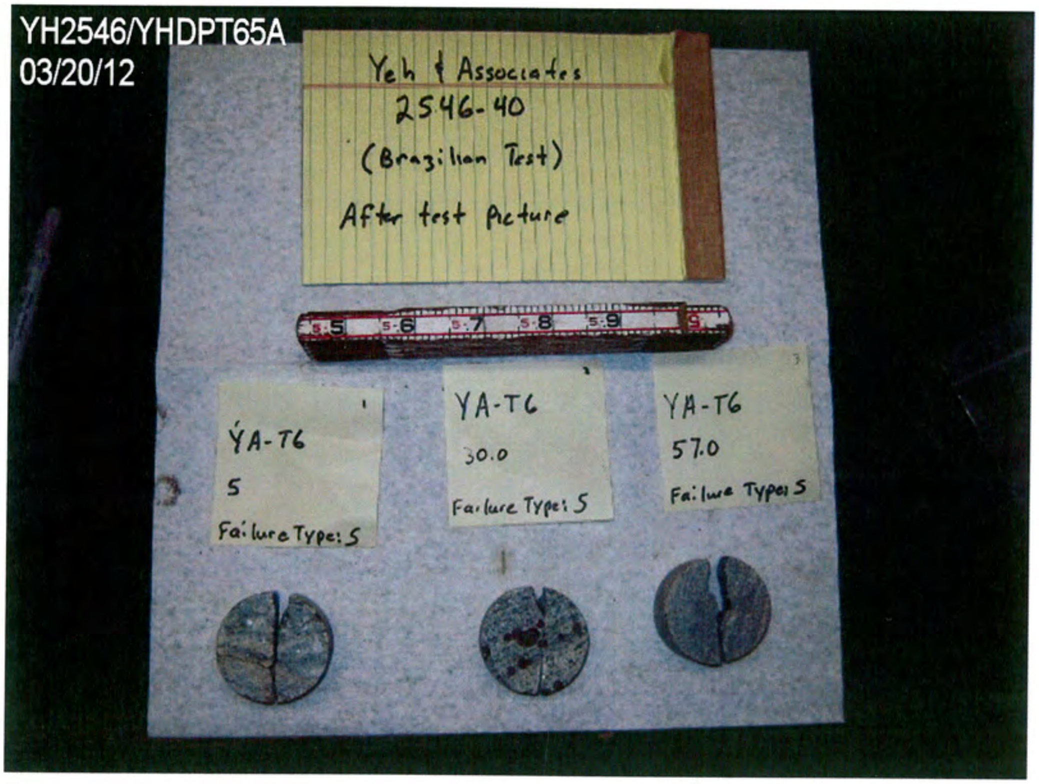
03/22/12
Yeh & Associates
2546- 40
(Brazilian)
Before test pictures
YA-T1
15'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03/20/12
Yeh & Associates
2546-40
(Brazilian Test)
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Failure Type: S
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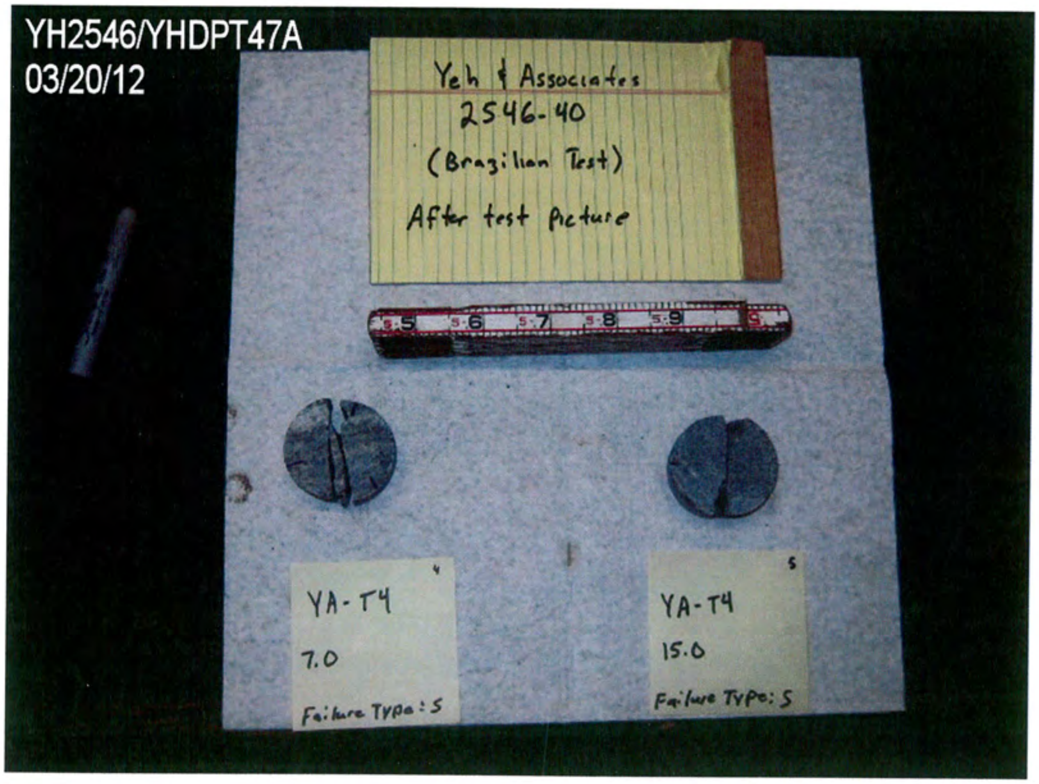
Failure Type: S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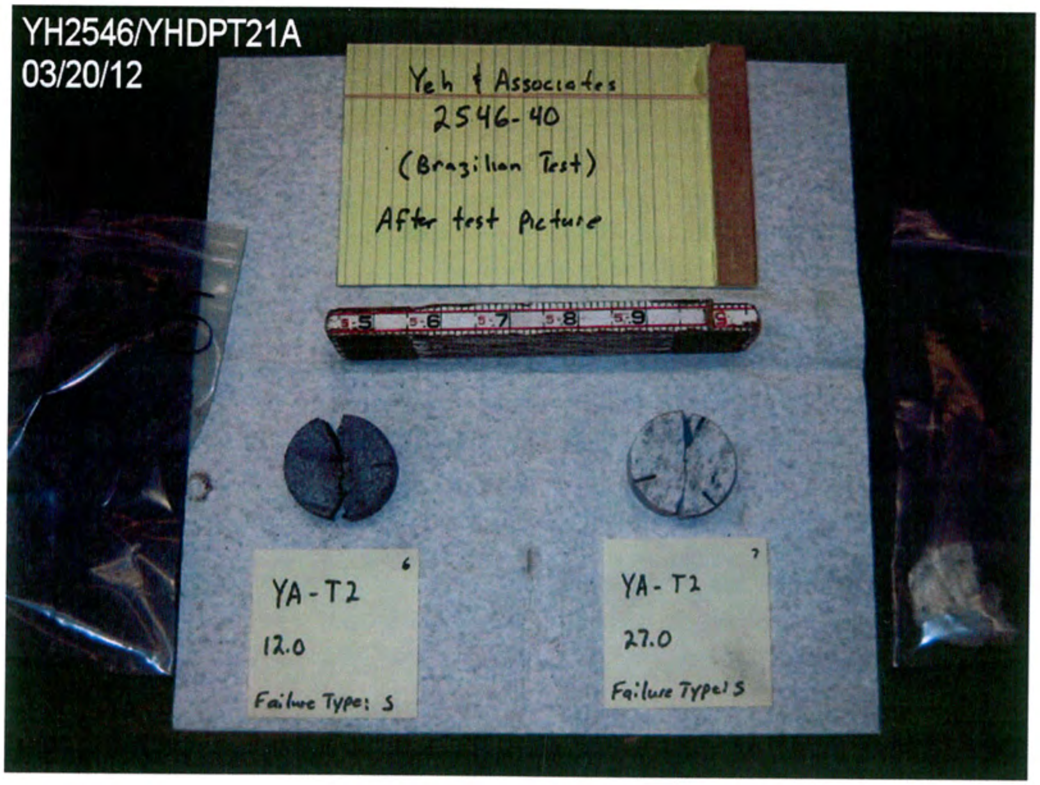
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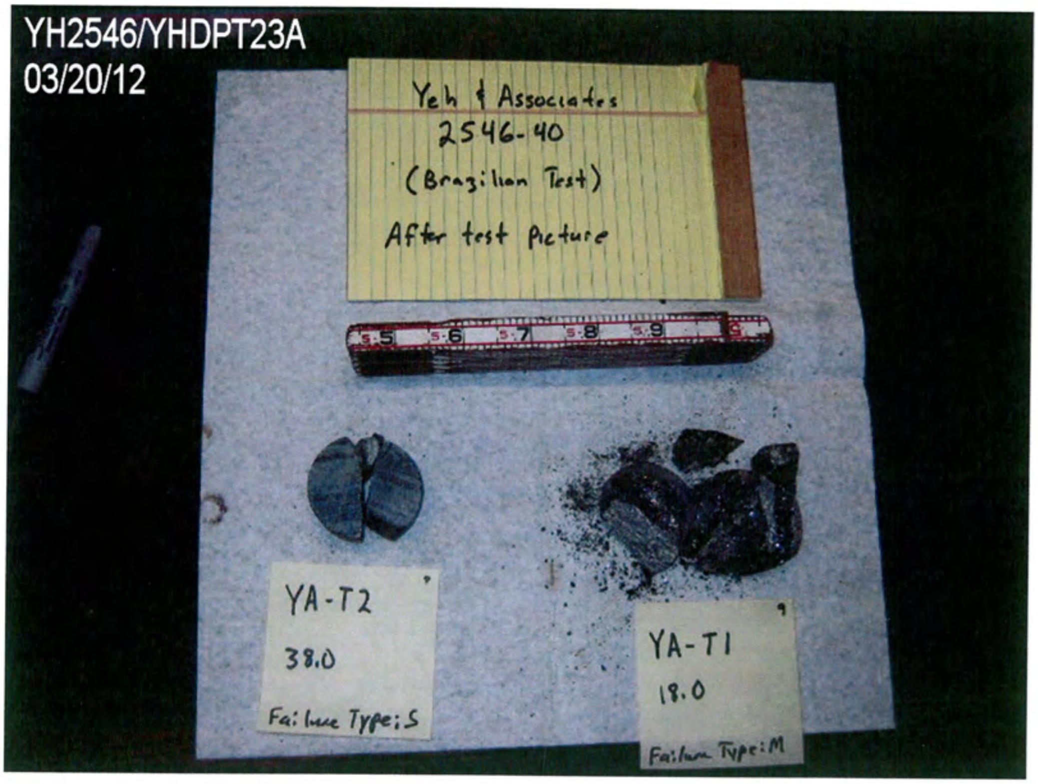
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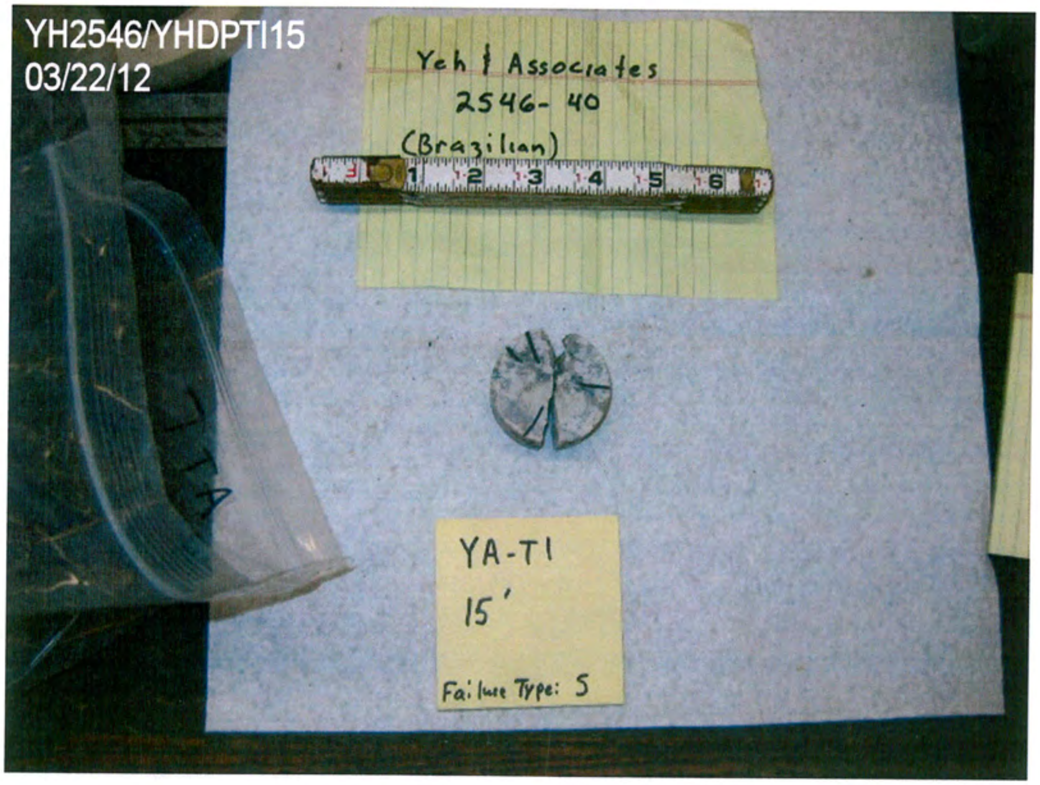
Failure Type: M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03/22/12
Yeh & Associates
2546- 40
(Brazilian)
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15'
Failure Type: S

UNCONFINED COMPRESSIVE STRENGTH

ASTM D 7012 METHOD C

UNCONFINED COMPRESSIVE STRENGTH
ASTM D 7012; Method C (Previously ASTM D 2938)

CLIENT: Yeh & Associates

JOB NO.: 2546-40

LOCATION:

DATE TESTED: 3/21/12 HN/BL

PROJECT: 211-231

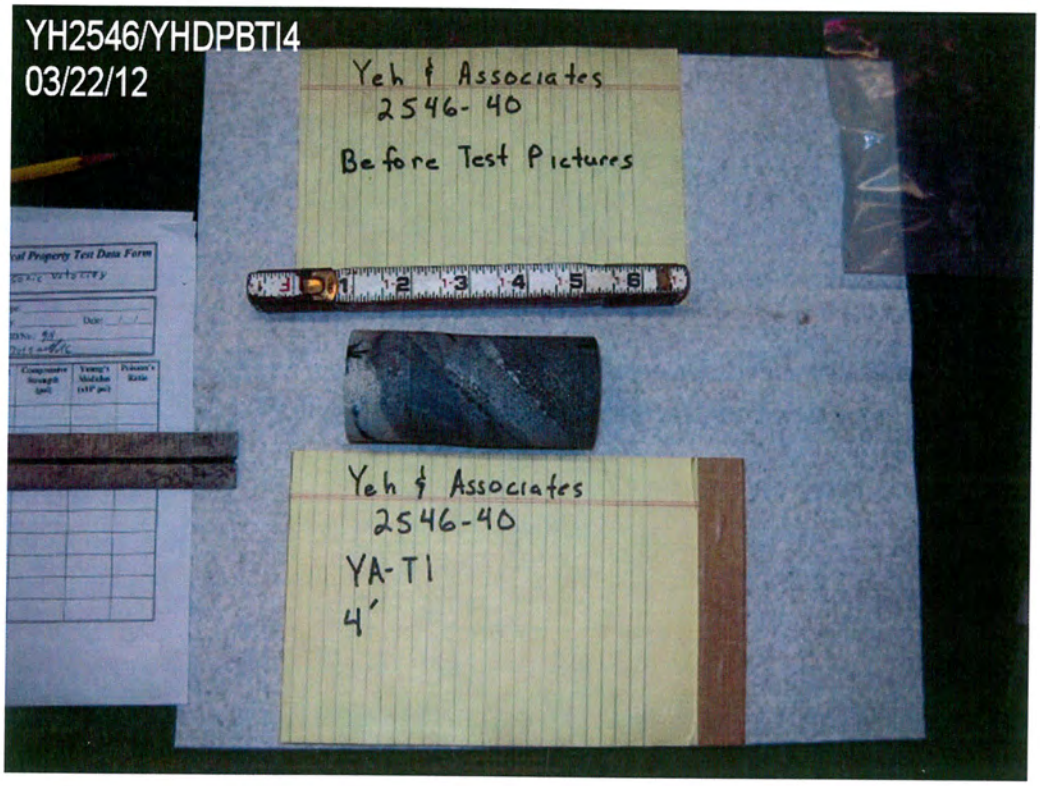
Page 1 of 1

Specimen ID Boring, Depth(ft.), Rock type	Diameter (in.)	Length (in.)	Mass (gms)	Wet Density (pcf)	Failure Load (lb)	Failure Types *	Compressive Strength (psi)
YA-T1, 4	1.853	4.064	506.7	176.1	19,490	F	7,230
YA-T1, 10	1.869	4.096	513.0	173.9	6,365	F	2,320
YA-T1, 18	1.870	3.797	489.1	178.7	2,728	F	990
YA-T5, 12	1.867	4.155	497.3	166.6	44,090	F/S	16,110
YA-T5, 17	1.888	4.007	487.7	165.6	44,396	F/S	15,860
YA-T3, 10	1.889	3.999	478.4	162.6	29,703	F	10,600
YA-T4, Liner	3.216	6.888	2079.1	141.6	38,403	M/F	4,730
YA-T5, Liner	3.223	6.847	2153.0	146.8	58,268	M/F	7,140

Notes and Comments: * Failure tyS: Shear Failure, M: Matrix Failure, F: Failure due to Fracture/Bedding, V: Void Failure,
C: Combination

Data Entered By: BKL Date: 03/22/2012
Data Checked By: HN Date: 03/22/2012
Filename: YHUC40U

ADVANCED TERRA TESTING, INC.
ATT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Yeh & Associates
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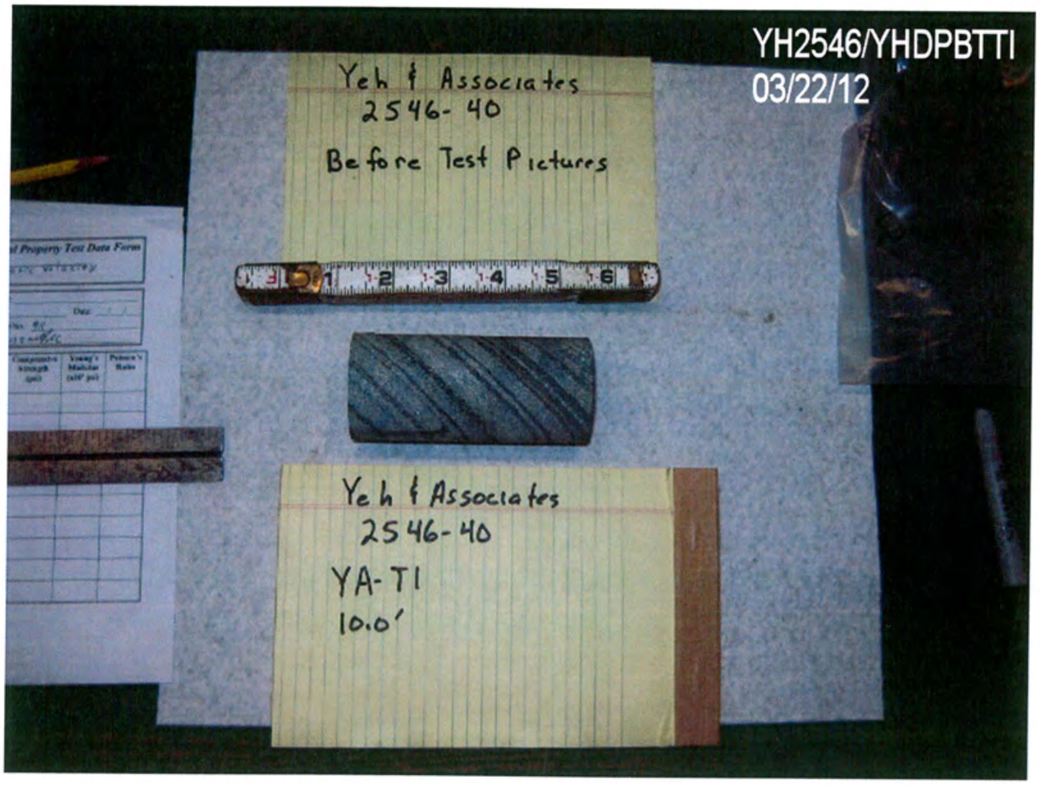
YA-T1
4'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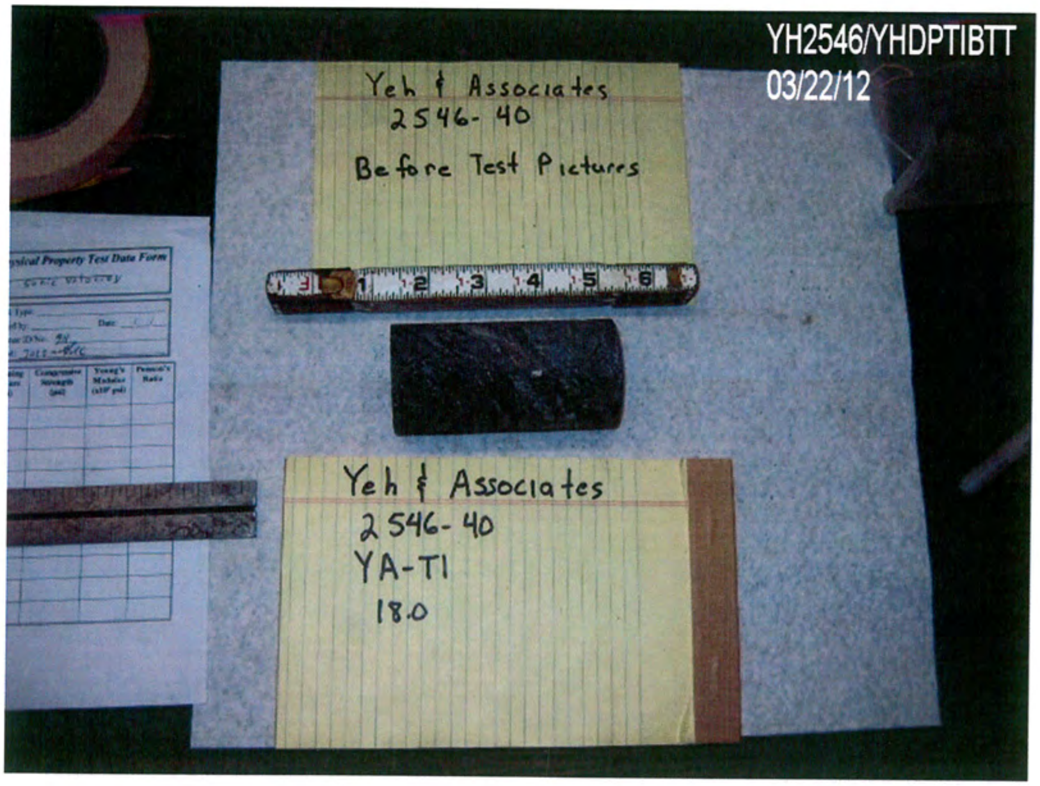
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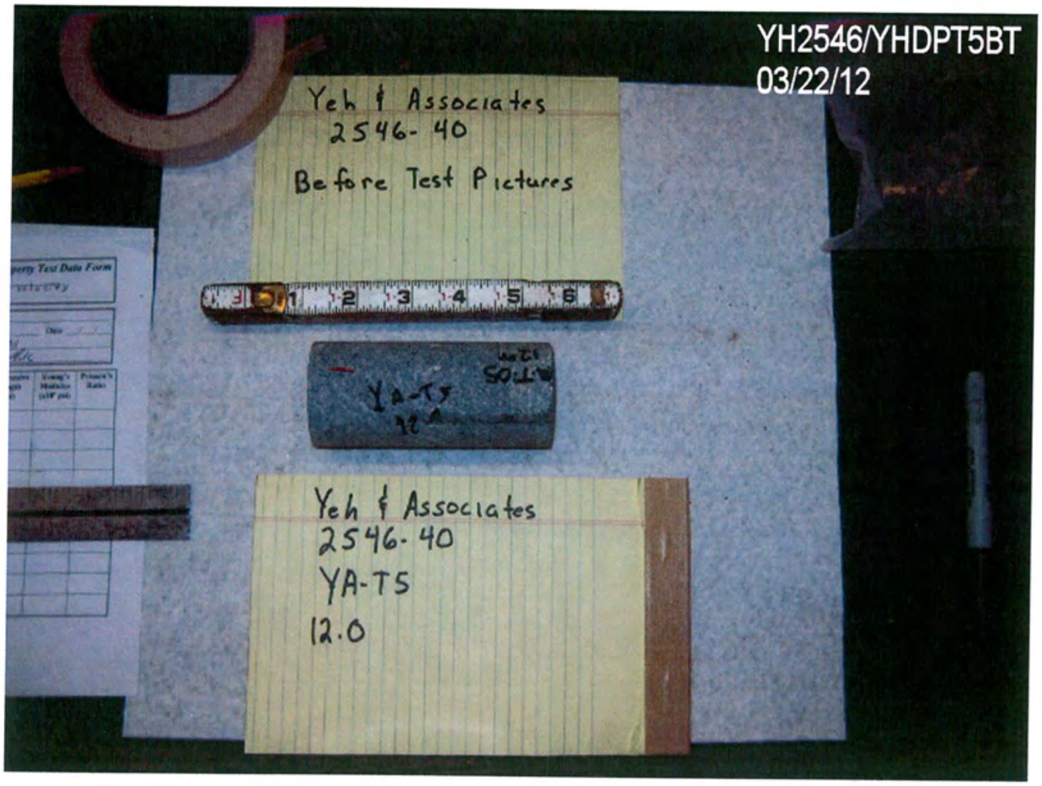
Young's Modulus
Poisson's Ratio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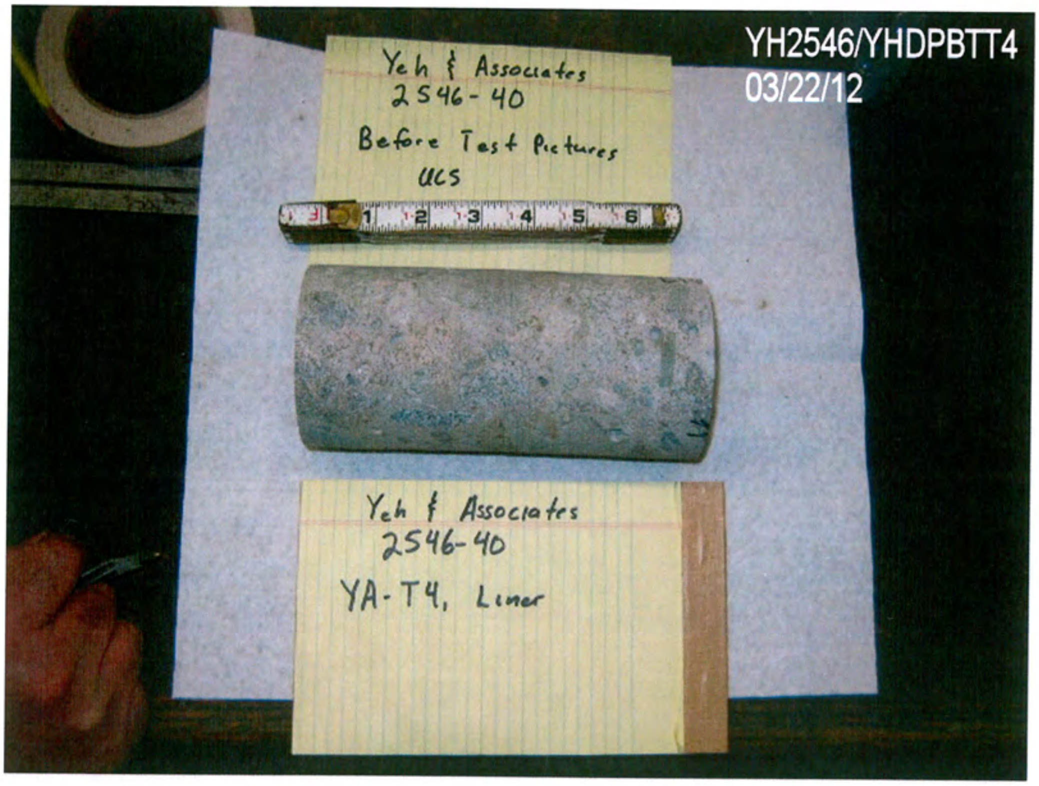
03/22/12
Yeh & Associates
2546-40
Before Test Pictures
1 2 3 4 5 6
YA-T5
12.0
Yeh & Associates
2546-40
YA-T5
12.0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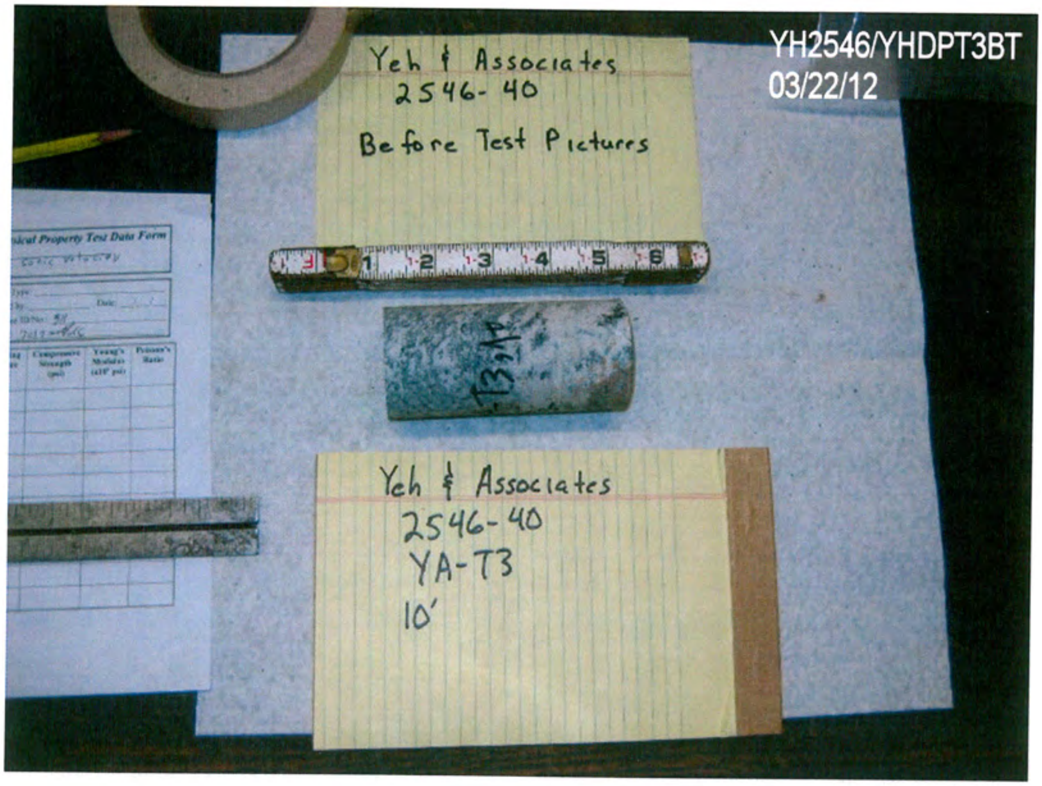
03/22/12
Yeh & Associates
2546-40
Before Test Pictures
UCS
Yeh & Associates
2546-40
YA-T4, Liner



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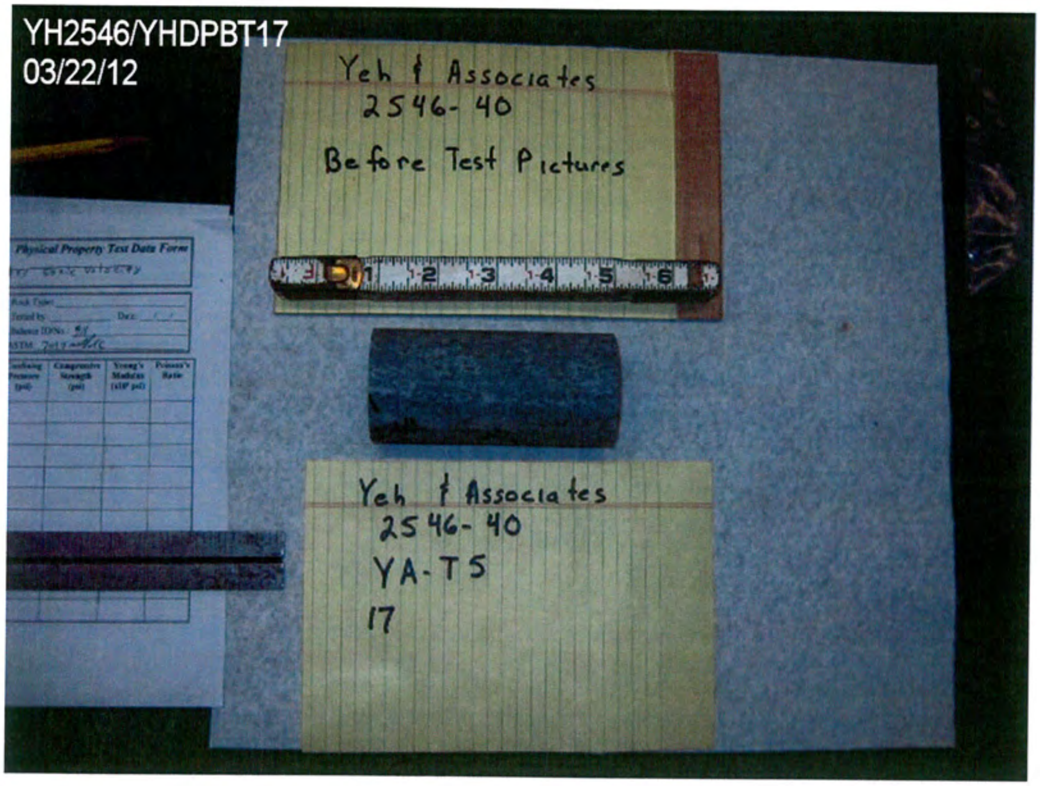
03/22/12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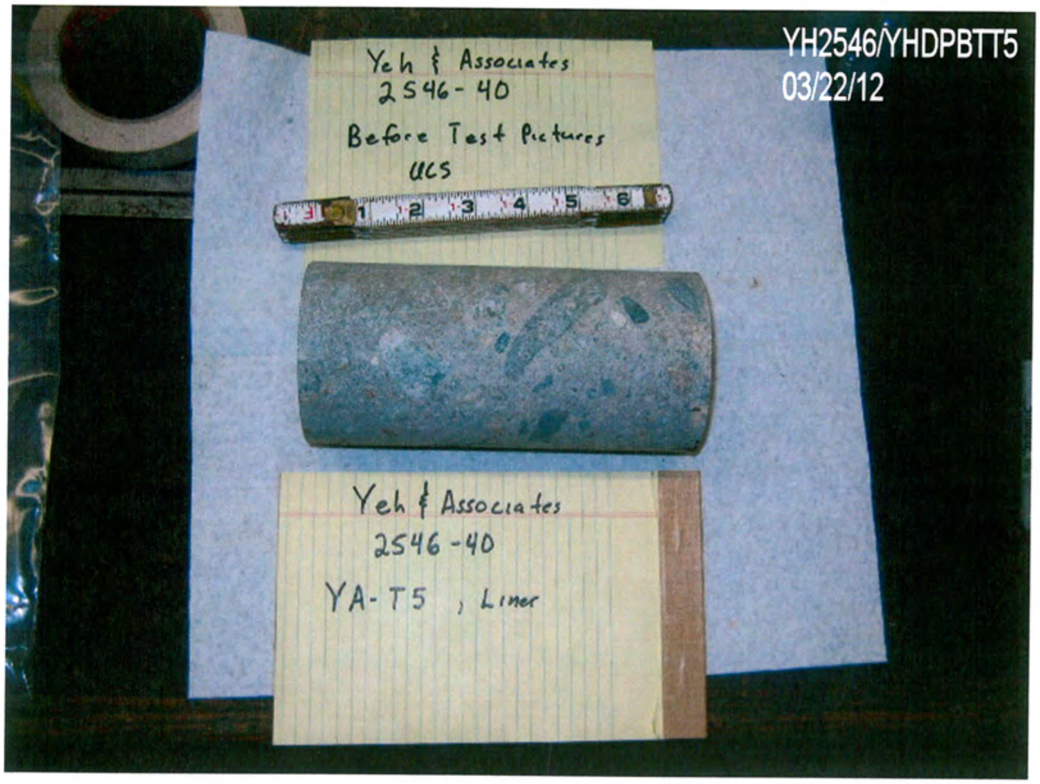
03/22/12
Yeh & Associates
2546-40
Before Test Pictures
Physical Property Test Data Form
Yeh & Associates
2546-40
YA-T5
17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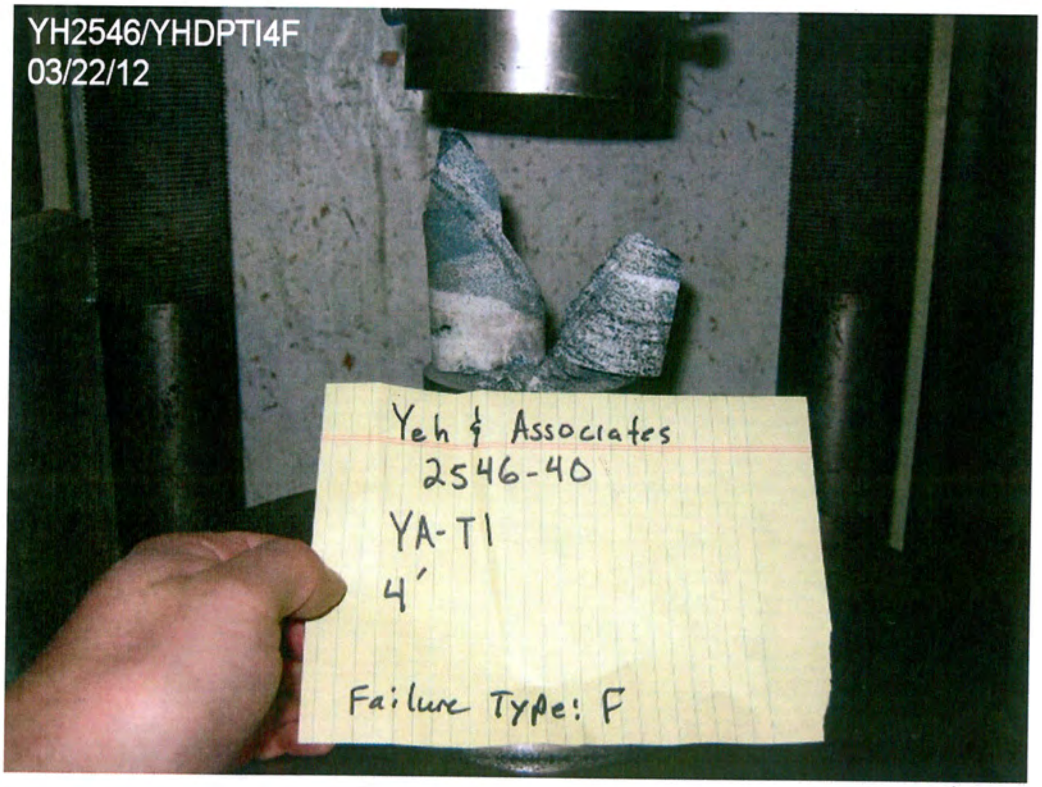
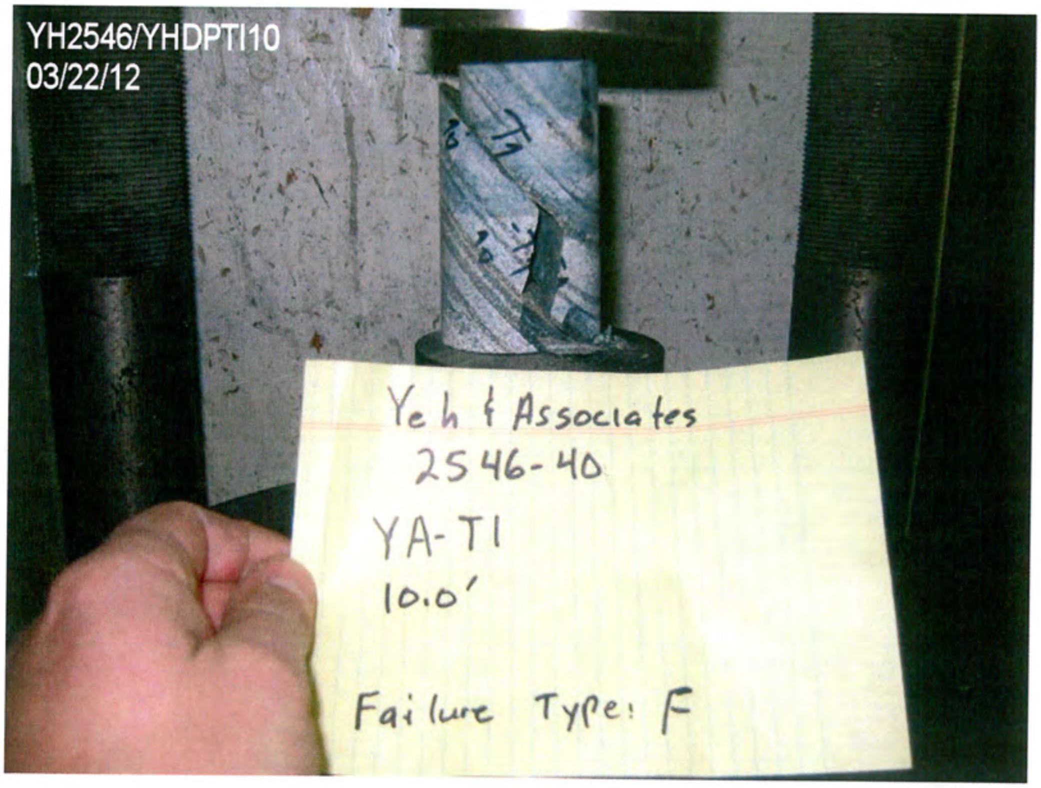
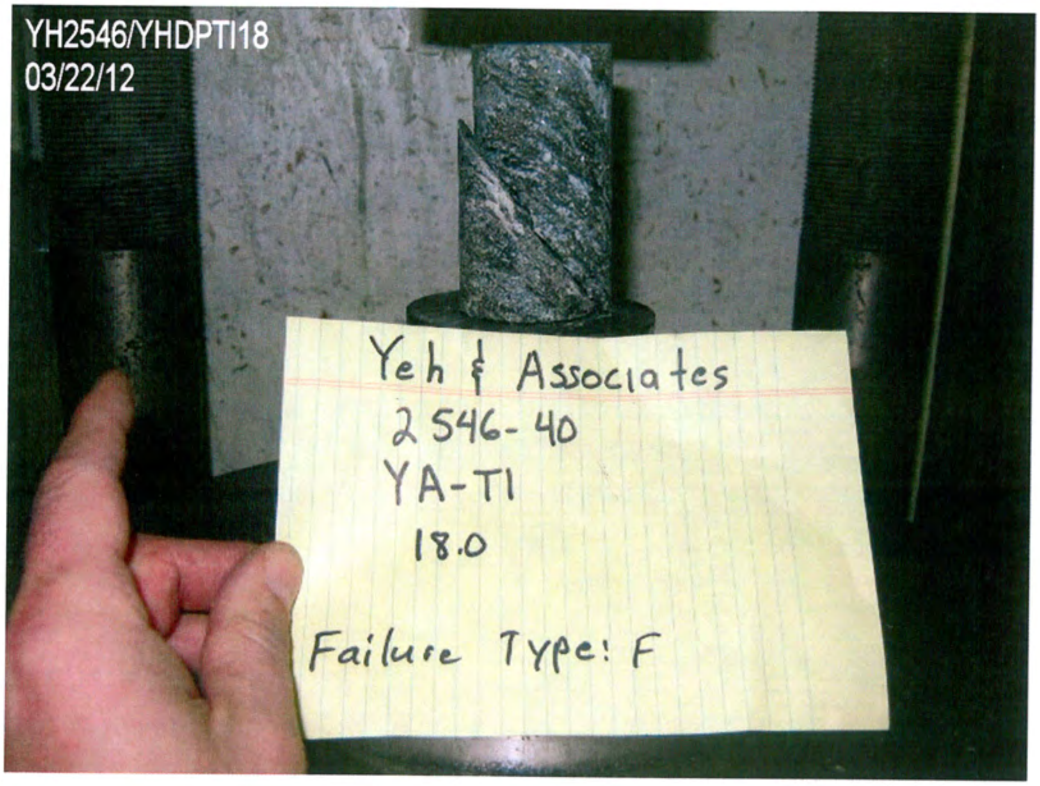
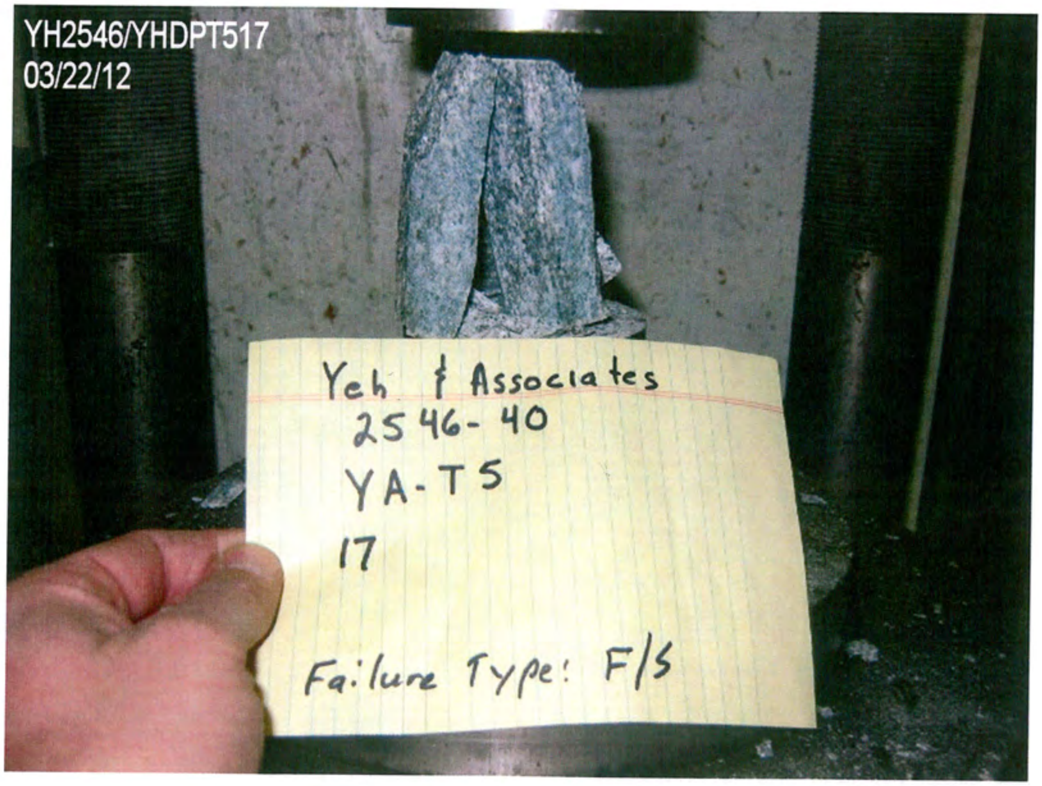
03/22/12
Yeh & Associates
2546-40
Before Test Pictures
UCS
1 2 3 4 5 6
Yeh & Associates
2546-40
YA-T5 , Liner

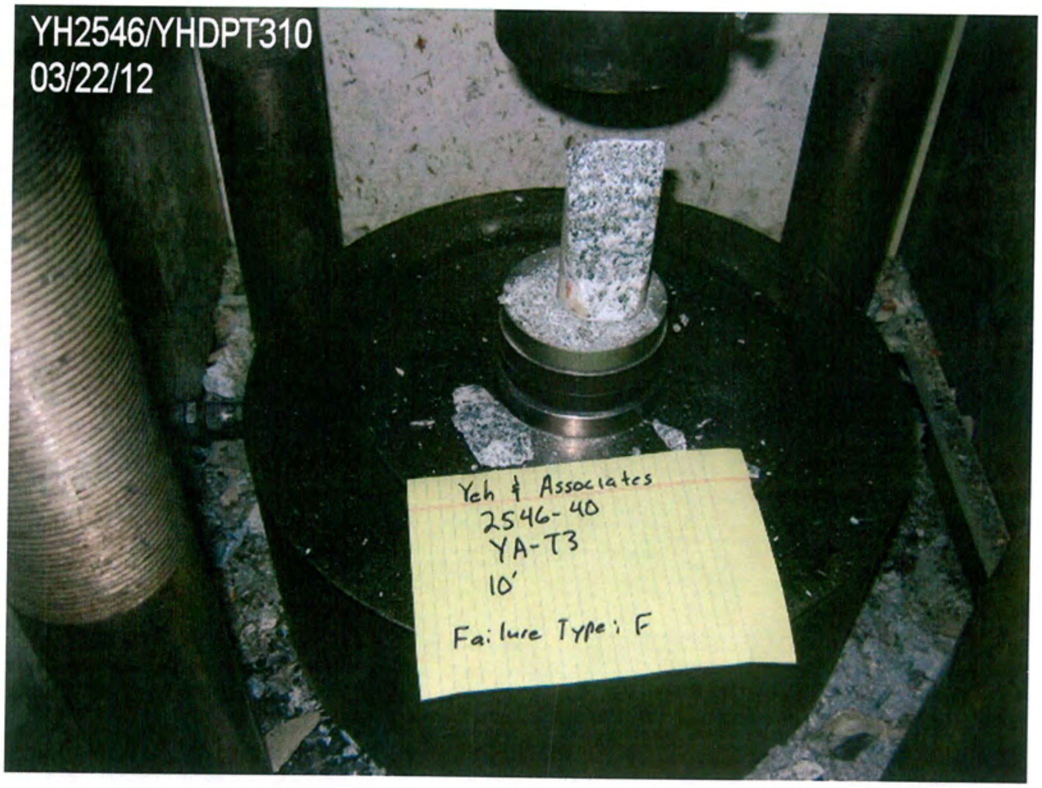

YH2546/YHDPTI4F
03/22/12
Yeh & Associates
2546-40
YA-T1
4'
Failure Type: F

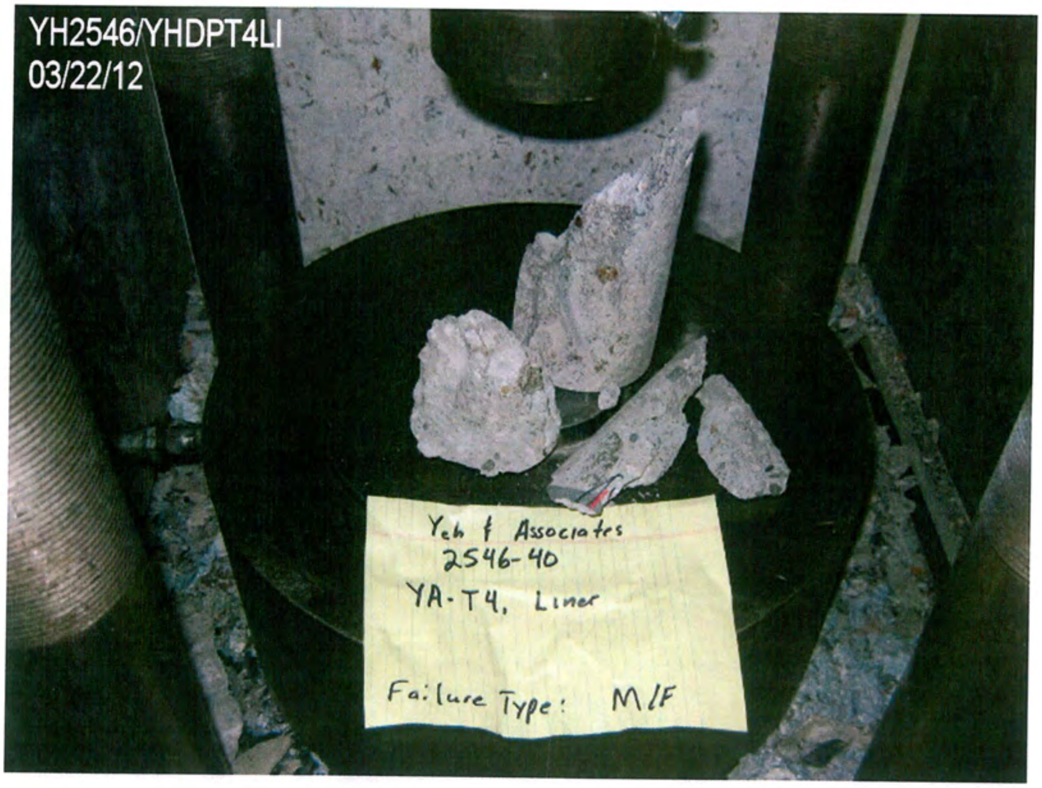

YH2546/YHDPTI10
03/22/12
Yeh & Associates
2546-40
YA-T1
10.0'
Failure Type: F


YH2546/YHDPTI18
03/22/12
Yeh & Associates
2546-40
YA-T1
18.0
Failure Type: F

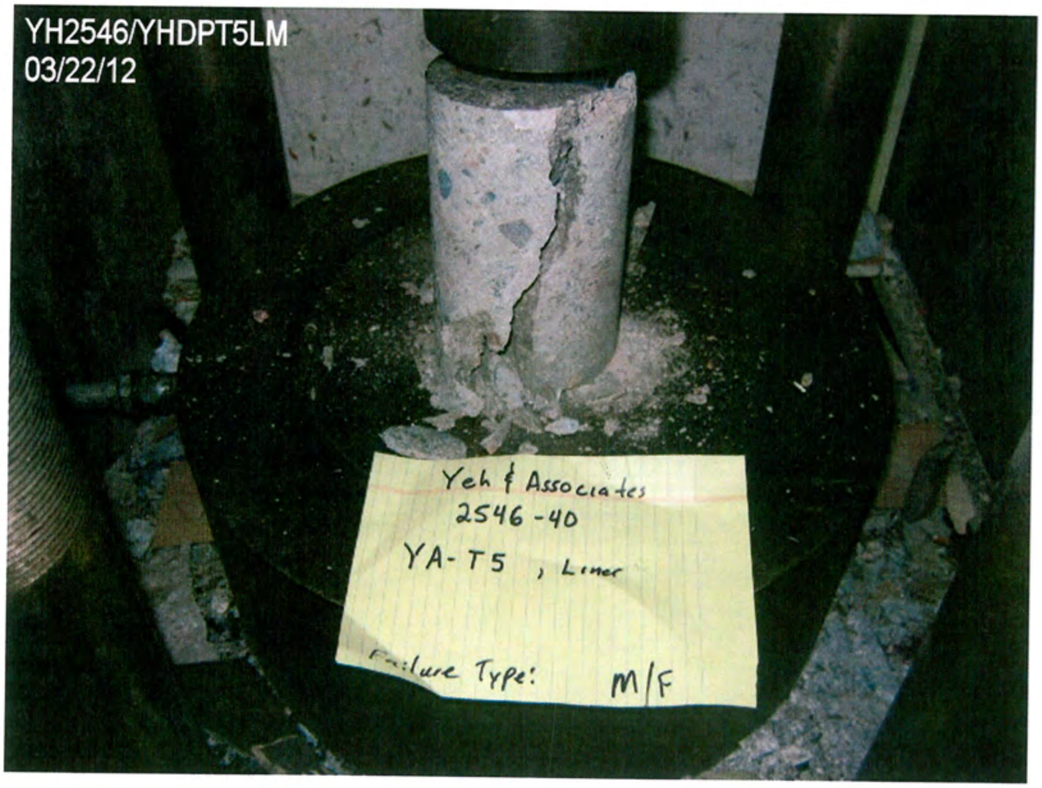

YH2546/YHDPT512
03/22/12
Yeh & Associates
2546-40
YA-TS
12.0
Failure Type: F/S


YH2546/YHDPT517
03/22/12
Yeh & Associates
2546-40
YA-TS
17
Failure Type: F/S


YH2546/YHDPT310
03/22/12
Yeh & Associates
2546-40
YA-T3
10'
Failure Type: F



YH2546/YHDPT4LI
03/22/12


YH2546/YHDPT5LM
03/22/12

UNCONFINDED COMPRESSIVE STRENGTH
ASTM D 7012 Method D

UNCONFINED COMPRESSIVE STRENGTH

With Stress / Strain Measurements

ASTM D 7012; Method D (Previously ASTM D 3148)

CLIENT: Yeh & Associates

JOB NO.: 2546-40

Project

DATE TESTED: 3/17-20/12 HN

LOCATION:

Specimen ID			Diameter (in.)	Length (in.)	Mass (gms)	Wet Density (pcf)	Failure Load (lb)	Failure Type *	Compressive Strength (psi)	Young's Modulus (X10^6 psi)	Poisson's Ratio
Boring	Depth (ft.)	Rock type									
YA-T6	5.0		1.869	3.935	472.1	166.6	42,000	F	15,310	5.99	0.141
YA-T6	30.0		1.870	3.959	468.2	164.0	31,000	F/S	11,290	4.79	0.155
YA-T6	57.0		1.872	3.847	458.1	164.8	53,500	F	19,440	10.69	0.183
YA-T4	7.0		1.864	3.942	472.1	167.2	49,000	F	17,960	8.59	0.210
YA-T4	15.0		1.871	4.025	486.3	167.4	27,250	F	9,910	6.82	0.184
YA-T2	12.0		1.869	4.094	519.7	176.3	10,500	F	3,830	4.88	0.227
YA-T2	27.0		1.868	3.793	447.9	164.1	25,750	F	9,400	7.35	0.135
YA-T2	38.0		1.855	3.928	487.0	174.8	25,650	F	9,490	8.61	0.209

Notes and Comments: * Failure Type:

S: Shear Failure, M: Matrix Failure, F/V Fracture, Bedding/Void Collapse, C: Combination

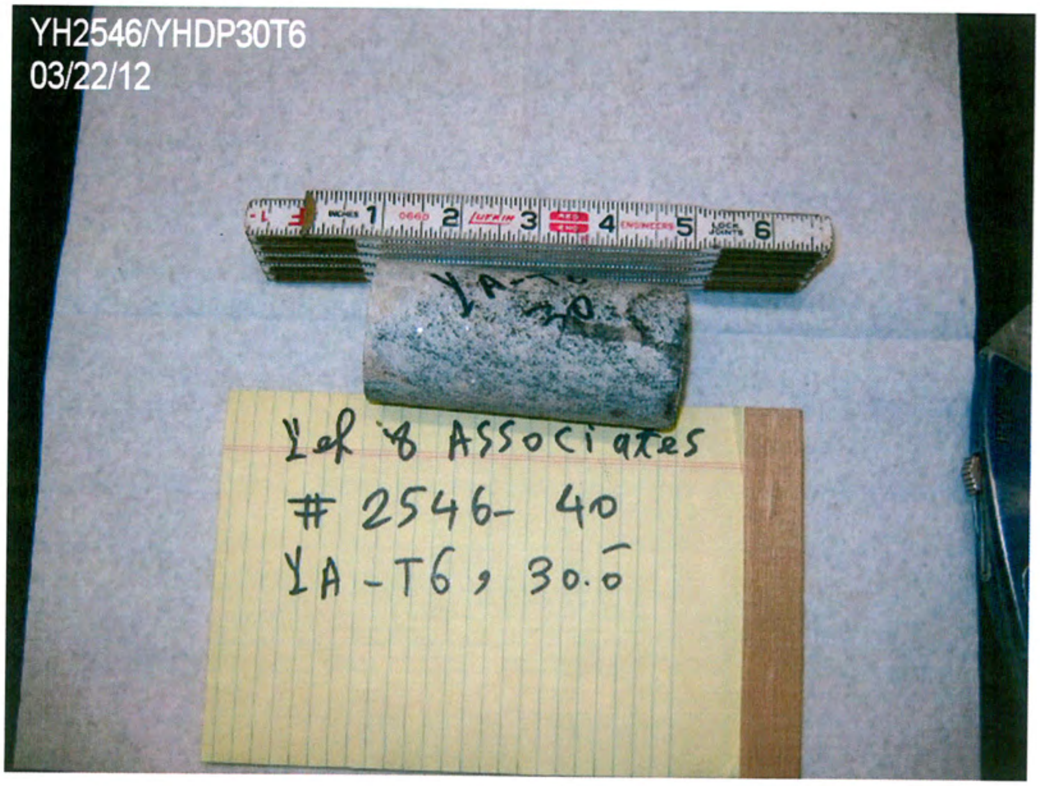
Data Entered By: HN Date: 03/21/2012

Data Checked By: BKL Date: 3/21/12

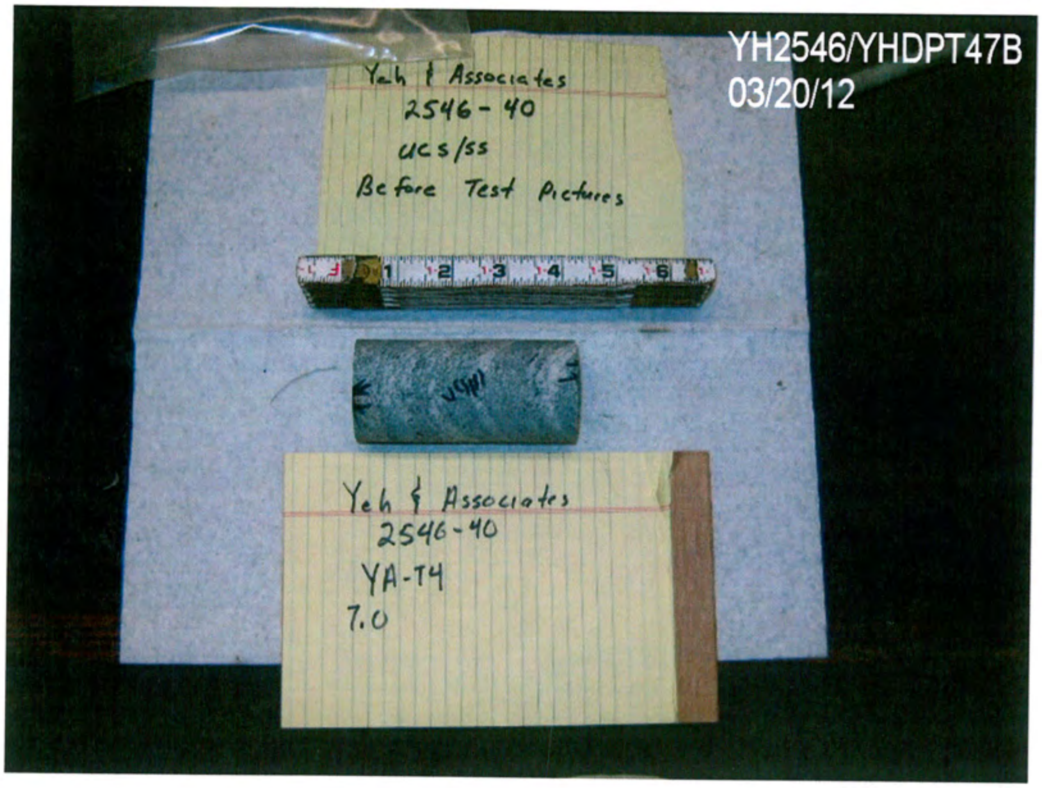
Filename: YHUCSS40

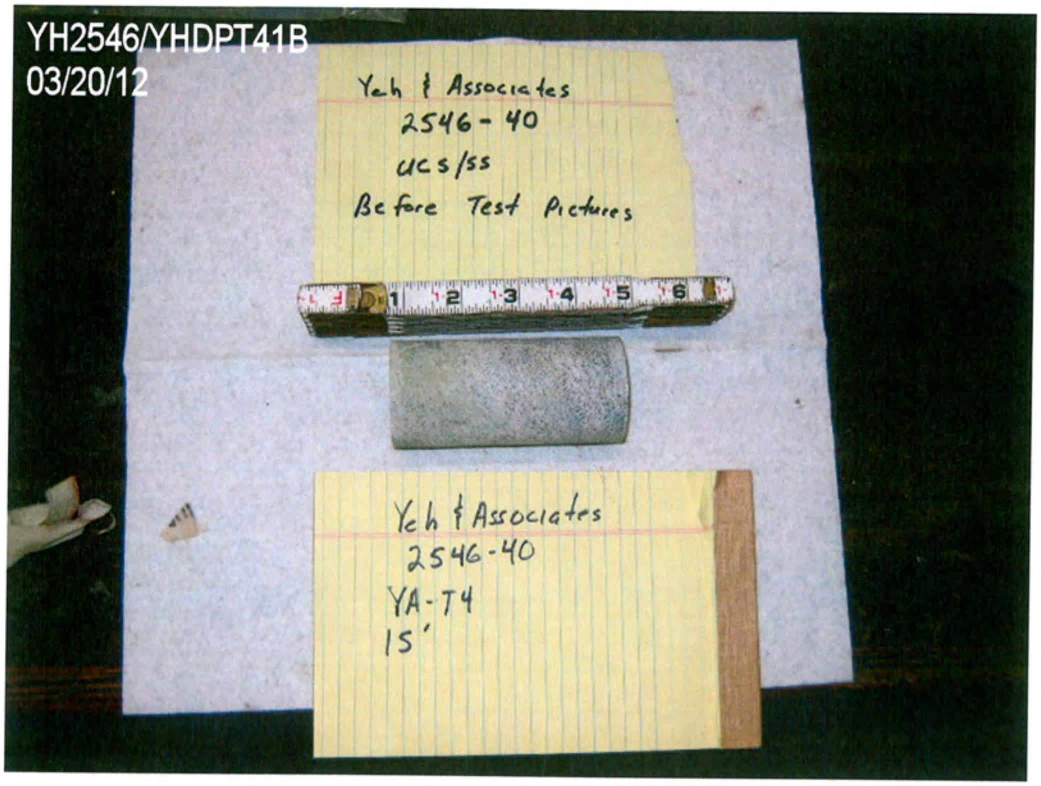
ADVANCED TERRA TESTING, INC.

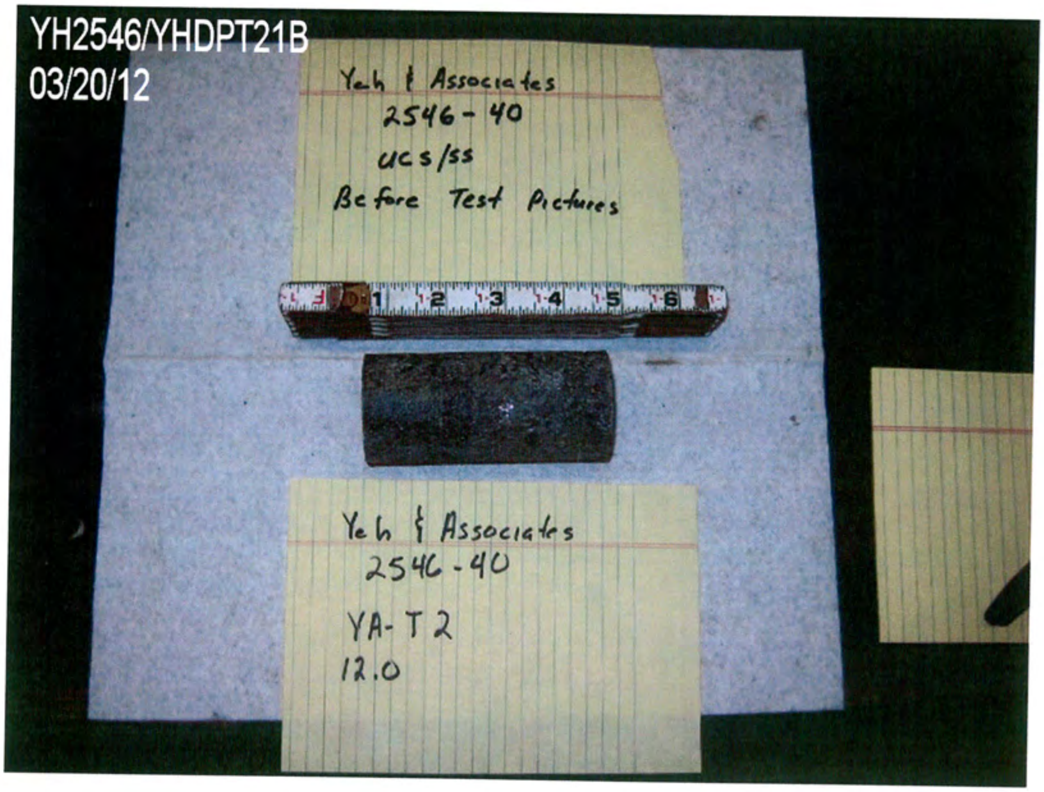
ATT

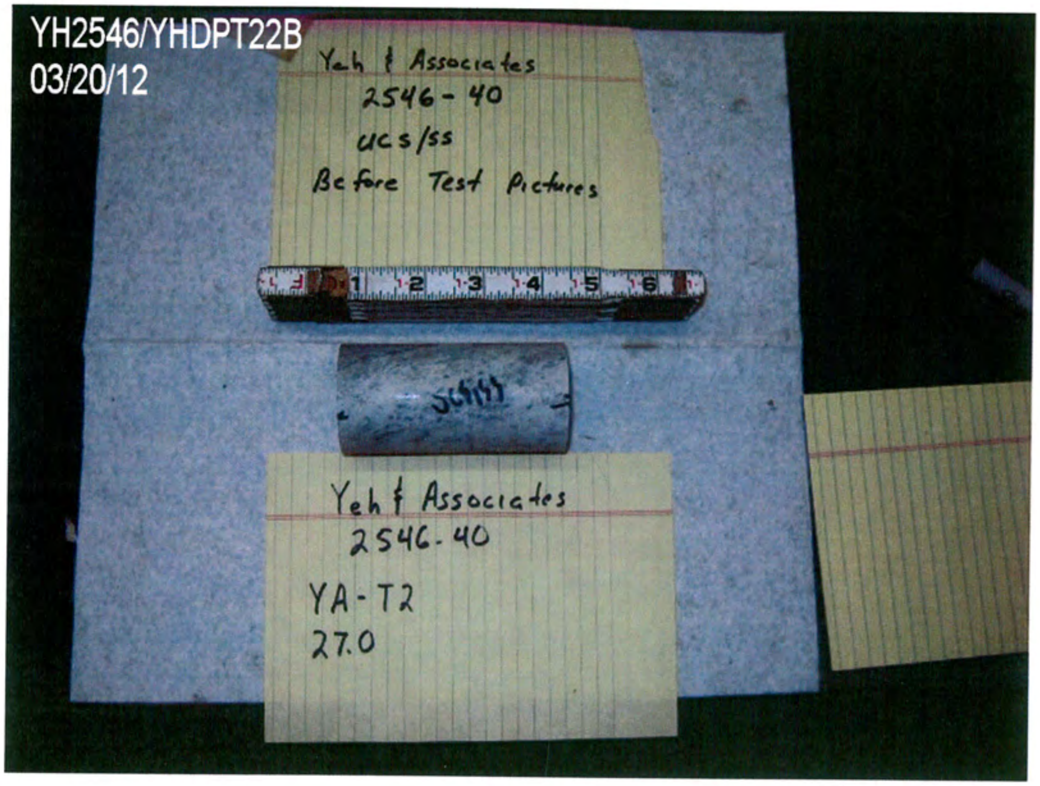

YH2546/YHDP30T6
03/22/12
INCHES 1 2 LUFKIN 3 RED END 4 ENGINEERS 5 LOCK JOINTS 6
Yeh & Associates
2546- 40
YA-T6, 30.$\bar{0}$

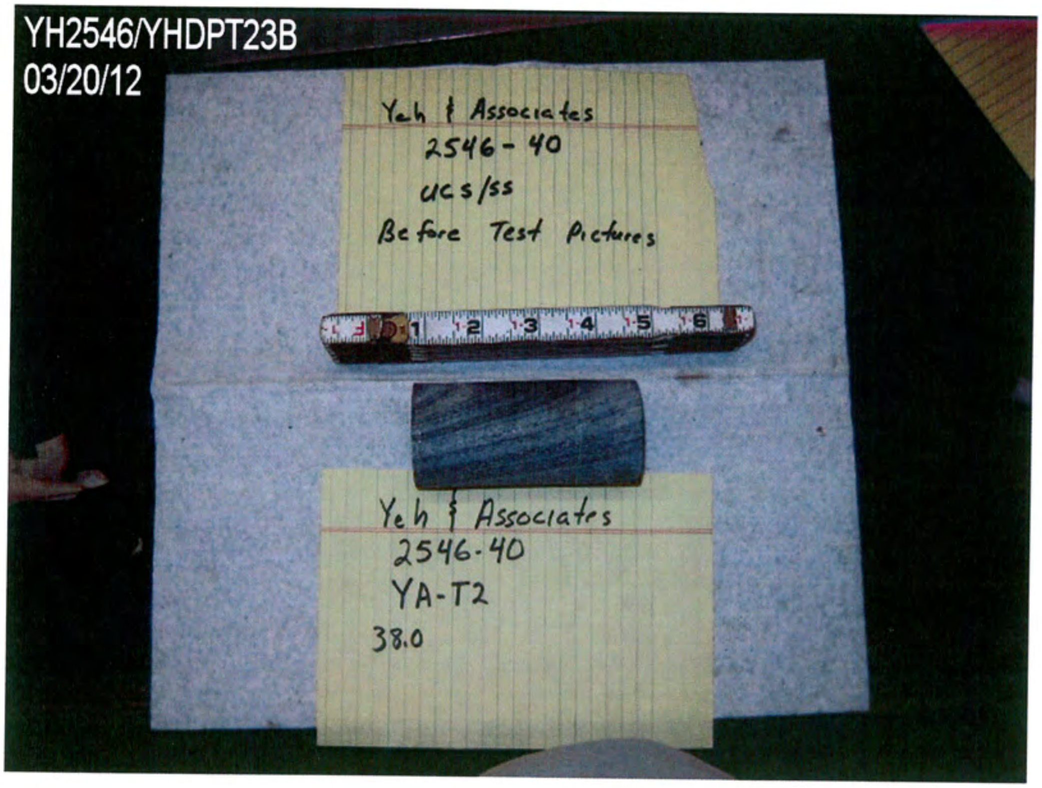

YH2546/YHDP57T6
03/22/12
T
5.0
Yeh & Associates
#2546-40
YA-T6, 57.0


YH2546/YHDPT47B
03/20/12
Yeh & Associates
2546-40
UCS/SS
Before Test Pictures
1
2
3
4
5
6
Yeh & Associates
2546-40
YA-T4
7.0


YH2546/YHDPT41B
03/20/12
Yeh & Associates
2546-40
UCS/SS
Before Test Pictures
1 2 3 4 5 6
Yeh & Associates
2546-40
YA-T4
15'




YH2546/YHDPT22B
03/20/12
Yeh & Associates
2546 - 40
UCS/SS
Before Test Pictures
Yeh & Associates
2546-40
YA-T2
27.0

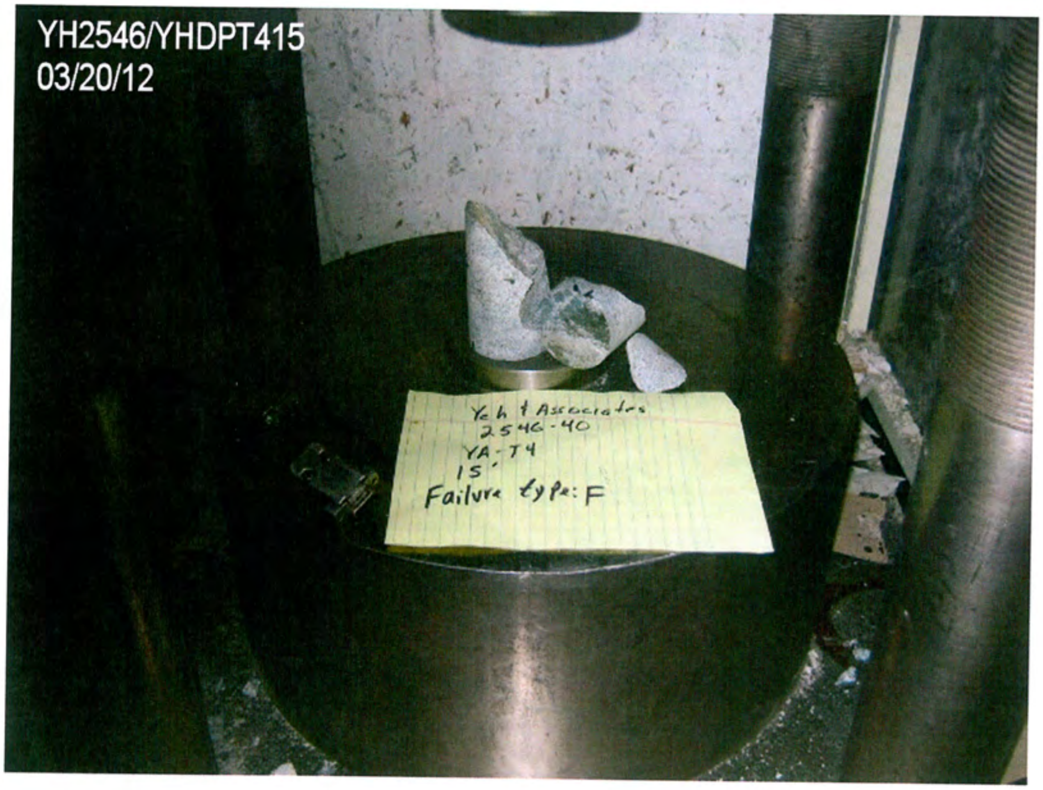

YH2546/YHDPT23B
03/20/12
Yeh & Associates
2546-40
UCS/SS
Before Test Pictures
1
2
3
4
5
6
Yeh & Associates
2546-40
YA-T2
38.0


YH2546/YHDPT65F
03/22/12
Yeh & Associates
#2546-40
YA-T6, 5.0'
Failure type: F


YH2546/YHDPT630
03/22/12
Yeh & Associates
#2546-40
YA-T6, 30.5'
Failure type: F/S


YH2546/YHDPT657
03/22/12
Yeh & Associates
2546-40
YA-T6, 57.0
Failure type: F

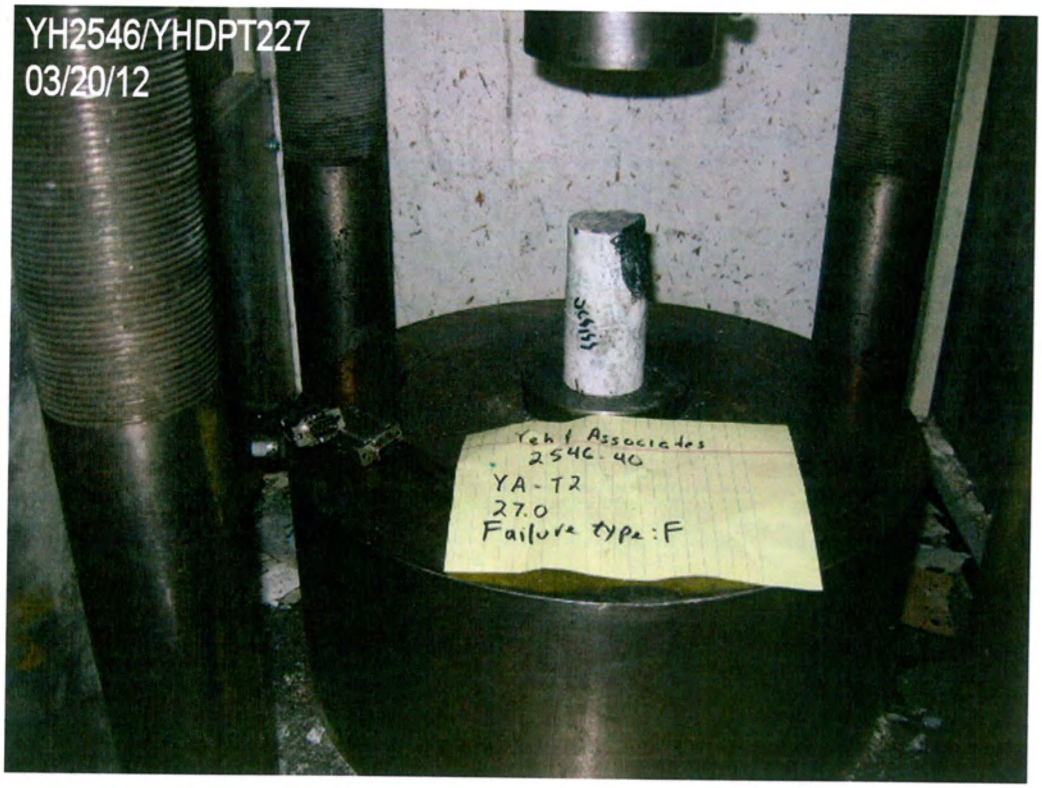

YH2546/YHDPT470
03/20/12
Yeh & Associates
2546-40
YA-T4
7.0
Failure type: F



YH2546/YHDPT415
03/20/12

Yeh & Associates
2546-40
YA-T4
15'
Failure type: F


YH2546/YHDPT212
03/20/12
Yeh & Associates
2546-40
YA-T2
12.0
Failure type: F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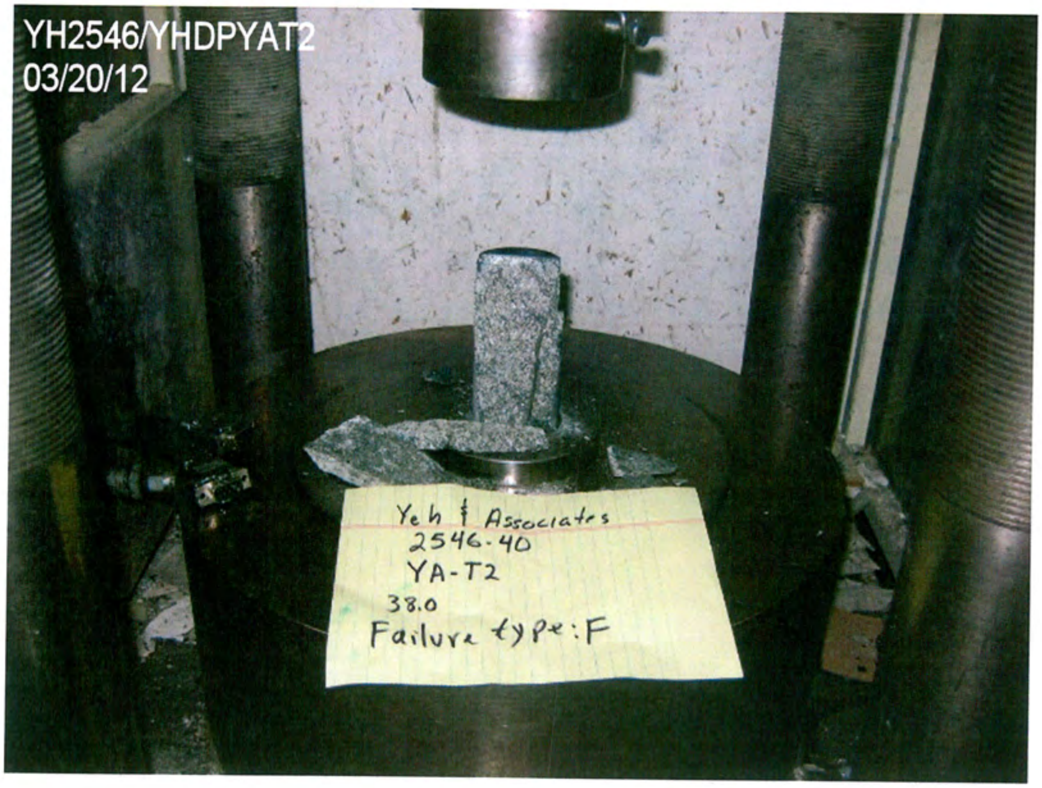
03/20/12
Yeh & Associates
2546.40
YA-T2
27.0
Failure type: F


YH2546/YHDPYAT2
03/20/12
Yeh & Associates
2546-40
YA-T2
38.0
Failure type: F

CLIENT: Yeh & Associates
BORING: YA-T6
SAMPLE NO:
DEPTH (ft): 5.0
AREA (in²) = 2.744
DIAMETER (in) = 1.869
AXIAL GAUGE LENGTH (in) = 2.5
ROCK TYPE:

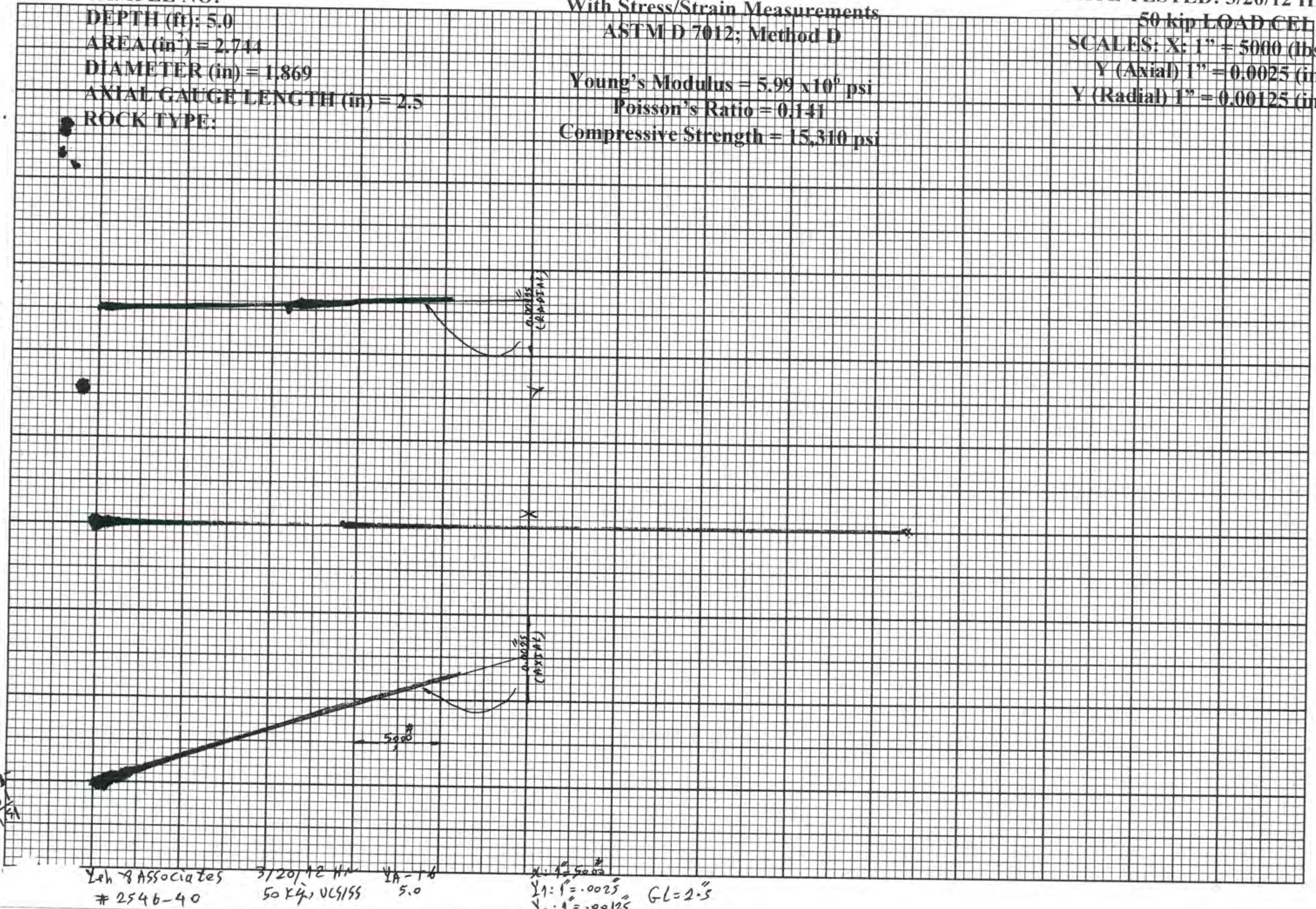
UNCONFINED COMPRESSIVE STRENGTH

With Stress/Strain Measurements

ASTM D 7012; Method D

Young's Modulus = 5.99 x10⁶ psi
Poisson's Ratio = 0.141
Compressive Strength = 15,310 psi

JOB NO: 2546-40
DATE TESTED: 3/20/12 HN
50 kip LOAD CELL
SCALES: X: 1" = 5000 (lbs)
Y (Axial) 1" = 0.0025 (in)
Y (Radial) 1" = 0.00125 (in)



Yeh & Associates
#2546-40

3/20/12 HN
50 Kip, UCS/SS

YA-T6
5.0

X: 1" = 5000#
Y1: 1" = .0025"
Y2: 1" = .00125"
GL = 2.5"

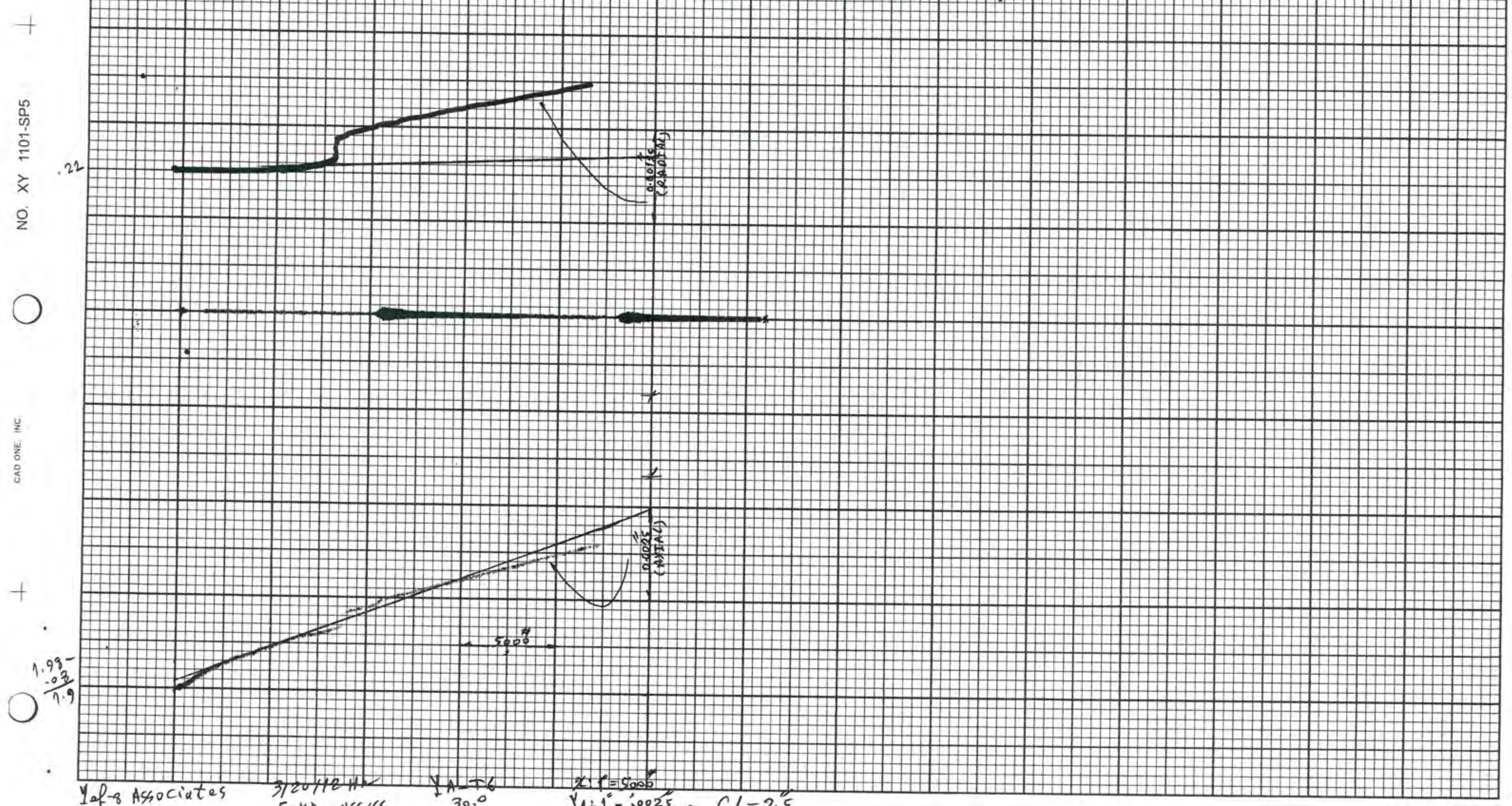
CLIENT: Yeh & Associates
BORING: YA-T6
SAMPLE NO:
DEPTH (ft): 30.0
AREA (in²) = 2.746
DIAMETER (in) = 1.870
AXIAL GAUGE LENGTH (in) = 2.5
ROCK TYPE:

UNCONFINED COMPRESSIVE STRENGTH

With Stress/Strain Measurements
ASTM D 7012; Method D

Young's Modulus = 4.79 x10⁶ psi
Poisson's Ratio = 0.155
Compressive Strength = 11,290 psi

JOB NO: 2546-40
DATE TESTED: 3/20/12 HN
50 kip LOAD CELL
SCALES: X: 1" = 5000 (lbs)
Y (Axial) 1" = 0.0025 (in)
Y (Radial) 1" = 0.00125 (in)



Yeh & Associates
#2546-40
3/20/12 HN
50K#, UCS/SS
YA-T6
30.0
X: 1" = 5000#
Y1: 1" = .0025"
Y2: 1" = .00125"
GL = 2.5"

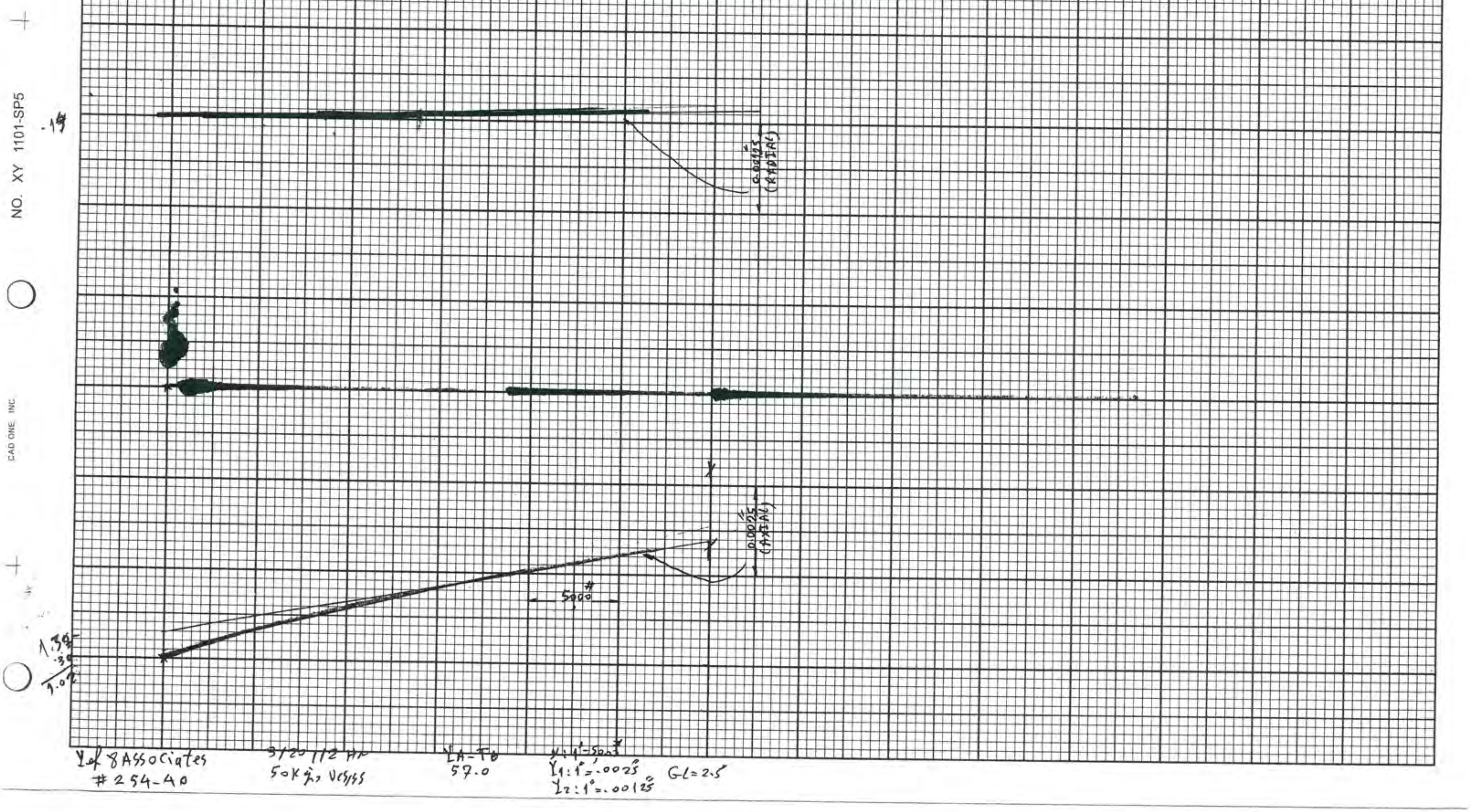
CLIENT: Yeh & Associates
BORING: YA-T6
SAMPLE NO:
DEPTH (ft): 57.0
AREA (in^2) = 2.752
DIAMETER (in) = 1.872
AXIAL GAUGE LENGTH (in) = 2.5
ROCK TYPE:

UNCONFINED COMPRESSIVE STRENGTH

With Stress/Strain Measurements
ASTM D 7012; Method D

Young's Modulus = 10.69 x10^6 psi
Poisson's Ratio = 0.183
Compressive Strength = 19,440 psi

JOB NO: 2546-40
DATE TESTED: 3/20/12 HN
50 kip LOAD CELL
SCALES: X: 1" = 5000 (lbs)
Y (Axial) 1" = 0.0025 (in)
Y (Radial) 1" = 0.00125 (in)



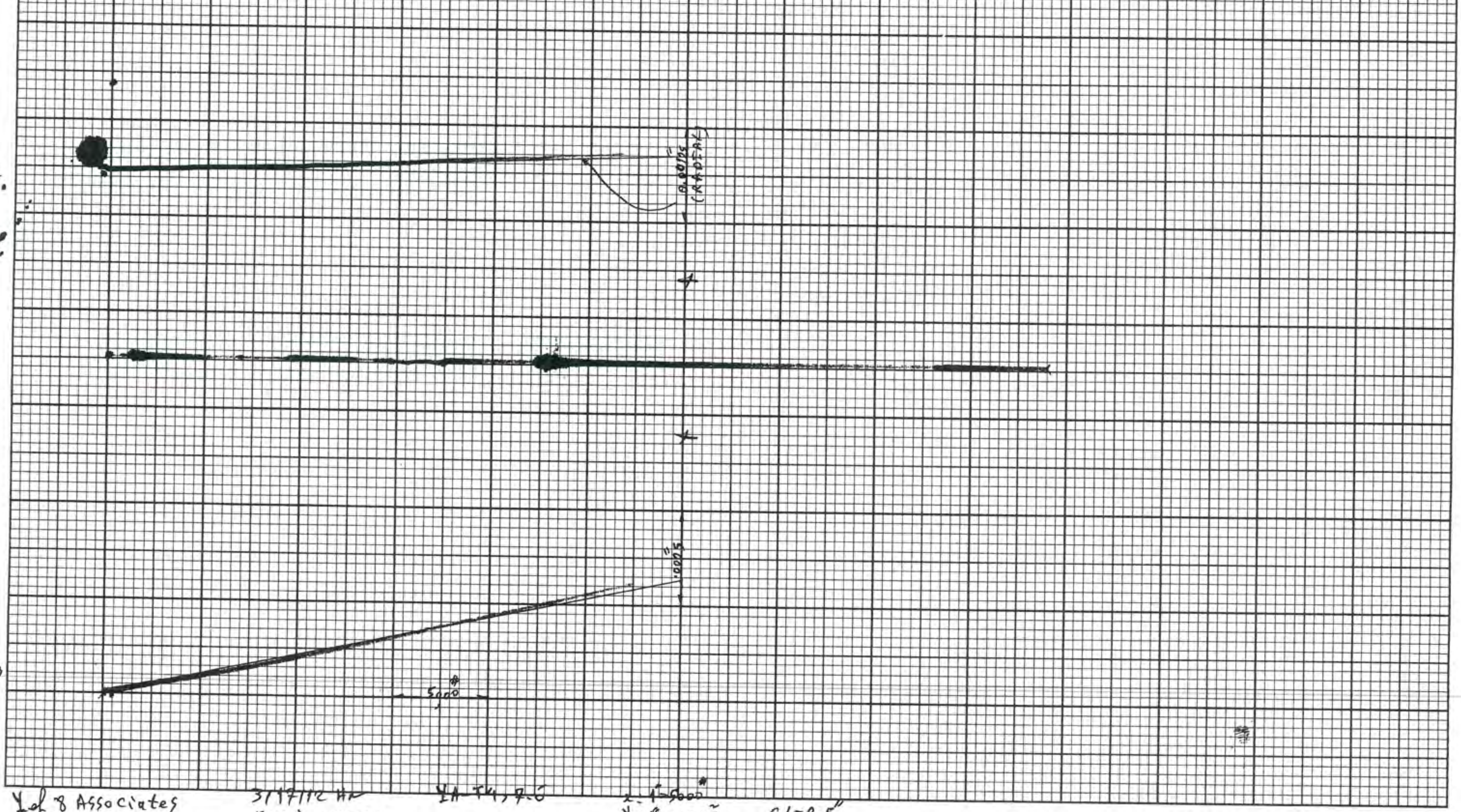
CLIENT: Yeh & Associates
BORING: YA-T4
SAMPLE NO:
DEPTH (ft): 7.0
AREA (in^2) = 2.729
DIAMETER (in) = 1.864
AXIAL GAUGE LENGTH (in) = 2.5
ROCK TYPE:

UNCONFINED COMPRESSIVE STRENGTH

With Stress/Strain Measurements
ASTM D 7012; Method D

Young's Modulus = 8.59 x10^6 psi
Poisson's Ratio = 0.210
Compressive Strength = 17,960 psi

JOB NO: 2546-40
DATE TESTED: 3/17/12 HN
50 kip LOAD CELL
SCALES: X: 1" = 5000 (lbs)
Y (Axial) 1" = 0.0025 (in)
Y (Radial) 1" = 0.00125 (in)



Y of 8 Associates
#2546-40

3/17/12 HN
50K, UCS/SS

YA-T4, 7.0

X: 1"=5000#
Y1: 1"=.0025"
Y1: 1"=.00125"

GL=2.5"

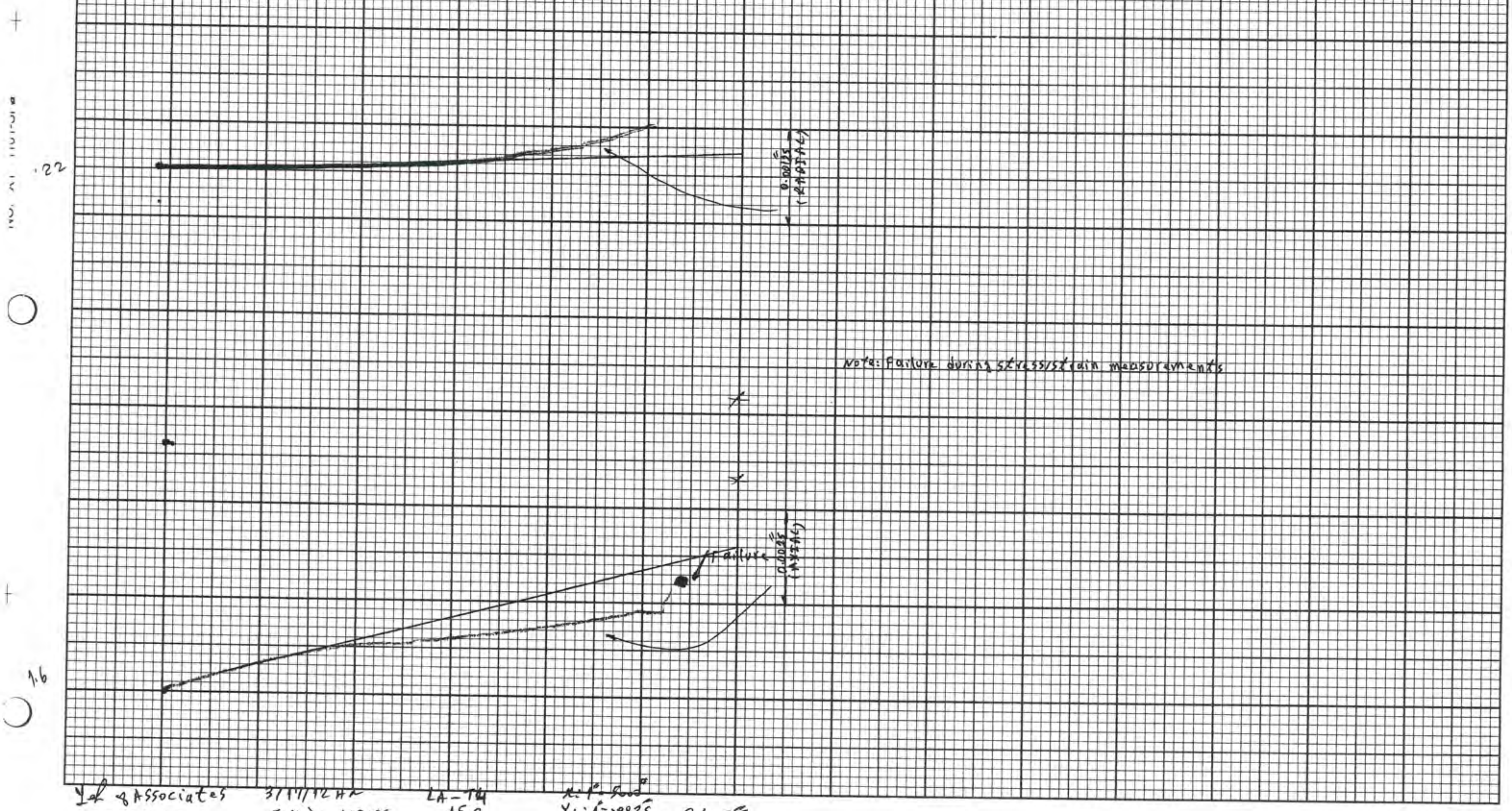
CLIENT: Yeh & Associates
BORING: YA-T4
SAMPLE NO:
DEPTH (ft): 15.0
AREA (in^2) = 2.749
DIAMETER (in) = 1.871
AXIAL GAUGE LENGTH (in) = 2.5
ROCK TYPE:

UNCONFINED COMPRESSIVE STRENGTH

With Stress/Strain Measurements
ASTM D 7012; Method D

Young's Modulus = 6.82 x10^6 psi
Poisson's Ratio = 0.184
Compressive Strength = 9,910 psi

JOB NO: 2546-40
DATE TESTED: 3/17/12 HN
50 kip LOAD CELL
SCALES: X: 1" = 5000 (lbs)
Y (Axial) 1" = 0.0025 (in)
Y (Radial) 1" = 0.00125 (in)



Note: Failure during stress/strain measurements

Yeh & Associates
#2546-40

3/17/12 HN
50 k¢, UCS/SS

YA-T4
15.0

X: 1" = 5000#
Y1: 1" = .0025"
Y2: 1" = .00125"

GL = 2.5

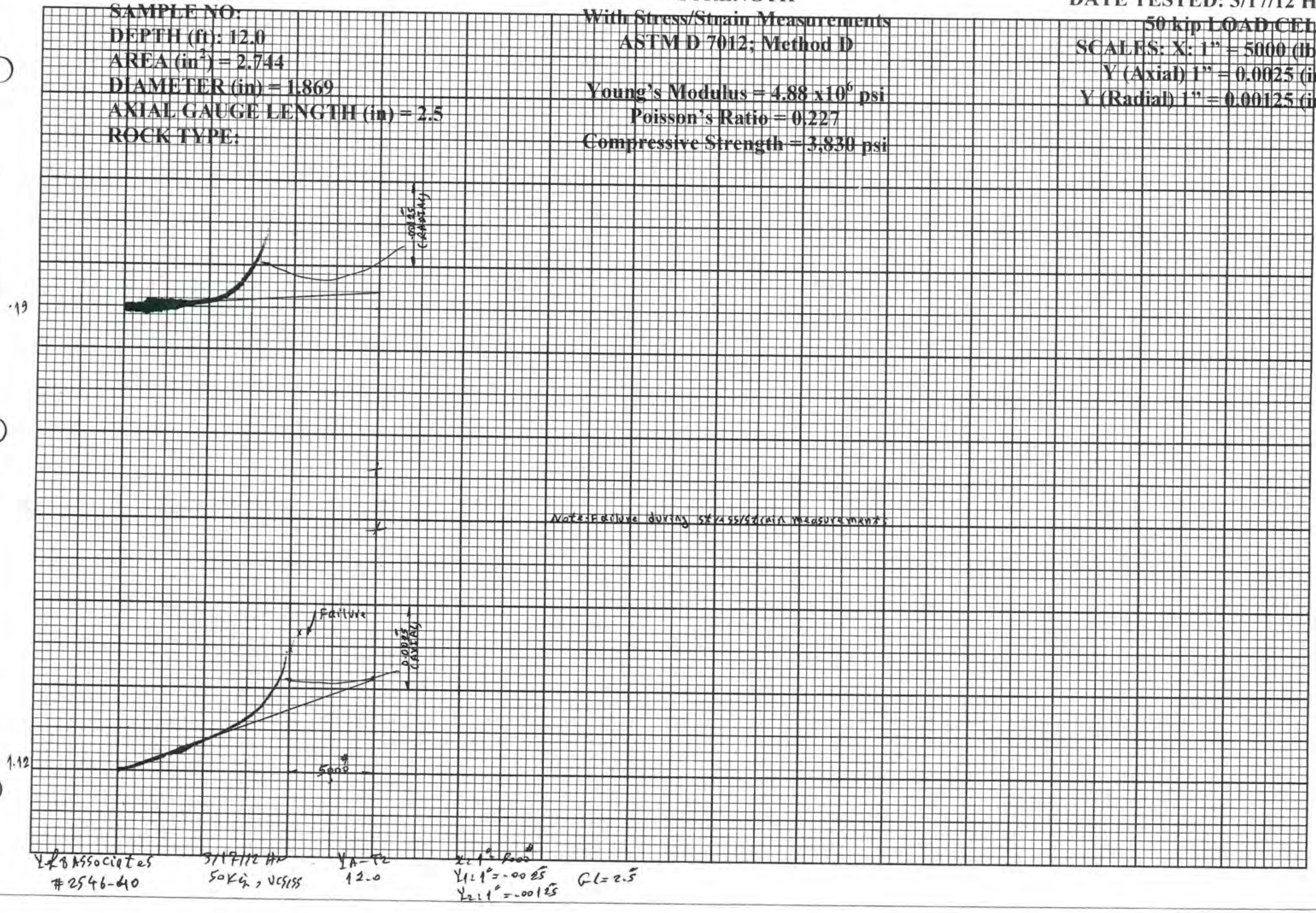
CLIENT: Yeh & Associates
BORING: YA-T2
SAMPLE NO:
DEPTH (ft): 12.0
AREA (in^2) = 2.744
DIAMETER (in) = 1.869
AXIAL GAUGE LENGTH (in) = 2.5
ROCK TYPE:

UNCONFINED COMPRESSIVE STRENGTH

With Stress/Strain Measurements
ASTM D 7012; Method D

Young's Modulus = 4.88 x10^6 psi
Poisson's Ratio = 0.227
Compressive Strength = 3,830 psi

JOB NO: 2546-40
DATE TESTED: 3/17/12 HN
50 kip LOAD CELL
SCALES: X: 1" = 5000 (lbs)
Y (Axial) 1" = 0.0025 (in)
Y (Radial) 1" = 0.00125 (in)



Note: Failure during stress/strain measurements

Y&B Associates
#2546-40

3/17/12 HN
50Kip, UCS/SS

YA-T2
12.0

X: 1" = 5000#
Y1: 1" = .0025
Y2: 1" = .00125

GL = 2.5"

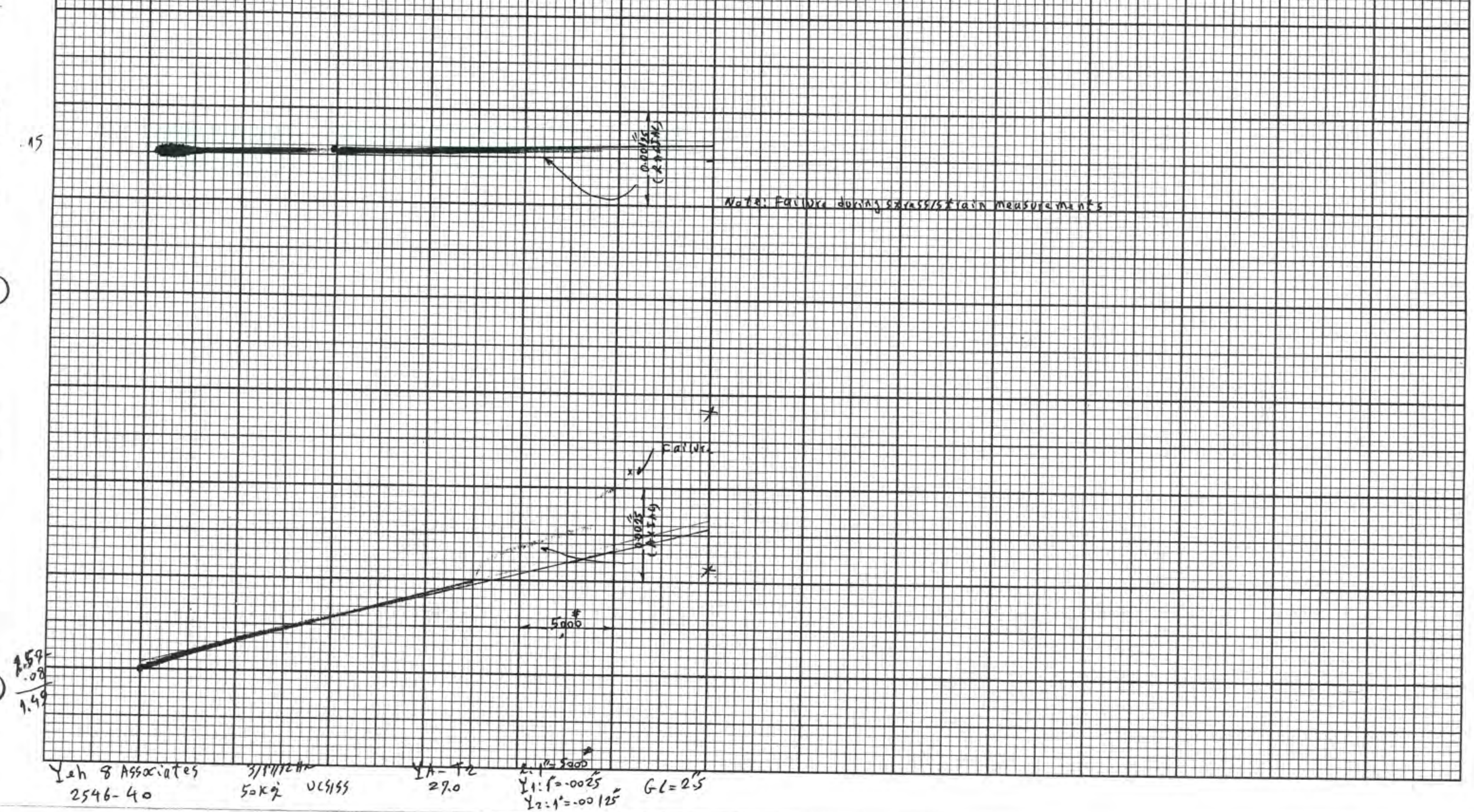
CLIENT: Yeh & Associates
BORING: YA-T2
SAMPLE NO:
DEPTH (ft): 27.0
AREA (in^2) = 2.741
DIAMETER (in) = 1.868
AXIAL GAUGE LENGTH (in) = 2.5
ROCK TYPE:

UNCONFINED COMPRESSIVE STRENGTH

With Stress/Strain Measurements
ASTM D 7012; Method D

Young's Modulus = 7.35 x10^6 psi
Poisson's Ratio = 0.135
Compressive Strength = 9,400 psi

JOB NO: 2546-40
DATE TESTED: 3/17/12 HN
50 kip LOAD CELL
SCALES: X: 1" = 5000 (lbs)
Y (Axial) 1" = 0.0025 (in)
Y (Radial) 1" = 0.00125 (in)



Note: Failure during stress/strain measurements

CLIENT: Yeh & Associates
BORING: YA-T2
SAMPLE NO:
DEPTH (ft): 38.0
AREA (in^2) = 2.703
DIAMETER (in) = 1.855
AXIAL GAUGE LENGTH (in) = 2.5
ROCK TYPE:

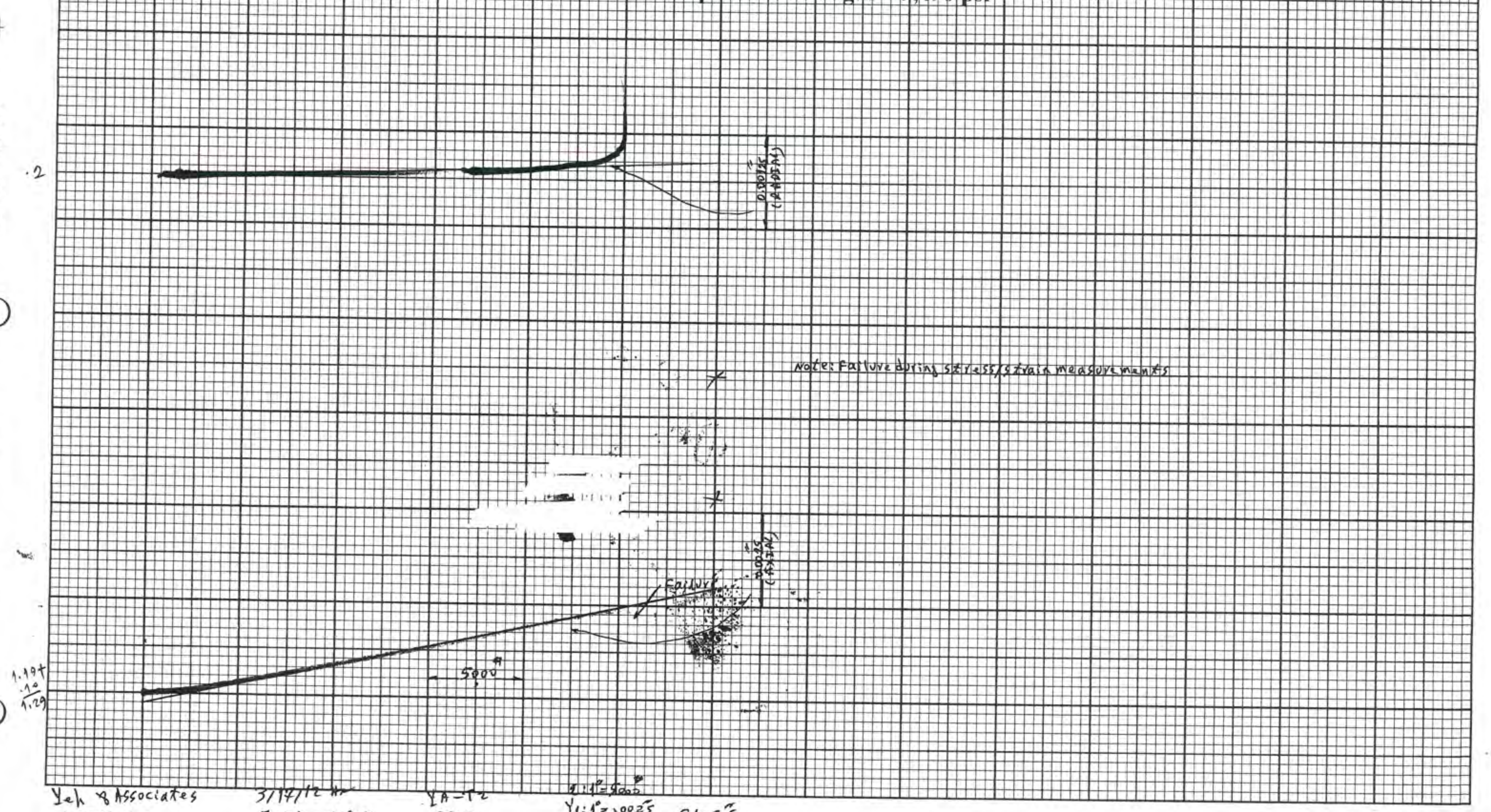
UNCONFINED COMPRESSIVE STRENGTH

With Stress/Strain Measurements

ASTM D 7012; Method D

Young's Modulus = 8.61 x10^6 psi
Poisson's Ratio = 0.209
Compressive Strength = 9,490 psi

JOB NO: 2546-40
DATE TESTED: 3/17/12 HN
50 kip LOAD CELL
SCALES: X: 1" = 5000 (lbs)
Y (Axial) 1" = 0.0025 (in)
Y (Radial) 1" = 0.00125 (in)



Note: Failure during stress/strain measurements

Yeh & Associates
#2546-40

3/17/12 HN
50 kip, UCS/SS

YA-T2
38.0

X: 1" = 5000#
Y1: 1" = .0025
Y2: 1" = .00125

GL = 2.5