ASSESSMENT AND REMEDIATION OF A NON-AQUEOUS PHASE LIQUID HYDROCARBON PLUME IN FRACTURED BEDROCK

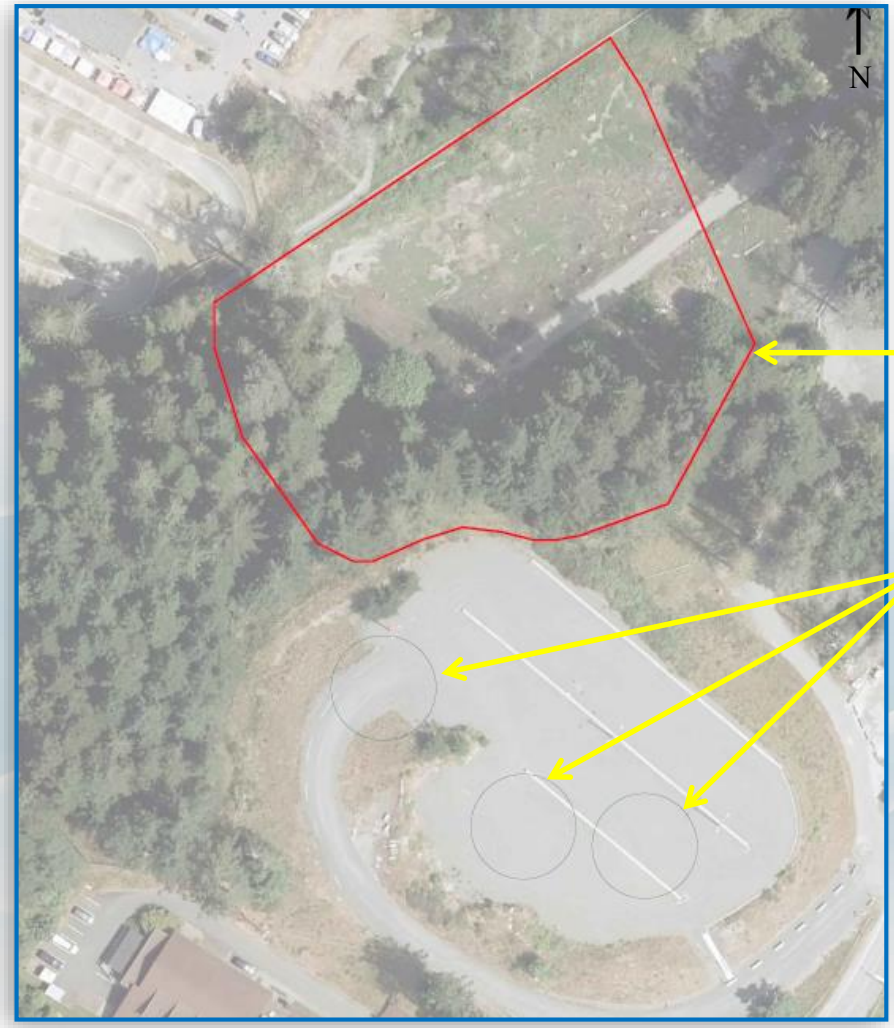
Ian Mitchell, M.Sc. P.Geo

Outline

- Background and Site Description
- Challenges of Assessment in Bedrock
- Fracture Flow Dynamics
- Fracture Mapping / Characterization
- Structural Geology Interpretation
- Developing Delineation Targets
- Remediation

Site Location

Site Setting

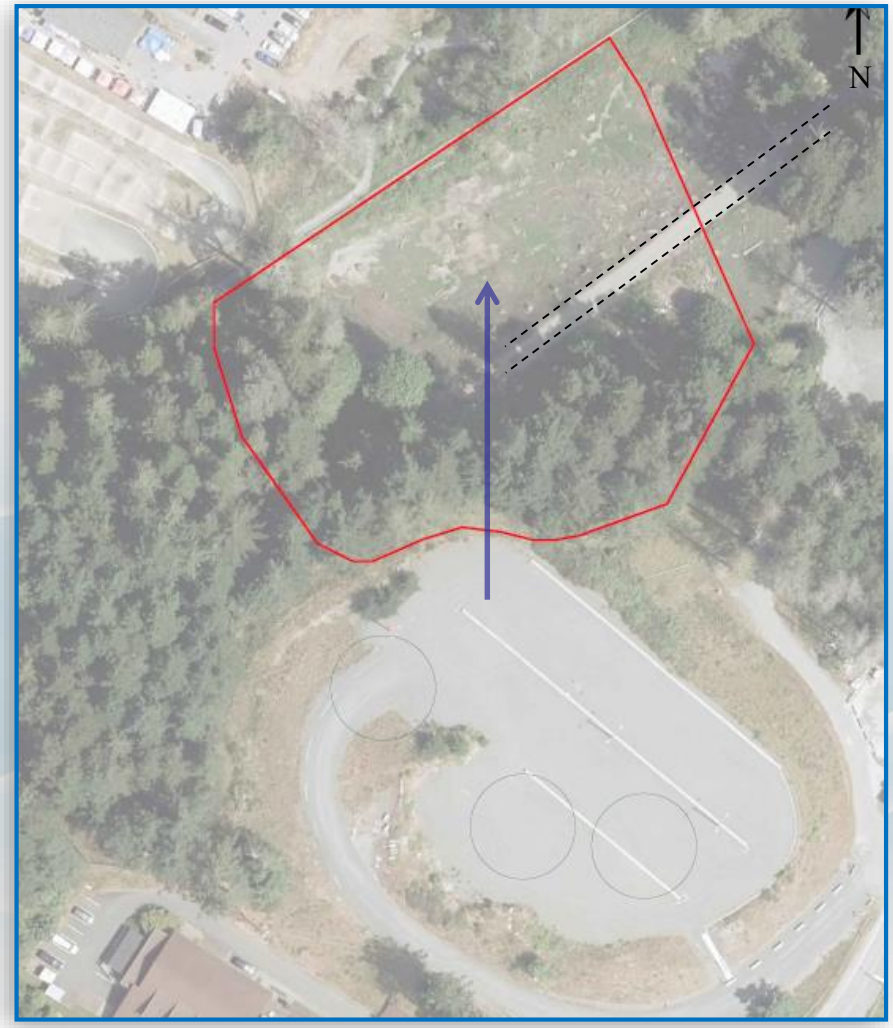


Site is a former fuel oil depot at the Department of National Defense Colwood, BC

Area under environmental investigation

Former fuel oil storage tanks, including a tank that held 40,000 barrels of Bunker C product located directly up gradient at higher elevation.

Site Setting



Moderately steep topography northward below the former tank farm

Numerous bedrock outcrops within treed areas

Groundwater flow towards the north

Site access road extended to create additional drill pads for investigation

Background

During road construction, a heavy-end non-aqueous liquid (NAPL) hydrocarbon product was observed oozing from fractures in a freshly excavated rock face

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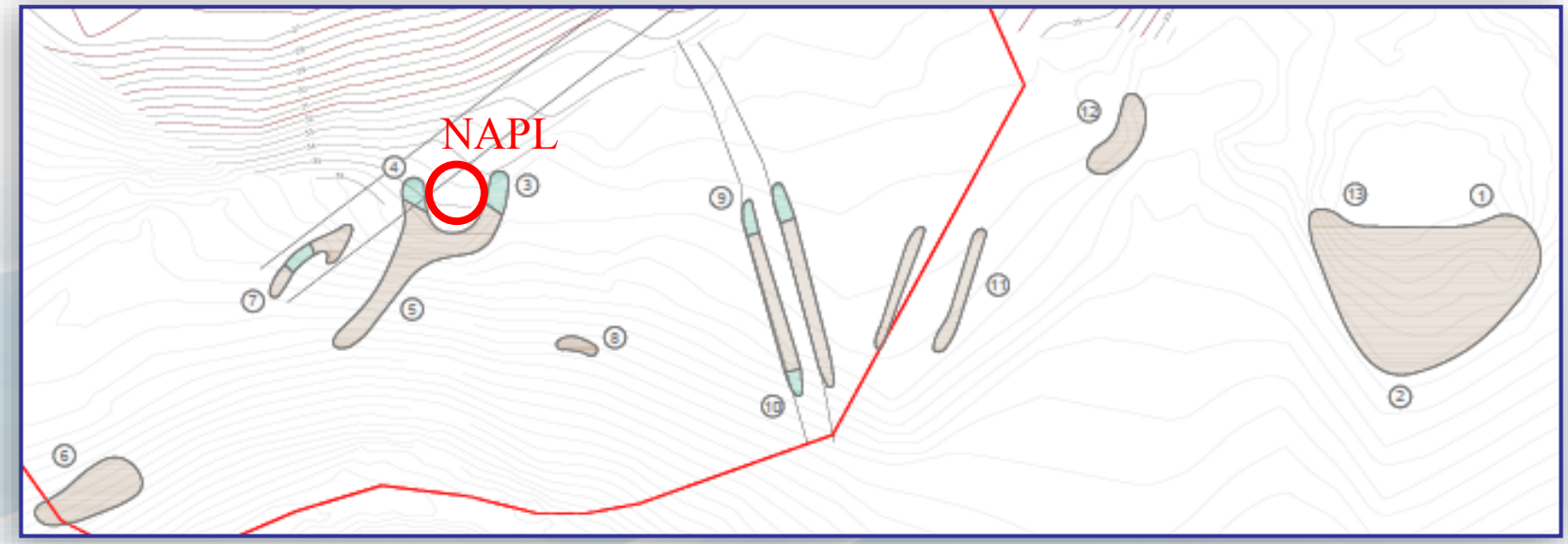
NAPL in Fractures

Background

- Impacted bedrock was dammed with sawdust, lined with a poly barrier and temporarily backfilled until an appropriate course of action could be determined
- Source of product unknown; former up gradient Bunker C tank considered likely
- However, prior assessment conducted in the tank farm area found no significant evidence of contamination
- Anecdotal information that a small asphalt manufacturing facility may have operated in the area several decades earlier; location unknown.

Site Bedrock Assessment

Significant number of bedrock outcrops on and off site

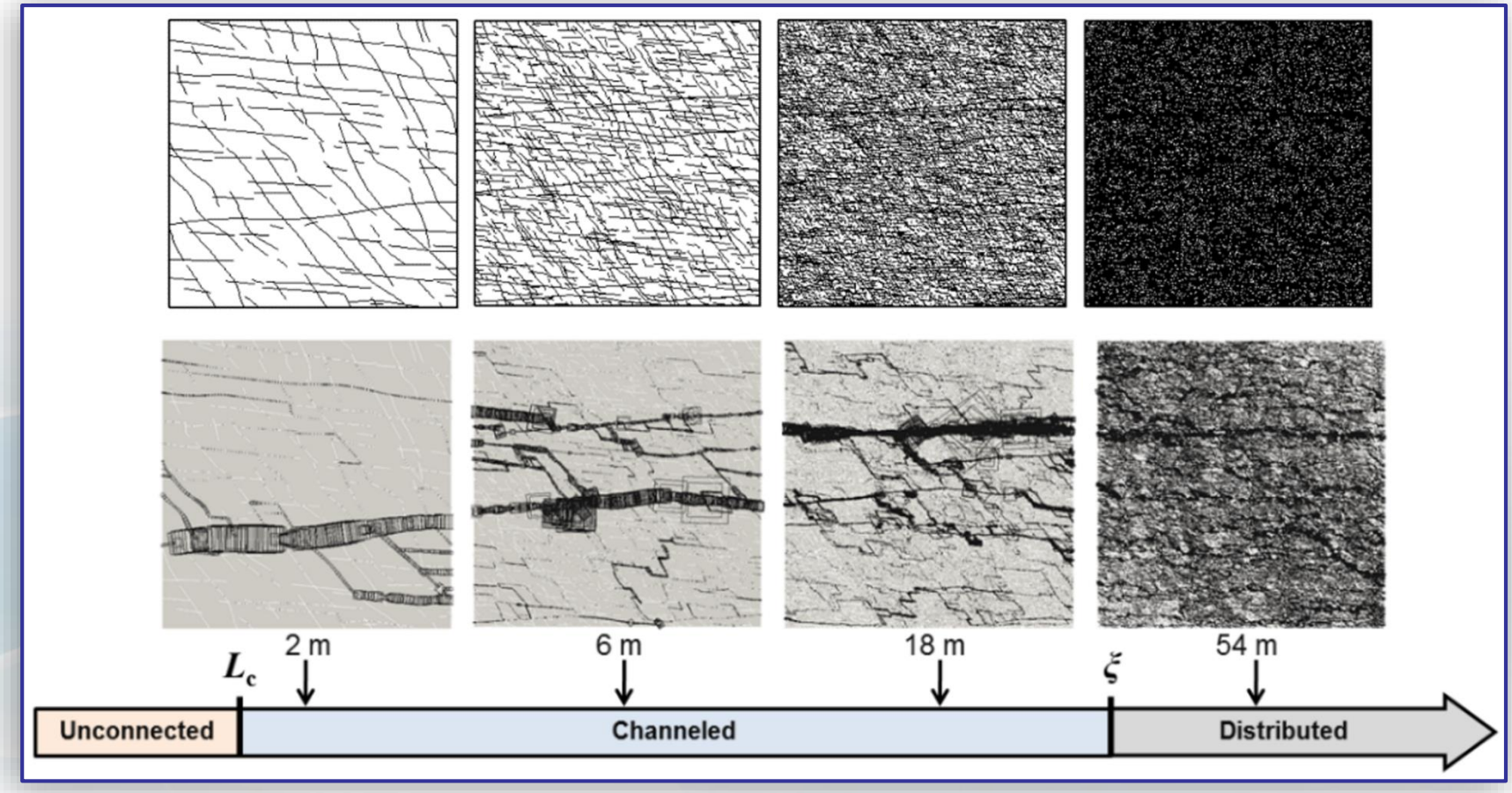


Recognized as an opportunity to gather cost-effective information on bedrock structures

Fracture Flow Dynamics

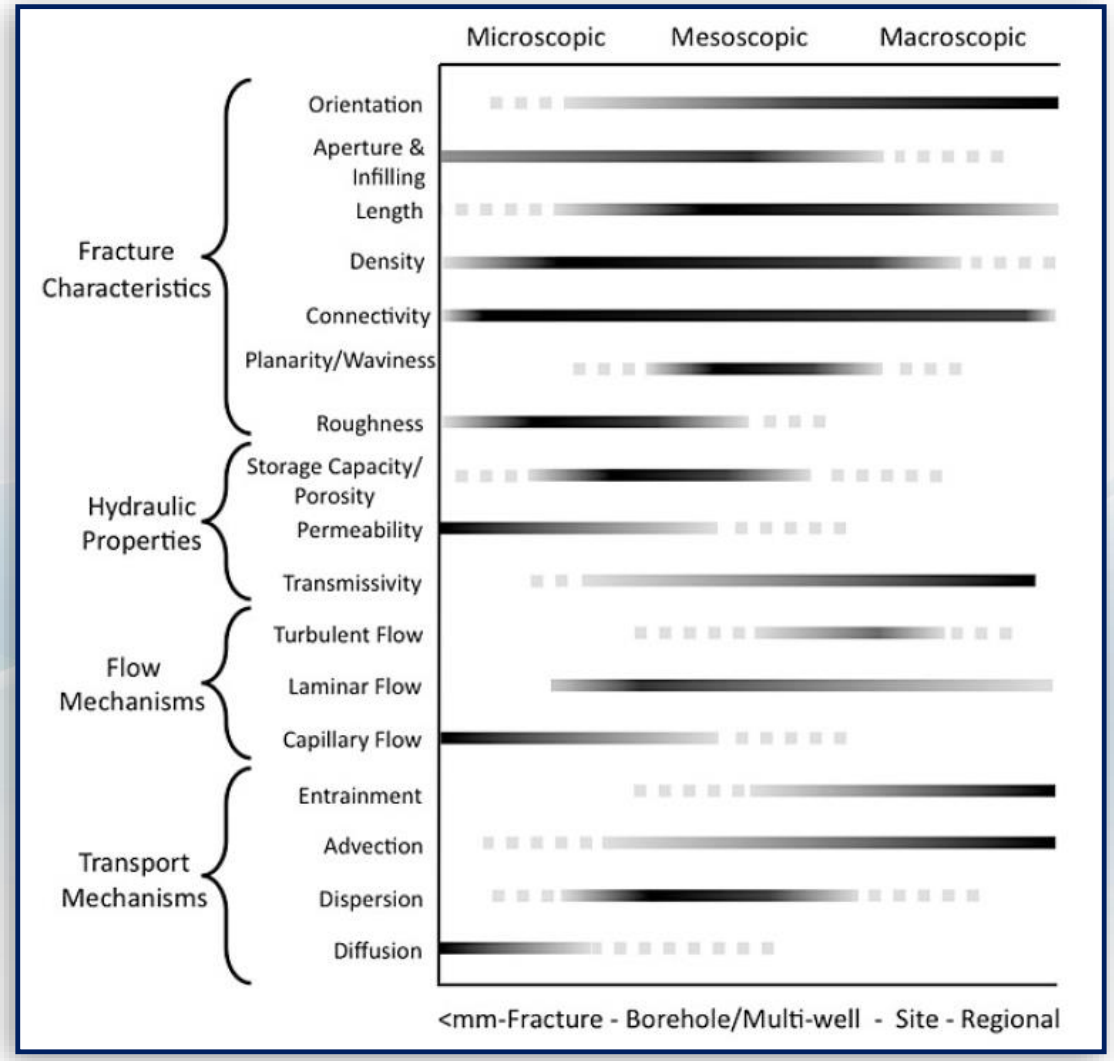
- Flow through bedrock can be significantly more complex than flow through unconsolidated materials
- Fractures can introduce significant heterogeneity
- Flow through unconsolidated materials governed by their hydraulic conductivity, porosity and hydraulic gradients
- Flow through bedrock also depends on density and connectivity of fractures, their aperture and orientation
- A sufficiently dense network of fractures that are well connected may behave like an unconsolidated porous medium

Fracture Flow Dynamics



Courtesy of Solidity Project

Fracture Flow – Scale Dependency



Courtesy of ITRC

Fracture Flow – Scale Dependency

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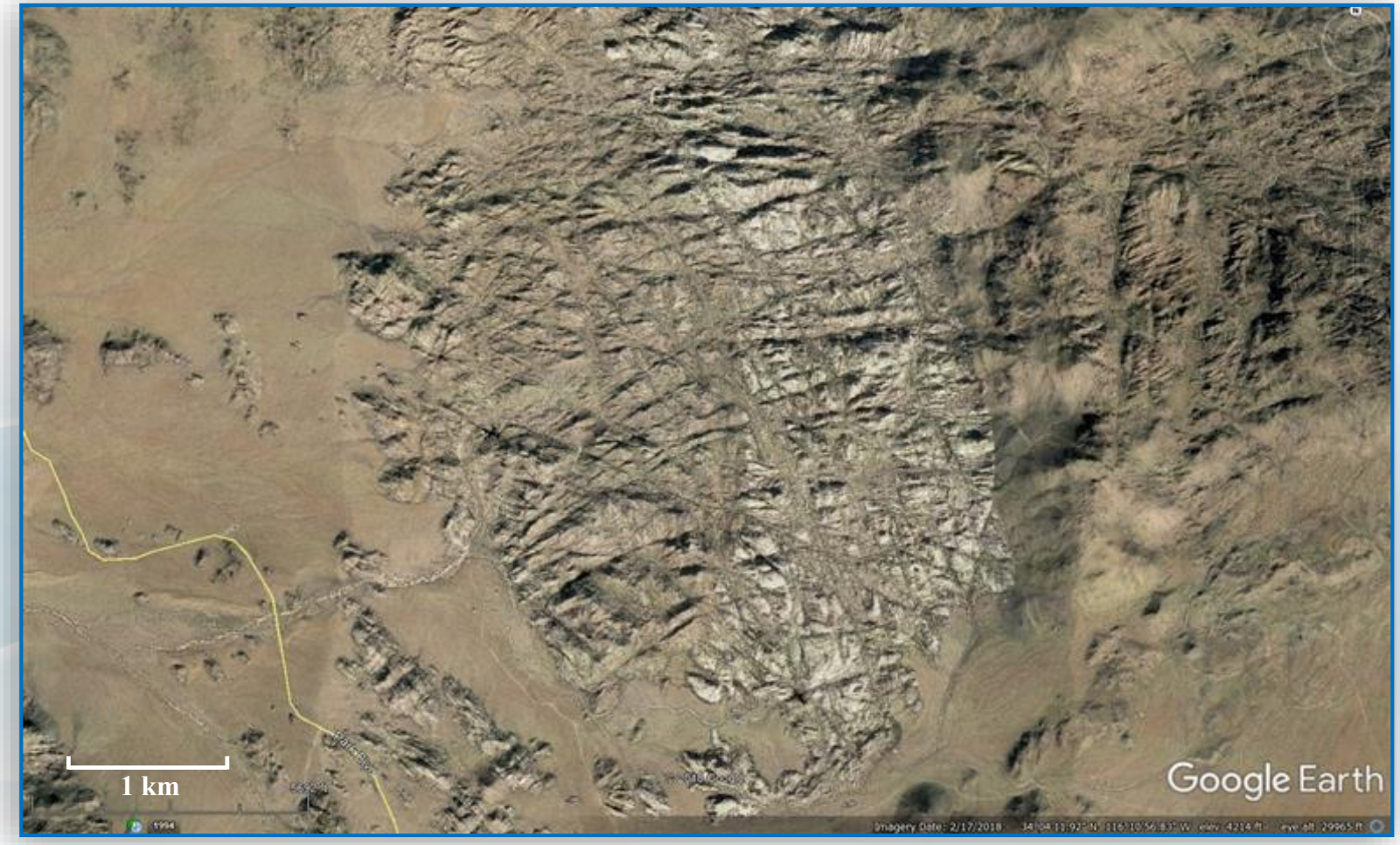
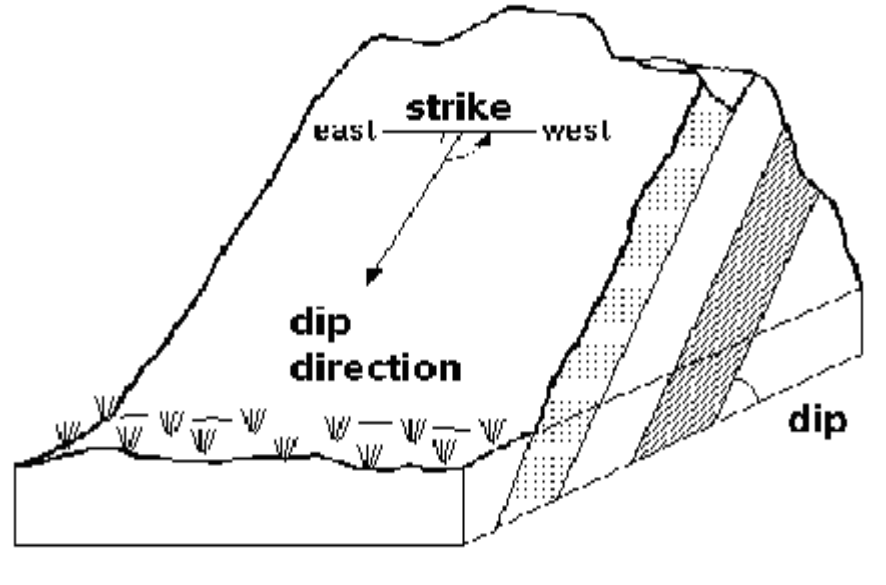
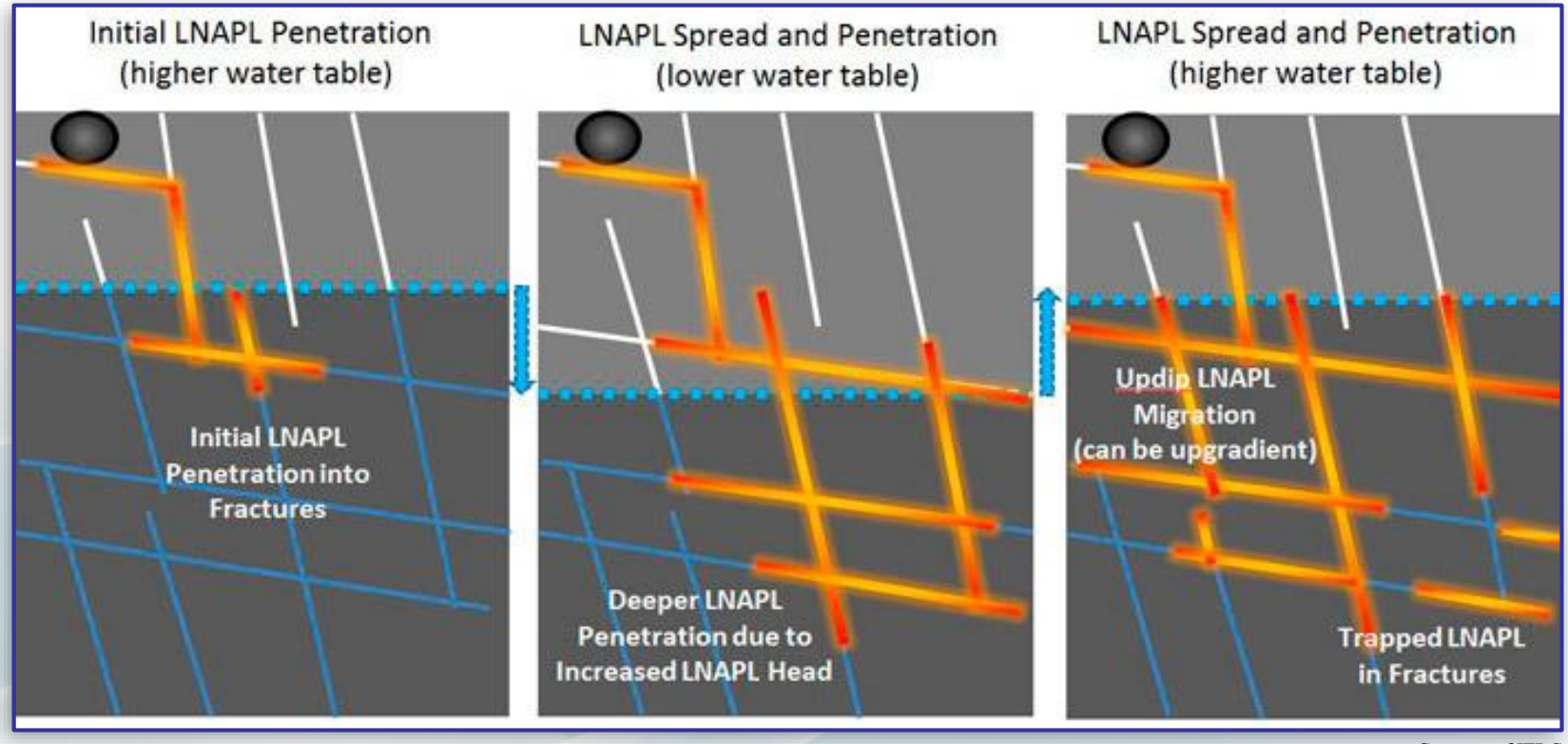


Fracture Mapping



Planes such as fractures, stratigraphic bedding and other structural features – we describe their orientation by strike and dip

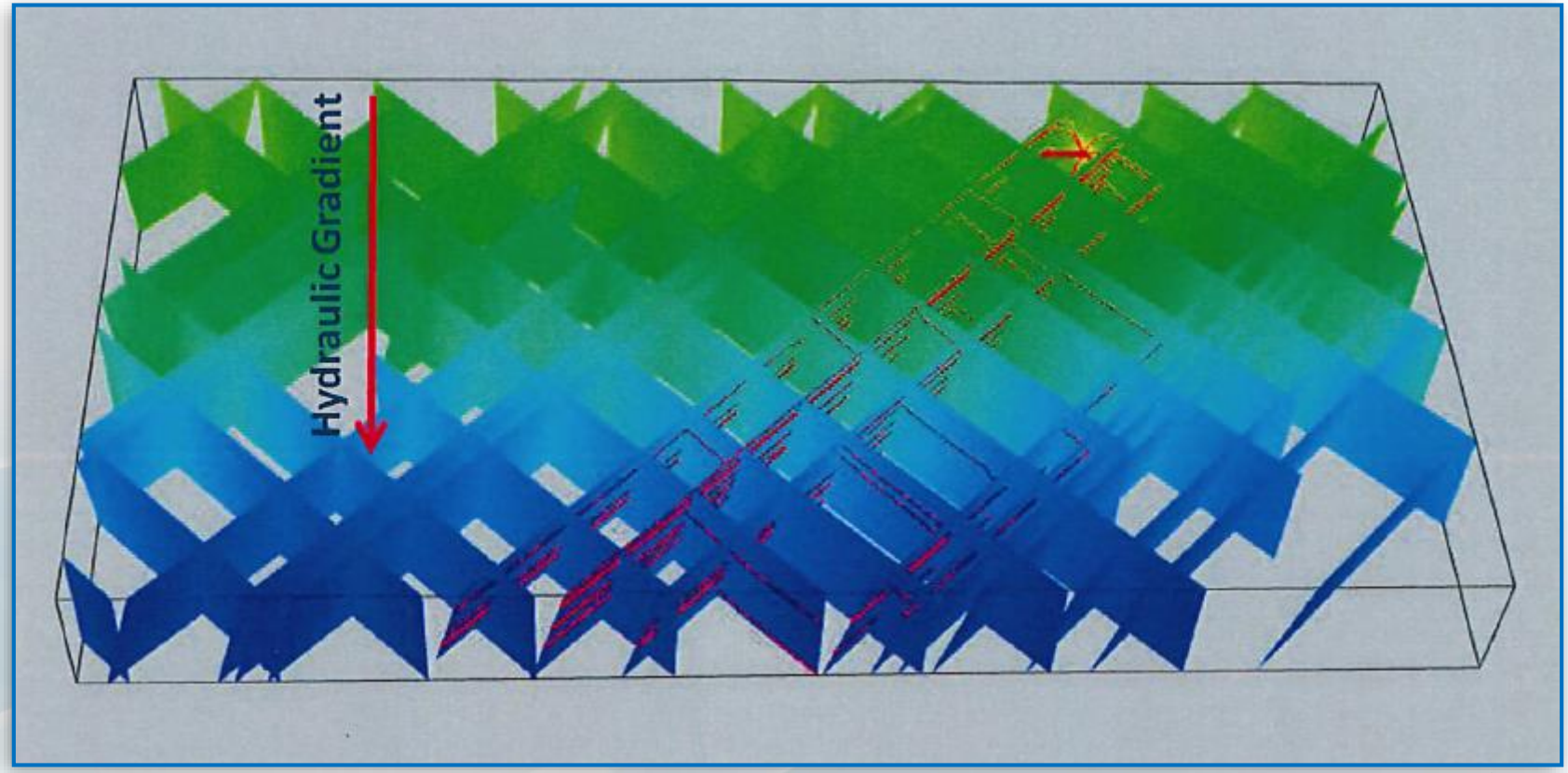
Fracture Flow Dynamics



Courtesy of ITRC

NAPL adds additional complexity – multiphase flow

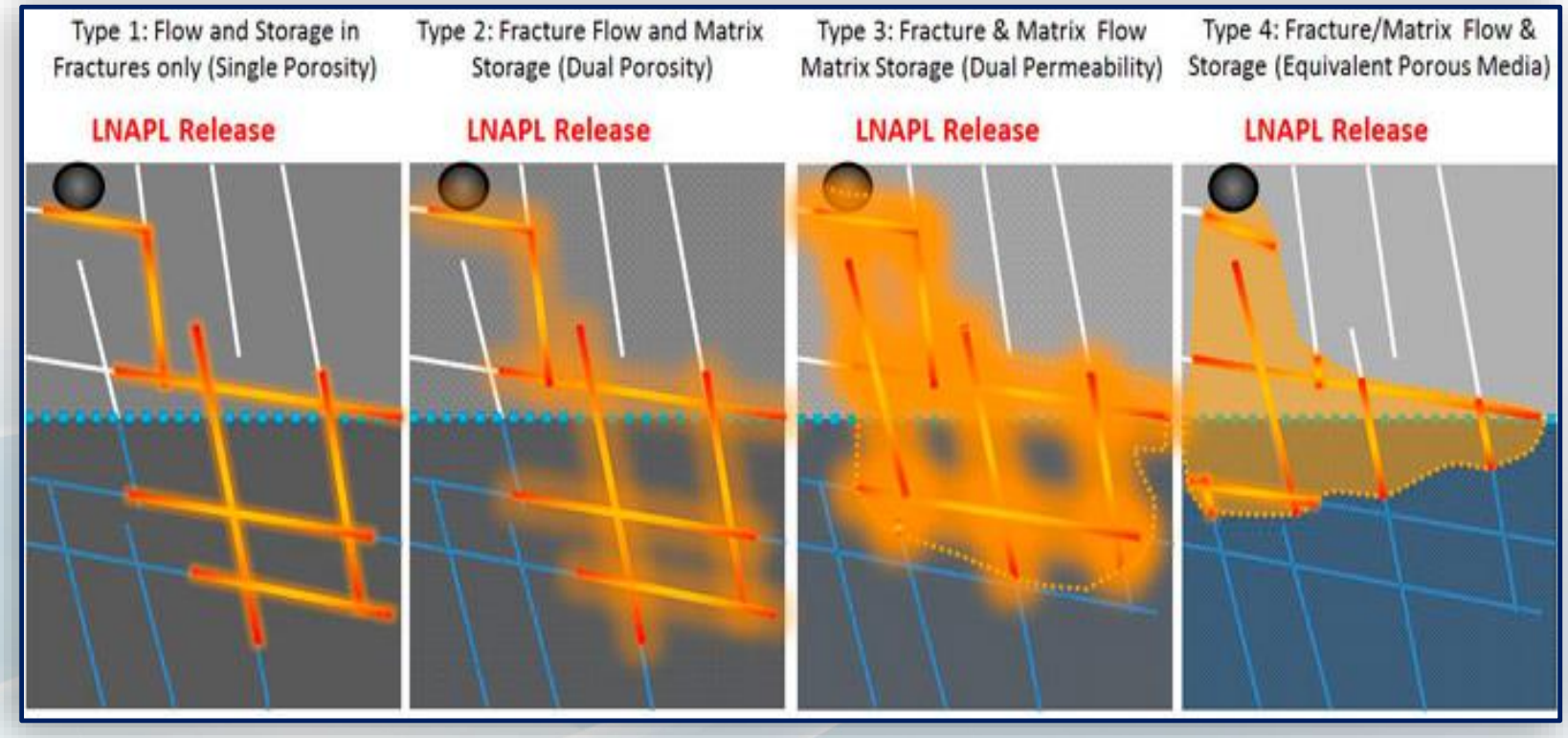
Fracture Flow Dynamics



Courtesy of SABCS

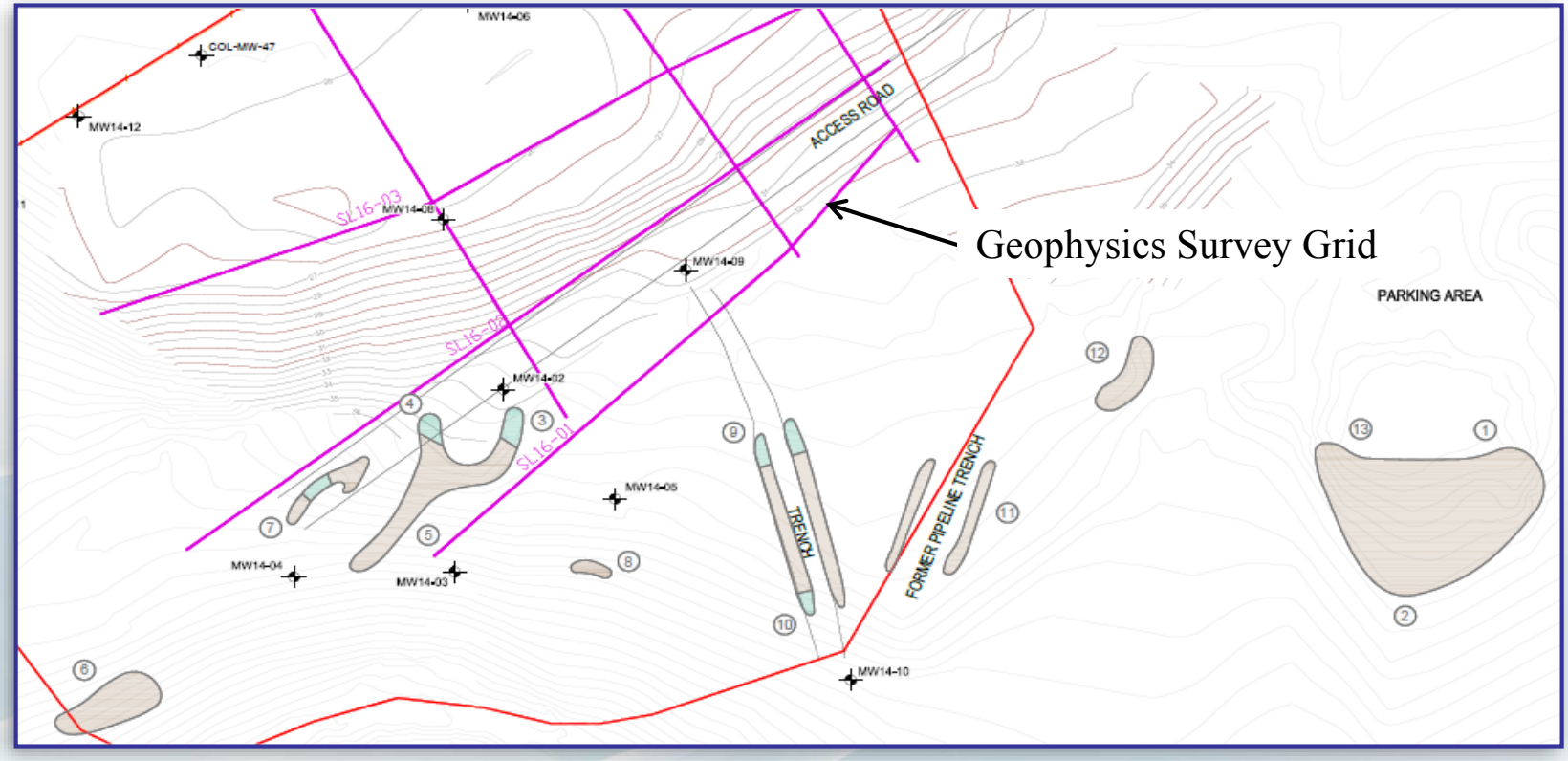
Fractures often act as preferential pathways that can transmit contamination cross gradient

Fracture Flow Dynamics



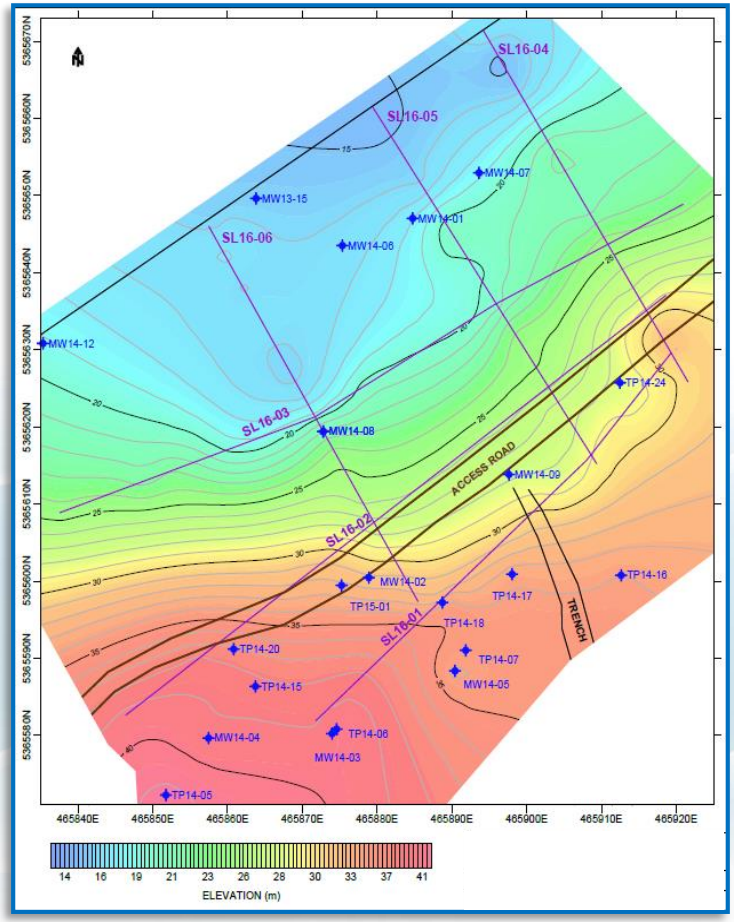
Primary porosity versus Dual Porosity

Site Bedrock Assessment

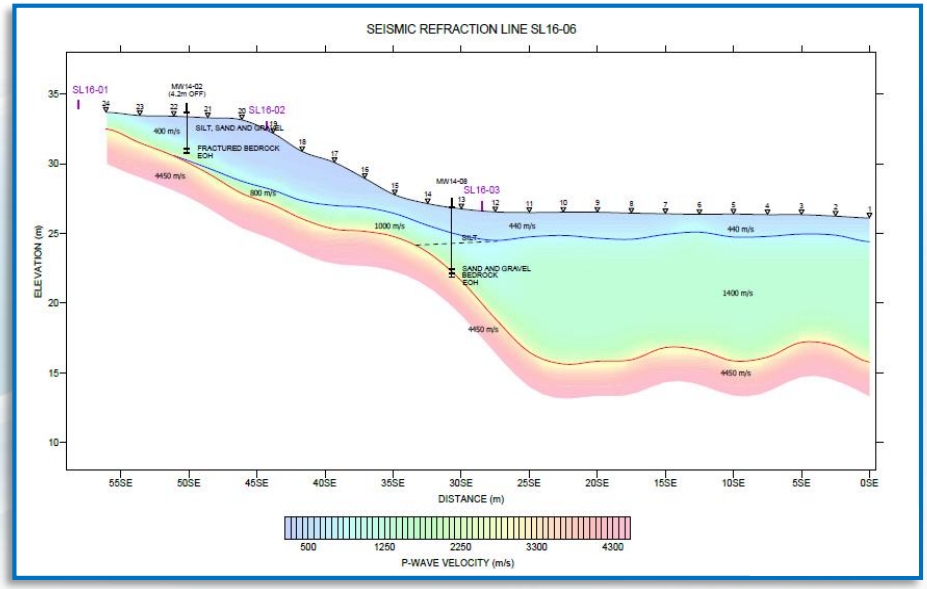


Bedrock outcrops catalogued and individually mapped for fracture orientations, unit contacts, other structural features

Geophysics Survey



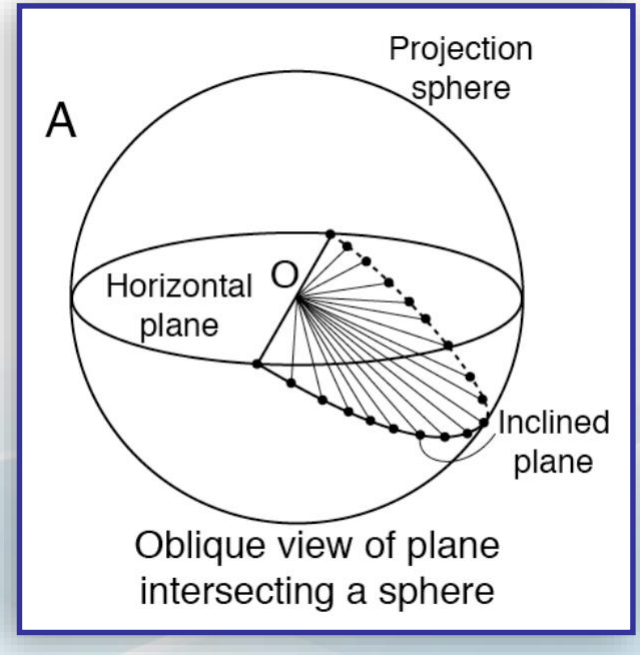
A seismic refraction survey was completed to determine subsurface bedrock topography to assist with delineation and remediation

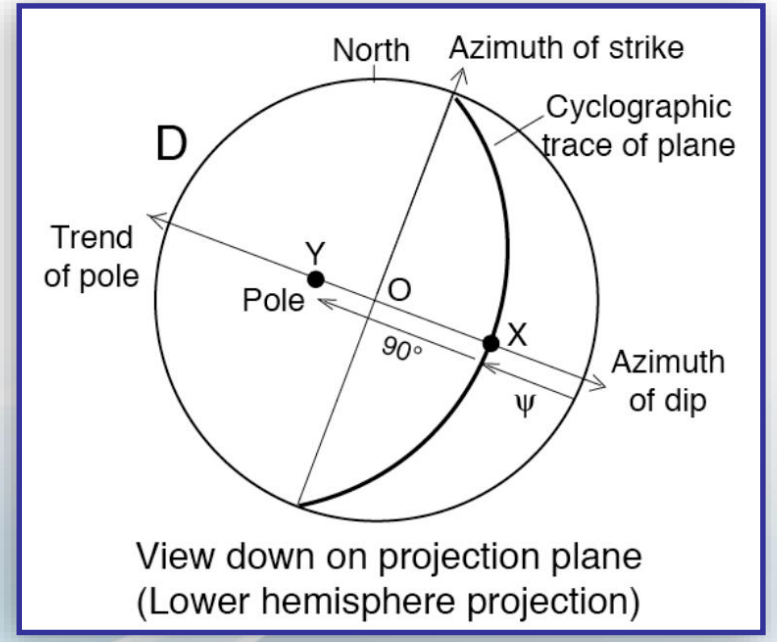


Fracture Mapping

Fracture Mapping Assessment Compass and Inclinometer					Colwood FOD, Colwood, BC GeoID Output		
Area	Strike (N)	Dip	Dip Orientation	NAPL	Strike (N)	Dip	Dip Orientation
1	161	79	E	-	341	79	E
1	148	75	E	-	328	75	NE
1	188	76	E	-	8	76	E
2	117	86	W	-	117	86	SW
2	70	84	SE	-	70	84	S
2	8	83	E	-	8	83	E
3	36	66	E	Y	36	66	SE
3	106	53	N	Y	286	53	N
3	110	63	N	Y	290	63	N
3	194	68	E	Y	14	68	E
3	89	63	N	Y	269	63	N
3	113	68	N	-	293	68	NE
3	193	65	E	-	13	65	E
3	167	40	W	-	167	40	W
3	137	7	S	Y	137	7	SW
3	176	3	W	-	176	3	W
4	290	75	N	Y	290	75	N

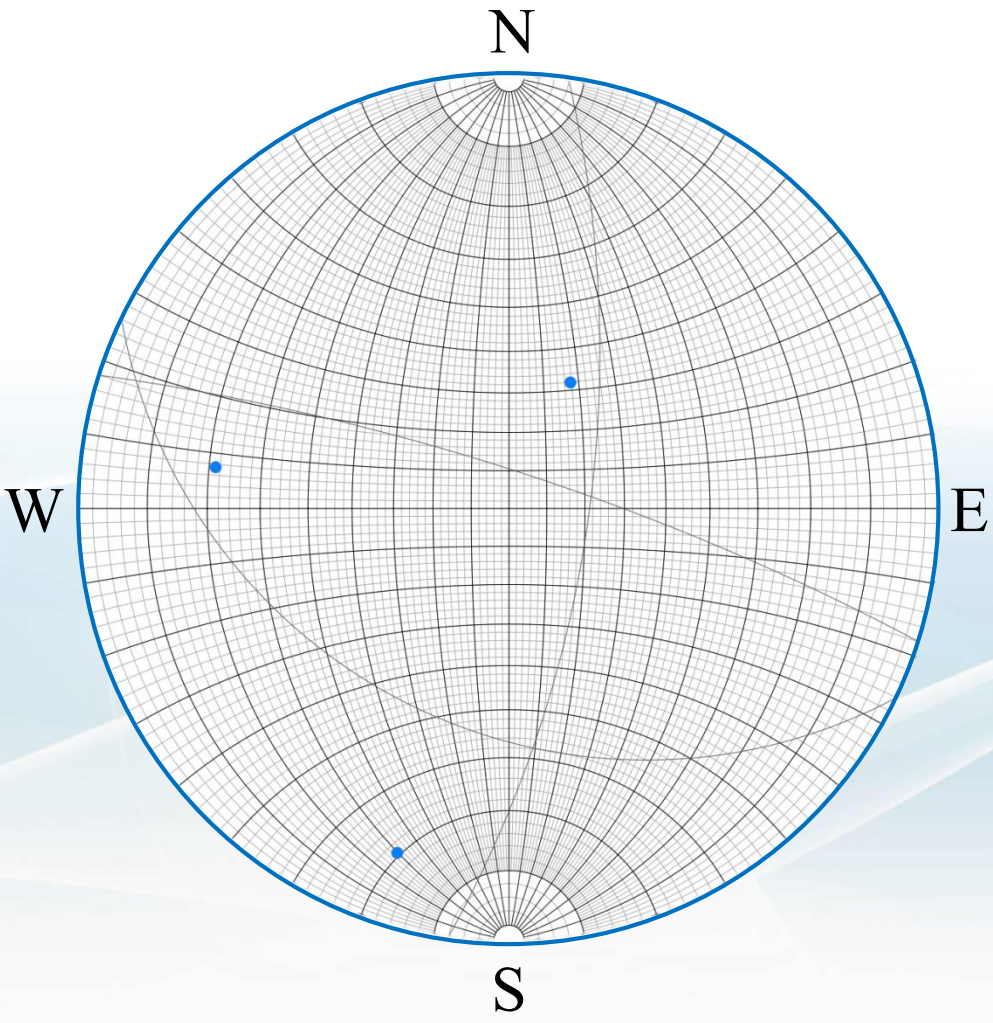
Stereonet Analysis





- When a plane is projected within a sphere, its intersection with the sphere surface forms an arc unique to that plane
- All planes have a unique axis, or pole, that is 90° to the surface of the plane; plots as a point on the sphere surface

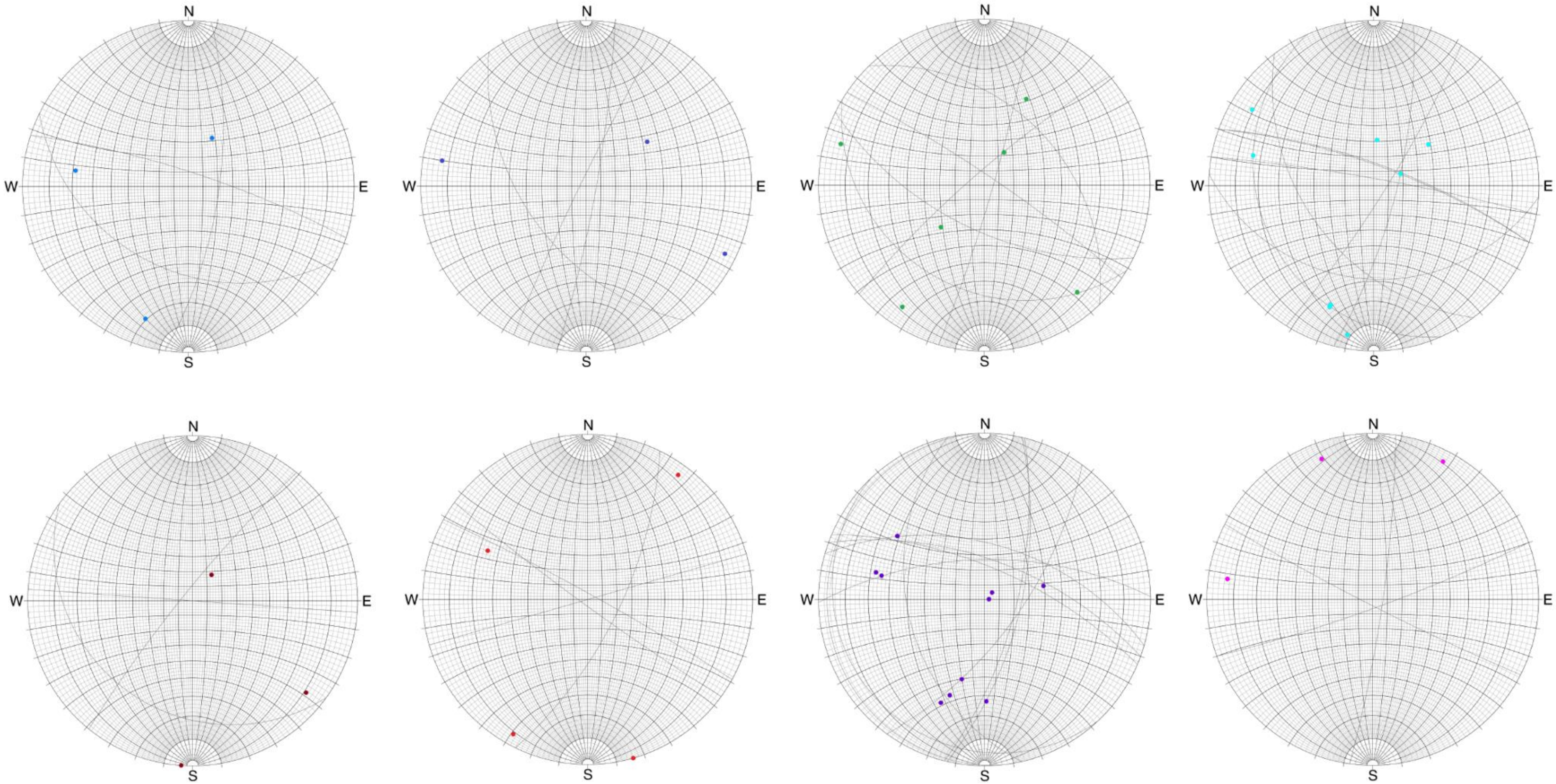
Stereonet Analysis



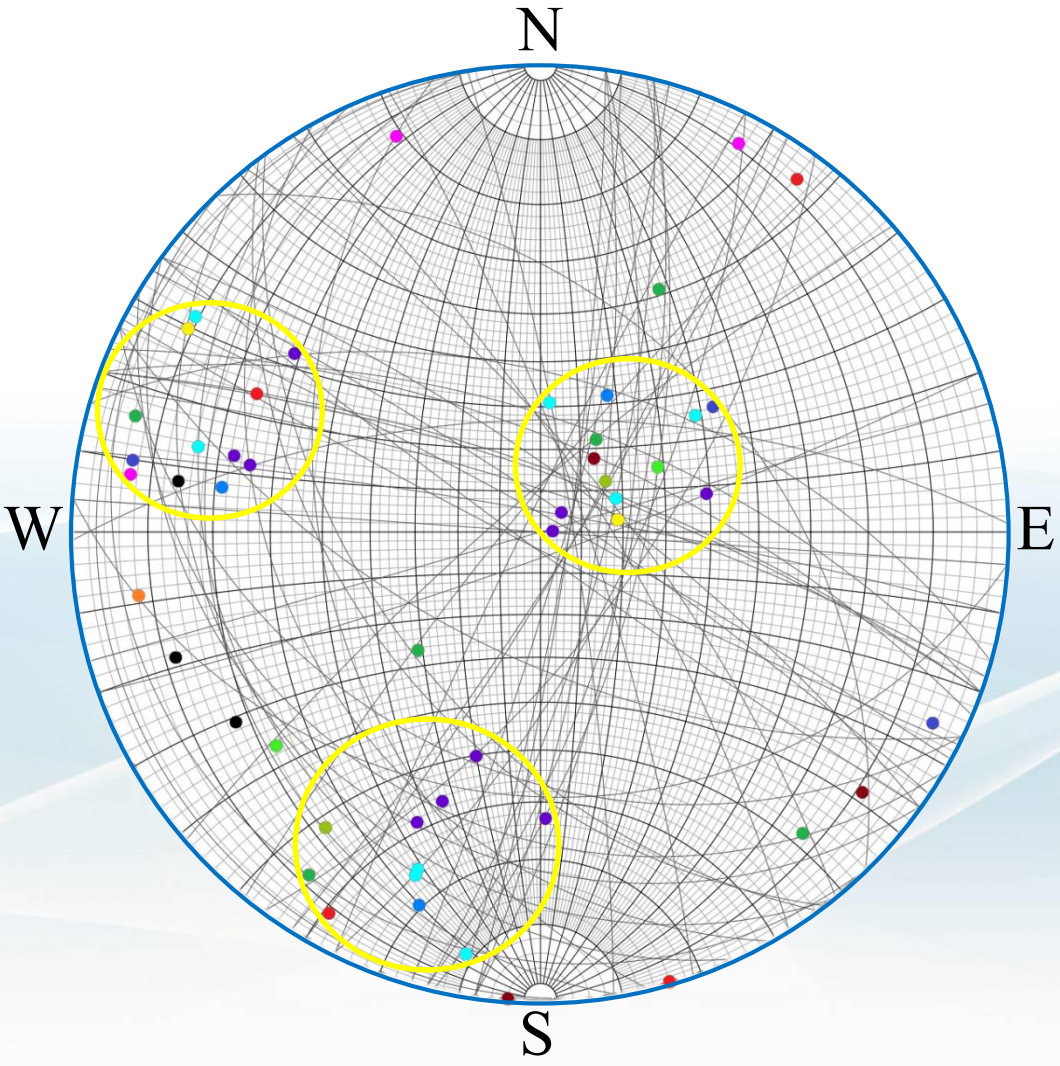
Stereographic projections are analytical tools routinely used by geologists to analyze planar features

Plotting the poles generally makes observation of relationships between features easier to distinguish

Stereonet Analysis



Composite Fracture Analysis

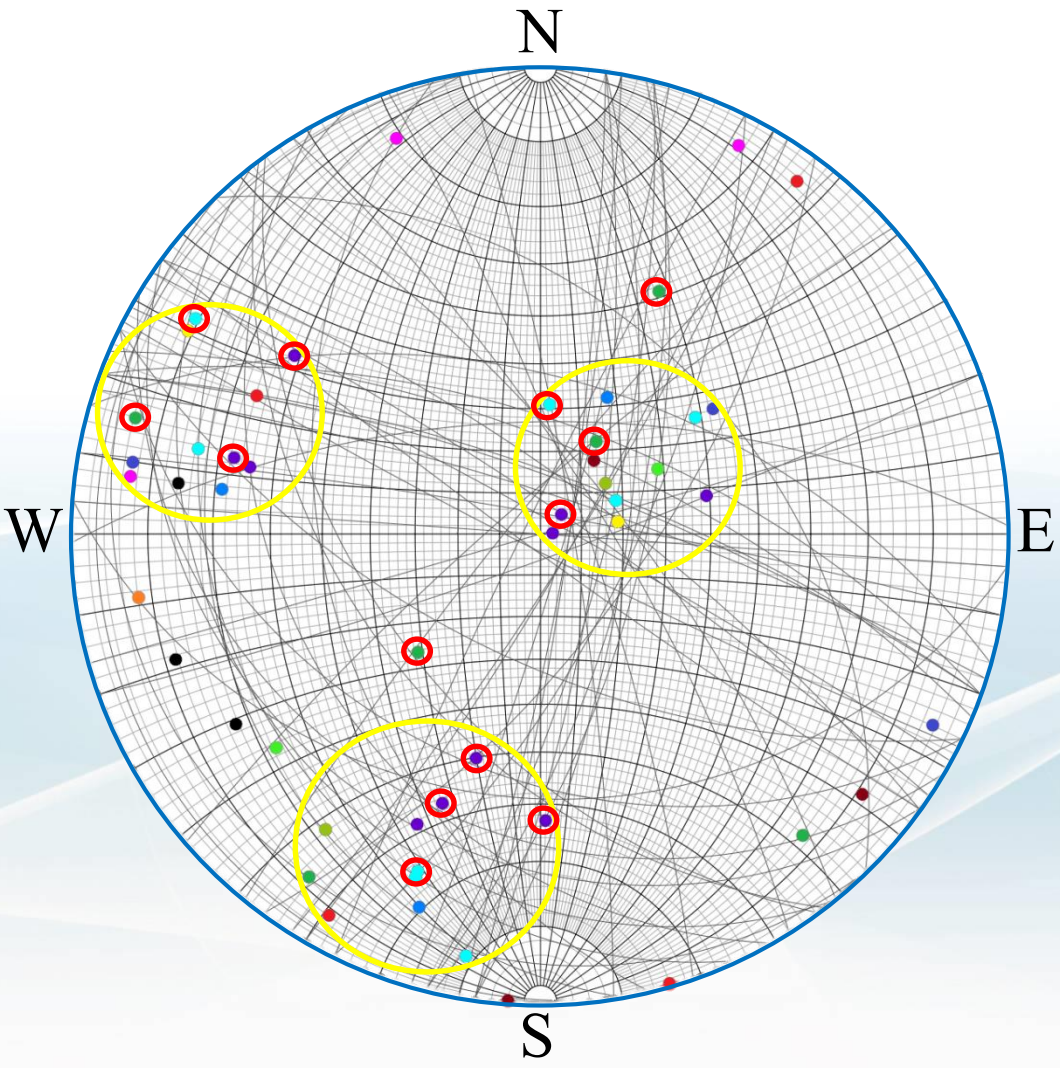


All Outcrop Areas

Area	Colour	No. of Data Point
1		3
2		3
3		10
4		8
5		3
6		3
7		2
8		2
9		6
10		3
11		2
12		1
13		4

Predominant Fracture Orientations Across Site

Composite Fracture Analysis



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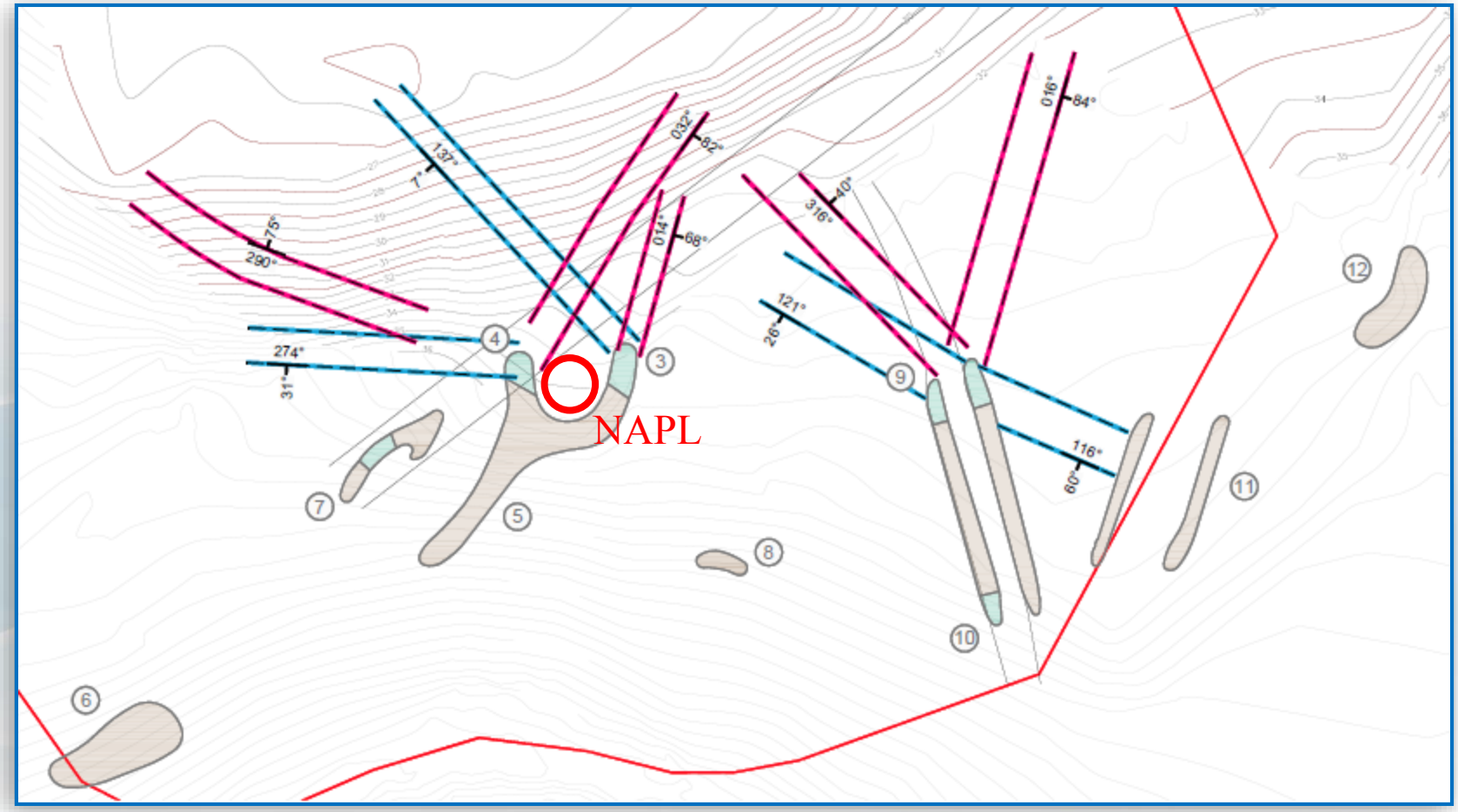
Predominant Fracture Orientations Across Site

Fractures with NAPL

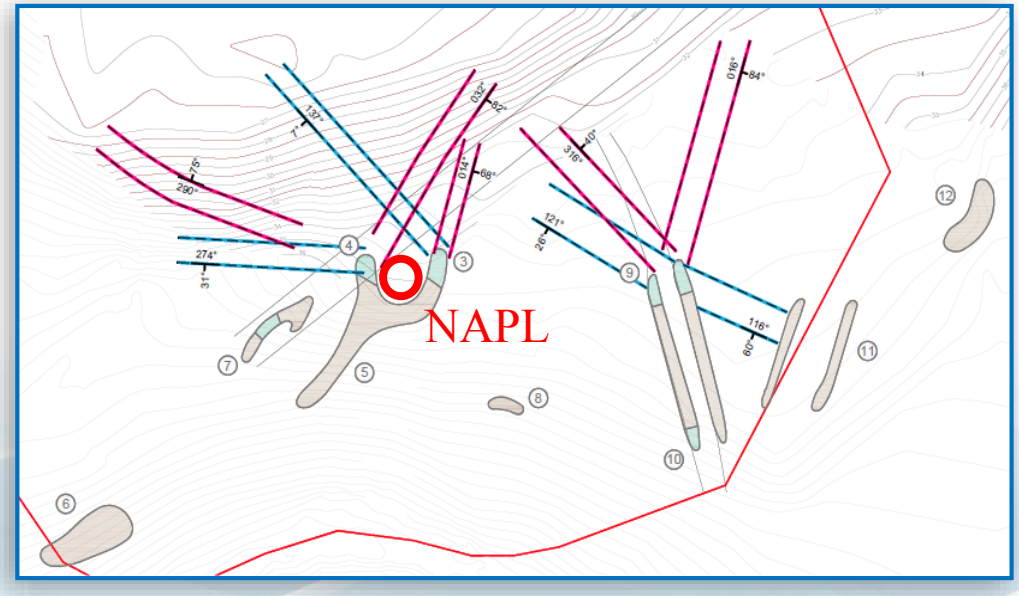
Delineation Target Zones

- Based on identification of the primary fractures linked to presence of NAPL, delineation targets were developed for drilling
- The orientation of these features was extrapolated from the area where NAPL was exposed; also from the former pipeline area below the tank farm, where minor staining was observed
- Extrapolated targets must be slope-corrected
- Important to drill perpendicular to targets

Delineation Target Zones



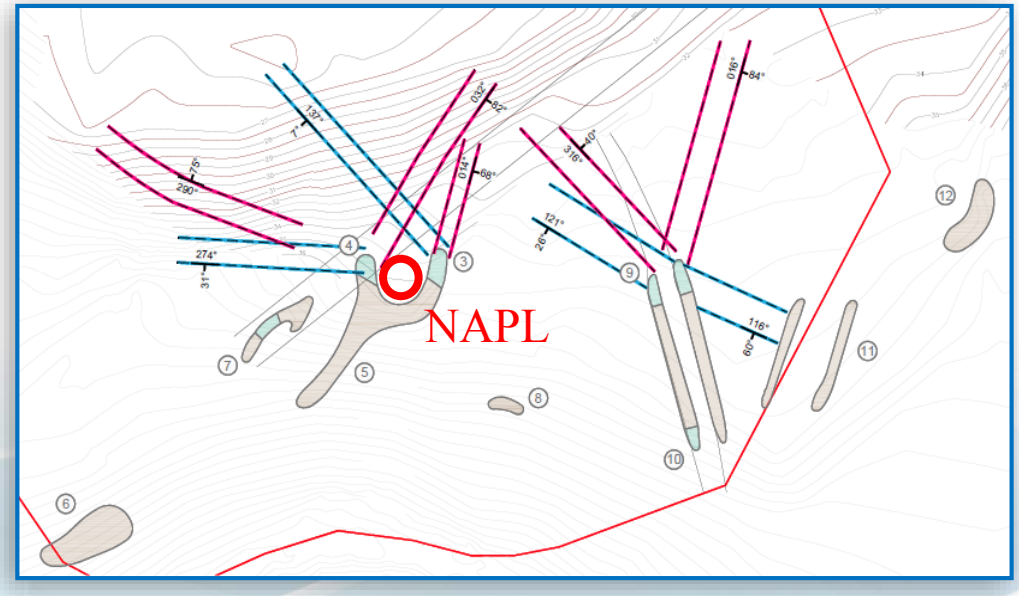
Delineation Target Zones



- Target zones were colour-coded by priority

- Red targets highest priority, greatest potential for down gradient migration of contamination
- Blue targets secondary priority, fractures dip back into the hill

Delineation Target Zones



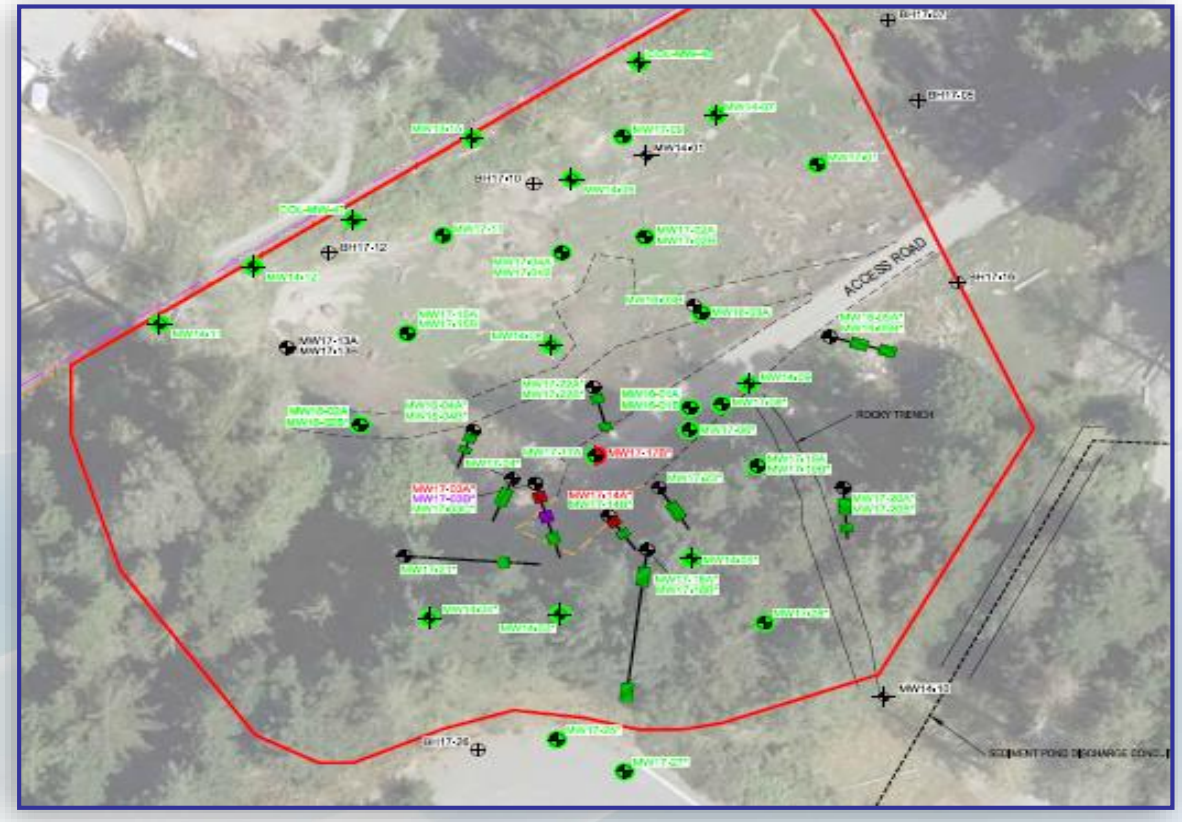
- Drilling conducted to evaluate all zones
- Diamond coring to permit observation of fractures

- Required angle drilling, included several nested wells
- Extrapolated target zones up gradient to evaluate most likely migration pathways between NAPL and former tank farm

Assessment Results

- NAPL was not found at any locations drilled
- No evidence of staining or oxidation on fracture surfaces except in immediate vicinity of road side NAPL exposure
- Pressure transducers with data loggers were subsequently installed at multiple locations to monitor water table response to precipitation events
- Data corroborated hydraulic connection between the NAPL area and the target zones investigated

Assessment Results

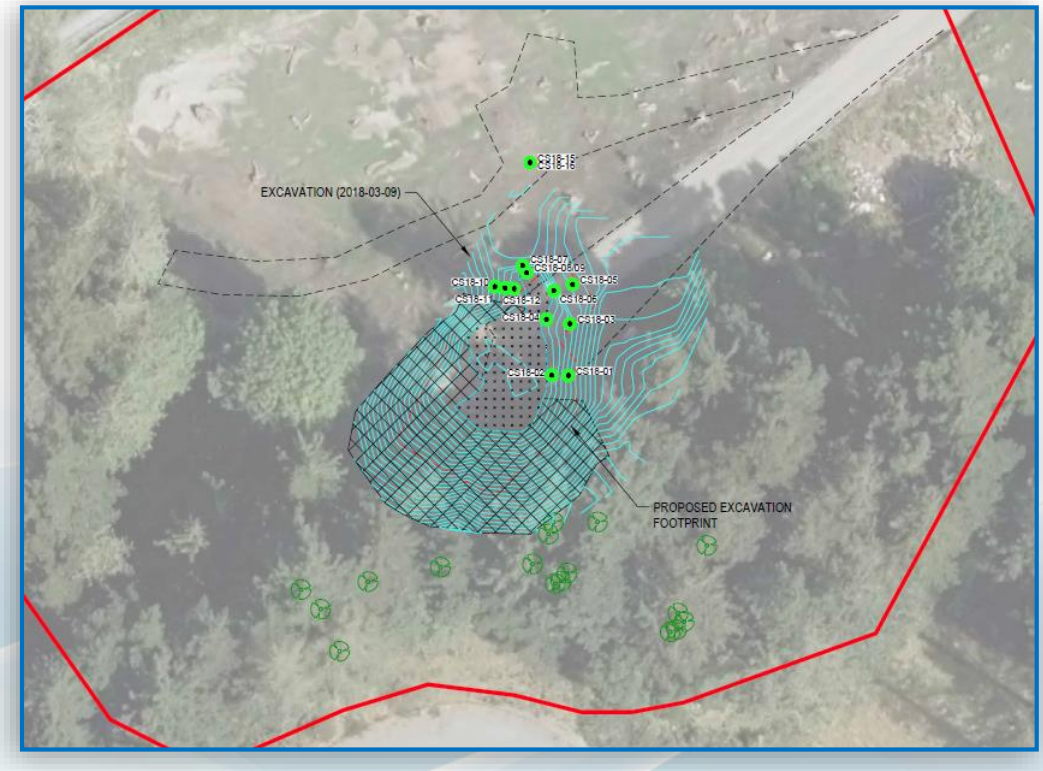


- Dissolved hydrocarbons (EPH and PAHs) highly localized to immediate vicinity of NAPL plume

Assessment Results

- Concluded that the NAPL was associated with historic asphalt manufacturing facility
- Structural analysis provided a high degree of confidence that the NAPL was localized and immobile
- Relatively low cost investment relative to other options
- Simply drilling up gradient or down gradient of the NAPL would not have provided the same level of confidence in a fractured bedrock environment
- Remedial options analysis determined that excavation and disposal was the preferred remediation strategy

Remediation



Approximately 2,600 m^3 of contaminated rock and overburden was removed through blasting and excavation

Remediation

Blast mats installed prior to blasting rock

Mechanical excavation used in tricky areas

Final excavation footprint

Clean backfilled excavation floor

Remediation

Contaminated waste rock stockpiled on liner

Stockpiled soil prior to disposal

Placement of topsoil over backfilled excavation

Final layer of hydroseeding

Summary

Shallow depth and localized nature of bedrock contamination was ideal for remediation via excavation and disposal

Clean excavation margins confirmed the contamination source was localized, likely associated with historic asphalt operation

Structural geological interpretation of contaminated fractures provided a defensible strategy and optimal delineation targets at relatively low cost


QUESTIONS?

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