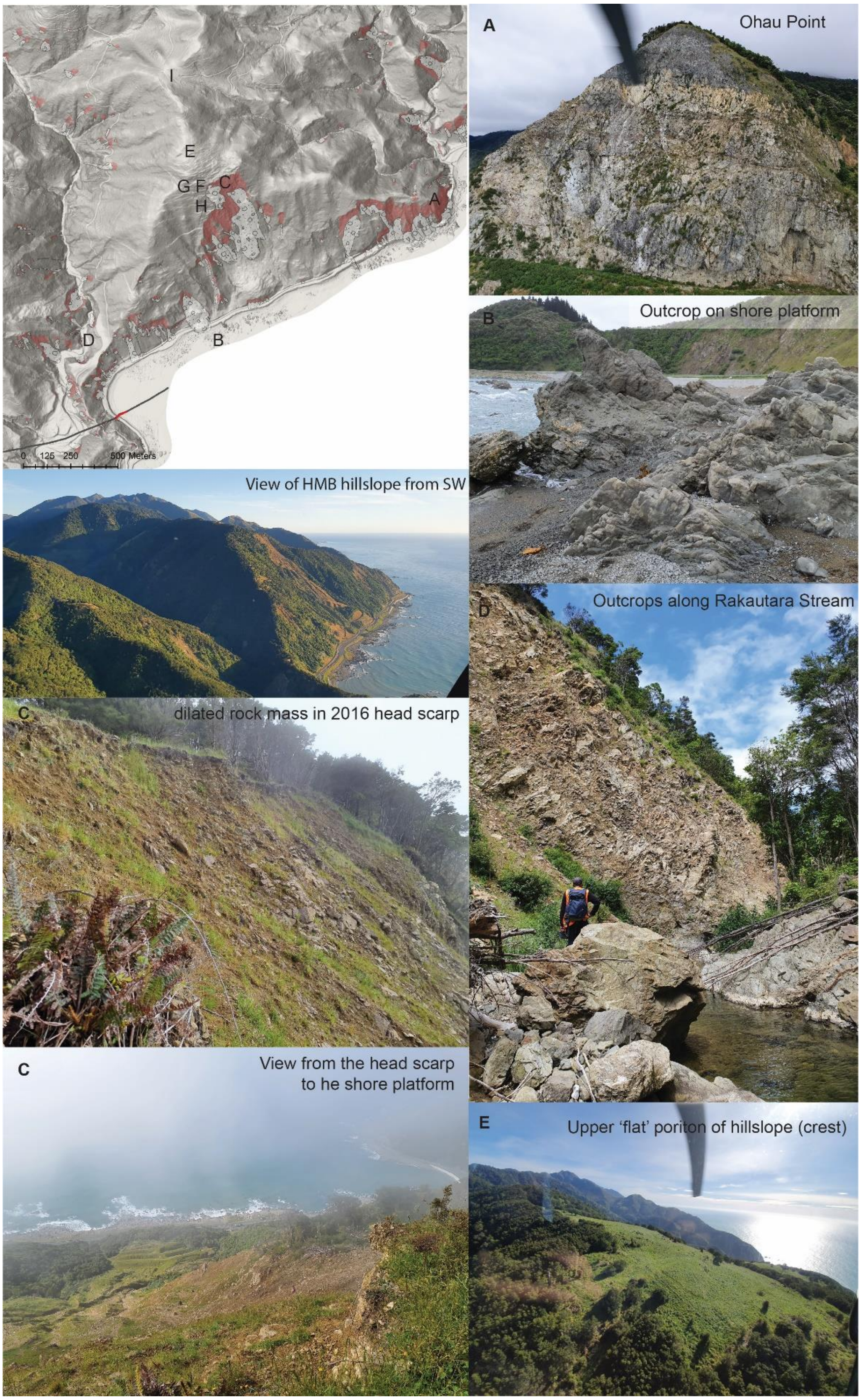
Singeisen, C., Massey, C., Wolter, A., Stahl, T., Kellett, R., Bruce, Z., Bloom, C., and Mason, D., 2024, Evolution of an earthquake-induced landslide complex in the South Island of New Zealand: How fault damage zones and seismicity contribute to slope failures: Geosphere, v. 20, https://doi.org/10.1130/GES02668.1.

Supplementary Information

1. Geomorphology

Figure S1: Line density of the mapped geomorphic features (Figure 3 in main manuscript) shows that the density of scarps, counterscarps, grabens and lineaments is highest in the central portion of the slope, in particular above the head scarp of the coseismic debris avalanche. Line density shown here is based on a 50 m grid size and is kept intentionally at a low resolution to resolve general trends across the landslide.

2. Additional Field Photos



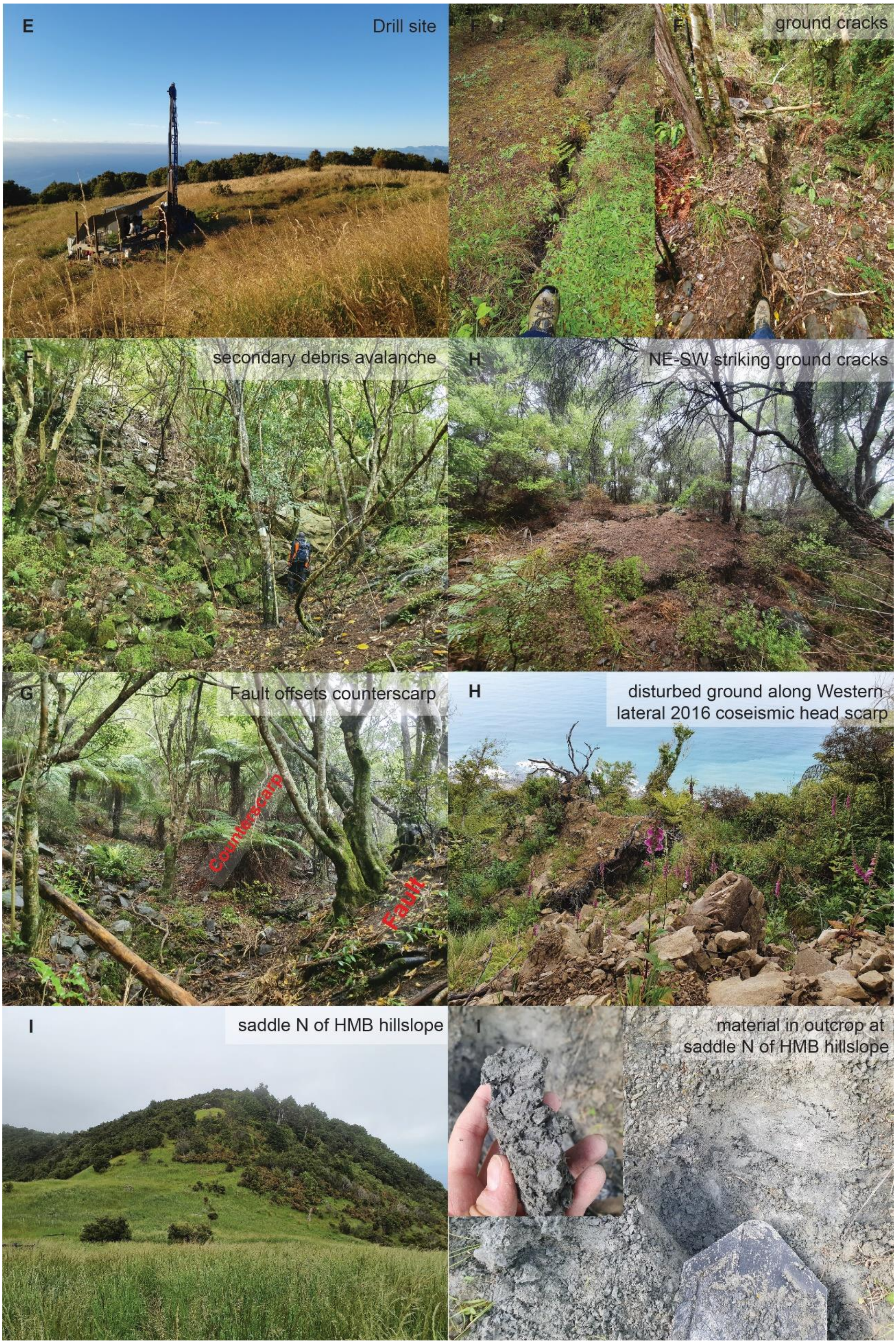


Figure S2: Field photos to illustrate observations regarding morphology, slope deformation and rock mass characteristics.

3. Landslide displacements

i. Methods

Site	Imagery	Imagery resolution	Window size	Filter	Swath width
Half Moon Bay	DSM hillshade	1 m	32 pixels	Spatial	20 m

Table S1: The specified settings used when applying the Fast-Fourier transformation DIC algorithm by Bickel et al. (2018). During post-processing, spatial mask filters were used to filter noise. Spatial mask filters were defined manually to filter data in areas with high ground disturbance (e.g. debris cover or high density of ground cracks).

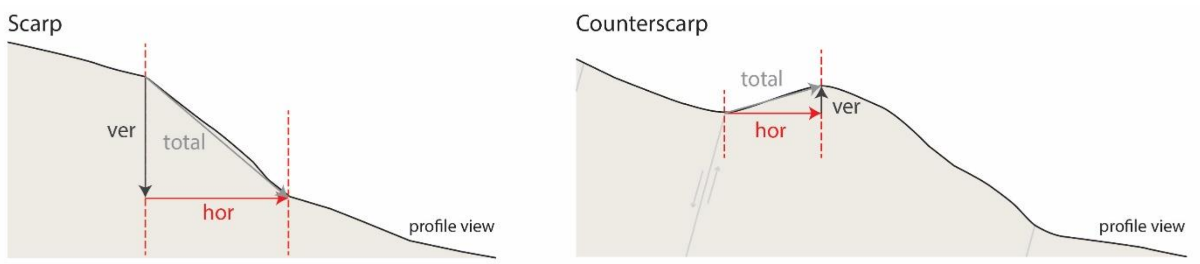


Figure S3: Schematic cross-section of how displacements were derived from scarp and counterscarp features along topographic profiles. The horizontal displacement estimate is based on the interpretation of changes in slope (indicated in red), and the vertical displacement is based on the resulting change in surface elevation (indicated in dark grey). The total surface displacement vector is indicated in light grey.

ii. Results

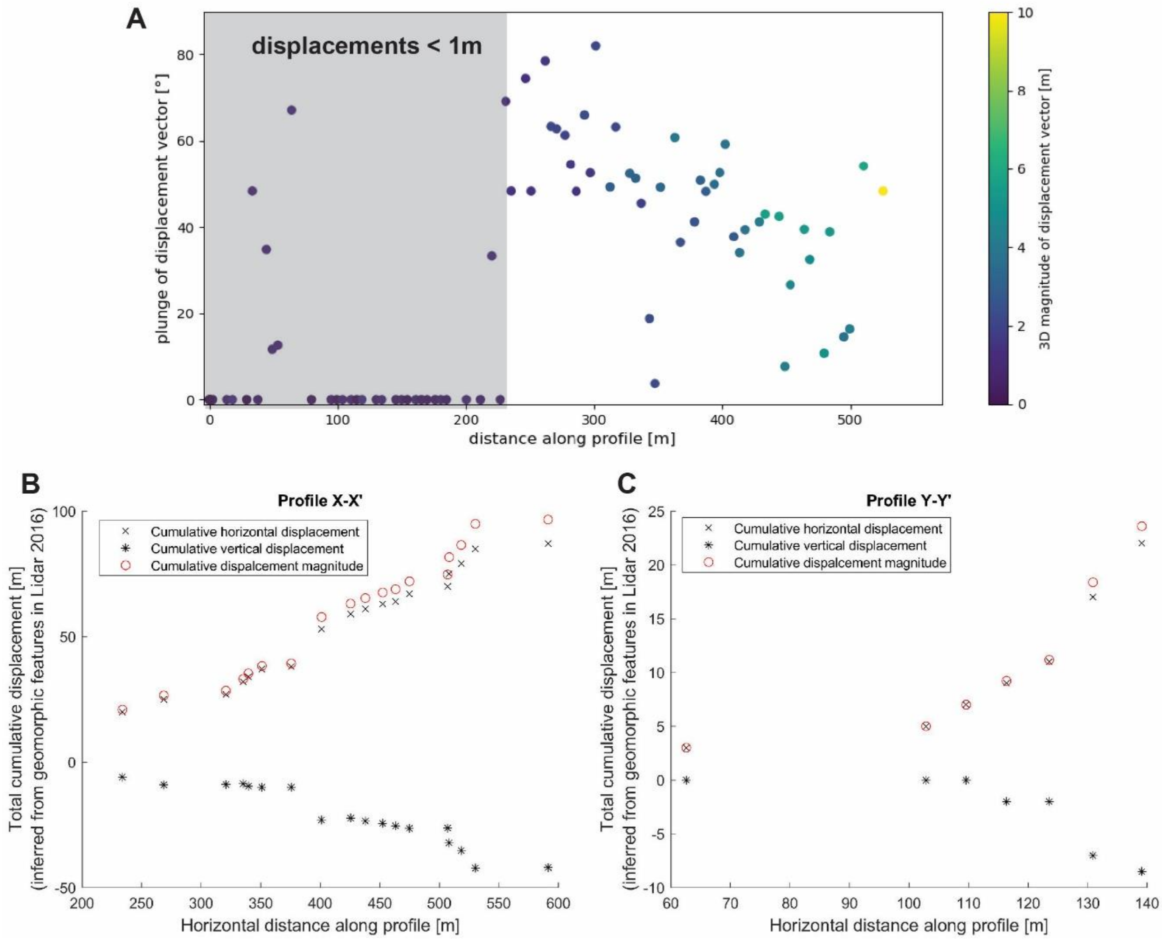


Figure S4: A) Plunge of coseismic displacement vectors within a 20 m swath width along Profile X-X'. B and C) Estimated total cumulative horizontal, vertical displacements and magnitude along profiles X-X' and Y-Y'. Negative vertical displacements indicate movement in the sense of negative elevation change (i.e. down).

4. Geophysical Surveys

i. Electrical Resistivity Tomography

The resistivity survey was undertaken using a multi-channel Electrical Resistivity Tomography system. The electrode array is deployed on a straight line with the electrodes at a constant interval determined by the preferred depth of investigation and the lateral resolution required. A series of measurements are made using combinations of two current electrodes (A and B) and two potential electrodes (M and N). The process is controlled by a computer located at the receiver that implements a pre-determined sequence (Dahlin 2001). Figure S5 shows the schematic of the acquisition system and the arrays collected. The survey was undertaken with an Iris Syscal Pro Switch-96 instrument collecting primarily Wenner α array but a test of the Dipole Dipole array was undertaken for part of the line. Time constraints prevented a complete Dipole-Dipole section from being acquired.

The unit electrode spacing was 2.5 m and the total line length was 357.5 m. The initial cable was laid out for 237.5 m starting at the top of the ridge. The line was extended in 3 sections of 40 m each until the terrain was too steep to safely collect data. The total number of measurements made with the Wenner α array was 1635. Figure S6 shows the apparent resistivity pseudosection for the Wenner α array. The Wenner α array has the highest signal to noise ratio because the potential measurements are made between the two current electrodes. However, there is a reduction in lateral sensitivity particularly at longer electrode spacings.

The Dipole-Dipole array is very sensitive to lateral changes but the signal strength decreases rapidly at longer offsets. A test was carried out using the Dipole-Dipole array from 0 to 185 m. A total of 773 data points were collected in the Dipole Dipole mode (Figure S7). Some of the measurements at longer offsets were removed due to noise. It is possible to combine both data sets in the inversion process. The inversion software produced a smooth resistivity model that fit the combined set of Wenner α and Dipole-Dipole data with a satisfactory misfit after 6 iterations (Loke and Dahlin 2002).

Figure S8 shows the response of the model for the Wenner α survey and Figure S9 shows the model response for the Dipole-Dipole dataset. Comparing Figures S6 and S8 and S7 and S9 provides a measure of the quality of the inversion results.

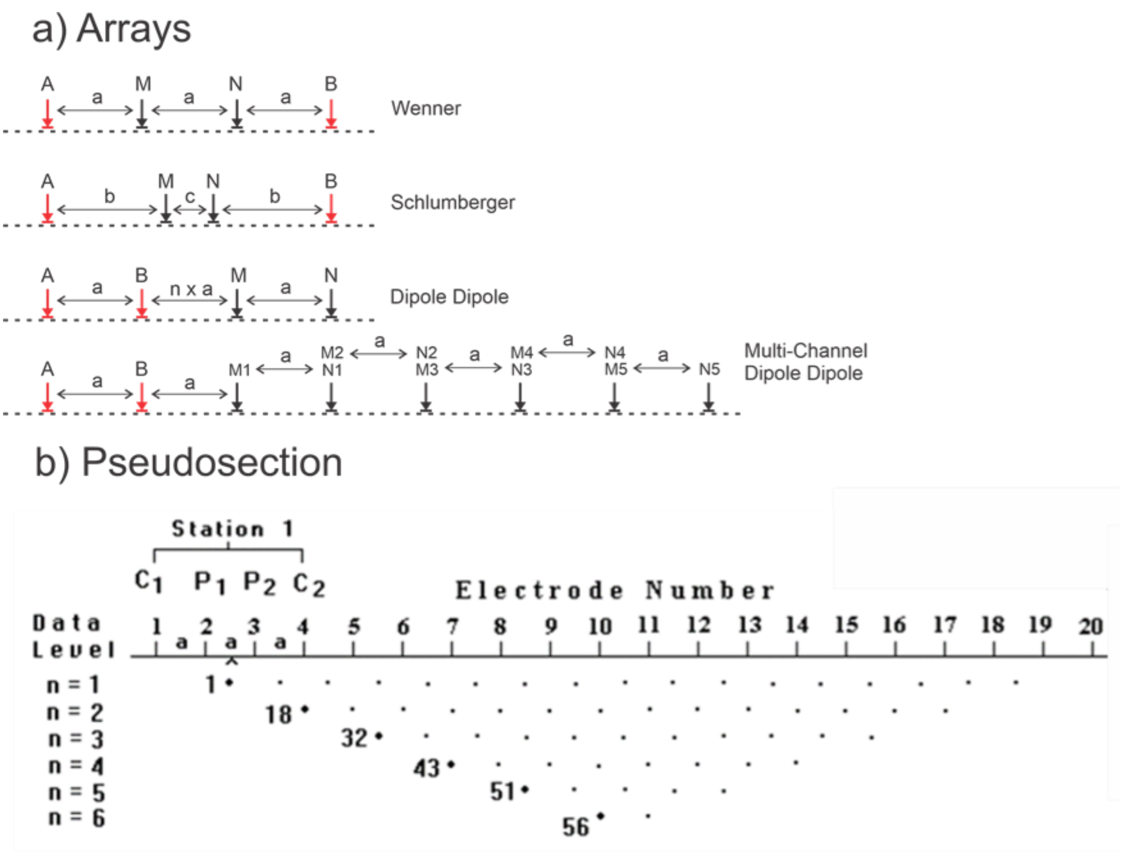


Figure S5. Diagram of electrode arrays. Current electrodes are shown in red and potential electrodes are shown in black; (a) Wenner, Schlumberger and Dipole Dipole. For the Wenner and Schlumberger array, the electrode spacing (a,b,c) is changed to vary the depth of investigation. For the Dipole Dipole array, the separation factor n is increased to image deeper (b) construction of a pseudosection with the Wenner array (after Loke and Dahlin 2002).

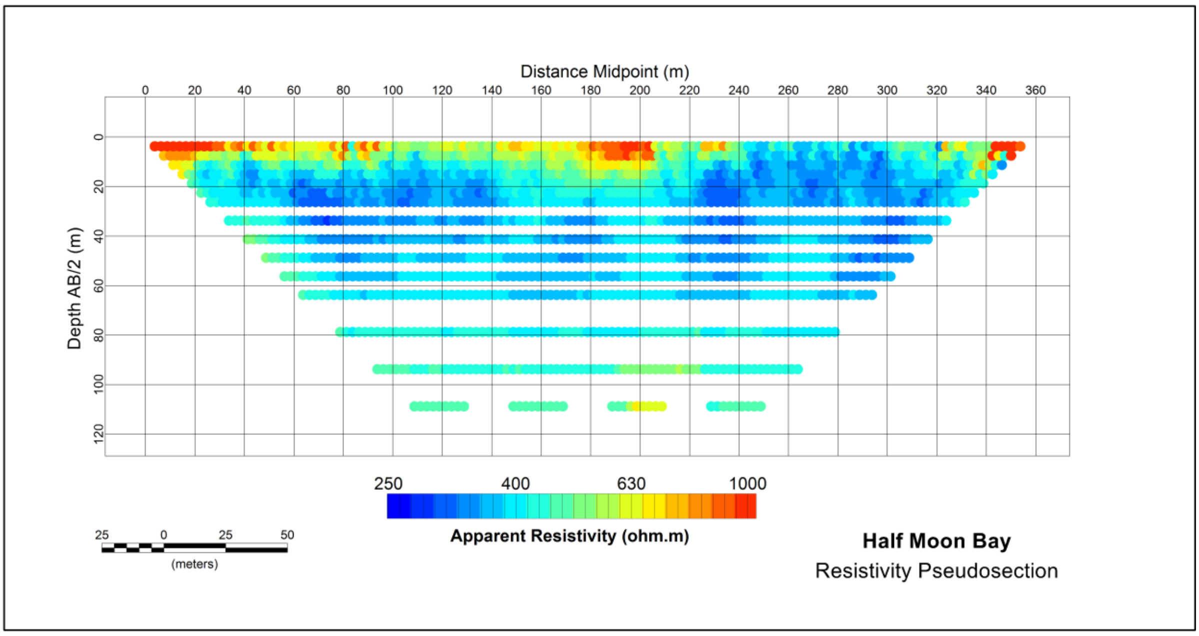


Figure S6. Pseudosection for the complete line with Wenner α data.

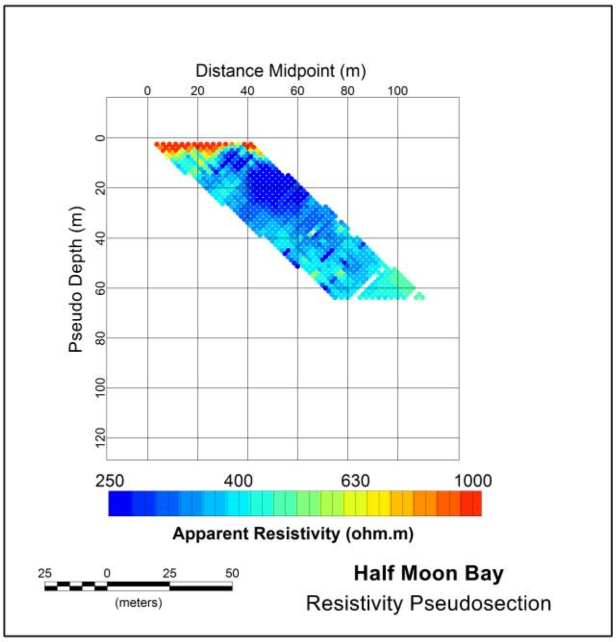


Figure S7. Pseudosection for the test Dipole-Dipole data

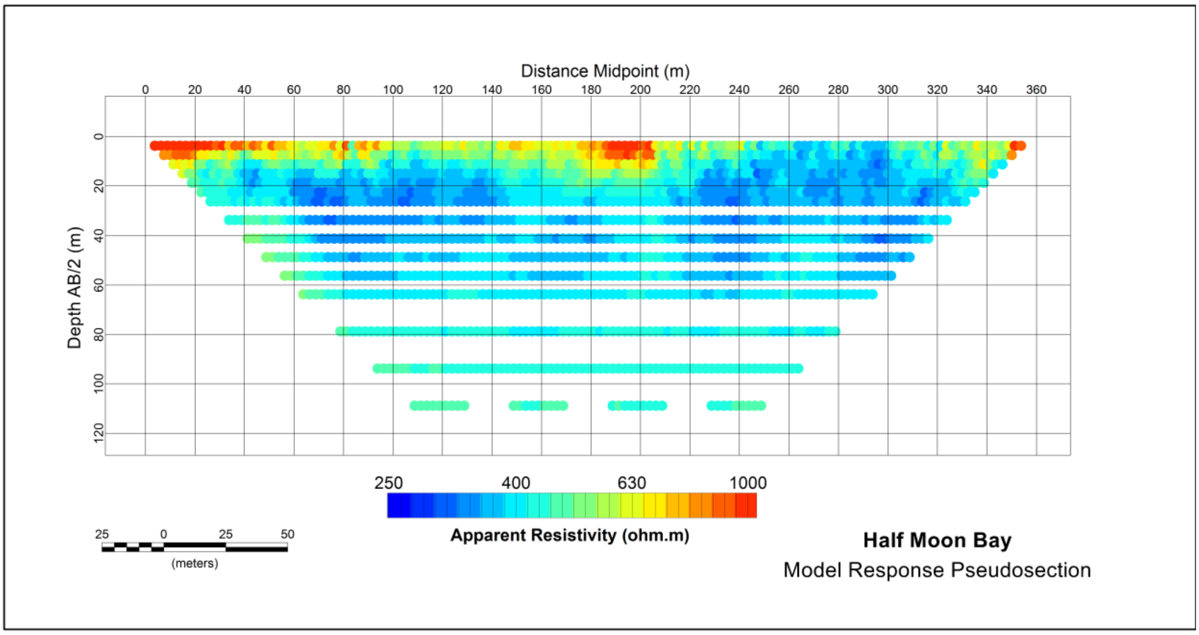


Figure S8. Pseudosection for the final model response with Wenner α array.

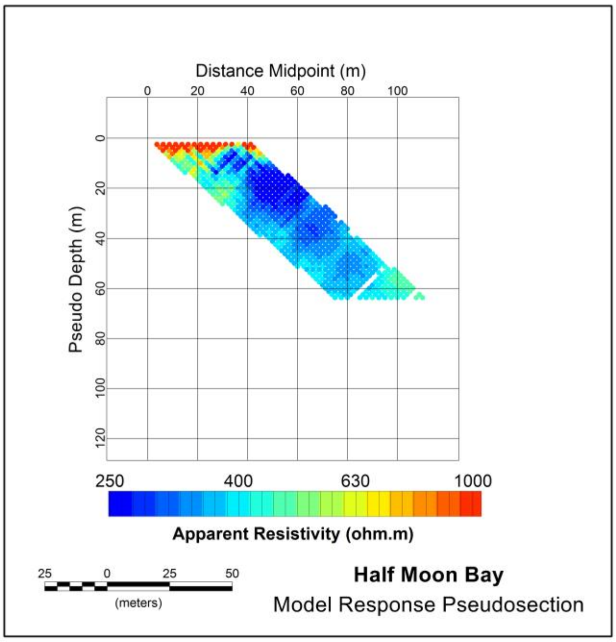


Figure S9. Pseudosection for final model response with the Dipole-Dipole array

ii. Seismic Refraction Tomography

The seismic refraction survey was undertaken using a 24 channel Geometrics Geode seismograph. The seismic source was a sledgehammer and a steel plate. The geophones were spaced at 4 m intervals. The line was composed of two spreads with an overlap of 8 m (2 channels) in order to ensure continuity of the arrivals picked from the shot gathers. Figure S10 shows the setup of the refraction line with the shot points and geophone station.

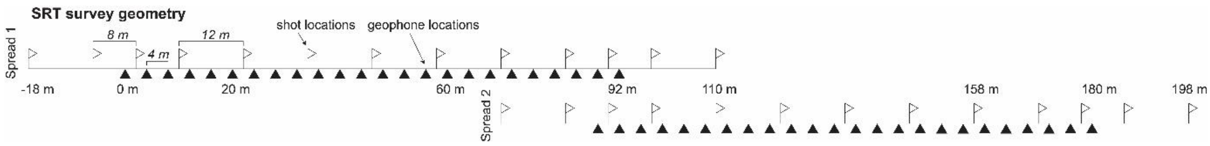


Figure S10: Seismic Refraction Tomography survey geometry used at the site Half Moon Bay.

A total of 26 shots were collected into the two spreads resulting in 21 unique source points and a total spread of 46 receivers. Initial tests indicated that 3 or 4 blows with the sledgehammer were sufficient to get clear first arrivals to a distance of 50 m. For the long offsets a total of 10 blows were needed to get good signal on the most distant geophone. The shots were stacked in the field and the records checked for data quality. Figure S11 shows a set of four typical stacked shot records for end and split spreads. A trace balance has been applied to normalise the average amplitude on each trace. The sample interval is 0.25 ms. The first breaks picked are shown in the figures. In most cases the first break can be picked with an accuracy of 1 ms. For some traces no first break is visible and the channel is set to null.

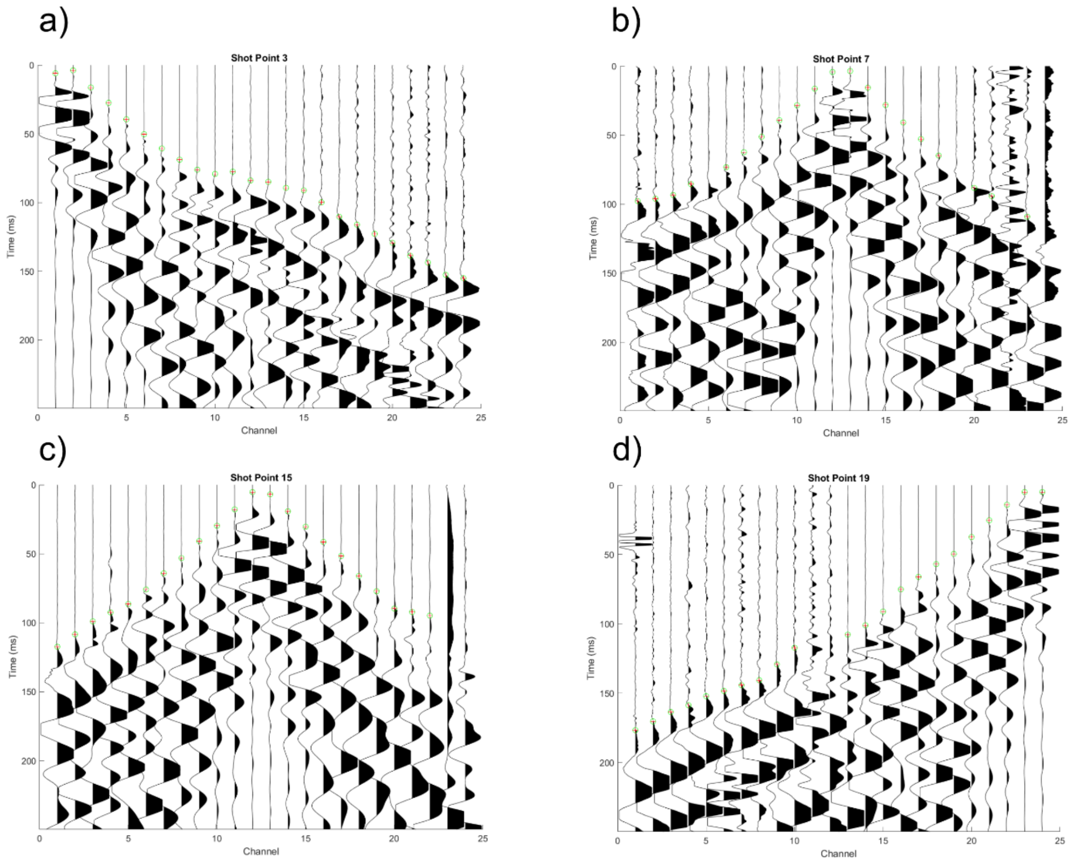


Figure S11: Stacked shot records for source points a) SP 3 (2 m) end shot on spread 1, b) SP 7 midpoint on spread 1, c) SP 15 mid-point on spread 2 and d) SP19 (180 m) end point on spread 2. The first break picks are shown as a red cross within a green circle.

The software ReflexW (www.sandmeier-geo.de) as used to import the shot records, add in the geometry and topography, balance the traces, pick the first arrivals, and merge the over-lapped spreads into a single line. Figure S12 shows the first arrivals for all source and receivers on the profile.

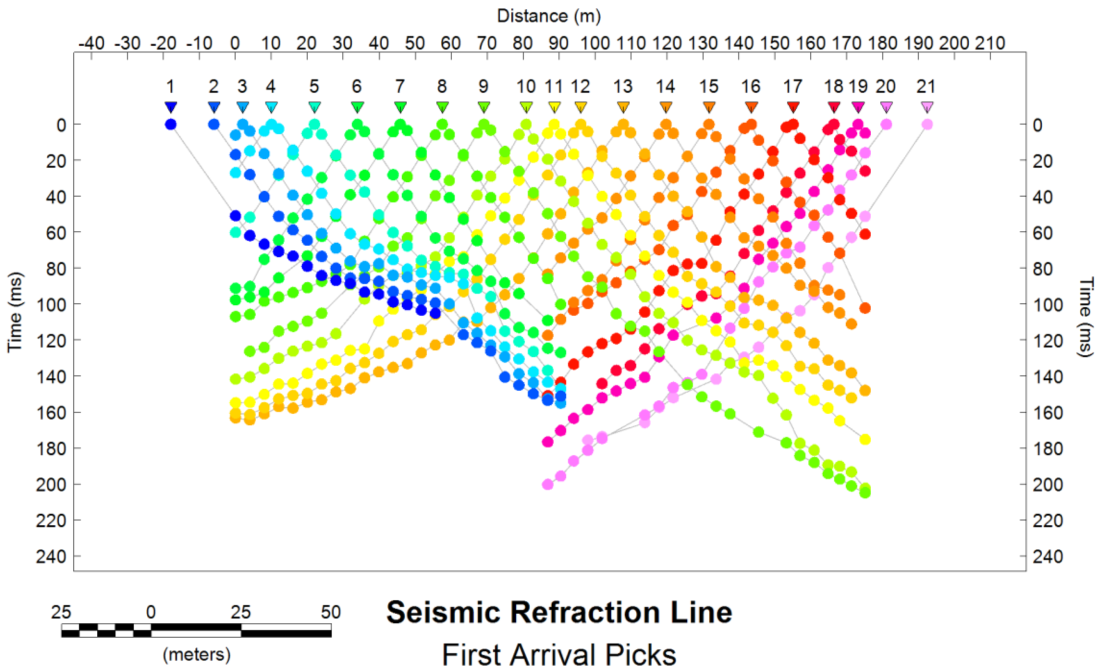


Figure S12: First arrival picks for all shots on the refraction profile.

Several options are available for the interpretation of shallow seismic refraction data (Whiteley and Eccleston 2006). In a fractured bedrock setting such as Half Moon Bay methods that rely on mapping sub-horizontal layers was not considered practical. The wavefront eikonal traveltime tomography option within the ReflexW software was used to generate a smooth velocity model along the profile. The software uses a turning ray assumption for the first arrivals and through a process of least squares minimisation of the mistfit between observed arrivals and computed arrivals, derives a smooth 2D velocity model. Smoothness constraints are imposed on the model to ensure the misfit reduces over a series of iterations. Several runs were made with different starting models. The starting model for the preferred result has an initial velocity of 300 m/s with a gradient of 100 m/s per metre imposed to produce the refracted arrivals. The smallest misfit was achieved after 16 iterations but differences between the observations and modelled response were still present between stations 120 m and 180 m for shots 9 and 10. Figure S13 shows the computed arrival times compared to the observed picks, and the ray coverage.

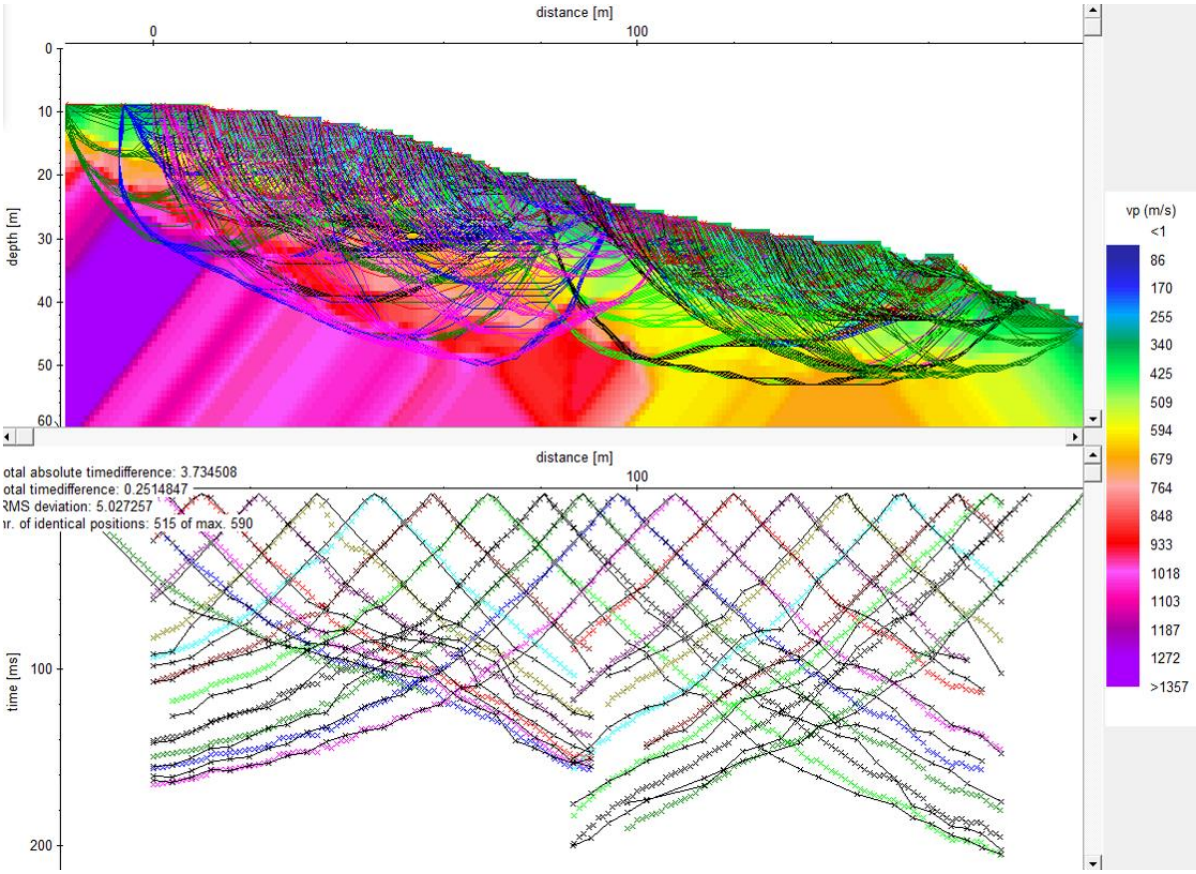


Figure S13: Preferred velocity model and ray paths. First arrival picks and model travel time curves for the preferred model.

The final model is presented with areas of low ray coverage blanked to illustrate which parts of the model are reliable.

iii. Interpretation

The ERT and seismic tomography model can be interpreted using all of the geological data from the interpretation of the LiDAR and the mapping of the fractures. Figure S14 shows a montage of images from the site showing the position of four key locations in terms of geomorphology and their geophysical signature on the ERT section.

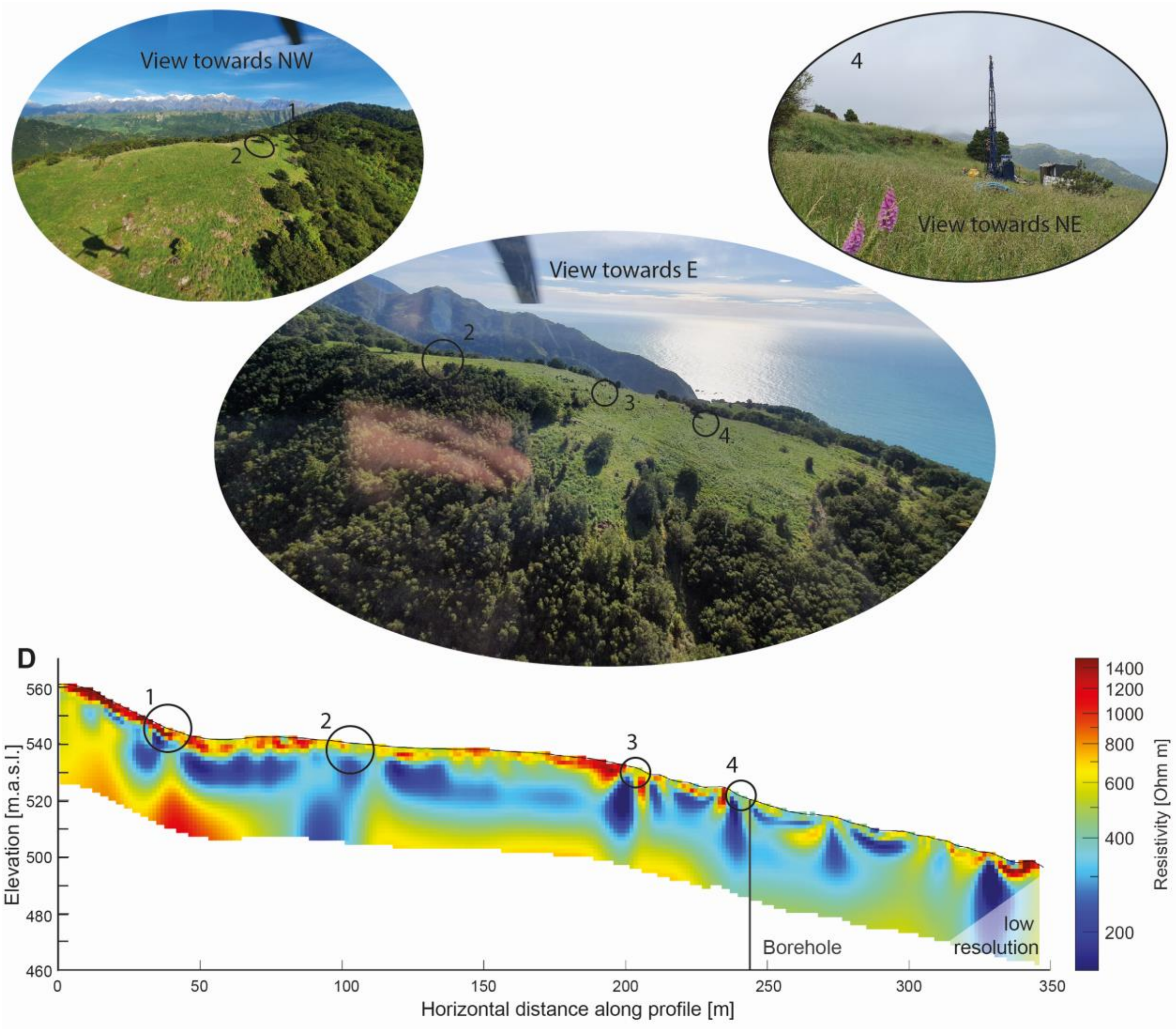


Figure S14: Location of sub-vertical low resistivity zones in the ERT section and their surface expression. As visible in the helicopter and field photos, these low resistivity zones – interpreted as high fracture zones – can be associated with topographic depressions and breaks in slope. Even though Subtle from a distance, these features can be distinct on the ground (e.g., c. 2 m high scarp for Nr. 4).

References

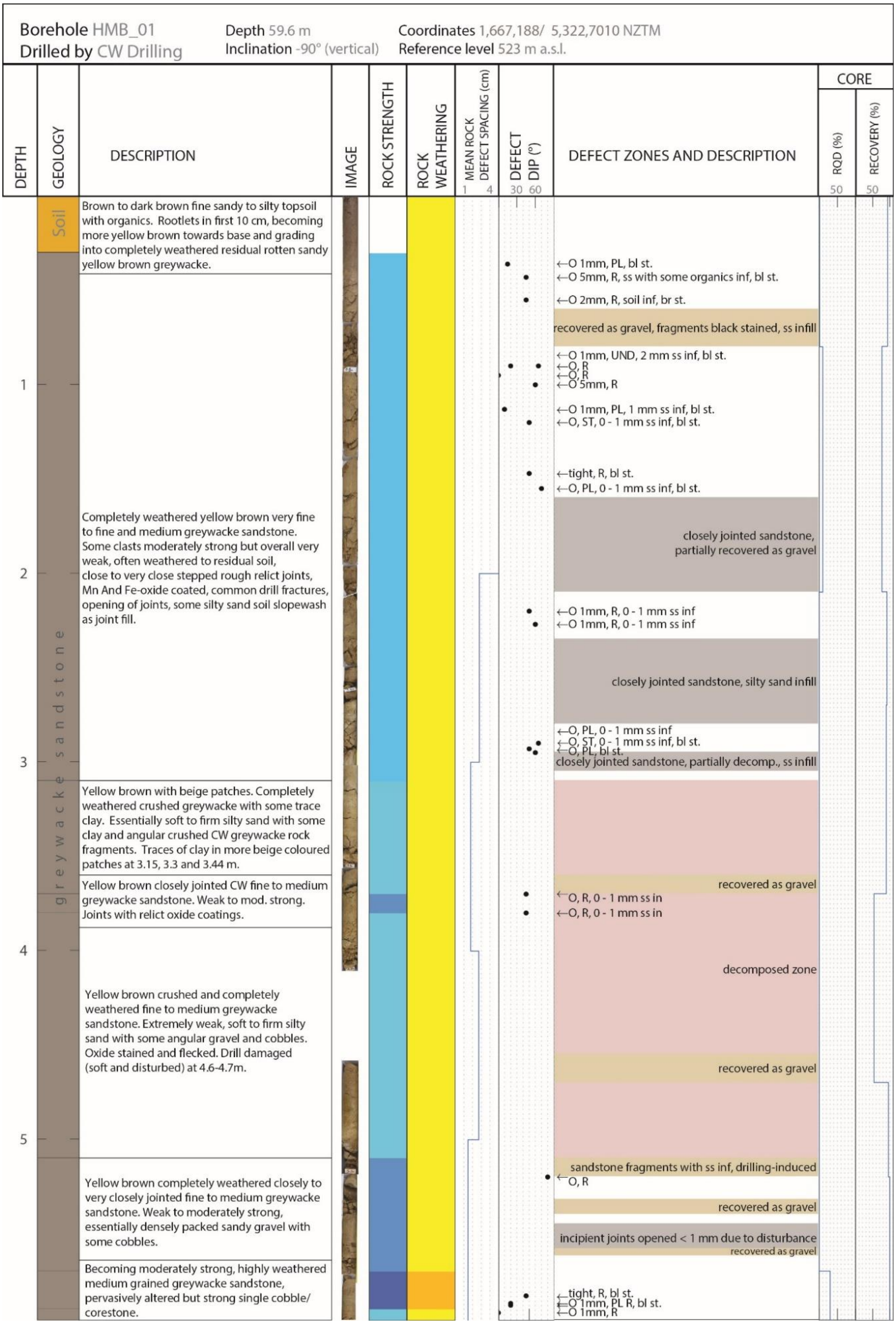
Dahlin T. 2001. The development of DC resistivity imaging techniques. *Computers & Geosciences*. 27(9):1019–1029. doi:10.1016/S0098-3004(00)00160-6.

Loke MH, Dahlin T. 2002. A comparison of the Gauss–Newton and quasi-Newton methods in resistivity imaging inversion. *Journal of Applied Geophysics*. 49(3):149–162. doi:10.1016/S0926-9851(01)00106-9.

Whiteley R.J. Eccleston P.J. (2006) Comparison of shallow seismic refraction interpretation methods for regolith mapping. Exploration Geophysics **37**, 340-347.

5. **Borehole**

Figure S15: Detailed borehole log of HMB-01



DEPTH	GEOLOGY	DESCRIPTION	IMAGE	ROCK STRENGTH	ROCK WEATHERING	MEAN ROCK DEFECT SPACING (m)	DEFECT DIP (°)	DEFECT ZONES AND DESCRIPTION	CORE RQD (%)	CORE RECOVERY (%)
6		Yellow brown crushed and CW medium grained greywacke sandstone. EW, firm to hard residual soil, soft and drill disturbed at 5.9m.								
		Yellow brown broken core recovered as completely weathered angular greywacke cobbles and gravel with interstitial silty sandy gravel matrix. Drill disturbed from 6.5-6.7m.								
7		Yellow brown to grey brown, becoming harder, moderately strong, CW to HW, closely to very closely jointed greywacke sandstone. Some relict HW cores surrounded by CW yellow brown rims, closely to very closely jointed, broken, open stepped rough oxide coated joints, often drill disturbed to small cobble and coarse gravel.								
		Grey brown to brown and beige, fine to medium grained greywacke sandstone. Extremely weak, HW to CW. Recovered as residual cobbles in fine, gravelly, clast supported weathered matrix.								
8	greywacke sandstone	Grey brown mottled, closely jointed medium greywacke sandstone. Strong to very strong, recovered as broken core, cobbles and gravel with some fine drill cuttings as infill/joint coating. Joints open, relict, oxide coated.								
9		Becoming very strong, less jointed, still highly weathered.								
		Yellow brown completely weathered and crushed greywacke sandstone. Extremely weak, crushed, soft, relict coarse sandy gravel.								
10		Grey brown medium grained greywacke sandstone, weak to moderately strong, closely jointed, open, often drill rounding on some blocks and cobbles, some yellow sandy gravel joint fill/crush.								
11	defect zone	More sandy gravel as joint infil/matrix towards 11.9 m, broken/highly weathered greywacke gravel and cobbles with some drill rounding/ damage.								

DEFECT ZONES AND DESCRIPTION

←tight

closely jointed sandstone, incipient and 1-2mm open joints, rough, partly black stained

←O 2mm, R, < 1mm ss inf

←O, R, 1 mm ss inf — recovered as gravel

←O, R, 5mm ss inf, bl st. — recovered as gravel

←O, R, < 1mm ss inf, bl st.

←O, R, bl st.

←O, R, bl st.

←O, R, br st.

←O, R, bl st.

←O, R, bl st.

←O, R, < 1 mm ss inf, br st.

←O, R, < 1 mm ss inf, bl st.

←O 1mm, R, < 1 mm dark brown ss inf, bl st.

←O 1mm, R, bl st.

closely jointed sandstone, partially decomposed, silty sand infill

←O 2mm, R, 1 mm ss inf, bl st.

cross-cutting joints 0-50°

←O 1cm, R, 1 cm light brown ss inf

←O, R, bl st.

←O 2mm, PL, bl st.

sandstone fragments with silty sand infill

←O, PL, < 1 mm ss inf, bl st.

sandstone fragments

←O, R, < 1 mm ss inf

←O, R

←O 2mm, R, 0 - 2 mm ss inf, bl st.

←O, PL R, br st.

←tight, , bl st.

←O, R, bl st.

←O, R, bl st.

←O, R, br st.

←O, R, 0 - 1 mm ss inf, bl st.

decomposed zone

←O, R, < 1 mm ss inf

←O, R, 1 mm ss inf, bl st.

←O 1mm, R, bl st.

sandstone fragments

←O, , 1 - 2 mm ss inf, bl st.

←O 1mm, R

←O, R, < 1 mm ss inf, bl st.

←O, R, < 1mm ss inf, bl st.

←O, R, bl st.

←O, R, < 1 mm ss inf, bl st.

sandstone fragments

decomposed zone

←O 1mm, R

infilled zone of gravel with some sand and silt, loosely packed, gravel angular to subangular

←O, ST, br st.

←O

infilled zone of gravel with some sand and silt, loosely packed, gravel angular to subangular

DEPTH	GEOLOGY	DESCRIPTION	IMAGE	ROCK STRENGTH	ROCK WEATHERING	MEAN ROCK DEFECT SPACING (m)	DEFECT DIP (°)	DEFECT ZONES AND DESCRIPTION	CORE RQD (%)	CORE RECOVERY (%)

Depth: 12, 13, 14, 15, 16, 17

Geology: greywacke sandstone

Description

Yellow brown completely weathered crushed greywacke. Extremely weak, essentially soft silty coarse sand with some gravel.

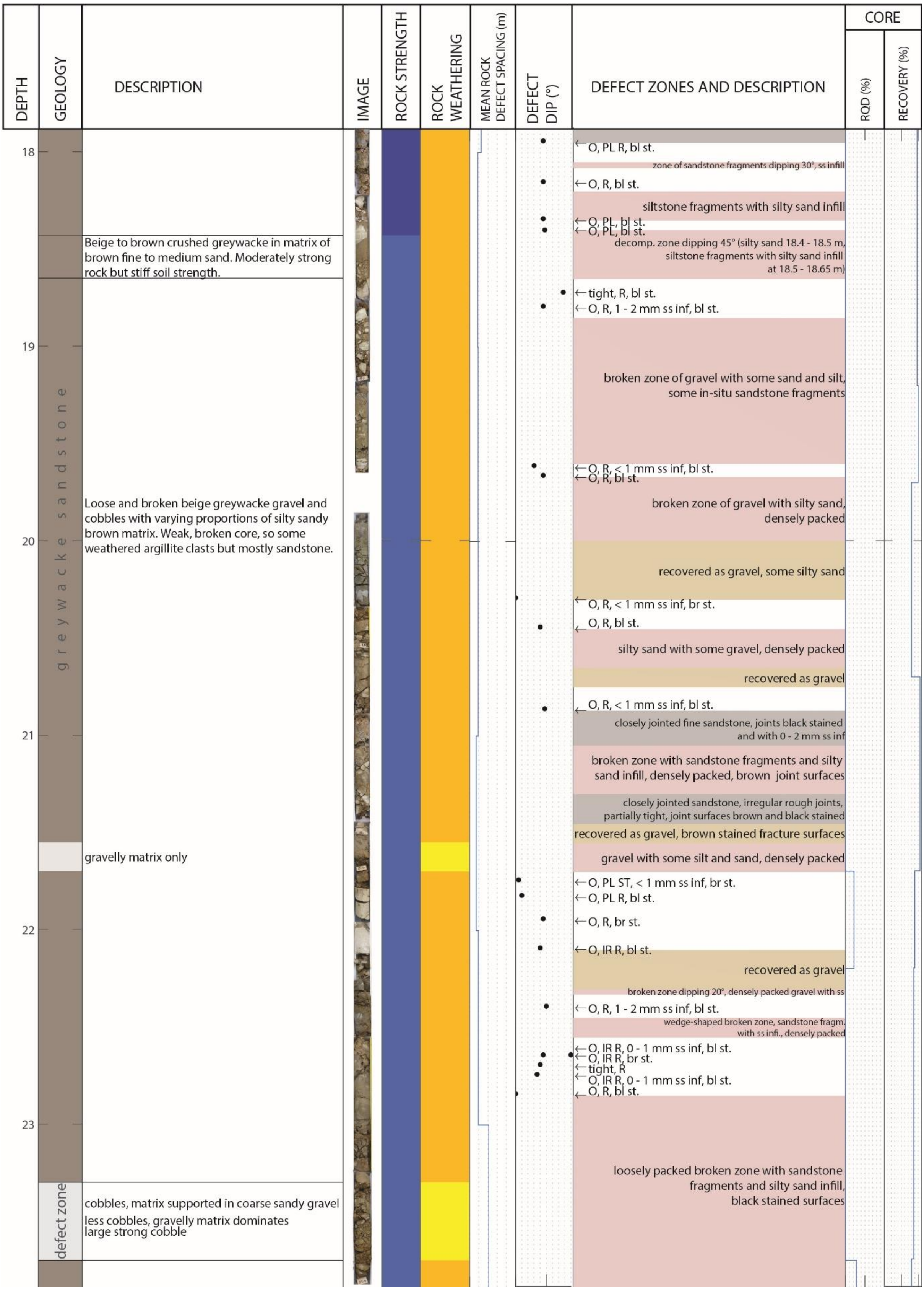
Grey brown highly weathered medium grained greywacke sandstone. Strong to very strong, closely jointed. Recovered as gravel 12.2-12.3m, and as broken core of gravel and cobbles at 12.65-12.9m and 13.2-13.3m.

Yellow brown completely weathered and crushed greywacke sandstone. Extremely weak, soft to firm matrix supported silty sandy gravel, fine gravel to small cobble clasts of HW greywacke in soft silty gravelly sand of completely weathered greywacke fragments.

Grey brown highly weathered medium grained greywacke sandstone. Strong but closely jointed, often broken and drill disturbed. Crushed to sandy gravel and cobbles below 16.2m, in situ but with loosely packed yellow brown sandy gravel between blocks at 17.7m, becoming blocks with interstitial tightly packed yellow brown sandy gravel in joints by 17.8-18.1m.

Defect zones and description

←O, R, < 1 mm ss inf, bl st.
←O, R, < 1 mm ss inf, bl st.
recovered as gravel, some silty sand
←O, R, 1 mm ss inf, bl st.
←O 0.5mm, R, bl st.
←O 1mm, R, br st.
←partially O, R, br st.
←O, R, < 1 mm ss inf, bl st.
sandstone fragments, some silty sand
recovered as gravel
←O, R, < 1 mm ss inf, bl st.
←tight, , bl st.
←O 2mm, PL, bl st.
←O 5mm, R, bl st.
decomposed zone/crush zone
←O, R, 1 - 2 mm ss inf, bl st.
sandstone fragm in br. zone dipping 30°, some ss
←O, R, bl st.
←O, PL R, < 1 mm ss inf
recovered as gravel
←O, IR R, 0 - 1 mm ss inf, bl st.
←,
←O, R, 0 - 1 mm ss inf, bl st.
←O, R, 0 - 1 mm ss inf, bl st.
←O 2mm, PL R, bl st.
wedge-shaped zone of in-situ sandstone fragments with silty sand infill
←tight, PL, bl st.
←O, P
wedge-shaped zone of closely jointed sandstone
broken zone of sandstone fragm. dipping 45°, ss inf
vertically oriented zone of sandstone fragm., ss inf
←O, R, 1 - 5 mm ss inf, bl st.
closely jointed sandstone
←O 2mm, PL R, 2mm ss inf, bl st.
←tight - O 1mm, R
←tight - O 1mm, R, < 1 mm ss inf
←O, R, bl st.
sandstone fragments, minor silty sand
sandstone fragments
sandstone fragm., mostly in-situ, joints steeply dipping, ss inf
←O, R, 1 - 2 mm ss inf, bl st.
vertically oriented zone with mostly in-situ sandstone fragments, minor ss inf
sandstone fragments with silty sand
recovered as gravel, minor silty sand
←O, R, < 1 mm ss inf, br st.
←O, IR R, < 1mm ss inf, bl st.
←O, PL R, bl st.
←O, PL R, bl st.
in-situ sandstone fragments, silty sand infill


DEPTH
GEOLOGY
DESCRIPTION
IMAGE
ROCK STRENGTH
ROCK WEATHERING
MEAN ROCK DEFECT SPACING (m)
DEFECT DIP (°)
DEFECT ZONES AND DESCRIPTION
CORE
RQD (%)
RECOVERY (%)
18
19
20
21
22
23
greywacke sandstone
defect zone
Beige to brown crushed greywacke in matrix of brown fine to medium sand. Moderately strong rock but stiff soil strength.
Loose and broken beige greywacke gravel and cobbles with varying proportions of silty sandy brown matrix. Weak, broken core, so some weathered argillite clasts but mostly sandstone.
gravelly matrix only
cobbles, matrix supported in coarse sandy gravel
less cobbles, gravelly matrix dominates
large strong cobble
O, PL R, bl st.
zone of sandstone fragments dipping 30°, ss infill
O, R, bl st.
siltstone fragments with silty sand infill
O, PL, bl st.
O, PL, bl st.
decomp. zone dipping 45° (silty sand 18.4 - 18.5 m, siltstone fragments with silty sand infill at 18.5 - 18.65 m)
tight, R, bl st.
O, R, 1 - 2 mm ss inf, bl st.
broken zone of gravel with some sand and silt, some in-situ sandstone fragments
O, R, < 1 mm ss inf, bl st.
O, R, bl st.
broken zone of gravel with silty sand, densely packed
recovered as gravel, some silty sand
O, R, < 1 mm ss inf, br st.
O, R, bl st.
silty sand with some gravel, densely packed
recovered as gravel
O, R, < 1 mm ss inf, bl st.
closely jointed fine sandstone, joints black stained and with 0 - 2 mm ss inf
broken zone with sandstone fragments and silty sand infill, densely packed, brown joint surfaces
closely jointed sandstone, irregular rough joints, partially tight, joint surfaces brown and black stained
recovered as gravel, brown stained fracture surfaces
gravel with some silt and sand, densely packed
O, PL ST, < 1 mm ss inf, br st.
O, PL R, bl st.
O, R, br st.
O, IR R, bl st.
recovered as gravel
broken zone dipping 20°, densely packed gravel with ss
O, R, 1 - 2 mm ss inf, bl st.
wedge-shaped broken zone, sandstone fragm. with ss infi., densely packed
O, IR R, 0 - 1 mm ss inf, bl st.
O, IR R, br st.
tight, R
O, IR R, 0 - 1 mm ss inf, bl st.
O, R, bl st.
loosely packed broken zone with sandstone fragments and silty sand infill, black stained surfaces

DEPTH	GEOLOGY	DESCRIPTION	IMAGE	ROCK STRENGTH	ROCK WEATHERING	MEAN ROCK DEFECT SPACING (m)	DEFECT DIP (°)	DEFECT ZONES AND DESCRIPTION	CORE RQD (%)	CORE RECOVERY (%)

24

Geology: greywacke sandstone

Defect zones and description:
- decomposed zone, sandstone fragments and silty sand, partially matrix-supported, densely packed, black stained, rough surfaces
- ←O, IR R, bl st.
- ←O, IR R
- sandstone fragments with silty sandy gravel infill

25

Geology: (crush zone)

Description: Yellow - brown silty coarse sand with some gravel. Extremely weak, stiff soil. Crush or movement zone filled with sand.

Defect zones and description:
- silty sand with some gravel, densely packed, clasts subangular
- recovered as gravel and cobbles
- gravel with loosely packed silty sand infill
- ←O, R, bl st.
- ←O, IR R
- ←O, PL R, 1 - 2 mm ss inf
- broken zone, sandstone fragments angular to subangular, clast-supported with silty sand matrix, densely packed

26

Geology: greywacke sandstone

Description: Yellow brown and beige mottled broken angular to subangular highly weathered greywacke gravel and cobbles in a silty gravelly sand matrix. Mostly matrix supported. Moderately strong rock but weak to extremely weak, often loosely consolidated soil.

Defect zones and description:
- ←O, IR R
- ←O, IR R, br st.
- broken zone, sandstone fragments mostly angular, some subangular with silty sand matrix, densely packed

27

Geology: defect zone

Description: Speckled yellow brown highly to completely weathered fine to medium sand with some gravel. Extremely weak to stiff or dense soil.

Defect zones and description:
- decomposed zone, silty sand with some gravel

28

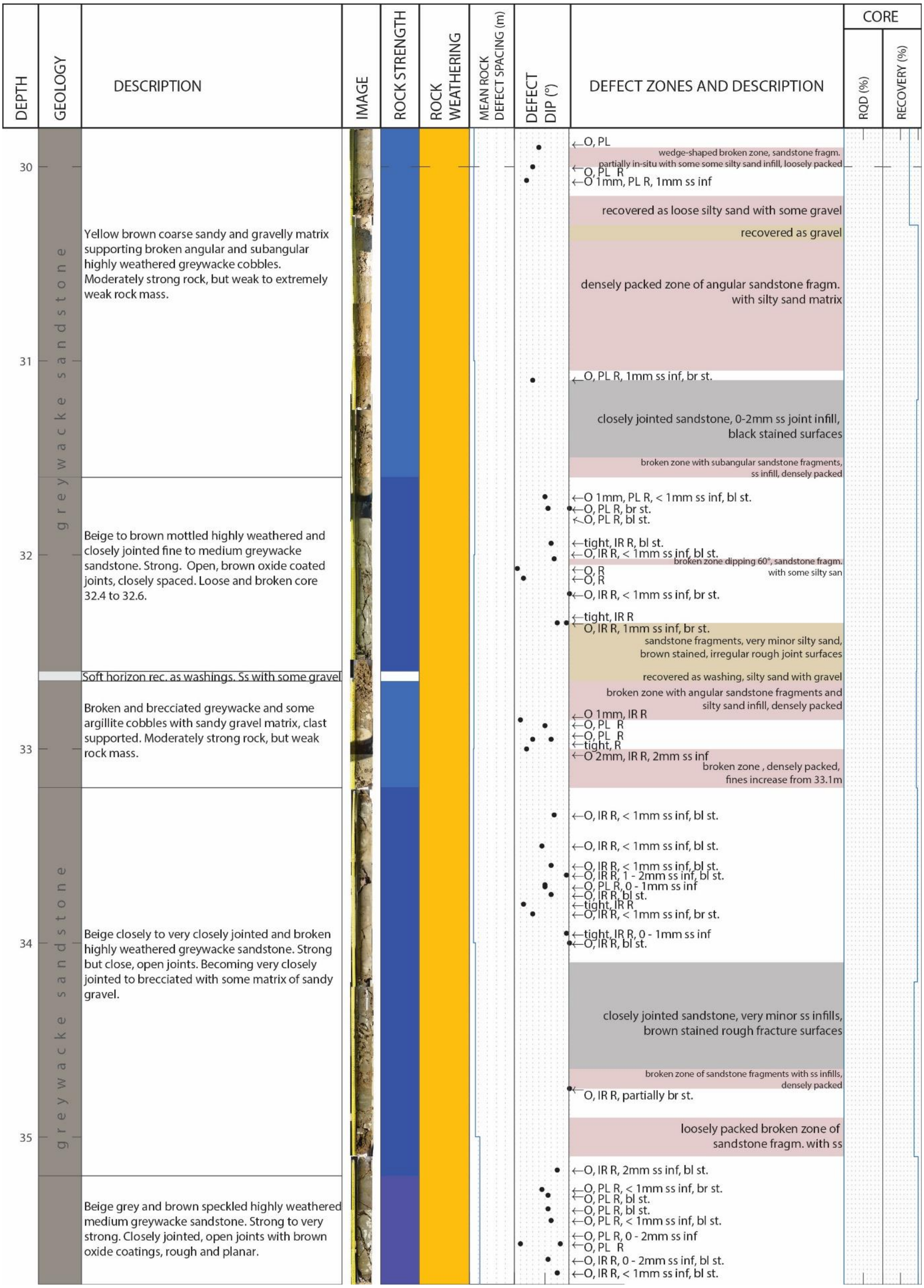
Geology: greywacke sandstone

Description: Yellow brown coarse sandy and gravelly matrix supporting broken angular and subangular highly weathered greywacke cobbles. Moderately strong rock, but weak to extremely weak rock mass.

Defect zones and description:
- recovered as gravel with silty sand, clasts subangular
- ←O, IR R
- broken zone, sandstone fragments angular to subangular, clast-supported with silty sand matrix, densely packed
- ←O, PL — broken zone dipping 55°, densely packed gravel with minor silty sand
- ←O, PL
- ←O 1cm, IR R, 1 cm ss inf, br st.
- ←O, IR R, 1 - 5 mm ss inf

29

Defect zones and description:
- recovered as gravel, some silty sand
- ←O, IR R, < 1 mm ss inf
- ←O, IR R, bl st.
- loosely packed broken zone, gravel with some silty sand, sandstone fragments partially in-situ
- ←O, IR R, < 1 mm ss inf
- recovered as gravel with minor sand and silt



DEPTH
GEOLOGY
DESCRIPTION
IMAGE
ROCK STRENGTH
ROCK WEATHERING
MEAN ROCK DEFECT SPACING (m)
DEFECT DIP (°)
DEFECT ZONES AND DESCRIPTION
CORE
RQD (%)
RECOVERY (%)
30
31
32
33
34
35
greywacke sandstone
greywacke sandstone
Yellow brown coarse sandy and gravelly matrix supporting broken angular and subangular highly weathered greywacke cobbles. Moderately strong rock, but weak to extremely weak rock mass.
Beige to brown mottled highly weathered and closely jointed fine to medium greywacke sandstone. Strong. Open, brown oxide coated joints, closely spaced. Loose and broken core 32.4 to 32.6.
Soft horizon rec. as washings. Ss with some gravel
Broken and brecciated greywacke and some argillite cobbles with sandy gravel matrix, clast supported. Moderately strong rock, but weak rock mass.
Beige closely to very closely jointed and broken highly weathered greywacke sandstone. Strong but close, open joints. Becoming very closely jointed to brecciated with some matrix of sandy gravel.
Beige grey and brown speckled highly weathered medium greywacke sandstone. Strong to very strong. Closely jointed, open joints with brown oxide coatings, rough and planar.
O, PL
wedge-shaped broken zone, sandstone fragm. partially in-situ with some some silty sand infill, loosely packed
O, PL R
O 1mm, PL R, 1mm ss inf
recovered as loose silty sand with some gravel
recovered as gravel
densely packed zone of angular sandstone fragm. with silty sand matrix
O, PL R, 1mm ss inf, br st.
closely jointed sandstone, 0-2mm ss joint infill, black stained surfaces
broken zone with subangular sandstone fragments, ss infill, densely packed
O 1mm, PL R, < 1mm ss inf, bl st.
O, PL R, br st.
O, PL R, bl st.
tight, IR R, bl st.
O, IR R, < 1mm ss inf, bl st.
broken zone dipping 60°, sandstone fragm. with some silty san
O, R
O, R
O, IR R, < 1mm ss inf, br st.
tight, IR R
O, IR R, 1mm ss inf, br st.
sandstone fragments, very minor silty sand, brown stained, irregular rough joint surfaces
recovered as washing, silty sand with gravel
broken zone with angular sandstone fragments and silty sand infill, densely packed
O 1mm, IR R
O, PL R
O, PL R
tight, R
O 2mm, IR R, 2mm ss inf
broken zone , densely packed, fines increase from 33.1m
O, IR R, < 1mm ss inf, bl st.
O, IR R, < 1mm ss inf, bl st.
O, IR R, < 1mm ss inf, bl st.
O, IR R, 1 - 2mm ss inf, bl st.
O, PL R, 0 - 1mm ss inf
O, IR R, bl st.
tight, IR R
O, IR R, < 1mm ss inf, br st.
tight, IR R, 0 - 1mm ss inf
O, IR R, bl st.
closely jointed sandstone, very minor ss infills, brown stained rough fracture surfaces
broken zone of sandstone fragments with ss infills, densely packed
O, IR R, partially br st.
loosely packed broken zone of sandstone fragm. with ss
O, IR R, 2mm ss inf, bl st.
O, PL R, < 1mm ss inf, br st.
O, PL R, bl st.
O, PL R, bl st.
O, PL R, < 1mm ss inf, bl st.
O, PL R, 0 - 2mm ss inf
O, PL R
O, IR R, 0 - 2mm ss inf, bl st.
O, IR R, < 1mm ss inf, bl st.

DEPTH	GEOLOGY	DESCRIPTION	IMAGE	ROCK STRENGTH	ROCK WEATHERING	MEAN ROCK DEFECT SPACING (m)	DEFECT DIP (°)	DEFECT ZONES AND DESCRIPTION	CORE RQD (%)	CORE RECOVERY (%)

Depth markers: 36, 37, 38, 39, 40, 41

Geology: greywacke sandstone

DESCRIPTION

Beige and brown mottled broken zone of highly weathered greywacke with brown sandy gravel crush between blocks. Crush material becomes less sandy to 36.5m

Beige greywacke, highly weathered grading to moderately weathered with some grey core relics visible. Moderately widely spaced open rough and stepped planar joints. Weathering discoloration width to grey core on larger blocks is 10 to 12 cm, smaller blocks are entirely discoloured.

Extant primary bedding contact remnant. Coarse sandstone with some fine gravel, erosive base into underlying fine to medium sandstone and soft sediment deformation with coarse sand sag into fine sand.

Grey brown fine to medium greywacke sandstone broken zone, closely spaced open joints with some brown silty sand and drill cutting fill with some gravel.

Beige fine to medium greywacke sandstone, moderately weathered, strong to very strong, closely spaced prismatic joints with some oxide coating and sometimes thin 1-2 mm silty brown infill.

Brown altered zone of highly weathered oxidised greywacke medium sandstone. Very weak, crumbles on corners and can be knife peeled. Gradational boundaries, appears altered by fluid flow.

DEFECT ZONES AND DESCRIPTION

←tight, PL, br st.
←tight, IR, br st.
←O 1mm, IR R, br st.
←tight, IR R
←O 1-5mm, PL R, < 1mm ss inf, bl st.
←O, IR R, bl st.
←O, PL R, 1mm ss inf, br st.
←O, R, 1mm ss inf, bl st.
broken zone with sandstone fragments containing incipient joints, silty sand joint infill, densely packed, becoming more loosely packed between 36.5 - 36.7m with less silty sand
←O, IR R, 0 - 1 mm ss inf, br st.
←O, PL R, < 1mm ss inf, br st.
←O, IR R, br weath.
←O, IR R
recovered as gravel
←O, IR R, < 1mm ss inf, br st.
←O, IR R, < 1mm ss inf, partially bl st.
←O, PL R, < 1mm ss inf, br st.
←O, PL R, br st.
←tight, P
←O, IR R, 1mm ss inf, bl st.
sandstone fragments with silty sand infill, zone of silty sand dipping 50° at 37.75-3
←O, IR R, partially br st.
←O, ST R, slightly br weath.
←O, PL R, br st.
←O, IR R, br/bl st.
recovered as gravel
←O, PL R, 1mm ss inf
←O, ST R, slightly br/bl st.
←tight, PL, br st.
←O, IR R, < 1 mm ss inf, br st.
←O, IR R, bl st.
←tight, PL R, br st.
←O 1-2mm, IR R, br/bl st.
closely jointed, fragmented sandstone with joints dipping 90° and 0°-20°, 1-2mm silty sand infill
←O, IR R, < 1 mm ss inf
←O, IR R, 0 - 1 mm ss inf
zone of closely jointed and fragmented sandstone, no fines, joints planar - irregular rough
←O, IR R
←O, PL R, 0 - 1 mm ss inf, partially bl st.
←O, PL R, 0 - 1 mm ss inf, bl st.
←O, PL R, br weath.
←O, IR R, br weath.
←O, IR R, br weath.
←O, PL R, br weath.
←O 1mm, S

DEPTH	GEOLOGY	DESCRIPTION	IMAGE	ROCK STRENGTH	ROCK WEATHERING	MEAN ROCK DEFECT SPACING (m)	DEFECT DIP (°)	DEFECT ZONES AND DESCRIPTION	CORE RQD (%)	CORE RECOVERY (%)
42	greywacke sandstone	Beige massive fine to medium greywacke sandstone, widely spaced open joints, some oxide coating. Sheared broken zone at 41.7 - 41.8 with coarse sandy silty gravel.						broken zone of sandstone fragm. with silty sand, steeply dipping, densely packed ←O, PL R ←O, PL R, br st. ←tight, PL R, br weath. ←O 1mm, IR - ST, partially br st. ←tight, , br weath. ←O, PL smooth, 0 - 1 mm ss inf, br st.		
	greywacke sandstone	Beige closely fractured and broken zone of moderately weathered fine to medium greywacke sandstone, open rough joints and subangular clasts with some brown silty sandy matrix with some gravel.						broken zone containing angular sandstone fragm., largely in-situ between 42.25-42.35m, joint infills of silty sand and angular gravel between 42.35-42.55m recovered as gravel, subangular clasts and minor fines		
43	argillite	Beige to grey brown closely fractured siltstone/ argillite. Moderately strong to strong, broken zone with shear damage at c. 43.6m.						←O, PL R, 1 mm ss inf, slightly br st. ←O, PL R, < 1 mm ss inf, br st. closely jointed argillite, black and brown stained joint surfaces, incipient joints with 0.5 - 3cm spacing ←O 5mm, PL, 5mm ss inf recovered as gravel, minor silty sand		
44	interbedded sandstone and argillite	Grey brown and beige mottled transitional contact zone between overlying siltstone and underlying sandstone. Solid blocks show relict ancient soft sediment mixing deformation of siltstone and sandstone. Closely jointed and often broken with silty sandy gravel between clasts.						recovered as gravel with some silty sand ←O, IR R ←tight, IR R ←O, IR R recovered as gravel, some silty sand broken zone dipping 0-70°, gravel with silty sand, densely packed ←O, P L broken zone of sandstone fragments, partially in-situ with some silty sand, densely packed		
45 46	g r e y w a c k e s a n d s t o n e	Grey brown closely jointed and broken medium grained greywacke sandstone, mostly coarse gravel with some cobbles and varying amounts of sandy gravel matrix. Loose broken core.						←O, PL R, slightly br weath. recovered as gravel broken zone, angular to subangular clasts, fines mostly washed out, loosely paccked and clast-supported recovered as gravel silty sand ←O, PL R, < 1 mm ss inf ←O, PL R, slightly br st. recovered as gravel with some silty sand, some fragment surfaces brown stained		
47								←O, PL smooth, weath. ←O, PL R, partially br st. ←O, ST, br st. ←O, PL R, br/bl st. closely jointed zone, dipping 70° (top) and 0° (bottom), no fines ←O, PL R, 1 mm ss inf, br st. ←O, PL smooth, br st. ←O, PL R recovered as fragments, minor silty sand		

DEPTH	GEOLOGY	DESCRIPTION	IMAGE	ROCK STRENGTH	ROCK WEATHERING	MEAN ROCK DEFECT SPACING (m)	DEFECT DIP (°)	DEFECT ZONES AND DESCRIPTION	CORE RQD (%)	CORE RECOVERY (%)

Depth markers: 48, 49, 50, 51, 52, 53

Geology: greywacke sandstone; interbedded sandstone and argillite

Description:

Light grey sometimes beige moderately weathered medium to fine greywacke sandstone. Widely spaced open joints, some broken zones at 47.1, 47.6, 47.8 m and at 49.2- 49.5 m.

Brown grey HW medium greywacke sandstone. Brown oxidised weak to very weak broken zone, easily crumbled with fingers and can be knife peeled on some clasts. Possible alteration on fluid flow zone.

Light grey moderately weathered fine to medium greywacke sandstone, very strong, closely spaced, open joints, broken at 50.5 to 50.65 m.

Brown to dark beige HW to CW greywacke sandstone. Extremely weak, crushed, drill disturbed with some drill cuttings and gravel. Gradational upper contact, lower contact lost.

Light grey closely jointed moderately weathered fine to medium greywacke sandstone.

Brown to grey brown broken zone of mixed siltstone and sandstone, relict deformation textures, oxidised and broken, weak to moderately strong. Some less weathered hard gray cores with visible oxidation front at margin of weathered rim. Occasional black carbonaceous fragments.

Grey brown massively bedded moderately weathered fine to medium greywacke sandstone. Closely jointed to 52.8 m then widely spaced joints to 53.5 m. Strong to very strong. Joints open, rough, oxide coated.

Defect zones and description:

← O, PL R
broken zone of sandstone fragments and some silty sand
← O, PL R, < 1 mm ss inf, br st.
← O, PL R, partially br st.
← O, IR R, < 1 mm ss inf
← O, IR R
← O, PL R, br/bl st.
← O, IR R, br st.
gravel with silty sand, densely packed
recovered as gravel, some fines (possibly drill mud)
← O, PL R, < 1 mm ss inf
← O, PL R, 0 - 1 mm ss inf, bl st.
← O, ST, 0 - 1 mm ss inf, br st.
← tight, R
← O, und. R, br/bl st.
closely jointed sandstone, HW between 50.05 - 50.15 m, predominant joint dip 40°
silty sand dipping 45°
closely jointed sandstone, fragmented, some black stained surfaces, no fines
← O, IR R, < 1 mm ss inf
← O, PL R, br st.
← O, PL R, 1 mm ss inf, br weath.
broken zone, transitioning from dark brown HW sandstone to sandy gravel with silt and minor clay
← O, IR R, red/br st.
← O, PL R, 1 mm ss inf
← O, PL R, partially br st.
recovered as gravel, angular clasts, very minor fines
← O, IR R, br/bl st.
← O, PL ST, br/bl st.
← O, ST
closely jointed HW brown sandstone and argillite, some joints along old sedimentary structures , flakes when peeled
← O, R
← tight, R
← O 0.5mm, ST R
← O 1mm, ST R, 1 mm ss inf
← O, IR R
← O, PL R, < 1 mm ss inf, partially br st.
← O, PL R, < 1 mm ss inf, partially br st.
← O, PL R, < 1 mm ss inf
← O, PL R, < 1 mm ss inf, partially br st.
← O, PL R, < 1 mm ss inf
← O, IR R, partially br st.
← O, ST R
← O, IR R, 1 mm ss inf, br/bl st.

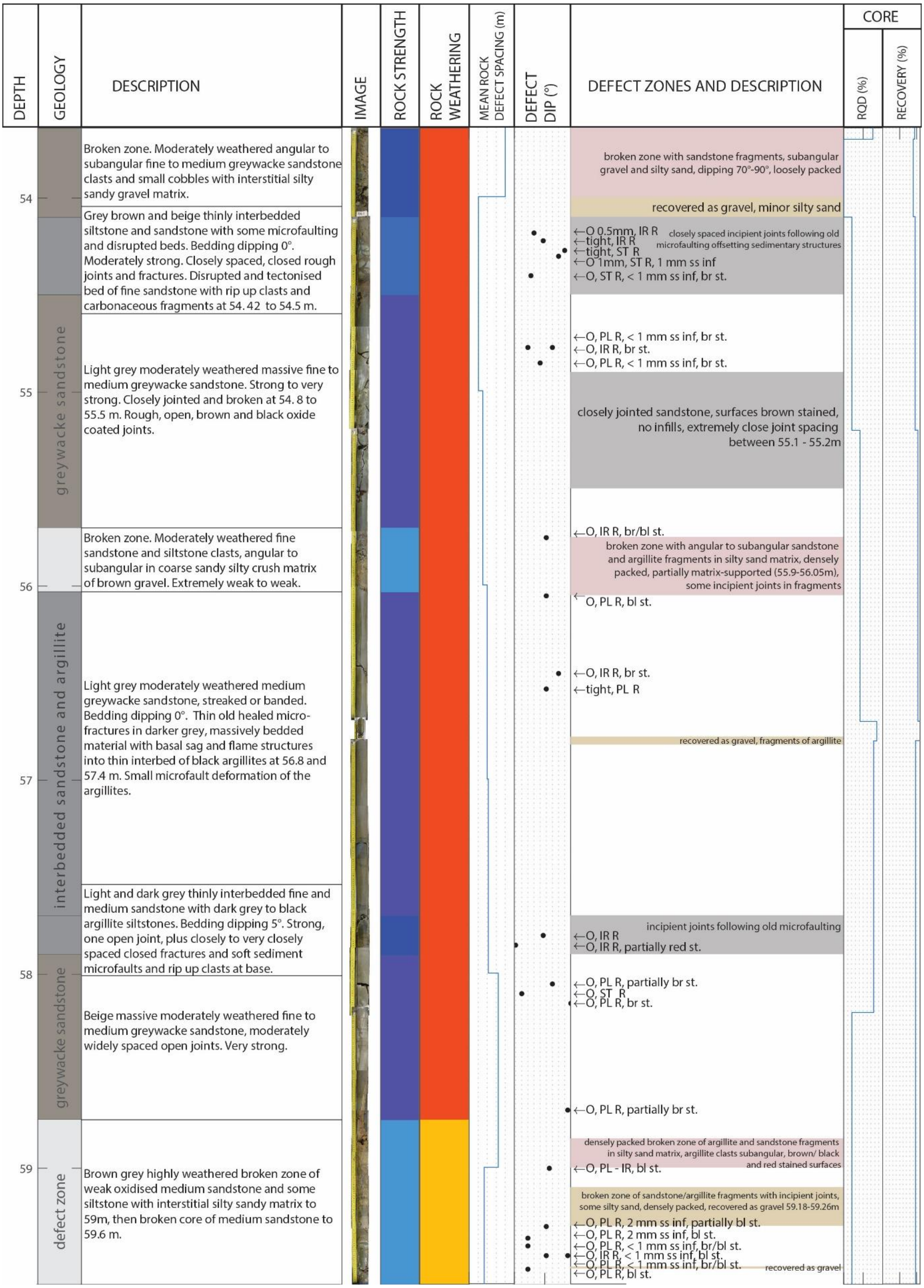
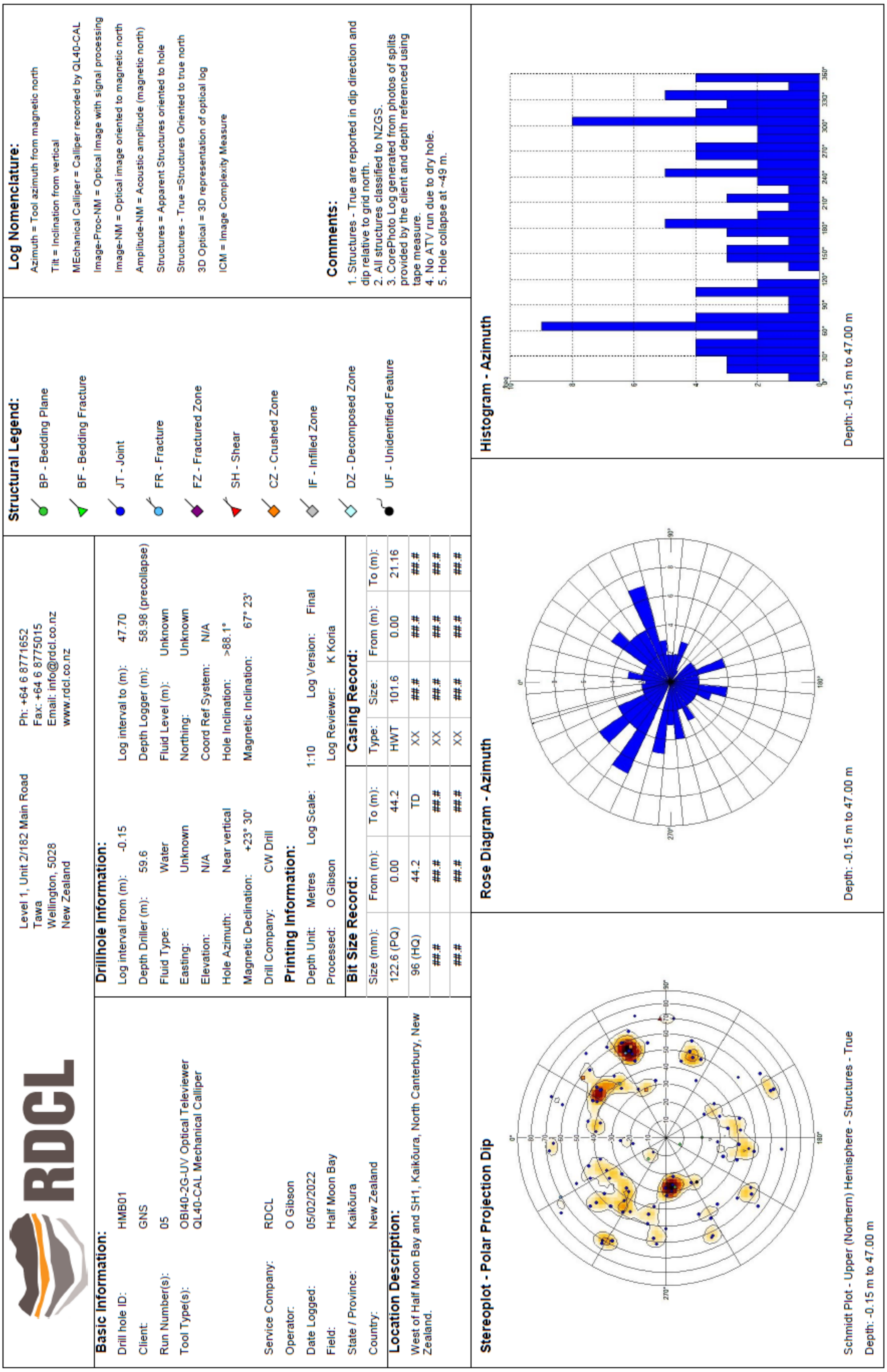
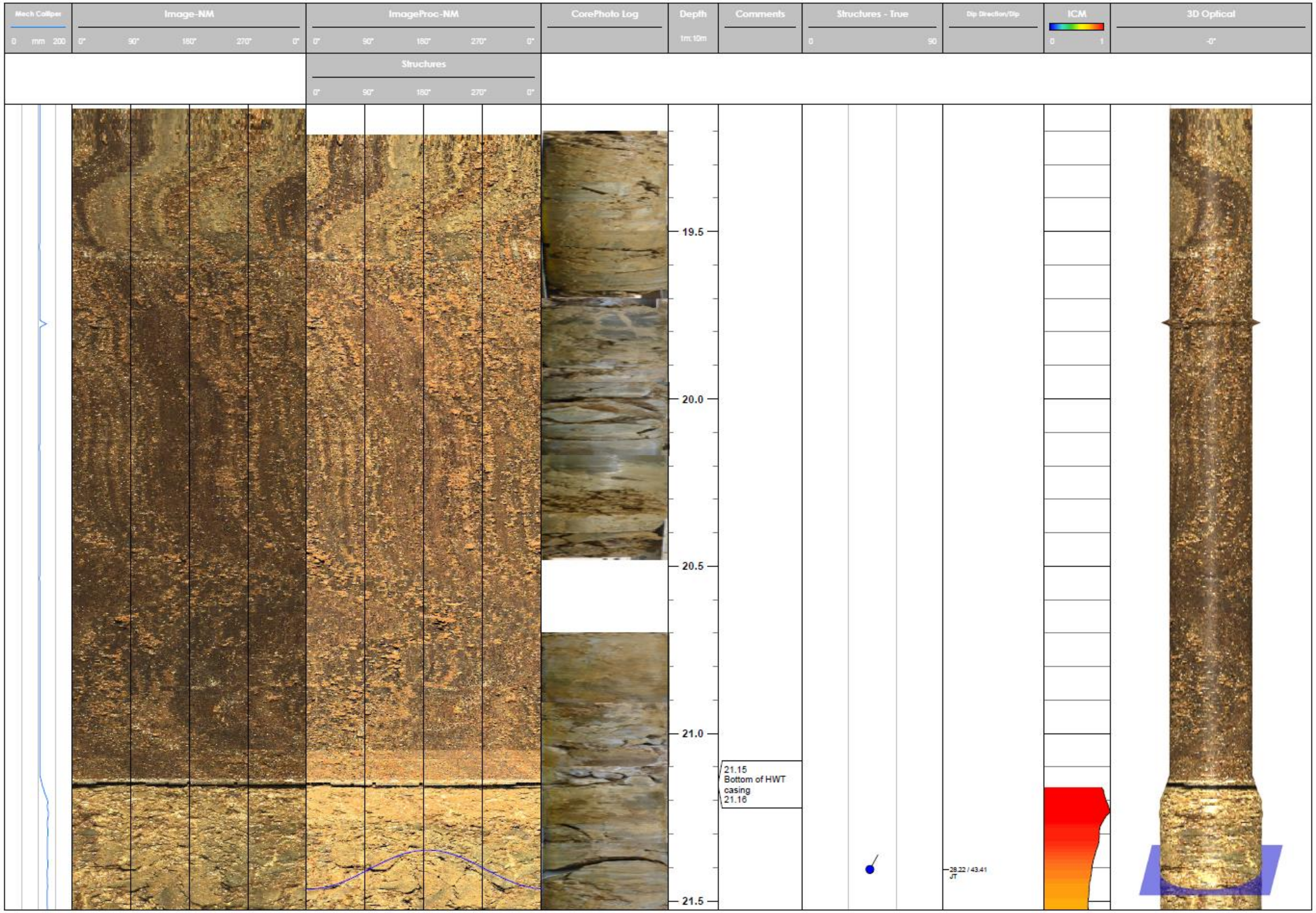

DEPTH
GEOLOGY
DESCRIPTION
IMAGE
ROCK STRENGTH
ROCK WEATHERING
MEAN ROCK DEFECT SPACING (m)
DEFECT DIP (°)
DEFECT ZONES AND DESCRIPTION
CORE
RQD (%)
RECOVERY (%)
54
55
56
57
58
59
greywacke sandstone
interbedded sandstone and argillite
greywacke sandstone
defect zone
Broken zone. Moderately weathered angular to subangular fine to medium greywacke sandstone clasts and small cobbles with interstitial silty sandy gravel matrix.
Grey brown and beige thinly interbedded siltstone and sandstone with some microfaulting and disrupted beds. Bedding dipping 0°. Moderately strong. Closely spaced, closed rough joints and fractures. Disrupted and tectonised bed of fine sandstone with rip up clasts and carbonaceous fragments at 54.42 to 54.5 m.
Light grey moderately weathered massive fine to medium greywacke sandstone. Strong to very strong. Closely jointed and broken at 54.8 to 55.5 m. Rough, open, brown and black oxide coated joints.
Broken zone. Moderately weathered fine sandstone and siltstone clasts, angular to subangular in coarse sandy silty crush matrix of brown gravel. Extremely weak to weak.
Light grey moderately weathered medium greywacke sandstone, streaked or banded. Bedding dipping 0°. Thin old healed micro-fractures in darker grey, massively bedded material with basal sag and flame structures into thin interbed of black argillites at 56.8 and 57.4 m. Small microfault deformation of the argillites.
Light and dark grey thinly interbedded fine and medium sandstone with dark grey to black argillite siltstones. Bedding dipping 5°. Strong, one open joint, plus closely to very closely spaced closed fractures and soft sediment microfaults and rip up clasts at base.
Beige massive moderately weathered fine to medium greywacke sandstone, moderately widely spaced open joints. Very strong.
Brown grey highly weathered broken zone of weak oxidised medium sandstone and some siltstone with interstitial silty sandy matrix to 59m, then broken core of medium sandstone to 59.6 m.
broken zone with sandstone fragments, subangular gravel and silty sand, dipping 70°-90°, loosely packed
recovered as gravel, minor silty sand
←O 0.5mm, IR R
←tight, IR R
←tight, ST R
←O 1mm, ST R, 1 mm ss inf
←O, ST R, < 1 mm ss inf, br st.
closely spaced incipient joints following old microfaulting offsetting sedimentary structures
←O, PL R, < 1 mm ss inf, br st.
←O, IR R, br st.
←O, PL R, < 1 mm ss inf, br st.
closely jointed sandstone, surfaces brown stained, no infills, extremely close joint spacing between 55.1 - 55.2m
←O, IR R, br/bl st.
broken zone with angular to subangular sandstone and argillite fragments in silty sand matrix, densely packed, partially matrix-supported (55.9-56.05m), some incipient joints in fragments
← O, PL R, bl st.
←O, IR R, br st.
←tight, PL R
recovered as gravel, fragments of argillite
incipient joints following old microfaulting
←O, IR R
←O, IR R, partially red st.
←O, PL R, partially br st.
←O, ST R
←O, PL R, br st.
←O, PL R, partially br st.
densely packed broken zone of argillite and sandstone fragments in silty sand matrix, argillite clasts subangular, brown/ black and red stained surfaces
←O, PL - IR, bl st.
broken zone of sandstone/argillite fragments with incipient joints, some silty sand, densely packed, recovered as gravel 59.18-59.26m
←O, PL R, 2 mm ss inf, partially bl st.
←O, PL R, 2 mm ss inf, bl st.
←O, PL R, < 1 mm ss inf, br/bl st.
←O, IR R, < 1 mm ss inf, bl st.
←O, PL R, < 1 mm ss inf, br/bl st.
←O, PL R, bl st.
recovered as gravel

Figure S16: Downhole geophysics of borehole HMB-01 (optical televiewer and mechanical caliper between depths 21.15 m - 46.2 m)





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ImageProc-NM
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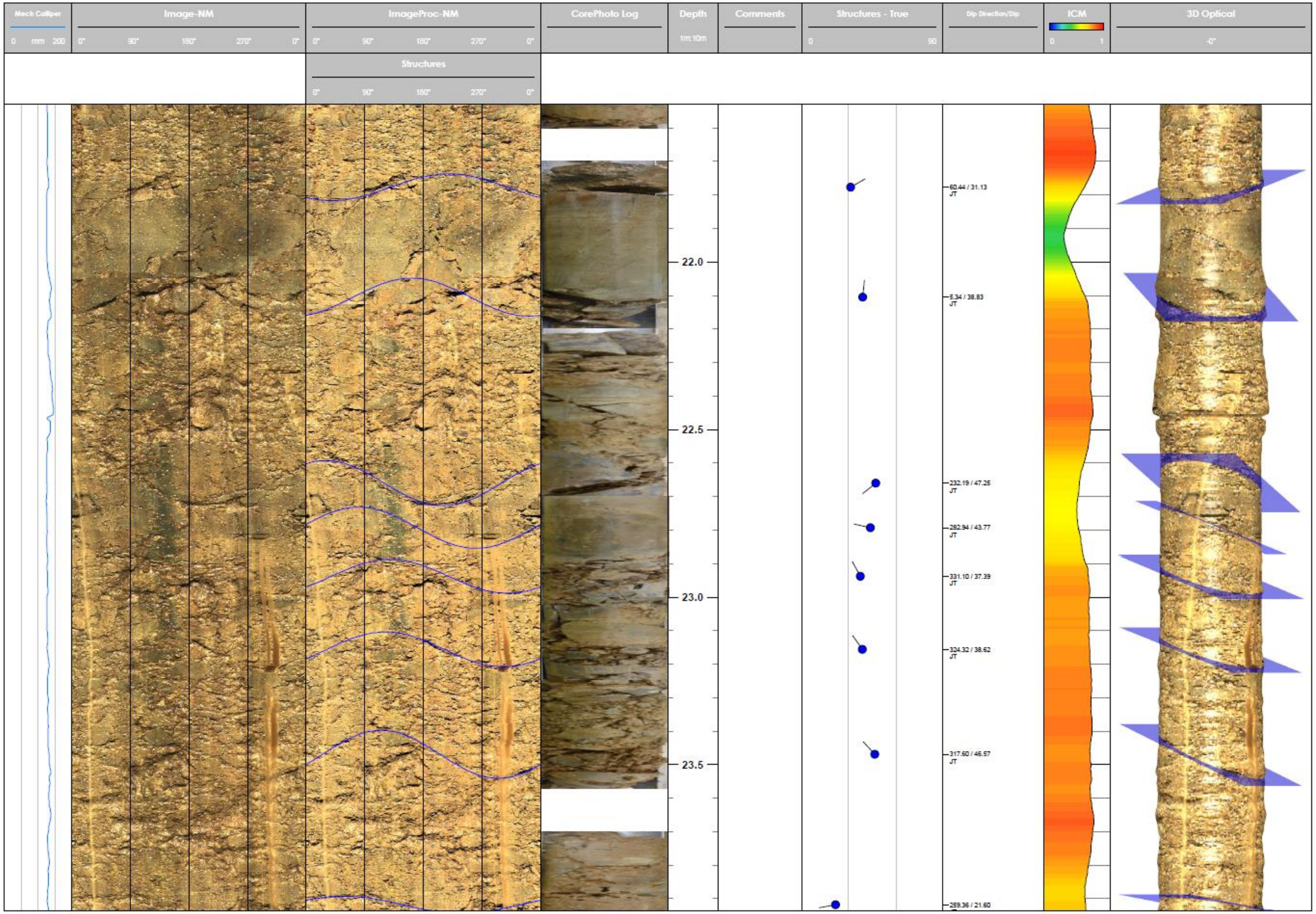
Structures
0° 90° 180° 270° 0°
CorePhoto Log
Depth
1m:10m
Comments
Structures - True
0 90
Dip Direction/Dip
ICM
0 1
3D Optical
-0°
19.5
20.0
20.5
21.0
21.5
21.15
Bottom of HWT
casing
21.16
28.22 / 43.41
JT



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ImageProc-NM
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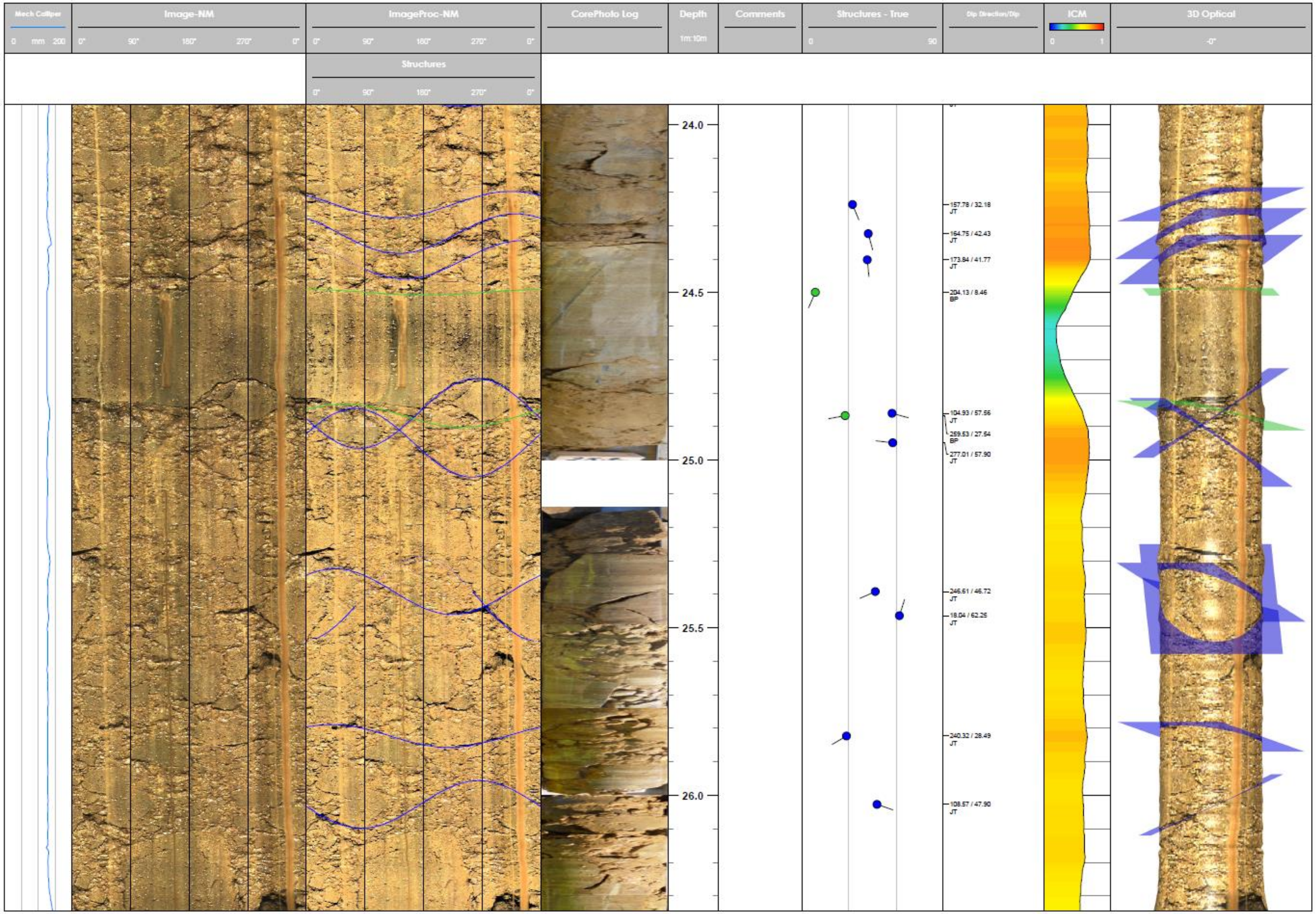
Structures
0° 90° 180° 270° 0°
CorePhoto Log
Depth
1m:10m
Comments
Structures - True
0 90
Dip Direction/Dip
ICM
0 1
3D Optical
-0°
22.0
22.5
23.0
23.5
60.44 / 31.13 JT
5.34 / 38.83 JT
232.19 / 47.25 JT
282.94 / 43.77 JT
331.10 / 37.39 JT
324.32 / 38.62 JT
317.60 / 46.57 JT
259.36 / 21.60



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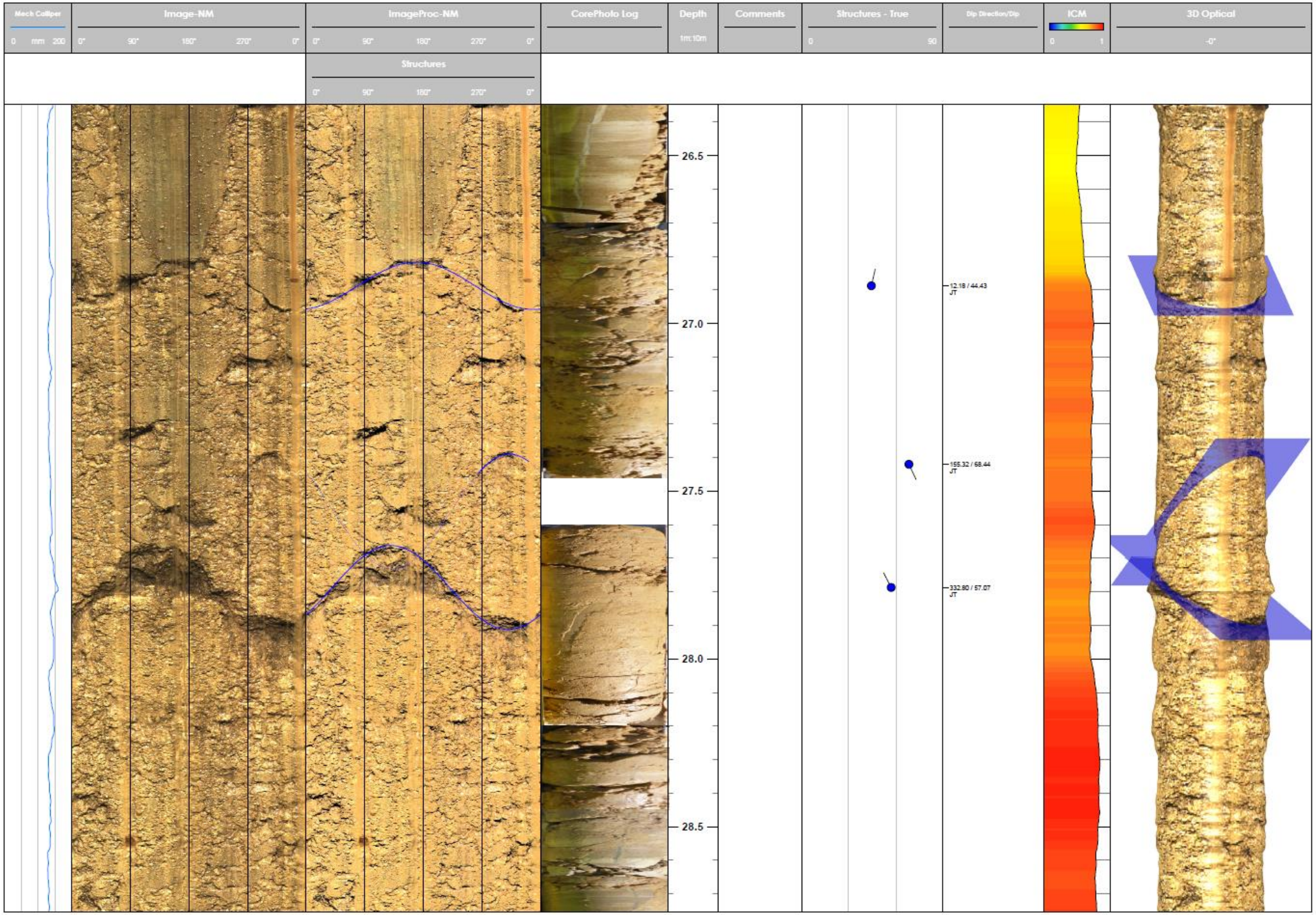
ImageProc-NM
0° 90° 180° 270° 0°
Structures
0° 90° 180° 270° 0°
CorePhoto Log
Depth
1m:10m
Comments
Structures - True
0 90
Dip Direction/Dip
ICM
0 1
3D Optical
-0°
24.0
24.5
25.0
25.5
26.0
157.78 / 32.18 JT
164.75 / 42.43 JT
173.84 / 41.77 JT
204.13 / 8.46 BP
104.93 / 57.56 JT
259.53 / 27.54 BP
277.01 / 57.90 JT
246.61 / 46.72 JT
18.04 / 62.25 JT
240.32 / 28.49 JT
108.57 / 47.90 JT



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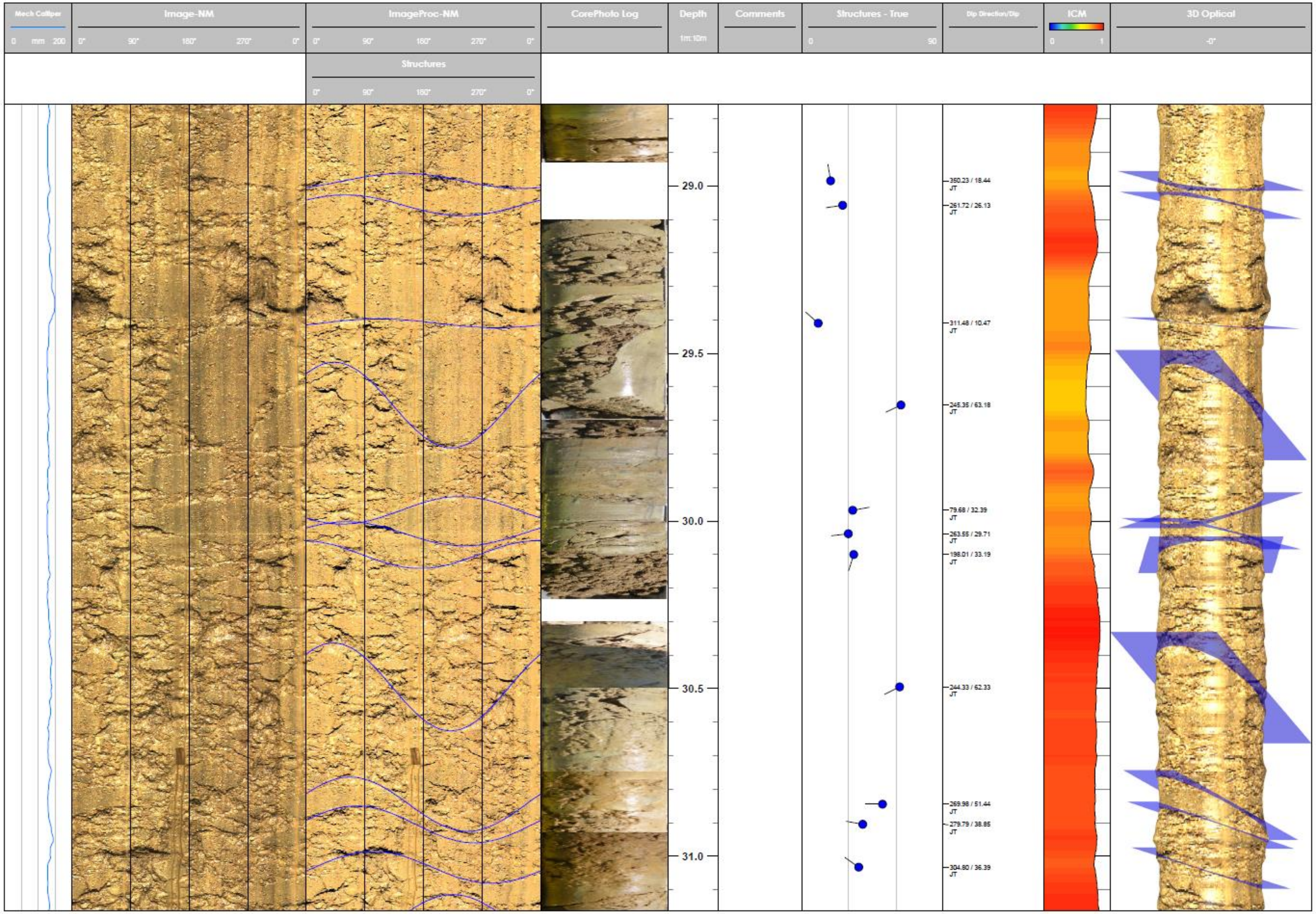
Structures
0° 90° 180° 270° 0°
CorePhoto Log
Depth
1m:10m
Comments
Structures - True
0 90
Dip Direction/Dip
ICM
0 1
3D Optical
-0°
26.5
27.0
27.5
28.0
28.5
12.18 / 44.43
JT
155.32 / 68.44
JT
332.80 / 57.07
JT



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Structures
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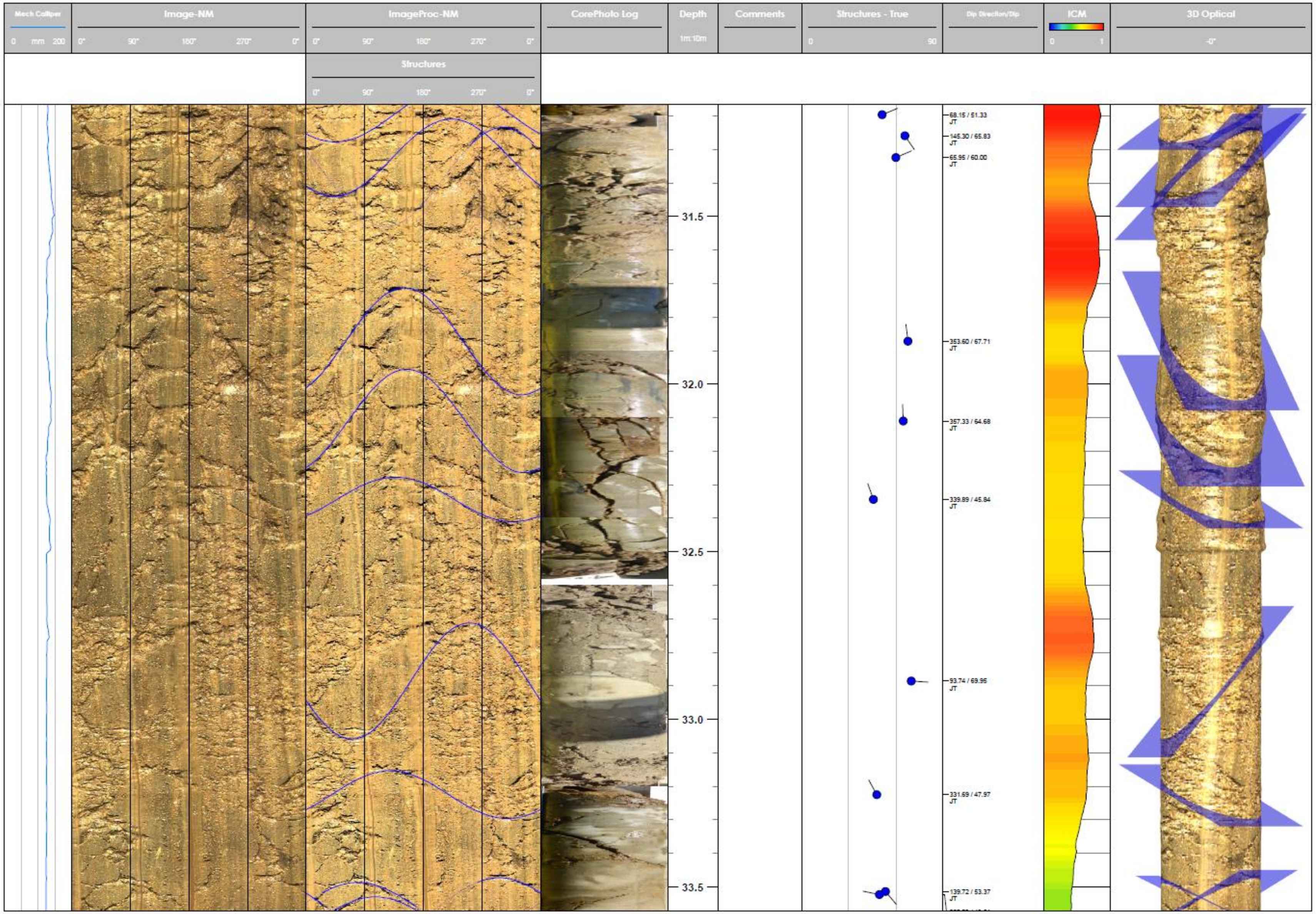
CorePhoto Log
Depth
1m:10m
29.0
29.5
30.0
30.5
31.0
Comments
Structures - True
0 90
Dip Direction/Dip
350.23 / 18.44 JT
261.72 / 26.13 JT
311.48 / 10.47 JT
245.35 / 63.18 JT
79.68 / 32.39 JT
263.55 / 29.71 JT
198.01 / 33.19 JT
244.33 / 62.33 JT
269.98 / 51.44 JT
279.79 / 38.85 JT
304.80 / 36.39 JT
ICM
0 1
3D Optical
-0°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ImageProc-NM
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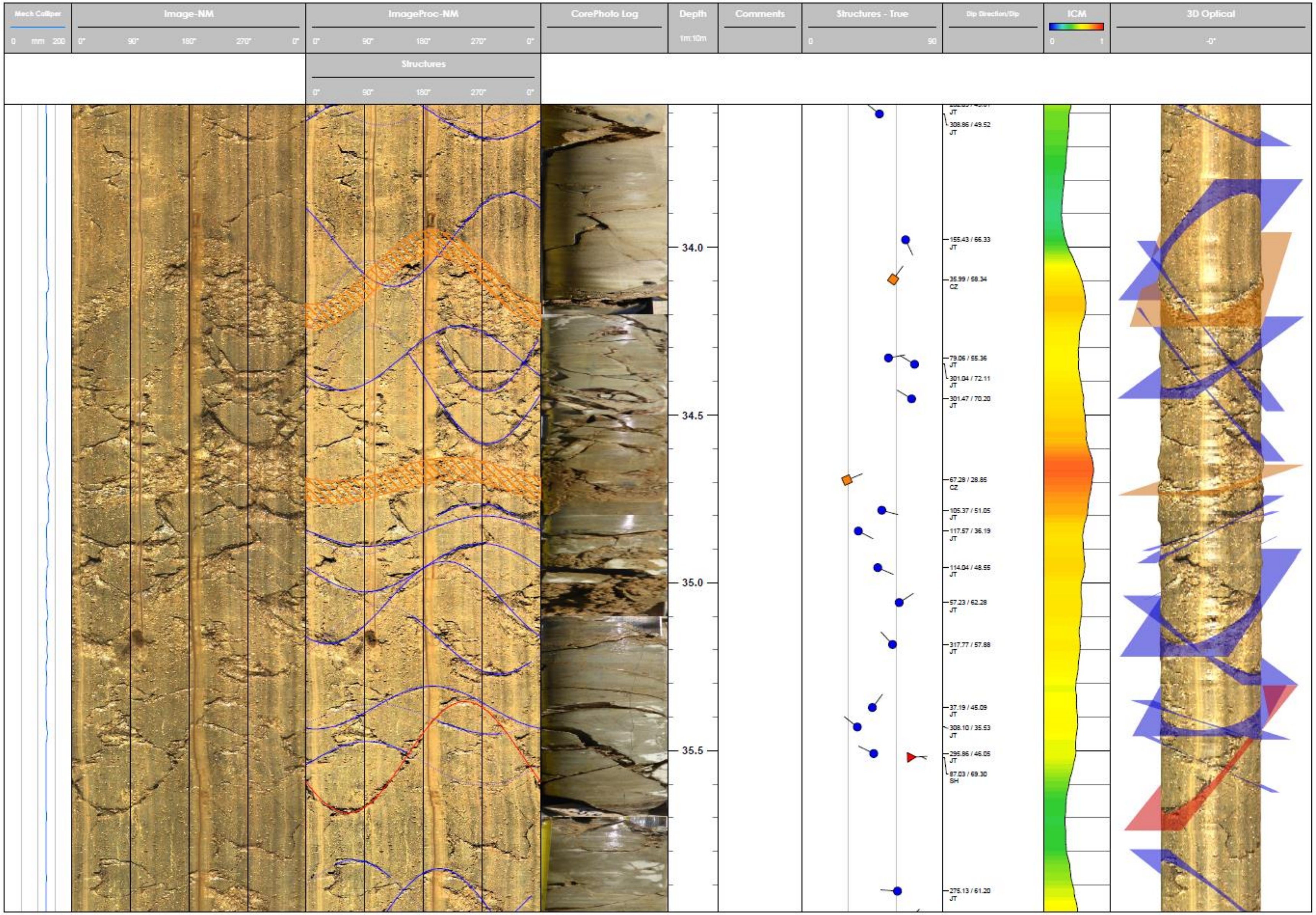
Structures
0° 90° 180° 270° 0°
CorePhoto Log
Depth
1m:10m
Comments
Structures - True
0 90
Dip Direction/Dip
ICM
0 1
3D Optical
-0°
31.5
32.0
32.5
33.0
33.5
68.15 / 51.33
JT
145.30 / 65.83
JT
65.95 / 60.00
JT
353.60 / 67.71
JT
357.33 / 64.68
JT
339.89 / 45.84
JT
93.74 / 69.96
JT
331.69 / 47.97
JT
139.72 / 53.37
JT



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ImageProc-NM
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Structures
0° 90° 180° 270° 0°
CorePhoto Log
Depth
1m:10m
Comments
Structures - True
0 90
Dip Direction/Dip
ICM
0 1
3D Optical
-0°
34.0
34.5
35.0
35.5
308.86 / 49.52
JT
155.43 / 66.33
JT
35.99 / 58.34
CZ
79.06 / 55.36
JT
301.04 / 72.11
JT
301.47 / 70.20
JT
67.28 / 28.86
CZ
105.37 / 51.05
JT
117.57 / 36.19
JT
114.04 / 48.55
JT
57.23 / 62.28
JT
317.77 / 57.88
JT
37.19 / 45.09
JT
308.10 / 35.53
JT
295.86 / 46.05
JT
87.03 / 69.30
SH
275.13 / 61.20
JT

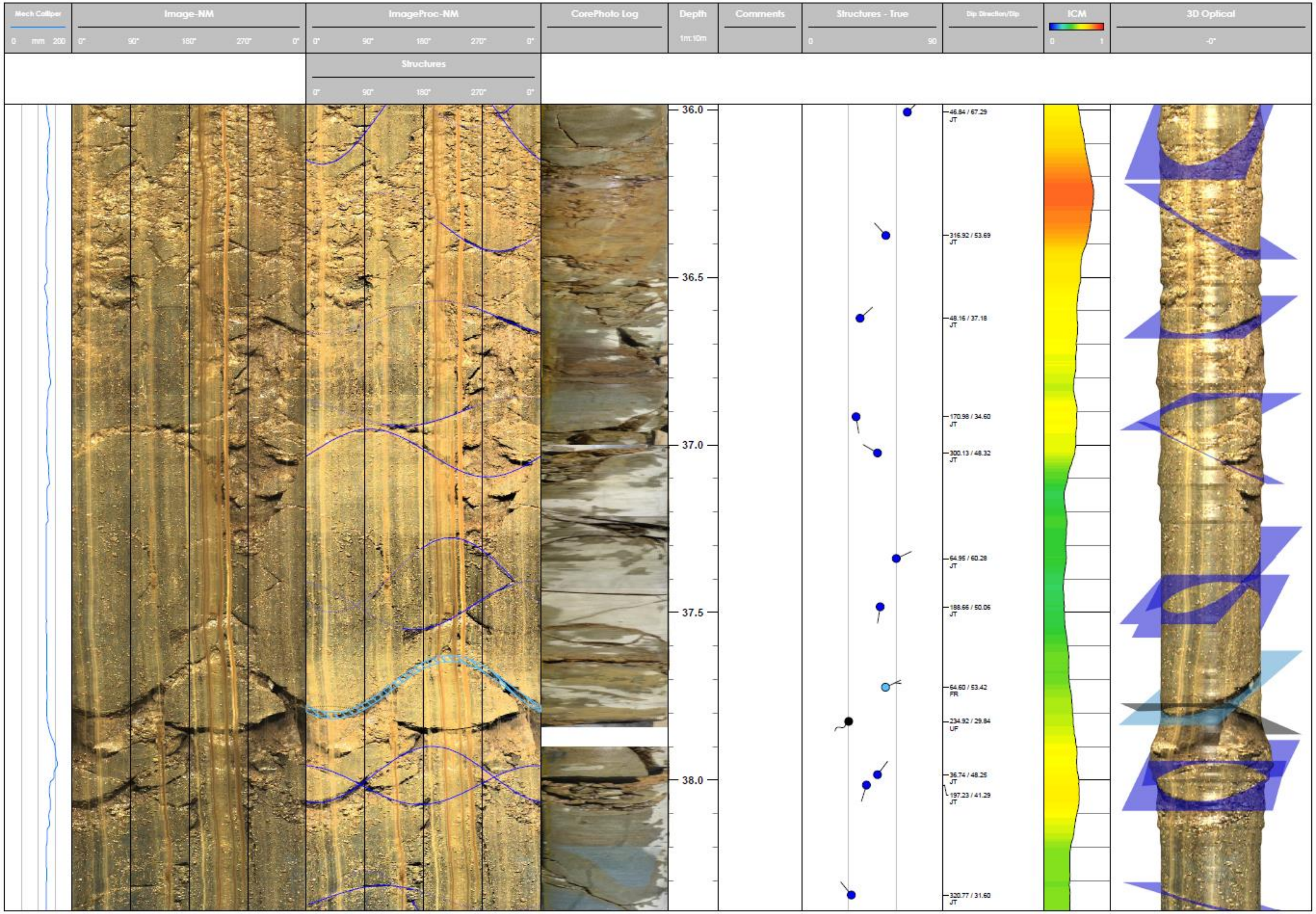
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Image-NM
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CorePhoto Log
Depth
1m:10m
Comments
Structures - True
0 90
Dip Direction/Dip
ICM
0 1
3D Optical
-0°
36.0
36.5
37.0
37.5
38.0
46.84 / 67.29 JT
316.92 / 53.69 JT
48.16 / 37.18 JT
170.98 / 34.60 JT
300.13 / 48.32 JT
64.95 / 60.28 JT
188.66 / 50.06 JT
64.60 / 53.42 FR
234.92 / 29.84 UF
36.74 / 48.25 JT
197.23 / 41.29 JT
320.77 / 31.60 JT

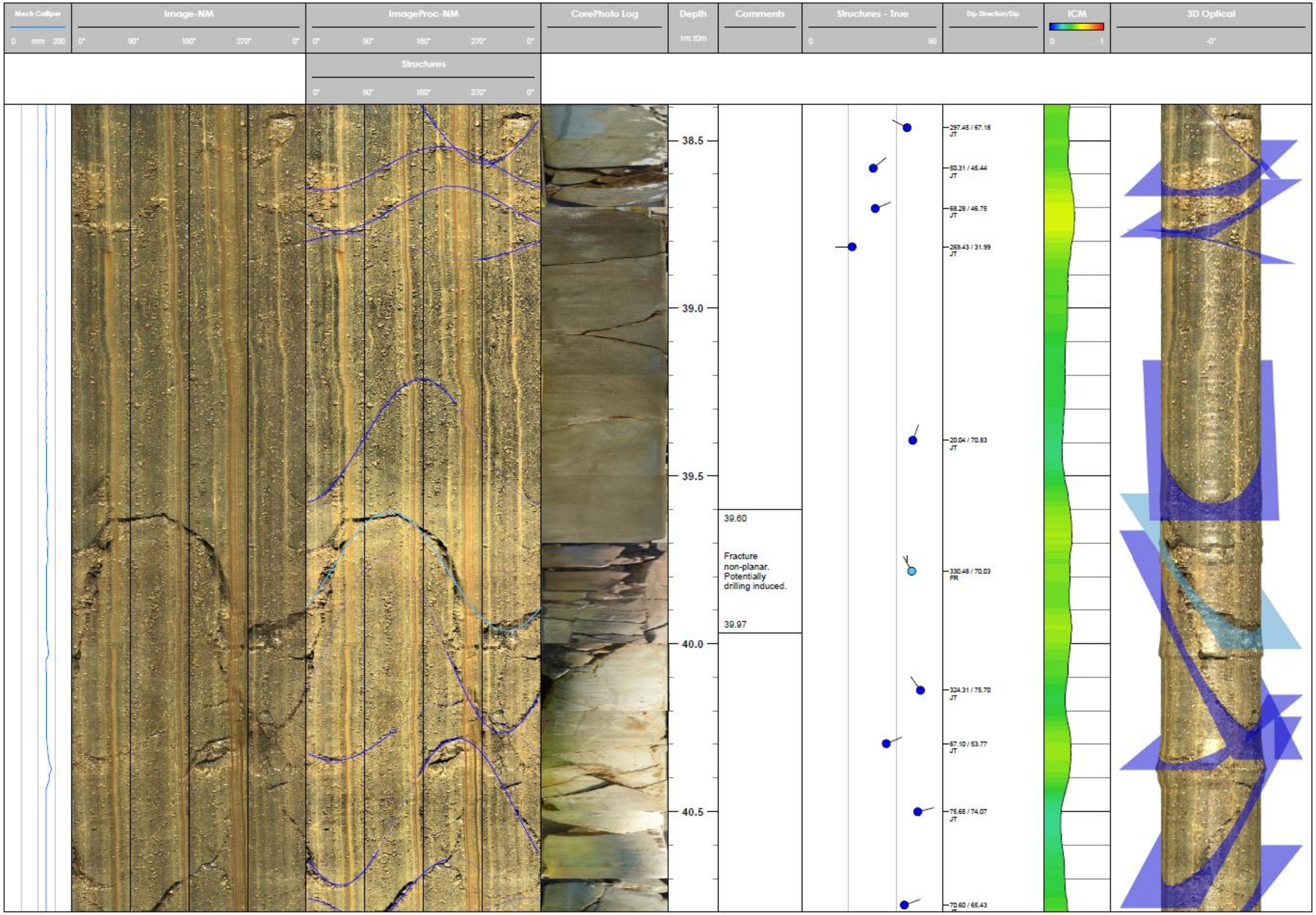
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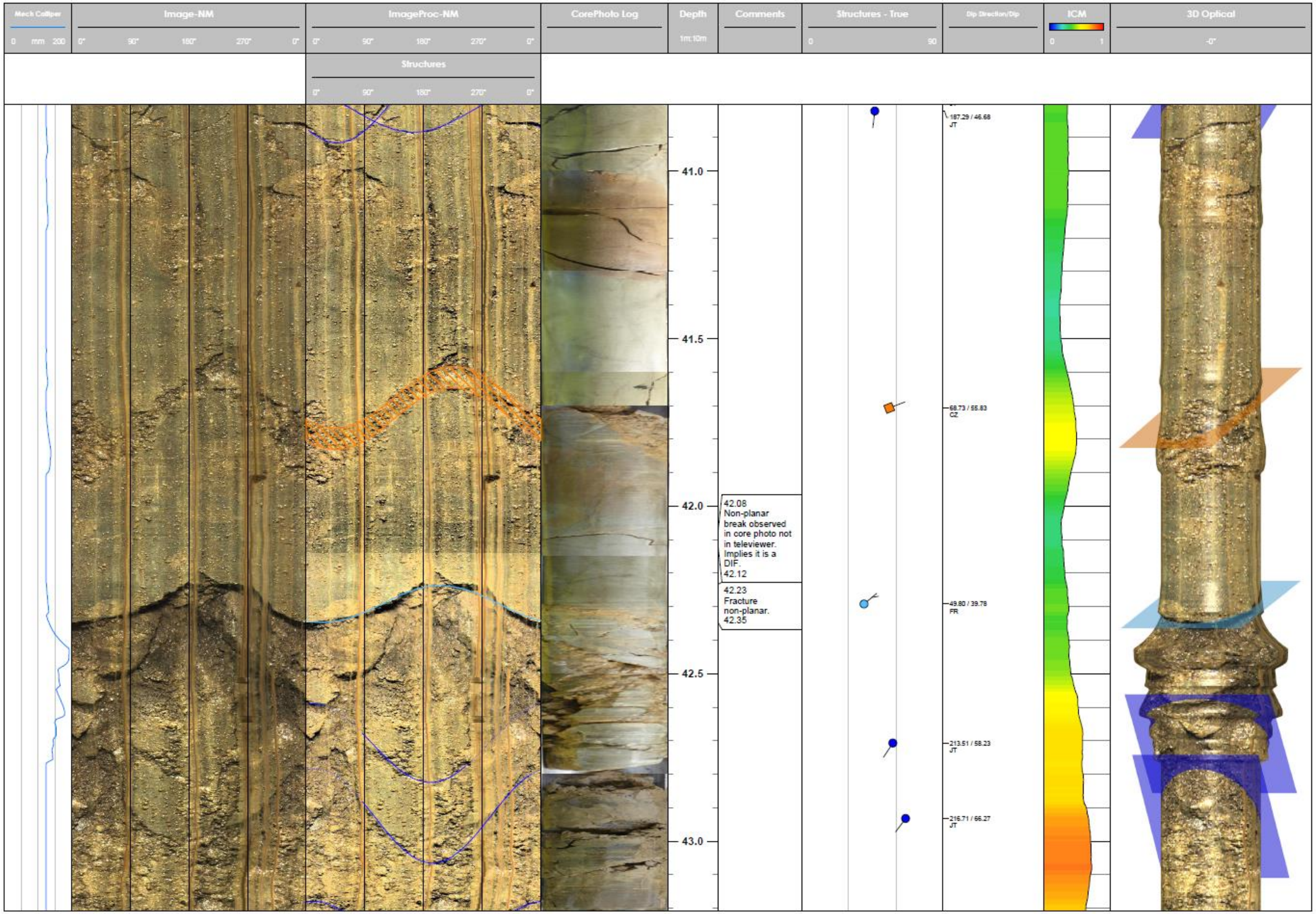
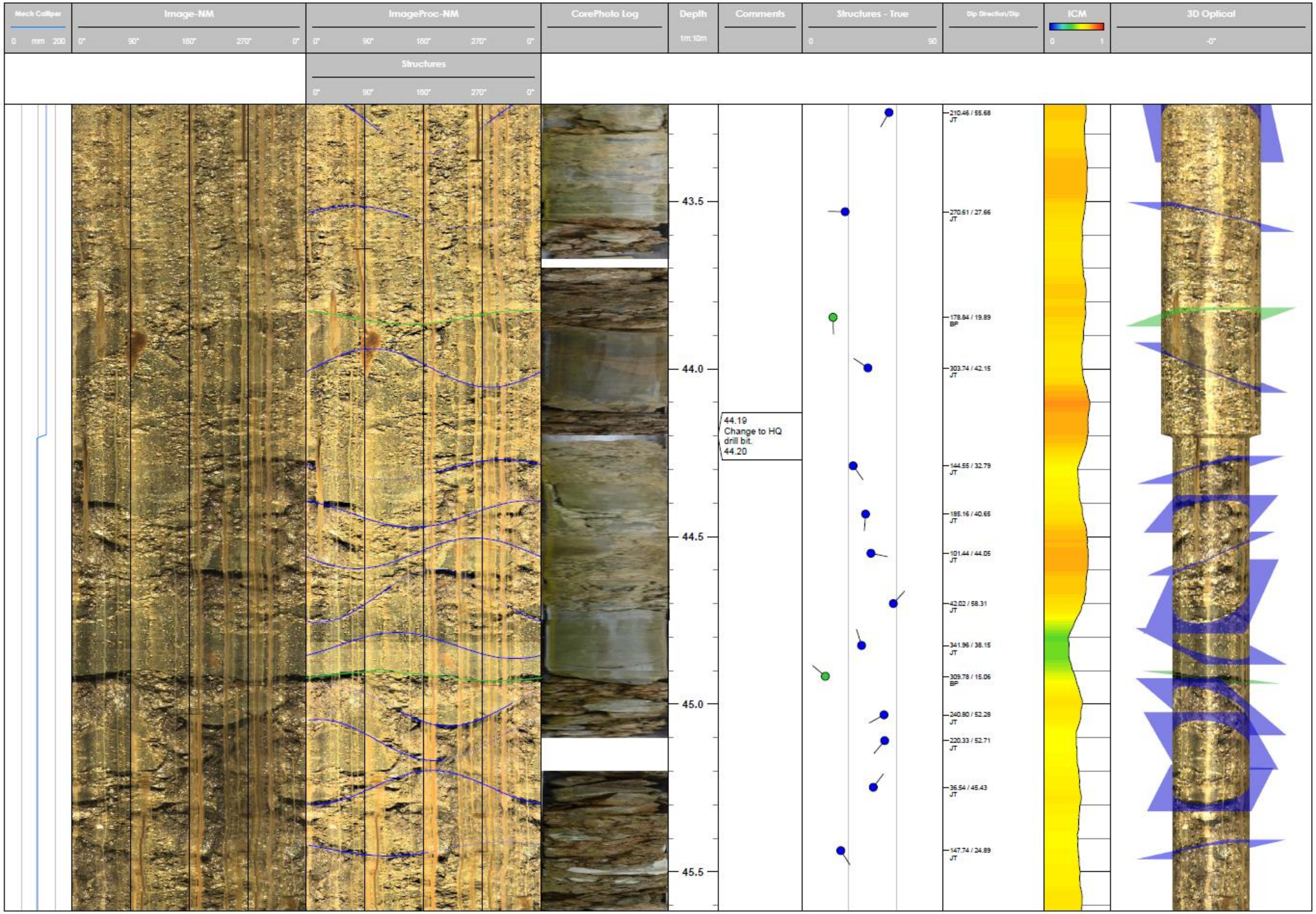
Image-NM
0° 90° 180° 270° 0°
ImageProc-NM
Structures
CorePhoto Log
Depth
1m:10m
Comments
Structures - True
0 90
Dip Direction/Dip
ICM
0 1
3D Optical
-0°
38.5
39.0
39.5
40.0
40.5
39.60
Fracture non-planar. Potentially drilling induced.
39.97
297.45 / 67.18 JT
50.31 / 45.44 JT
68.28 / 46.75 JT
269.43 / 31.99 JT
20.04 / 70.83 JT
330.48 / 70.03 FR
324.31 / 75.70 JT
67.10 / 53.77 JT
75.65 / 74.07 JT
70.60 / 65.43


Mech Caliper
0 mm 200
Image-NM
0° 90° 180° 270° 0°
ImageProc-NM
Structures
CorePhoto Log
Depth
1m:10m
Comments
Structures - True
0 90
Dip Direction/Dip
ICM
0 1
3D Optical
-0°
41.0
41.5
42.0
42.5
43.0
42.08
Non-planar break observed in core photo not in televiewer. Implies it is a DIF.
42.12
42.23
Fracture non-planar.
42.35
187.29 / 46.68
JT
68.73 / 55.83
CZ
49.80 / 39.78
FR
213.51 / 58.23
JT
216.71 / 66.27
JT



Mech Calliper
0 mm 200
Image-NM
0° 90° 180° 270° 0°
ImageProc-NM
Structures
CorePhoto Log
Depth
1m:10m
Comments
Structures - True
0 90
Dip Direction/Dip
ICM
0 1
3D Optical
-0°
43.5
44.0
44.5
45.0
45.5
44.19
Change to HQ
drill bit.
44.20
210.46 / 55.68 JT
270.61 / 27.66 JT
178.84 / 19.89 BP
303.74 / 42.15 JT
144.55 / 32.79 JT
185.16 / 40.65 JT
101.44 / 44.05 JT
42.02 / 58.31 JT
341.96 / 38.15 JT
309.78 / 15.06 BP
240.80 / 52.28 JT
220.33 / 52.71 JT
36.54 / 45.43 JT
147.74 / 24.89 JT

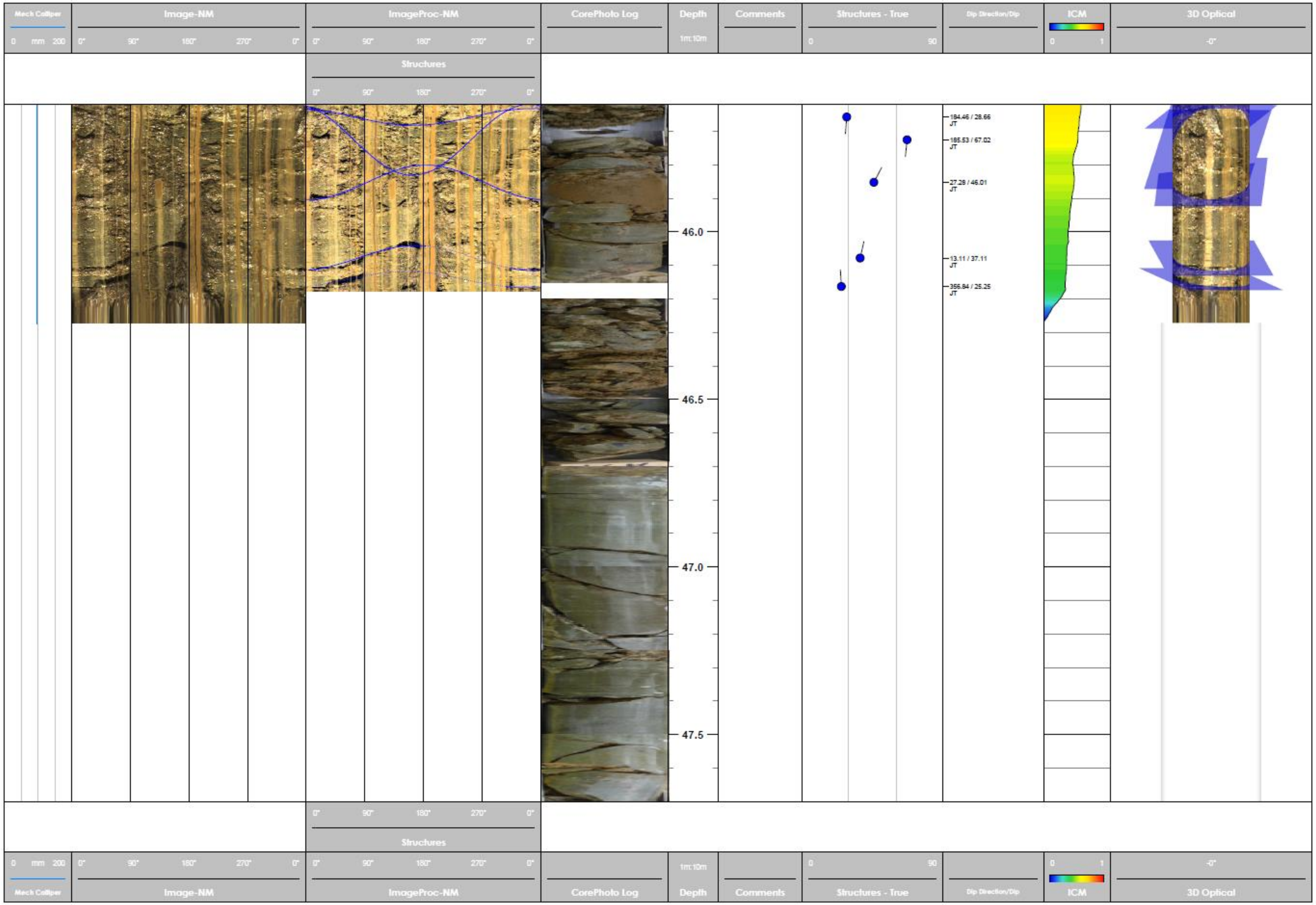

Mech Caliper
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Image-NM
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ImageProc-NM
Structures
CorePhoto Log
Depth
1m:10m
Comments
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0 90
Dip Direction/Dip
ICM
0 1
3D Optical
-0°
184.46 / 28.66 JT
185.53 / 67.02 JT
27.28 / 46.01 JT
13.11 / 37.11 JT
356.84 / 25.25 JT
46.0
46.5
47.0
47.5

6. Outcrop observations and structural analysis

Greywacke rock is exposed in several outcrops in the incipient portion of the landslide, at which we qualitatively described the rock mass and collected structural measurements (Fig. S8). Since the outcrops in the incipient portion of the landslide are mainly located along scarps and grabens, the rock mass appears dilated and disturbed. The rock mass consists predominantly of highly weathered greywacke sandstone and, to a lesser extent, argillite beds. Bedding was measured at an average orientation (dip direction/dip) of 321/15 (Fig. S8A), which is consistent with the shallow dip of bedding in the borehole (Fig. S8D) and aerial observations in the coastal cliffs at Ohau Point (Fig. S2A). Apart from bedding, two major joint sets were observed in the outcrops. Joint set 1 (mean orientation 331/71) was described as the joint set dominant in terms of persistence at several outcrops. Joint set 2 (mean orientation 269/62) shows a larger variability of orientations (Fig. S8A). Due to the highly jointed nature of the rock mass (and additional disturbance and dilation in outcrops along scarps and grabens within the landslide), measured joint orientations are scattered and many joint measurements could not be clearly assigned to a joint set when using a minimum of 5 measurement cut-off to define a joint set (Fig. S8A).

Structural field mapping was also carried out on the shore platform between Te Ana Pōuri and Ohau Point and along the Rakautara Stream (Fig. S8B). In the structural measurements taken on the shore platform, five joint sets were identified. The direction of the joint set identified as dominant in the landslide (JS1) is not present in the structural measurements on the shore platform. Bedding was not observed in the shore platform, but aerial observation suggests that, in the coastal cliff at Ohau Point (Fig. S2A), bedding is oriented sub-horizontally and dipping towards the NNW. A joint set with similar mean orientation to JS2 within the landslide is present (253/86) on the shore platform. In similar orientation, though rotated by c. 40°, we identified joint set 3 (JS3: 034/80). Joint set 4 (JS4) has a mean orientation of 290/77 and partially coincides with JS1 and JS2 observed in the outcrops within the landslide (Fig. S8). Joint set 5 (JS5) has a mean orientation of 136/70, which does not correspond to any joints measured in outcrops within the landslide. This is likely a sampling bias since the landslide displacement direction is oriented normal to these surfaces resulting in poor preservation of this joint orientation due to rock mass dilation in outcrops parallel to JS5. Joint set JS6 is the only discontinuity set identified on the shore platform that is oriented sub-horizontally (179/22).

Lineament mapping of the shore platform (Fig. S8B) reveals a predominant orientation of structures striking NW-SE. This orientation coincides with JS3 identified in the structural measurements taken on the shore platform. To a lesser extent, lineaments oriented NE-SW are present in the shore platform (Fig. S8B). This orientation appears to be more dominant in the footwall of the Hope fault and coincides with JS4 and JS5 identified in the shore platform structural measurements (Fig. S8B).

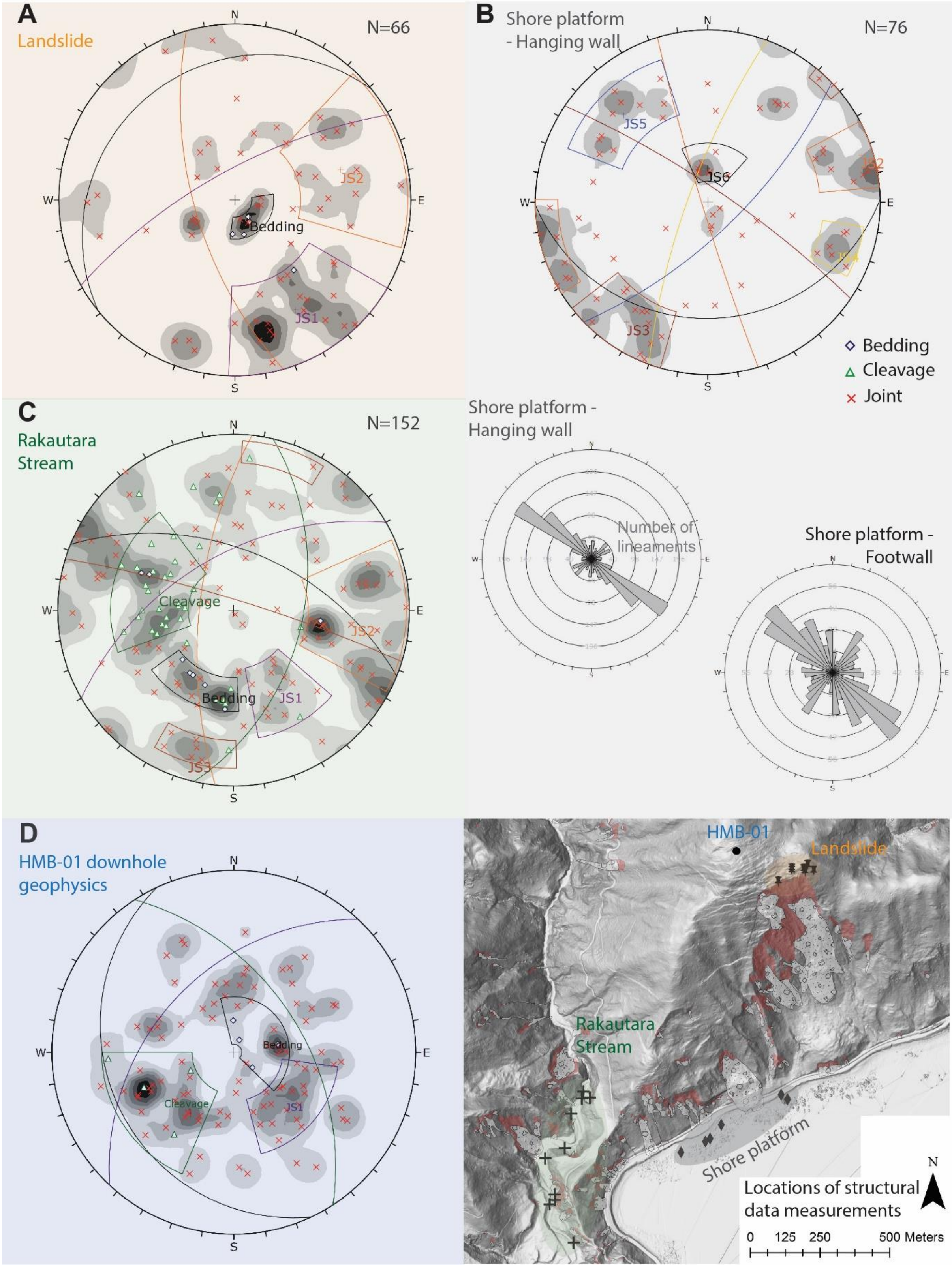

Figure S17. Structural analysis of discontinuities measured at different outcrop locations and in downhole geophysics. Measurements come from four general locations, indicated in the map (lower right). Where lineaments were mapped from aerial photographs, rose diagrams indicate trend; bar lengths are equal in bins 180° from each other. Stereonets of structural measurements are displayed using equal angle projection and Fisher contour distributions.

Along the Rakautara Stream, five discontinuity sets were identified (Fig. S8C). Bedding, measured at several localities, has a mean orientation of 022/52. In comparison to bedding measurements at localities within the landslide and observations at Ohau Point, bedding is dipping more steeply and towards the NE. In addition, cleavage was observed in outcrops along the Rakautara stream with cleavage orientations primarily assigned to one cluster with a resulting mean orientation of 103/47. No joint sets with similar orientation to the cleavage cluster were observed within the landslide or on the shore platform. The remaining three joint sets identified are of similar orientations to the previously defined joint sets JS1, JS3 and JS4.

The orientation of structures measured through downhole geophysics show a large scatter for dip angles typically ranging between 0° and 70° (Fig S8D) with a maximum dip angle of 75.7°. Due to the large scatter and lack of clustering in the data, discontinuity sets can only loosely be assigned based on pole density contours. Three main discontinuity set orientations were picked. Bedding is dipping sub-horizontally with an average orientation of 245/20 (Fig. S8D). JS1 has a mean orientation of 313/43 and is therefore similarly oriented to JS1 identified in outcrop (Fig. S8B and S8C), although it is shallower dipping. Furthermore, cleavage orientations and a cluster of joint measurements were grouped into a discontinuity set with a mean orientation of 057/49.