WHARF RESOURCES (U.S.A.), INC.
WHARF AND GOLDEN REWARD MINES
LEAD, SOUTH DAKOTA

SPILL CONTINGENCY PLAN

(SPILL PREVENTION CONTROL AND COUNTER MEASURE PLAN)

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1.0 SITE DESCRIPTION

The Wharf Mine is an open pit, heap leach, gold and silver mine with a carbon in column recovery system processing facility. The mine is located approximately 3.5 miles west of Lead, South Dakota. The mine is accessed by the Nevada Gulch Road and then the Wharf Road, an access road constructed on privately held property. The legal description of the land is: Sections 25, 26, 33, 34, 35 and 36 of T.5N., R.2E., and Sections 1, 2, 3 and 4 of T.4N., R.2E., Black Hills Meridian, Lawrence County, South Dakota.

The mine is permitted by the South Dakota Department of Environment and Natural Resources, Board of Minerals and Environment, with 5 permits: numbers 356, 434, 435, 464 and 476.

The Golden Reward Mine is located in the SE ¼ of Section 1 and NE ¼ of Section 12, Township 4 North, Range 3 East, in Lawrence County, South Dakota. Gold and silver mining and milling had taken place in this area since 1877. However, no mining, leaching, or gold recovery has occurred at the mine site since 1997. The Golden Reward Mine site underwent final reclamation in 2002 and was granted Reclamation Bond Release in 2009.

In 2012, Wharf Resources was granted a new large scale mining permit (Permit No. 476) which would allow Wharf to mine new areas including Green Mountain, Bald Mountain, and part of Golden Reward.

2.0 SPILL CONTINGENCY PLAN

Wharf Resources (U.S.A.), Inc., has developed a contingency plan to deal with any emergency situation arising from an accidental spill of substances with significant contaminant potential. This Spill Contingency Plan (SCP) has been prepared in accordance with 40 CFR 116, pursuant to chapter 311 of the Clean Water Act and South Dakota Administrative Rules Chapter 74:34:01. The plan is designed to guide responders through the processes for first aid, containment and clean-up, and notification requirements for accidental spills at the site. The SCP describes procedures for handling on-site spills of:

30% Liquid Cyanide Solution, Process Leach Solution, Fuel, Chemicals and Reagents

As part of the SCP, Wharf shall routinely conduct in-house inspections of the mine facility for situations and/or conditions that may represent potential spill hazards. Appropriate actions will be taken to minimize the potential for the occurrence of a spill or release of toxic materials.

2.1 **Cyanide**

Hazards

- Because of the toxicity of sodium cyanide, all persons working with it should be completely familiar with and observe the established safety practices.

  ⇒ Sodium Cyanide is a rapidly fatal poison when taken internally.
  ⇒ Prolonged contact with the skin may cause irritation and possibly poisoning, particularly if there are open wounds or skin abrasions.
  ⇒ Sodium Cyanide is alkaline and causes eye burns. Severe damage can occur.

- **Sodium Cyanide in contact with acids or weak alkalis liberates highly toxic and flammable Hydrocyanic Acid (HCN) Gas.**
- **Toxic amounts of HCN can be liberated from water solutions of sodium cyanide.**
- **Never work alone when working on or with Cyanide.**
- **Consult MSDS prior to working with cyanide.**
- **Contain spills or clean up solutions to the extent safely possible.**
- **If contact made with skin or eyes flush with copious quantity of water.**

2.1.1 **Emergency Response**

EMERGENCY ACTION
(PERSON DISCOVERING THE SPILL)

Contained Spill
Contained Spills are unplanned releases of cyanide solution onto some type of secondary containment. Examples include the cyanide storage tank overflowing into secondary containment or pipes leaking over liner. In the event of a contained spill;

- **Safety –**

  - Protect Yourself from Spills - Don't Become a Casualty.
    - ♦ Never enter an area where there is a cyanide spill unless the area has been determined to be safe to enter with the HCN (Hydrogen Cyanide) detectors
    - ♦ Never assist victims unless you, the rescuer, is wearing the proper personal protective equipment (PPE) for potential cyanide touching.

In the event a spill of highly concentrated cyanide solution (30% Cyanide Solution) to secondary containment has occurred,

- Personal Protective Equipment (PPE) Required During Cleanup

- ♦ Full rubber suits
- ♦ Rubber boots and gloves
- ♦ Face shield
- ♦ Safety goggles
- ♦ Portable HCN monitor

Steel toe boots
Hard hat
SCBA (if HCN > 4.7 mg/L detected)

- If HCN monitor readings are 4.7 ppm or greater follow evacuation procedures for all personnel

- Use the buddy system - No one is to perform cyanide neutralization and cleanup procedures without adequate personnel standing by in a safe place in the event of an emergency. The stand-by person is to be suited up with the same safety gear required for the person doing the neutralization and cleanup.

- Follow the decontamination procedures for the secondary containment affected by the release.

In the event a spill of low concentrated cyanide solution (Process Leach Solution, < 50 mg/L) to secondary containment has occurred,

- PPE required
  - ♦ Rubber or nitrile gloves
  - ♦ Hard hat
  - ♦ Safety glasses

  Steel toe boots

- Follow the decontamination procedures for the secondary containment affected by the release.

<u>Uncontained Spill</u>
Uncontained spills are unplanned releases of cyanide solution off containment and onto soil. Uncontained spills include:

- Spills from ponds including: pond leakage, overtopping, and dam failure.

- Spills at leach pads including: ruptured pipes, drip lines too close to the edge, inadvertent openings of valves, and seepage or flow from the leach pad base.

- Spills from the plant, including: sump overflows, broken pipes, etc.

Depending upon the concentration of cyanide in the solution released, the following actions will be taken.

<u>HIGH CONCENTRATION 30% LIQUID CYANIDE SOLUTION SPILL</u>

In the event of a highly concentrated uncontained cyanide solution spill ;
- **CALL A MAYDAY!**

- **Safety –**

  - Protect Yourself from Spills - Don’t Become a Casualty.
    - ♦ Never enter an area where there is a cyanide spill unless the area has been determined to be safe to enter with the HCN (Hydrogen Cyanide) detectors
    - ♦ Never assist victims unless you, the rescuer, is wearing the proper personal protective equipment (PPE) for potential cyanide contact.

  - Personal Protective Equipment (PPE) Required
    - ♦ Full rubber suits
    - ♦ Rubber boots and gloves
    - ♦ Face shield
    - ♦ Safety goggles
    - ♦ Portable HCN monitor
    - Steel toe boots
    - Hard hat
    - SCBA (if HCN > 4.7 mg/L detected)

  - If HCN monitor readings are 4.7 ppm or greater follow evacuation procedures for all personnel

  - Use the buddy system - No one is to perform cyanide neutralization and cleanup procedures without adequate personnel standing by in a safe place in the event of an emergency. The stand-by person is to be suited up with the same safety gear required for the person doing the neutralization and cleanup.

- **Spill Response –**

  - If necessary, render Emergency First Aid.
    - ♦ Never exceed your trained capacity to render First Aid
    - ♦ Administer cyanide antidote using amyl nitrite and oxygen.

  - Response and Cleanup
    - ♦ Stop the spill at the source
    - ♦ Contain run-off by damming solution with available materials or re-directing flow back onto containment.
    - ♦ Sample spill solution for WAD cyanide
    - ♦ First dilute the cyanide spill with caustic solution or water, then neutralized with a 1:2 solution of bleach and water
    - ♦ Remove contaminated soil and place on containment
    - ♦ Reneutralize the area with the 1:2 bleach solution
    - ♦ Sample soil in spill area and analyze for WAD cyanide. If results are below 0.5 mg/L, the area is considered neutralized. If results are above 0.5 mg/L, the area must be reneutralized and resampled.

- Notify Supervisor and Environmental Personnel and Give Information On:
  - ♦ Spill location

- What, when, where, and how much was spilled
- Injuries and problems caused by the spill
- Emergency actions you have taken

- Maintain Watch on the Spill Until Otherwise Advised by Supervisor.

- Fill Out Spill Report (Appendix A) and Incident Report Forms. Submit forms to supervisor.

<u>LOW CONCENTRATION LIQUID CYANIDE SPILL</u>
<u>(Process Leach Solution)</u>

- **CALL MAYDAY! MAYDAY! MAYDAY!**

- Protect Yourself from Spills - Don't Become a Casualty.
  - Never enter an area where there is a cyanide spill unless the area has been determined to be safe to enter with the HCN (Hydrogen Cyanide) detectors
  - Never assist victims unless you, the rescuer, is wearing the proper personal protective equipment (PPE) for potential cyanide contact.

- **<u>Spill Response</u> –**

- PPE required
  - Steel toe boots rubber or nitrile gloves
  - Hard hat
  - Safety glasses

- Response and Cleanup
  - Stop the spill at the source
  - Contain run-off by damming solution with available materials or re-directing flow back onto containment Sample spill solution for WAD cyanide
  - First dilute the cyanide spill with water, then neutralized with a 1:2 solution of bleach and water
  - Remove contaminated soil and place on containment
  - Reneutralize the area with the 1:2 bleach solution
  - Sample soil in spill area and analyze for WAD cyanide. If results are below 0.5 mg/L, the area is considered neutralized. If results are above 0.5 mg/L, the area must be reneutralized and resampled.

- Notify Supervisor and Environmental Personnel and Give Information On:
  - Spill location
  - What, when, where, and how much was spilled
  - Injuries and problems caused by the spill
  - Emergency actions you have taken
- Maintain Watch on the Spill Until Otherwise Advised by Supervisor.

- Fill Out Spill Report (Appendix A) and Incident Report Forms. Submit forms to supervisor.

EMERGENCY ACTION
(SUPERVISOR)

High and Low Cyanide Concentration Spills
The immediate supervisor responding to the scene of a cyanide spill will take the following actions:

- Wear the proper PPE as required above, depending upon the cyanide concentration of the spill

- Ensure the above listed safety and response procedures are being followed by all personnel involved in the spill response including the supervisor

- Eliminate or reduce health or life hazards and perform first aid. Arrange for removal and transport of injured and notify hospitals, doctors, etc. Emergency Medical Services will not transport contaminated patients. The patients must be removed from a decontaminated area (cold zone).

- Assess the Problem and Damage. Determine:
    - ♦ Spill source, quantity, estimated concentration of cyanide, and extent of contamination.
    - ♦ Health and environmental hazards - toxic vapor, groundwater and surface water contamination.

- **EVACUATE ALL UNNEEDED PERSONNEL AND RESTRICT ENTRY TO THE AREA.**

- NOTIFY: While emergency actions are being taken, contact one of the following mine personnel:

Name	Work Phone	Home / Cell Phone	Radio
Lynne Blackman	584-4190	(605) 641-7377	207
John Key	584-4113	(605) 580-7919	60
Amy Gilpin	584-4112	(402) 630-1159	
Ken Nelson	584-4177	(605) 580-0441	106
Tony Auld	584-4146	(605) 591-9837	25
Matt Zietlow	584-4155	(775) 304-1682	108
Jay Hasquet	584-4166	(307) 689-6222	30
Plant Foreman	584-4148		211

On weekends call Management on Duty.

- Information to be given will include:
  - Injury Information.
  - Immediate health or environmental hazards such as cyanide (CN) vapors in the air, water pollution, etc.
  - What, where, when, and how the spill happened.
  - Volume and concentration of spilled material.
  - Containment and neutralization actions taken.

- Ensure Spill Report and Incident Report Forms have been filled out completely and correctly.

EMERGENCY ACTION
(MANAGER)
LIQUID CYANIDE AND MET PROCESS SOLUTION

High and Low Cyanide Concentration Spills

- Managers will take the following actions:

- Ensure supervisor emergency actions (above) have been taken.

- Issue necessary warning of potential hazards.

- Determine on-site damage and extent of spill.

- Determine containment and/or neutralization measures to be continued or initiated.

- Contact Environmental Personnel and they will notify the following immediately upon becoming aware of the spill or as soon as is practical - no later than 24 hours:

A. **State Agencies**

1. South Dakota Department of Environment and Natural Resources

	Minerals and Mining Program	(605) 773-4201
or	Point Source Control Program	(605) 773-3351
or	Groundwater Quality Program	(605) 773-3296
or	State Radio	(605) 773-3536

After business hours or on weekends contact:

Emergency Management	(605) 773-3231

2. * South Dakota Department of Game, Fish, and Parks (605) 394-2391

* Depends on the location and affected area of the spill.

B. **County Agencies Ψ**

Lawrence County Emergency Management Officer:

Paul L. Thomson	(Office)	(605) 578-2122
	(Home)	(605) 642-4019

If unable to contact Emergency Management Officer:

Hazardous Materials Officer:

Ken Hawki	(Office)	(605) 578-2122
	(Home)	(605) 578-3425

If unable to contact either of the above:

Lawrence County Central Dispatch Office
(605) 578-2230

Ψ Please see Appendix C.

C. **Federal Agencies**

1. # Environmental Protection Agency (EPA)
1-800-424-8802

Dependant on substance spilled and size of the spill.

2. * U.S. Forest Service (Spearfish Ranger District)
(605) 642-4662

* Depends on the location and affected area of the spill.

D. **Emergency Response Consultants**

Emergency response consultants will be contacted by Environmental or Metallurgical Personnel if deemed necessary.

See Section 4.0 for additional persons and agencies to contact in case of an emergency.

2.1.2 Containment, Neutralization, Clean-Up, and Monitoring

After initial emergency actions have been taken, additional actions may be necessary to contain, neutralize, clean-up, and monitor the spill.

- CONTAINMENT

Spills can occur resulting in uncontained contaminated soil or water that requires additional corrective measures. Spills that escape mine containment facilities may result in some form of surface and/or groundwater cyanide contamination.

♦ Contaminated surface flow down a drainage:

Flow should be dammed near the site of the contamination using earth or impermeable materials (plastic liners, etc.). Collected water should be pumped back to a leach pad or a liquid containment facility.

♦ Groundwater Contamination

Cyanide detected in one or more monitoring wells:

Pump well(s) if possible to remove contaminated groundwater and control spread of cyanide contamination. Well discharge should be pumped back to a suitable disposal area. Additional wells may need to be drilled in contaminated areas for monitoring movement and removal of contaminated groundwater. Personnel in the Groundwater Quality Program (DENR) must be notified before injecting any neutralization solutions in groundwater [(605) 773-3296].

Cyanide detection in water supplies:

Immediately prohibit usage of water supply and provide bottled water. Locate source of contamination and contain and treat accordingly to reduce or eliminate contamination.

♦ Surface Water Contamination

Sodium hypochlorite (bleach), hydrogen peroxide, ferrous sulfate or any other treatment chemical is not to be used to treat a cyanide release to surface water. This also applies to dry drainages such as McKinley Gulch.

Notify the appropriate agencies for proper spill response measures in the event of a cyanide release to surface water.

- NEUTRALIZATION

Neutralization procedures for cyanide spills are dependent on:

1. Cyanide concentration
2. pH

3. Location and extent of contamination.

Highly concentrated cyanide solution should never be treated with concentrated sodium hypochlorite to avoid release of toxic cyanogen chloride gas.

To reduce formation and release of dangerous amounts of hydrogen cyanide or cyanogen chloride gas, a concentrated cyanide solution spill should be diluted with lime or caustic solution. The alkali solution raises the pH and lowers the hydrogen cyanide concentration. When cyanide has been diluted to concentrations of 100 - 200 milligrams per liter and pH has been raised to 10 or above, sodium hypochlorite can be added to neutralize the spill as described for mine process waters.

Note: Current cyanide solutions at Wharf Resources contain 50 milligrams per liter or less and do not require dilution prior to treatment. More concentrated cyanide solutions can be safely treated with NaOCl (bleach solution) in the open air with the pH above 10. If necessary, treatment of up to 5000 mg/liter is possible.

Neutralizing chemicals will be stored at the warehouse and plant or be readily available in quantities sufficient to neutralize the maximum amount of cyanide that may occur in the normal working solution inventory in the processing ponds at any one time.

- CLEAN-UPS

After containment and neutralization of the solution, the contaminated materials should be eliminated and/or neutralization should be continued until contamination concentrations comply with state or federal law or to SD DENR approval, as applicable.

Clean-up will involve removal and disposal of contaminated material, soil, etc. in a lined containment area (heap leach pad). Clean-up may involve flushing of soils or pumping shallow aquifers to remove contaminated material. All clean-up activities should be carefully planned and recorded to establish a clear record of what actions were taken and where and when the actions occurred.

- MONITORING

  - The South Dakota Department of Environment and Natural Resources will be consulted as to the frequency and duration of surface and groundwater monitoring in the event of a spill.

- ♦ Sampling and analysis of water and/or soil will follow proper EPA protocols (as outlined in Wharf's Sample Collection Procedure and SD DENR Groundwater Quality QAPP).

2.1.3 **Documentation and Reporting**

A written report is to be made immediately after termination of spill response operations. The report should include:

- SUMMARY OF EVENTS
  - ♦ Injury Information
  - ♦ Immediate health or environmental hazards (CN vapor, water pollution, etc.)
  - ♦ What, where, when, and how the spill happened
  - ♦ Volume and concentration of the spill material
  - ♦ Containment and neutralization actions taken
  - ♦ Organization of the response
  - ♦ Resources used

- EFFECTIVENESS OF RESPONSE AND CLEAN-UP ACTIVITIES

  Note any changes of water quality as clean-up and neutralization progress.

- COPIES OF WATER QUALITY ANALYSES

- RECOMMENDATIONS OR PREVENTATIVE MEASURES
  - ♦ Precautions to prevent recurrence of the spill or incident
  - ♦ Suggestions for improved response

- FIGURE SHOWING LOCATION OF SPILL
  - ♦ Containment facilities used
  - ♦ Locations of neutralization sites
  - ♦ Monitoring sites

- SPILL DOCUMENTATION AND REPORTING

  The Environmental Department shall be notified within 24 hours of a spill event. A completed spill report form will be submitted to the Department within 72 hours. * The form shall include, but is not limited to:

  - ♦ The title of the person reporting the incident
  - ♦ Containment measures taken
  - ♦ Treatment measures taken
  - ♦ Recovery measures taken

- Proposed further mitigation if required
- Monitoring and sampling results
- Location of disposal of removed contaminants
- Photographic documentation when practical

* If requested by the Department, written progress reports shall be submitted after the initial report, until corrective action is complete.

2.1.4 **Cyanide Antidote Location and Administration Procedures**

First Aid Supplies

First aid supplies should be immediately accessible at all times and should be inspected monthly by the individuals who would be using them in an emergency. The following items are required:

- Two boxes (two dozen) amyl nitrite pearls.
  - **CAUTION:** UNSTABLE - REPLACE EVERY YEAR. Store in cool, dark location.
- Oxygen inhalators.
- Cyanco kit
- A set of instructions on First Aid Treatment.

First Aid Rescue Procedures

- Call for nearby help.
- Protect yourself from cyanide exposure.

  In areas of high cyanide concentration, the following PPE is required:
  - Full rubber suits
  - Rubber boots and gloves
  - Face shield
  - Safety goggles
  - Portable HCN monitor

  In areas of low cyanide concentrations, PPE required
  - Rubber or nitrile gloves

- Move victim to fresh air.
- Flush contaminated skin areas with large quantities of water.
- Quickly determine the victim’s condition.
- Give first aid immediately as outlined below, even while clothing is being removed or flushing is taking place.
- **Send for trained medical help** (to administer amyl nitrite and Cyanco kit, if necessary).

INHALATION

- Fully Conscious
  - Give Oxygen
- Unconscious / Not Fully Conscious
  - Give Oxygen and amyl nitrite immediately (see procedure).
- Not Breathing
  - Give Oxygen and amyl nitrite immediately (see procedure)
  - Force breathing with oxygen resuscitator or protected artificial respiration.

ABSORBED THROUGH EYE/SKIN

- Give oxygen and amyl nitrite as for inhalation (see procedure).
- Immediately rinse with plenty of plain water for at least 15 minutes and remove contaminated clothing.
- Lay victim down and keep warm.
- Watch victim for at least 1-2 hours.
- Cyanide can also cause caustic burns.

SWALLOWING

- Conscious
  - Give oxygen and amyl nitrite as for inhalation (see procedure).
  - Immediately rinse mouth with plain water and expectorate.
  - DO NOT induce vomiting.

- Unconscious / Not Breathing
  - DO NOT give unconscious person anything by mouth.
  - Give oxygen and amyl nitrite immediately as for inhalation (see procedure).
  - DO NOT induce vomiting.

AMYL NITRITE PROCEDURE

Amyl nitrite is flammable. Remove all sources of ignition; do not smoke! To avoid dizziness, do not inhale amyl nitrite.

Caution: The uninterrupted administration of amyl nitrite can cause low blood pressure or dizziness.

IF BREATHING

- Crush ampule in gauze or cloth.
- Hold ampule in gauze or cloth under nose 15 seconds then away for 15 seconds.
- Repeat step two (above) 5-6 times per ampule, using a new ampule every 3 minutes if needed (1-4 ampules).
- Continue treatment until victim is conscious or medical help arrives.

IF NOT BREATHING

- Crush ampule in gauze or cloth.
- Hold ampule and gauze under oxygen resuscitator face mask to avoid choking from ampule in throat.
- Force deep breathing with resuscitator, 1 breath every 4-5 seconds. Hold ampule for 3 breaths, take out for 3 breaths.
- Repeat 5-6 times per ampule, using new ampule every 3 minutes (1-4 ampules).
- Continue treatment until victim is conscious or until relieved by medical personnel. Avoid overusing amyl nitrite.

2.2 **Fuel**

A separate SPCC plan for petroleum products has been prepared in compliance with the provisions of 40 CFR, Part 112 and signed by a registered professional engineer. This plan is available for use in the environmental office.

Fuels, including diesel, gasoline, lubricating oils (considered as fuel in this discussion), propane, and methanol must be handled carefully to avoid spills. Adherence to the transportation plan (see Section 3.0.4 and Attachment 1) will significantly reduce the potential for fuel spills. On-site fuels will be stored in facilities designed to contain spills, and fueling sites will be located and constructed to minimize fuel losses.

Three types of spills must be considered. These are:

1. Spills during transport to the site.
2. Fuel losses in storage and fueling area.
3. Fuel spills in areas not designed for containment, such as fuel trucks servicing construction equipment.

2.2.1 HEALTH AND SAFETY

All fuels should be considered highly flammable and sparks or open flames must be avoided around spills. In case of fire, immediately call a MAYDAY. Attempt to put out the fire without exposing yourself to risk or injury. If there is any question as to safety, evacuate the area of all personnel immediately. Immediately call your supervisor. The supervisor will then immediately contact the safety coordinator and department head or management on duty.

Propane is a colorless, odorless gas that may be stenched. Exposure will cause eye and skin freeze burns, dizziness, headache, fatigue, coughing, unconsciousness, and death. First aid should include flushing of eyes and skin with running water and using cool wet bandages. Transport immediately to a medical facility.

Methanol is a clear, colorless liquid that may liberate methane gas and methanol fumes. Methanol may be fatal or cause blindness if swallowed. Breathing the vapor may cause headache, vomiting, dizziness, narcosis, respiratory failure, low blood pressure, and central nervous system depression. Contact with eyes or skin will cause temporary corneal damage and dermatitis. Medical conditions generally aggravated by exposure are eye disorders, skin disorders, and liver and kidney disorders. First aid should include:

1. Drink large amounts of water and induce vomiting if swallowed.
2. Move to fresh air and give oxygen if breathing is difficult.
3. Flush skin and eyes with water for at least 15 minutes.
4. Remove contaminated clothing.
5. Transport to a medical facility.

2.2.2 FUEL SPILL EMERGENCY RESPONSE

1. **CALL MAYDAY! MAYDAY! MAYDAY!**
2. Protect Yourself - Don't Become a Casualty.
3. Render Emergency First Aid.
4. Evacuate Unnecessary Personnel.
5. Protect from Ignition.
6. Identify Source - Stop the Spill - Contain Run-off.
7. Ventilate Area.
8. Initiate Clean-up, if possible.
9. Notify Supervisor and Environmental Personnel.
10. Maintain Watch on Spill Until Otherwise Advised by Supervisor.
11. Fill Out Spill Report and Incident Report Forms

2.2.3 SPILL CONTAINMENT

If possible, all flammable materials in and adjacent to the spill site should be removed immediately. Fuel spills must then be contained as soon as possible after the loss has occurred to prevent its spreading and to simplify clean-up procedures.

A Spill Response Kit is available for use at the Warehouse. Please report any materials used, removed, or missing to the SMRTeam or the Environmental Department. An inventory list of all spill kit supplies is included in Appendix B.

A. Fueling Pad Spills (in lined area)

Fueling pad spills, in a lined area, do not require further containment. Fueling pad spills, in an unlined area, will be treated as land spills.

B. Land Spills

To prevent the spill from spreading laterally, construct an earthen dike or dam of sufficient size to intercept both the fuel and any impacted water.

C. Water Spills

Contain the floating fuel with a boom, which is any device that will float on water and prevent the spread of the fuel. Commercial booms are available in the spill response kit, or a boom may be constructed of logs or any readily available flotation device. Ideally, the boom will extend a few feet into the water. A filter fence is recommended for small streams and ditches.

Deploy a boom across the channel, downstream from the spill - the higher the current, the more acute the angle needed between the boom and the shore. Spread sorbent material on the upstream side of the boom to prevent fuel from passing through joints or gaps. Fuel coming from upstream should strike the boom and be diverted to the shore where it can be recovered by sorption.

2.2.4 SPILL NOTIFICATION

The necessary notification of outside agencies will be made by the Environmental Department after notifying the Mine Manager (or Management on Duty during the weekends). Please see page 5, section 2.1.1, Emergency Action Liquid Cyanide - Part 5 for details.

2.2.5 REMOVAL OF FUEL AND CONTAMINATED MATERIAL

A. From fuel tank containment

Fuel may be removed by suction and used or placed in a designated lined containment area in containers. The containers will be moved to an approved disposal site.

B. From land

First remove free product by suction. Contaminated soil beneath the spill must then be removed to a lined containment area. Both the product and soil will be moved to an approved disposal site. If considered a potential groundwater or surface water contamination problem, the SD DENR will be consulted regarding the frequency and duration of surface and groundwater monitoring.

C. From water

A suction pump may be used to remove fuel or a commercial skimmer may remove fuel mechanically. Booms may also be used as recommended above. If any of these methods is unfeasible, incineration may be used with the approval of fire control authorities. Prior to incineration of unrecoverable fuel spills on water, Point Source Control Program, DENR, shall be notified.

If groundwater is contaminated, then fuel must be removed with recovery wells or trenches and the water/fuel mixture taken to a disposal area. The Groundwater Quality Program, DENR, shall be notified immediately upon Wharf's becoming aware of a groundwater contamination problem.

2.3 **Chemicals and Reagents**

Various chemicals and reagents will be used in the mining and mineral processing operation. Substances of most concern will include hydrogen peroxide (H_2O_2) for neutralization of spent ore, Sodium Hypochlorite (NaOCl) for neutralization of cyanide spills, caustic and lime to maintain high pH in process solution, hydrochloric acid (HCL) for pH control, sulfuric acid (H_2SO_4) for pH control as well as cleaning screens and carbon for the columns, and phosphoric acid (H_3PO_4) that may be used for the metabolic process in the biological de-nitrification facilities.

An important factor in the handling of these substances will be the method of transportation and storage. Transportation to the site will minimize or eliminate chemical and reagent spills (See Section 3.0.4 and Attachment 1). On-site storage of chemicals and reagents will be in facilities designed to handle these substances, which will significantly reduce the possibility of spills.

2.3.1 **Hydrogen Peroxide**

Hydrogen Peroxide is a clear, colorless liquid that is mixable with water in all proportions. Hydrogen Peroxide is a strong oxidizer, and if it is spilled on combustible materials (including ordinary clothing), it can ignite them. In case of spontaneous combustion, use only water to fight the fire. **Do not** use chemical fire retardants. Since hydrogen peroxide is a corrosive liquid, fire fighters should wear full body protection and self-contained breathing apparatus.

First Aid

In case of contact, immediately flush the skin and/or eyes with large amounts of water for at least 15 minutes while quickly removing contaminated clothing and shoes. Wash contaminated clothing and shoes thoroughly and promptly. Clothing left to dry before washing may ignite. Contact a physician.

Spill Containment and Clean-up

<u>Stop the spill</u> at the source and <u>contain run-off.</u> Hydrogen peroxide is not flammable. However, it will accelerate fires because it is an excellent oxygen source; therefore, do not use any combustible material in containing the spill. Most spills will occur in contained areas where dilution of the spill with water and washing it into the appropriate pond is satisfactory.

Small spills occurring off contained areas should be diluted with large quantities of water. Large spills require containment and pump-back to the neutralization pond. Note: Only qualified personnel wearing the proper PPE should initiate hydrogen peroxide neutralization.

2.3.2 **Sodium Hypochlorite**

Sodium Hypochlorite is light yellow green in color with a slight chlorine odor. It is completely soluble in water.

First Aid

In case of contact, immediately flush the skin and/or eyes with large amounts of water for at least 15 minutes. Contact a physician.

Spill Containment and Clean-up

Stop the spill at the source and contain run-off. Most spills will occur in contained areas where dilution of the spill with water and washing it into the appropriate pond is satisfactory.

Spills occurring off contained areas should be diluted with large quantities of water and/or neutralized with sodium bisulfite. Large spills require containment and pump-back to the neutralization pond. Note: Only qualified personnel should initiate sodium hypochlorite neutralization.

2.3.3 **Caustic and Lime**

Caustic (Sodium Hydroxide - NaOH) is colorless with no odor and is non-combustible.

Lime (Calcium Hydroxide - $Ca(OH)_2$, Hydrated Lime, Slaked Lime) is a white powder with no odor and is non-flammable and non-combustible.

First Aid

Health hazards include severe burning of the skin and eyes with possible blindness, irritation of the respiratory tract, and severe tissue damage if ingested. First aid should include immediate and continuous irrigation with water, remove the victim to fresh air, do not induce vomiting, and contact a physician.

Spill Containment and Clean-up

Stop the spill at the source and contain run-off. Spills should be flushed with water and taken to containment (neutralization pond preferably).

2.3.4 **Sulfuric Acid**

Sulfuric Acid is an oily, colorless to slightly yellow, clear to turbid liquid with no odor. It is non-flammable.

First Aid

Sulfuric acid may cause severe irritation, blisters or burns to the skin, digestive tract, nose, throat, and eyes. In case of contact, immediately flush the skin and/or eyes with large amounts of water for at least 15 minutes while quickly removing contaminated clothing and shoes. Move the victim to fresh air. Do <u>not</u> induce vomiting; instead, immediately give victim plenty of milk or water to drink. Contact a physician.

Spill Containment and Clean-up

<u>Stop the spill</u> at the source and <u>contain run-off.</u> Sulfuric acid is stored in a bulk tank on containment. In case of a <u>small spill</u>, dilute with plenty of water. Neutralize residue with alkali such as soda ash or lime. Adequate ventilation is required for soda ash due to release of carbon dioxide gas. For <u>major spills</u>, keep unprotected persons away. Protected persons should contain the acid by diking the spill with soil or clay. Recover the acid if possible and dispose of on the leach pad. Vapor may contain explosive hydrogen. Note: Only qualified personnel wearing the proper PPE should initiate sulfuric acid neutralization.

2.3.5 **Nitric Acid**

Nitric Acid is a colorless liquid with a pungent odor. It is non-flammable, but will increase the flammability of wood and organics. It can cause explosions with sulfuric acid, metal powders, carbides, and turpentine.

First Aid

In case of contact, immediately flush the skin with large amounts of water. If the eyes are affected, flush with water for at least 15 minutes and get immediate medical attention. In case of inhalation, remove to fresh air and get immediate medical attention. In case of ingestion, do <u>not</u> induce vomiting. Immediately give large quantities of water.

Spill Containment and Clean-up

<u>Stop the spill</u> at the source and <u>contain run-off</u>. Flush the area with plenty of water and neutralize with alkaline material, such as soda ash, lime, etc. Wear suitable protective clothing and eye protection. Adequate ventilation is required.

2.3.6 **Hydrochloric Acid**

Hydrochloric Acid is a clear, colorless fuming liquid with a pungent odor.

First Aid

Hydrochloric acid may cause severe irritation, blisters or burns to the skin, digestive tract, nose, throat, and eyes. In case of contact, immediately flush the skin and/or eyes with large amounts of water for at least 15 minutes while quickly removing contaminated clothing and shoes. Move the victim to fresh air. Do <u>not</u> induce vomiting; instead immediately give victim plenty of milk and water to drink. Contact a physician.

Spill Containment and Clean-up

<u>Stop the spill</u> at the source and <u>contain run-off.</u> Hydrochloric acid is stored in bulk tanks on containment. In case of a spill to soils, treat with excess caustic to neutralize the acid and dispose of on the heap leach pad. Note: Only qualified personnel wearing the proper PPE should initiate hydrochloric acid neutralization.

<u>Spill Response, Monitoring, and Reporting</u>

Spill response, monitoring, and reporting of chemical or reagent spills will be follow the same procedures outlined in Section 2.1.

3.0 MISCELLANEOUS INFORMATION

3.1 Reportable Quantities

ALL SPILLS MUST BE TREATED EQUALLY!

Any quantity of liquid cyanide, met process solution, or chemicals and reagents must be properly reported.

All petroleum spills over 25 gallons (whether overland or discharged to surface waters) shall be properly reported.

Any oil spill to surface water less than 25 gallons that causes sheen on the water shall be reported. Any overland oil spills less than 25 gallons that cannot be corrected within 24 hours must be properly reported.

3.2 Spill Response Equipment

A spill response kit is available for use at the Warehouse. Please report any materials used, removed, or missing to the SMRTeam or the Environmental Department. An inventory list of all spill kit supplies is included in Appendix B.

3.3 Spill Reporting

Spill information is recorded in Coeur Wharf's Intelex Environmental Incident system. An example of the form is included in Appendix A.

3.4 Transportation Routes

Access routes within Lawrence County used to transport any hazardous material, special waste, or oil to the mine site are illustrated in Attachment 1. These routes include Interstate 90, Highway 85, Highway 14A, Nevada Gulch Road, and the Wharf Road. A copy of these transportation routes is on file with the Lawrence County Civil Defense Office.

3.5 Potential Overland Spills

Attachment 2 consists of an inventory map of potential points of containment for potential overland spills. Attachment 3 consists of a inventory of the locations of all previous spills that have occurred since the Wharf Mine has been in operation.

4.0 EMERGENCY CONTACT LIST

EMERGENCY MEDICAL

Wharf Emergency Response Team	(605) 584-4163
Monument Health Deadwood Clinic	(605) 717-6431
Monument Health Lead Deadwood Hospital	(605) 722-6100
Lawrence County Sheriff's Department	(605) 578-2230
Lawrence County Emergency Response Office (Search and Rescue, Emergency Response)	(605) 578-2122

STATE AGENCIES

Department of Environment and Natural Resources (DENR)

Minerals and Mining Program	(605) 773-4201
Point Source Control Program	(605) 773-3351
Groundwater Quality Program	(605) 773-3296
State Radio	(605) 773-3536

After business hours or on weekends, contact:

Emergency Management	(605) 773-3231

FEDERAL AGENCIES

Environmental Protection Agency (EPA)	1-800-424-8802
U.S. Forest Service (Nemo Ranger District)	(605) 642-4662

EMERGENCY RESPONSE CONSULTANTS

NAME	PHONE	ALTERNATE PHONE #
Brenntag West, Inc. (Lime, Hydrogen Peroxide, Acetic Acid) (Phosphoric Acid)	1-800-531-0799	(701) 225-8760
Cyanco (Cyanide)	1-775-623-1214	
Great Western Chemical (Sulfuric Acid, Sodium Hypochlorite) (Sodium Bisulfite)	1-800-544-2436	(406) 442-8900
NALCO Chemical Company (Anti-scalants)	(801) 273-1462	
Mid-Continent (Rapid City, South Dakota)	(605) 348-0111	

WHARF PERSONNEL

(Weekdays and Weeknights)

NAME	HOME / CELL PHONE
Lynne Blackman	(605) 641-7377
Ken Nelson	(605) 580-0441
John Key	(605) 580-7919
Matt Zietlow	(775) 304-1682
Tony Auld	(605) 591-9837
Jay Hasquet	(307) 689-6222
Amy Gilpin	(402) 630-1159

(Weekends)

1)	Management on Duty	See Weekend Roster
2)	Pit Foreman	(605) 584-4163
	(Mobile)	(605) 580-1327
3)	Process Plant	(605) 584-4148
		(605) 584-4149

DEPARTMENT of ENVIRONMENT and NATURAL RESOURCES

JOE FOSS BUILDING
523 EAST CAPITOL
PIERRE, SOUTH DAKOTA 57501-3181
www.state.sd.us/denr

September 30, 2002

Mr. James F. Lessard
Engineering Manager
Wharf Resources (USA), Inc.
HC 37 Box 811
Lead, South Dakota
57754-9710

RE: Acid Rock Drainage Prevention and Management Plan for Lower Deadwood Formation and Precambrian rock units in Trojan Pit

Dear Jim,

Department review is complete on the Acid Rock Drainage Prevention and Management Plan (Plan) submitted in November, 2001, the plan appendix submitted in July 2002, and the associated Technical Revision to substitute the NAG pH procedure for the pyritic sulfur cutoff criteria required in the Acid Rock Drainage Management and Prevention Conditions to Mine Permit #464. Based on the review of this plan, supplementary data submitted in the appendix, and associated negotiations and discussions, the department grants approval for the plan and the associated Technical Revision with the following conditions:

1. Wharf shall complete static Net Acid Generation (NAG) tests and paste pH tests of all lower Deadwood formation and Precambrian rock units encountered in the Trojan Pit. At a minimum, these tests shall be completed on representative splits of 20' intervals from development drill hole samples located on a 50'x50' grid throughout the entire pit.

2. Based on a correlation of NAG results to Acid Base Accounting tests from 152 samples from the Lower Deadwood Formation, a NAG pH cutoff criterion of 5.0 is established (Fig. 1). In the event that Wharf encounters rock exhibiting a NAG pH of less than 5.0 in the 50'x50' development drill holes, this rock zone will be deemed a special management zone. Prior to mining the Special Management Zone, Wharf shall define the volume of the zone using additional NAG pH tests of blast holes surrounding the development drill hole(s), visual geologic inspection, mapping, and surface sample analyses as necessary

3. Based on the NAG pH tests completed within the special management zone, a mean NAG pH value will be calculated as follows:

$$\bar{x} = -\log\left[\frac{1}{n}\sum_{i=1}^{n} 10^{-xi}\right]$$

Where:

$\bar{x}$ = Average NAG pH of samples within Special Management Zone

n = Number of samples within Special Management Zone

i = Independent sample within Special Management Zone

xi = NAG pH of independent sample

A Net Neutralization Potential (NNP) will be estimated for the special management zone based on the mean NAG pH value using the attached NAG pH-NNP correlation chart to determine base amendment requirements

4. All shot muck containing special management rock zones will be flagged in the field using colored pin flags or other method prior to mining.

5. All NAG pH values collected and any special management rock zones identified will be recorded on mine bench maps and assigned a unique tracking code or sample number. These maps will be constructed for each bench containing lower Deadwood Formation or Precambrian rocks, will be permanently stored in the mine office, and will be available for inspection by the department at any time.

6. Rock mined from any special management zones will be blended with net neutralizing rock to achieve a minimum 3:1 neutralization potential to acid potential ratio. Lime addition during the gold recovery process will not be included in calculation of the required 3:1 ratio.

The required amendment quantity will be calculated as follows:

4 for ore (3 for waste rock)

$$Q_{BA} = \frac{-3Q_{SMZ}NNP_{SMZ}}{NNP_{BA}}$$

Where:

Q_{BA} = Quantity of required base amendment (tons)

NNP_{BA} = Estimated NNP of base amendment (t/kt $CaCO_3$ eq.)

Q_{SHZ} = Quantity of Special Handling Zone (tons)

NNP_{SMZ} = Estimated NNP of Special Management Zone (t/kt $CaCO_3$ eq)

7. The Net Neutralization Potential of the rock used for base amendment will be estimated as follows:

   Lower Deadwood Formation: The Net Neutralization Potential of lower Deadwood Formation rock used for base amendment will be estimated based on the mean NAG pH of the rock volume using the NAG pH-NNP correlation chart shown as Figure 1. All lower Deadwood Formation rock used for base amendment shall have a NAG pH of greater than 7.0, correlating to a NP:AP ratio of greater than 3:1 as shown on Figure 1.

   Intermediate and upper Deadwood Formation: The Net Neutralization Potential of the intermediate and upper Deadwood Formation will be estimated based on the existing ABA database for the respective rock units using geostatistical methods. Estimating parameters will be developed by Wharf Resources based on best professional judgement, and will be reported to the department along with the quarterly reports described below.

   Intrusive porphyry rock units: Intrusive porphyry rock units will not be used as base amendment.

   Precambrian rock units: Precambrian rock units will not be used as base amendment.

   If the available volume or NNP proves insufficient to create the 3:1 ratio, other suitable base amendments will be required prior to mining.

8. A database will be developed and maintained containing the pre-mining location, volume, NAG pH, and estimated NNP of all special management rock zones. The database shall also contain records of all blending completed including the corresponding special management rock unit; the estimated NNP of the base amendment; the volume of the base amendment; pre-mining location of the base amendment; and the final location of the blended unit. This information will be submitted to the department on a quarterly basis.

9. Wharf shall prepare representative splits of –200 mesh sample pulps for all NAG pH samples. These representative splits shall be stored at the mine site until mine closure and adequately cataloged to allow retrieval of specific samples when requested by the department. At the department's request, Wharf shall provide duplicate sample pulps specified by the department for analysis at an independent third party lab at department expense.

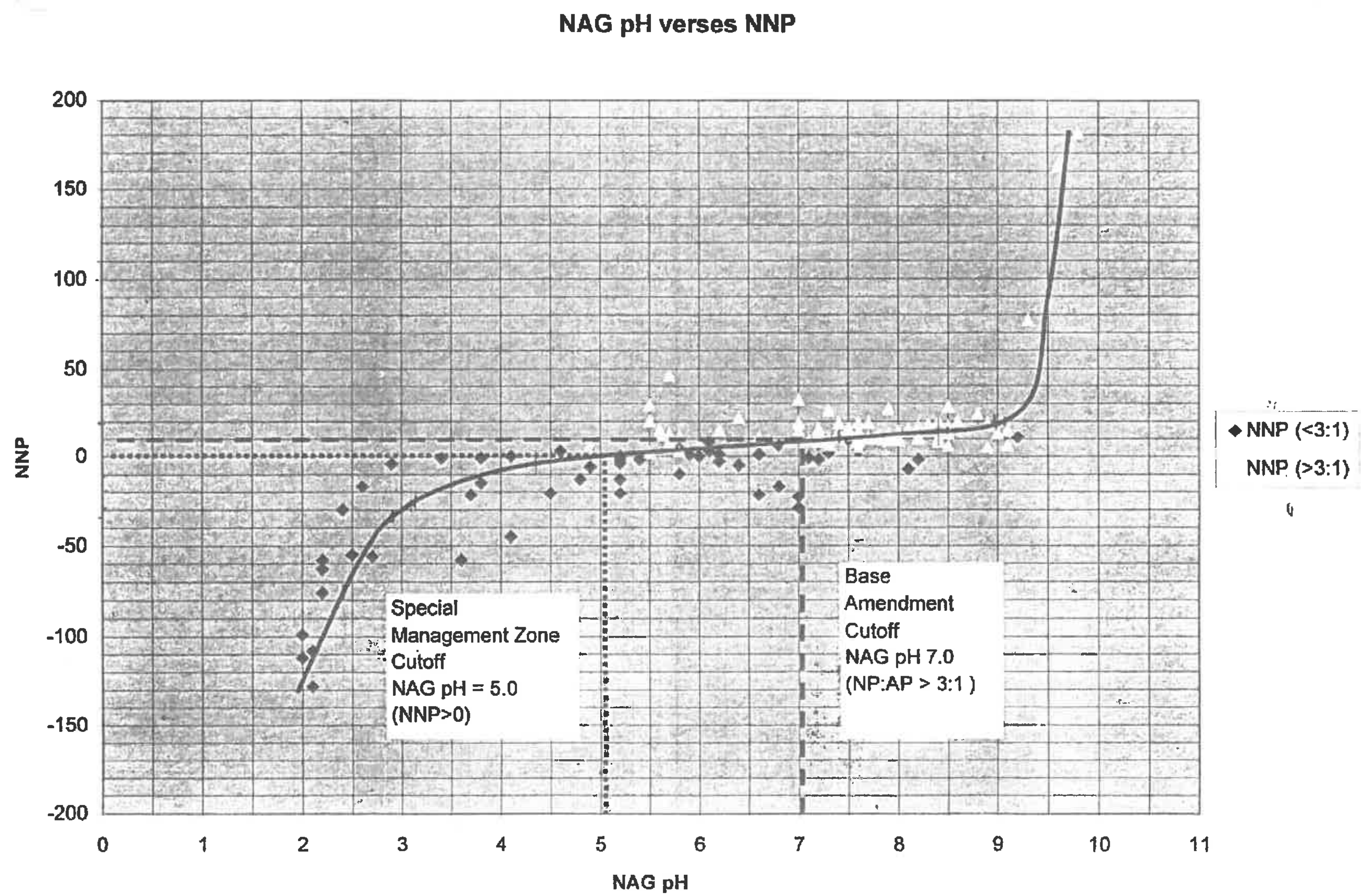


Figure 1. Correlation chart of calculated Net Neutralization Potential versus NAG pH showing correlation curve to be used for estimation of NNP for lower Deadwood Formation.

10. Wharf shall maintain quality assurance records for all internal NAG pH analyses including but not limited to pre-analysis pH of the hydrogen peroxide reagent, laboratory instrument calibration records, time and date of analyses, and the laboratory personnel completing the analyses. These records shall be available for inspection by the department at any time.

11. In conjunction with the fourth quarter report of each year, Wharf shall delineate any Special Management Zones that have been exposed in the ultimate pit walls or floors or are expected to be exposed in the following year. For the purpose of compliance with permit condition 7 of the Acid Rock Drainage Prevention and Management Conditions of Mine Permit #464, Special Management Zones delineated on the basis of NAG pH will be deemed potentially acid generating. Wharf shall provide a mitigation plan for department approval describing actions that will be taken to maintain compliance with permit condition 7.

12. The department reserves the right to alter this plan if it does not prove effective in meeting the permit conditions of Wharf's Mine Permits or if field conditions, additional geochemical data, or environmental monitoring data indicate a change is warranted.

13. Wharf may submit proposed modifications to this plan based on additional geochemical and geological data developed in consultation with the department as mining progresses through the lower unit of the Deadwood Formation.

We appreciate Wharf's cooperation in this matter. Please feel free to contact our office should you have any questions regarding this correspondence.

Sincerely,

Mark Nelson

Mark R. Nelson, CPG
Senior Hydrologist
Minerals and Mining Program

cc: S. Michals, SD GF&P

SLOPE STABILITY ANALYSIS OF THE PORTLAND AND GREEN MOUNTAIN PITS (PHASE 1)

TOPICAL REPORT RSI-3122 (REVISION 1)

PREPARED FOR
Coeur Wharf Resources (USA), Inc.
10928 Wharf Road
Lead, South Dakota 57754

JUNE 2021

SLOPE STABILITY ANALYSIS OF THE PORTLAND AND GREEN MOUNTAIN PITS (PHASE 1)

TOPICAL REPORT RSI-3122 (REVISION 1)

PREPARED BY

Jason E. Fritch
Benjamin D. Haugen

RESPEC
3824 Jet Drive
Rapid City, South Dakota 57703

PREPARED FOR

Coeur Wharf Resources (USA), Inc.
10928 Wharf Road
Lead, South Dakota 57754

JUNE 2021

Project Number 4254

EXECUTIVE SUMMARY

RESPEC has prepared this report for Coeur Wharf Resources (USA), Inc. (Wharf) to summarize the results and conclusions of kinematic and two-dimensional (2D) limit-equilibrium (LE) slope stability analyses performed for the Green Mountain and Portland open pits at the Wharf Mine (Site). RESPEC performed this Phase 1 evaluation to assess the potential for highwall instabilities at the Site and provide recommendations for a geotechnical slope optimization study (Phase 2).

The slopes in Wharf's Ultimate Pit designs are compliant with recommendations made by Dr. Charles Kliche, Professional Engineer (PE), following a kinematic stability analysis performed by the South Dakota School of Mines & Technology [Kliche, 2007].[1] Current design and operational practices at the Site include 45-degree Inter-Ramp Angles (IRAs) when mining in the Deadwood Formation and up to 50-degree IRAs in the more competent Trachyte Porphyry. Operational experience and Kliche [2007] indicate that steeper, safe slopes may be possible at the Site, and RESPEC was contracted to review existing data and perform a slope stability evaluation specific to the Green Mountain and Portland Pits.

To support the current stability evaluation, RESPEC used historical geotechnical data to estimate the rock mass properties and intact rock strengths of geologic units present at the Site. Rock mass properties and intact rock strengths were used in four 2D LE slope stability models to calculate factor-of-safety (FS) values for overall (i.e., global) slope stability. The LE models were analyzed to identify stability risks and opportunities associated with Wharf's Ultimate Pit design.

Laser-scan and drone photogrammetry point cloud data were used to measure discontinuity orientations in the current Green Mountain, Portland, and Flossie Pits. Discontinuity orientations and historical laboratory test results were used to perform kinematic stability analyses on each of the four highwall configurations evaluated in the LE models. Probabilities of wedge, toppling, and planar sliding failures were calculated using estimated discontinuity strength parameters from previous studies.

From a geotechnical perspective, the results of RESPEC's analyses indicate that Wharf's current design practices are reasonable and meet industry standard FS criteria for open pits. Toppling rockfall events have been observed in the field and confirmed by kinematic analyses to be the most significant geotechnical risk at the Site. Multi-bench wedge or planar sliding failures were found to be unlikely, and although expected to be more probable in igneous rock units, they are not expected to pose significant operational or safety risks. Steeper pit-slope designs can likely be safely achieved if more favorable site-specific geotechnical data are collected in the Phase 2 stability study.

Because RESPEC's stability evaluation was based on unverified laboratory test and field data, we recommend proceeding to Phase 2 of the evaluation before steepening the pit slopes. Phase 2 should include a geotechnical drilling, core logging, and laboratory testing program, as well as updates to the LE and kinematic models used in Phase 1 and recommendations for slope performance monitoring. The results of the Phase 1 stability evaluation are described in more detail in this report.

[1] Kliche, C. A., 2007. *A Slope Stability Analysis of the Trojan Pit – An Update for the Deep Portland, the American Eagle, and the South Wall of the Trojan Pit,* prepared by South Dakota School of Mines & Technology, Rapid City, SD, for Wharf Resources, Lead, SD.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Coeur Wharf Resources (USA), Inc. (Wharf) is planning to expand the footprints of the current Green Mountain and Portland Pits and eventually merge them to create a single, larger Ultimate Pit. Wharf contracted RESPEC to evaluate the stability of the planned pit slopes. The primary objective of the slope stability analyses summarized herein was to assess the feasibility of steepening the design Inter-Ramp Angles (IRAs) and Bench-Face Angles (BFAs) of the Ultimate Pit, thereby increasing ore recovery. An additional goal of the current stability evaluation (Phase 1) was to determine whether or not a second project phase (Phase 2) is necessary and, if so, to outline the scope of Phase 2. The Phase 1 stability evaluation was based on historical rock mass properties and recent discontinuity measurements and field observations. The map of the Wharf Mine (Site) in Figure 1-1 shows the approximate extents of the pits and locations of other mine facilities.

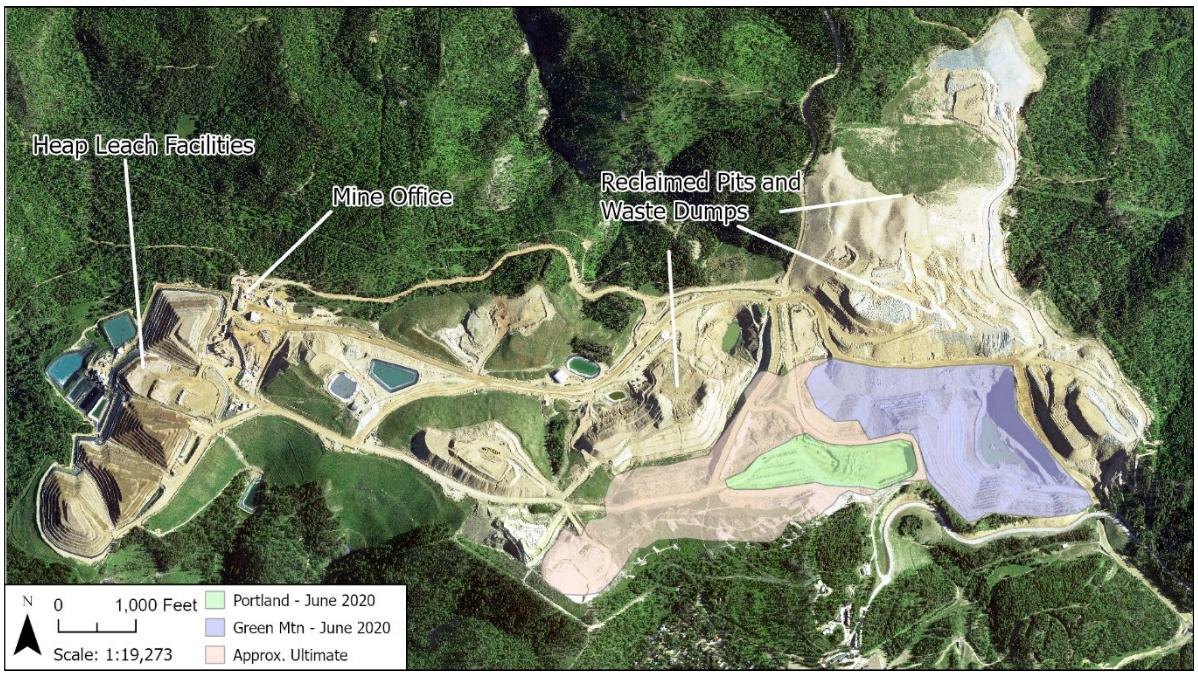


Figure 1-1. Map of the Wharf Mine as of June 2020 Showing the Approximate Extents of the Portland (Green), Green Mountain (Blue), and Ultimate (Pink) Pits.

This report contains seven chapters, including this introduction. Information regarding previous geotechnical studies at the Site are provided in Chapter 2.0. A brief discussion of the geologic setting is given in Chapter 3.0. Chapter 4.0 describes RESPEC's stability analysis methodology, including the available rock mass and geomechanical properties, kinematic stability analyses, and limit-equilibrium stability analyses. The results and conclusions of the stability analyses are provided in Chapter 5.0, and recommendations are given in Chapter 6.0. The report concludes with cited references in Chapter 7.0.

2.0 PREVIOUS WORK

The most recent pit-slope stability evaluation at the Site was completed by RESPEC in 2011 [Nopola and Roberts, 2011]. In this study, the stability of a portion of the East Liberty Pit (now reclaimed) adjacent to the Terry Cemetery was modeled and found to be stable if the groundwater table was low. RESPEC also performed a stability assessment for the realignment of Highway 473 [Nopola and Roberts, 2013]. Although the 2013 study was not a pit-slope assessment, useful material properties from an area just south of the current Portland and Green Mountain Pits were included in that study.

In addition to RESPEC's 2011 and 2013 studies, three geotechnical reports were reviewed in detail:

- *Stability Assessment of the Highwalls at the Golden Reward Mine, Lead, South Dakota* [Nelson and Osnes, 2008]
- *A Slope Stability Analysis of the Trojan Pit – An Update for the Deep Portland, the American Eagle, and the South Wall of the Trojan Pit* [Kliche, 2007]
- *Strength Properties of the Rock Discontinuities at the Annie Creek Gold Mine, Lead, South Dakota* [Smith and Kliche, 1988].

Additional historical geotechnical data included in the reports listed above were sourced from the following studies:

- *A Slope Stability Analysis of the Trojan Pit* [Kliche and Hladysz, 1997]
- *Direct Shear Tests* [Hladysz, 1996]
- *Backfill Design Recommendations for the East Liberty Pit* [Blankenship, 1994]
- *Report on Liberty Pit Highwall Stability as Regards Cemetery Stability* [Blankenship and Osnes, 1994]
- *Golden Reward Mining Company, L.P., East Liberty Pit Stability Problem* [Solseng, 1994]
- *Final Report on East Liberty Pit "Nose" Stability Evaluation* [Bronson, 1992]
- *Design Update Report for Part of Liberty Hill Pit for Golden Reward Project, Lawrence County, South Dakota* [Tape, 1988]
- Unpublished Project Results [Kliche et al., 1987].

The most recent pit-slope design recommendations were provided by Kliche [2007]. Other reports that RESPEC reviewed in detail (i.e., Smith and Kliche [1988], Nelson and Osnes, [2008], Nopola and Roberts [2011], and Nopola and Roberts [2013]) did not contain relevant pit-slope design recommendations. Site geology information used in this study was sourced from Wharf's most recent NI-43-101 Technical Report [Nelson, et al., 2018] and unpublished slideshows and figures provided by Wharf personnel.

According to Wharf personnel, the guidance provided by Kliche [2007] has been incorporated in their mine design practices, and existing pit slopes comply with the design recommendations therein. Wharf personnel have stated that final highwall slopes are double- or triple-benched with an IRA of 50 degrees where competent and continuous igneous rocks are present. Kliche [2007] states IRAs as steep as 60 degrees could be feasible in these units, but the Site opted for a flatter IRA of 50 degrees.

In less-competent sedimentary rocks, the mine uses a double-bench final highwall configuration with an IRA of 45 degrees. Kliche [2007] states that a 45-degree IRA for final highwall slopes in sedimentary rock were expected to be stable. Before the stability studies completed in 1997 and 2007, Smith and Kliche [1988] evaluated the shear strengths of the discontinuities at the Annie Creek Gold Mine, which is located southwest of the current study area.

RESPEC compiled the data and information included in historical reports to develop the material and rock mass properties for the most recent stability assessments [Nopola and Roberts, 2011; 2013]. An Excel file containing the rock mass and material properties used in the 2011 and 2013 studies was adapted for the current assessment. Many of the data contained in the Excel file are from pit areas outside the current study area but were considered sufficient for this Phase 1 stability evaluation.

3.0 GEOLOGIC AND MINING SETTING

The Wharf Mine is in the northeastern Black Hills of South Dakota. The Black Hills are part of a Laramide-age uplift that occurred along monoclines and deep thrust faults to form an asymmetrical dome [Lisenbee and DeWitt, 1993]. The uplifted dome and subsequent erosion have exposed the underlying Precambrian igneous rocks beneath younger sedimentary units of Cambrian and Ordovician age. Major intrusive rock types include Phonolite, rhyolite, trachyte, latite, dacite, and lati-andesite [Redden and DeWitt, 2008]. Intrusives at the Site form dikes, sills, and laccoliths of various thicknesses. Outcrops of crystalline Precambrian rocks in the northern Black Hills are rare, and the Site's highwalls expose only a thick package of sedimentary rocks that have been cut by younger intrusives. Figure 3-1 shows the regional geology map and generalized stratigraphic column of the Wharf Mine.

A single large fault (the Bald Mountain Fault) has been mapped at the Site. The Bald Mountain Fault is located to the east of the current area of interest. Smaller faults that are subparallel to the Bald Mountain Fault have been identified at the Green Mountain Pit but are not well-expressed and typically show up as narrow, shear zones adjacent to slightly offset sedimentary layers. Intrusives likely followed preexisting faults and fractures, indicating that faulting throughout the study area predates the intrusions [Nelson et al., 2018]. Regionally, fault structures mapped near the Site are related to minor antiforms or synforms [Redden and DeWitt, 2008] and, based on communications with Wharf geologists, the regional fault structures have no surface expression in the current pits. Detailed site geology information is provided by Nelson et al. [2018].

Gold mineralization in the northeastern Black Hills has drawn miners to the area since the late 1800s. Deeper deposits in the Precambrian rocks contain sulfides and are not mined by Wharf. Shallower oxide deposits are in places cut by historical underground mine workings that follow high-grade mineralization zones. Many of the workings are now collapsed, but some open voids remain and are occasionally encountered during production drilling and excavation activities. The voids are generally 5 to 10 feet (ft) in diameter. In some cases, ground support timbers are preserved in the historical workings. Wharf has developed a general understanding of the locations of historical mine workings, but it is difficult to accurately predict when and where they might be encountered in the highwalls.

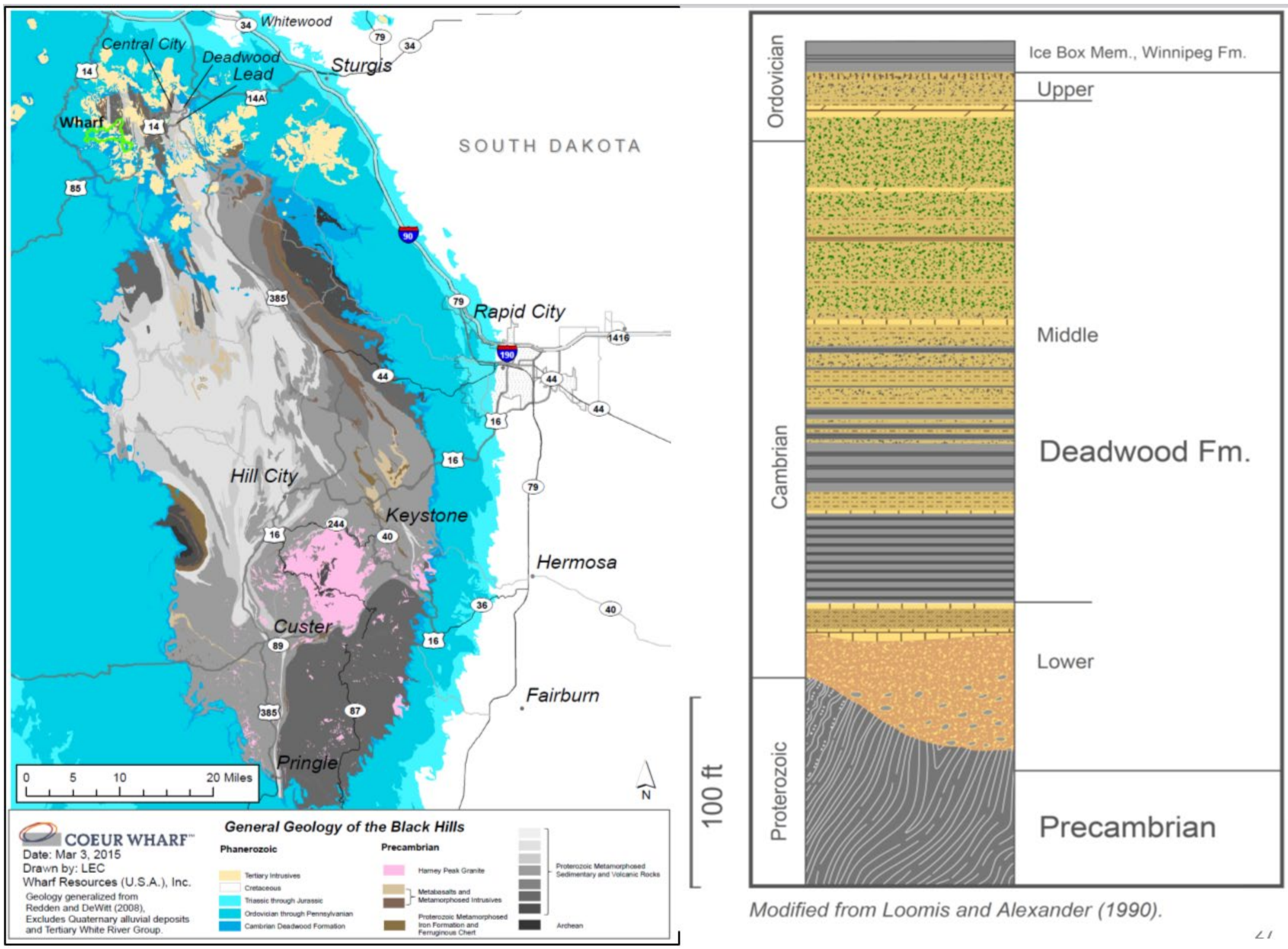


Figure 3-1. Stratigraphic Column at the Wharf Mine Site (Right) and Regional Geologic Map (Left) of the Black Hills [Nelson et al., 2018].

4.0 METHODOLOGY

RESPEC performed two types of analyses to assess the stability of the planned Ultimate Pit: two-dimensional (2D) limit-equilibrium (LE) slope stability modeling and probabilistic kinematic analyses. The 2D LE models were developed using Wharf's current geological model, historical laboratory testing, and rock mass property data. The kinematic analyses were performed using structural orientation measurements obtained from laser-scan and photogrammetric point clouds. Historical fault and fracture orientations were also incorporated in the kinematic models.

The 2D LE and kinematic stability models were used to evaluate the likelihood of global slope instabilities. Global instabilities are distinguished from bench-scale (i.e., local) instabilities in that they tend to occur through several benches, are generally controlled by the IRA and/or overall slope angle, and typically result in major operational disruptions. Bench-scale stability is typically controlled by the orientations of bedding, jointing, faults, or shears (collectively called discontinuities) relative to the orientation and angle of bench faces. Discontinuities can also control global stability if they are highly continuous and are less resistant to sliding than the rock mass between them. Kinematic sensitivity analysis was used to evaluate the possibility of steepening the Wharf's design BFAs and IRAs. Additional details regarding the stability analysis methods and geotechnical data used are provided in the remainder of this chapter.

4.1 AVAILABLE DATA

RESPEC reviewed historical slope stability reports and geomechanical test data from 1987 to 2013 (refer to Chapter 2.0). An Excel workbook (titled "Rock Test Summary.xlsx") that was developed by Nopola and Roberts [2011; 2013] containing historical rock mass properties and strength test results was updated and adapted for the current study. RESPEC's geotechnical data were combined with Wharf's geological model to produce a geotechnical model that was the basis for the LE and kinematic stability analyses.

4.1.1 GEOLOGICAL MODEL AND CROSS SECTIONS

Wharf personnel developed a detailed geological model of the Wharf Mine and provided RESPEC with screenshots, PowerPoint presentations, and ad hoc information regarding site geology. Geological information provided by Nelson et al. [2018] were also reviewed. At RESPEC's request, Wharf personnel provided four geologic cross sections that were used in the 2D LE stability models. The locations of the cross sections are shown in Figure 4-1. The cross sections included the Ultimate Pit boundary, topography, and geologic units. The Ultimate Pit shell shown in Figure 4-1 is the "merged" Ultimate Pit comprising the expanded Green Mountain and Portland Pits and a small satellite pit called Flossie appearing in the southwestern corner of the map in Figure 4-1. The Flossie Pit was not included in the current stability assessment. A summary of the cross sections is included in Table 4-1.

RESPEC selected the locations of the geologic cross sections based on several criteria. Highwalls that Wharf expects to be exposed for more than 2 years were prioritized. Two cross sections from each of the current Green Mountain and the Portland Pit areas that represented the tallest and most common pit-slope orientations in the Ultimate Pit slope were selected. RESPEC also considered lithologic and structural conditions by selecting cross sections that had potentially unfavorable geotechnical and/or geology conditions. The selected cross sections were perpendicular to the Ultimate Pit slopes and extended beyond the outer edge of the pit shell to aid in assessing the likelihood of deep-seated slope failures.

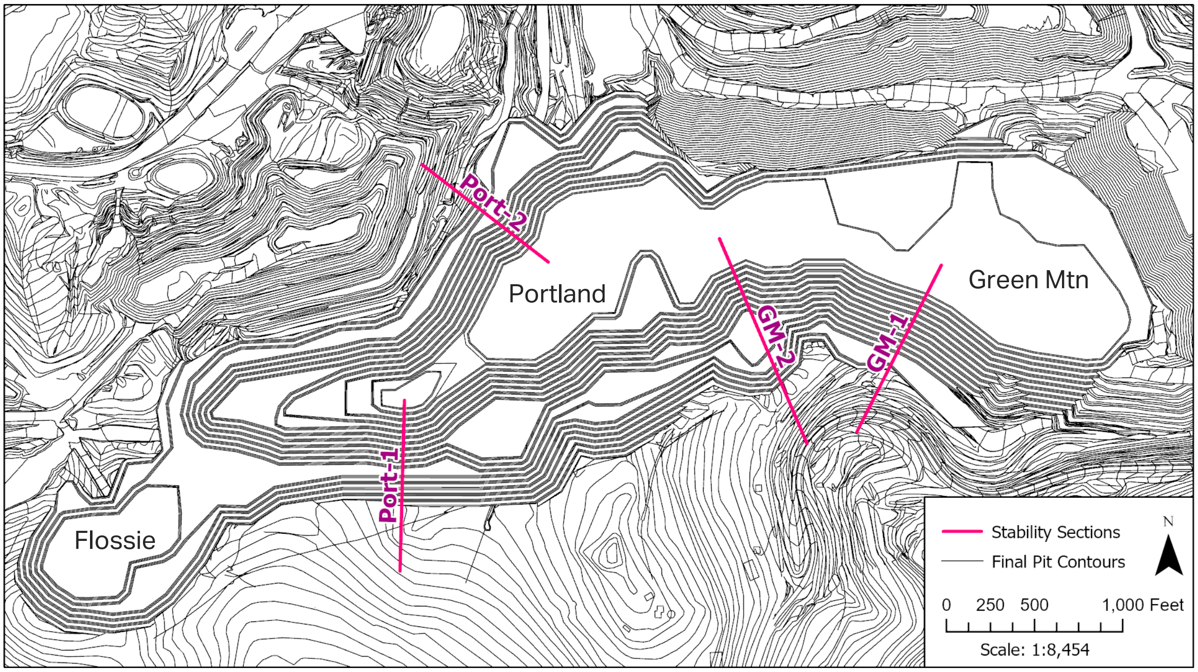


Figure 4-1. Locations of the Geological Cross Sections Used to Develop the Global Slope Stability Models.

Table 4-1. Summary of Geological Cross Sections Used in the Slope Stability Models

Section Name	Location	Slope Dip Direction (degrees)	Overall Slope Height (feet)	Average Inter-Ramp Slope Angle[(a)] (degrees)	Bench-Face Angle (degrees)
GM-1	Northeast-dipping slope of the Green Mountain Pit	028	498	49	71
GM-2	Northwest-dipping slope of the Green Mountain Pit	338	521	49	71
PORT-1	North-dipping slope of the Portland Pit	002	626	49	71
PORT-2	Southeast-dipping slope of the Portland Pit	128	430	49	71

(a) Average inter-ramp angle includes a mixture of 45-degree slopes in Deadwood Shale and 50-degree slopes in igneous rocks.

The geologic units present at the Site include Precambrian metavolcanic rocks, the sedimentary Cambrian- and Ordovician-age Deadwood Formation, and the Icebox Shale member of the Winnipeg Formation. The Precambrian units on site are not exposed in any of the current or planned highwalls and, thus, are not expected to affect the stability of the pit slopes. The Deadwood Formation is approximately 350 ft thick and is divided into four subunits that are the primary hosts for gold production [Loomis and Alexander, 1990].

The Deadwood Formation consists of a near-shore sequence of sandstones, siltstones, conglomerates, and shales. A basal conglomerate is up to 40 ft thick in some areas. Above the basal conglomerate are the lower sandstones and interbedded sandstones, sandy shales, and dolomite that range between 30 and 60 ft thick each. The middle subunit comprises up to 180 ft of calcareous shale and interbedded shale, siltstone, and sandstone. The uppermost subunit is a coarse-grained glauconitic sandstone that grades at depth from an interbedded unit up to a quartz sandstone that is up to 155 ft thick. Overlying the Deadwood Formation is the Icebox Shale of the Winnipeg Formation, which is up to 80 ft thick [Loomis and Alexander,1990]. Trachyte and Phonolite dikes and sills cut the Deadwood Formation and Icebox Shale. An isometric view of the south and west highwalls of the current Green Mountain Pit with geological interpretation is shown in Figure 4-2, and a similar view of Wharf's geological block model is shown in Figure 4-3. The stratigraphy in the Portland Pit is similar, except it is higher in section and shows exposures of an upper Phonolite sill that is significantly thicker than the Biotite Phonolite shown in Figures 4-2 and 4-3.

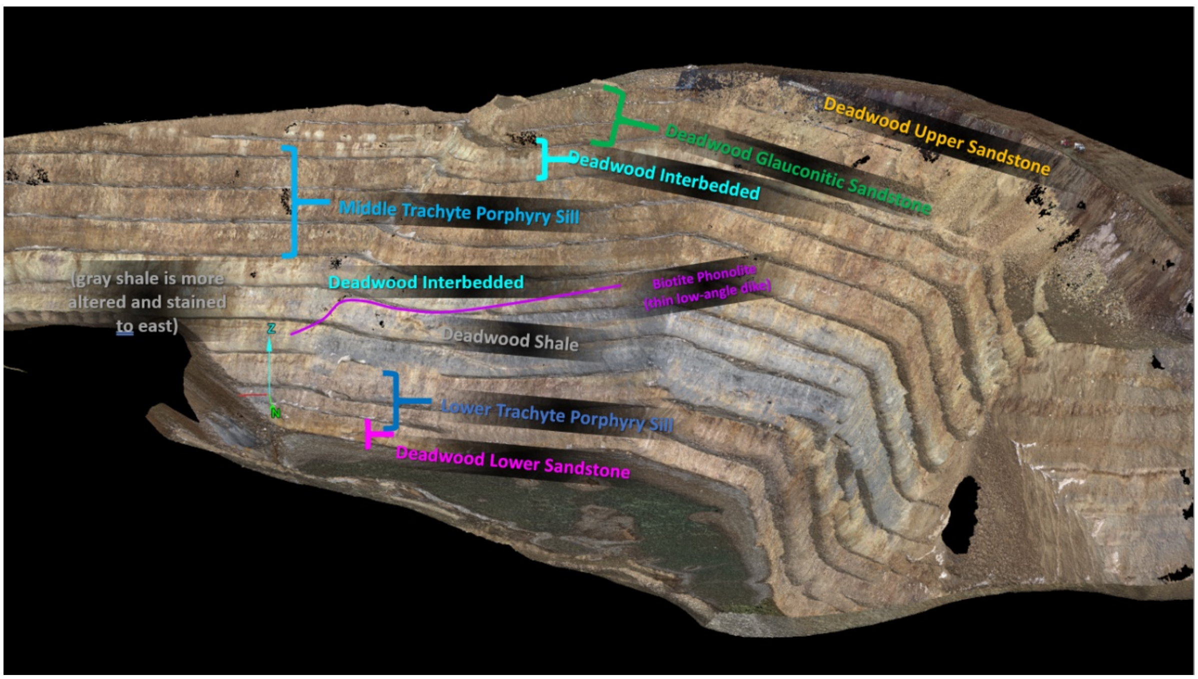


Figure 4-2. Isometric View of the South and West Walls of the Current Green Mountain Pit Showing Geological Interpretation.

4.1.2 DISCONTINUITY ORIENTATIONS

The discontinuity measurements that Kliche [2007] used to perform his kinematic analysis were from a now-backfilled pit area and were not available for use in RESPEC's analyses. For the current study, discontinuity measurements were made using two types of point cloud data: drone-based photogrammetric point clouds collected by Site personnel and laser-scan point clouds collected by RESPEC personnel. The drone data were collected in December 2020, and the laser-scan data were collected in April 2021. The drone point clouds covered the Green Mountain, Portland, and Flossie pits; the laser scans only covered the Green Mountain and Portland Pits. Measuring discontinuities with point clouds allows for wider coverage areas than traditional scan-line or cell-mapping surveys. Point clouds also allow discontinuity orientations to be measured when highwall access is not available or unsafe. The primary disadvantage of measuring discontinuity orientations with point cloud data is that flat-dipping (< 20 degrees) discontinuities such as bedding and joint infilling, aperture, and roughness are difficult to measure. Additional information about this limitation is provided in Section 4.2.

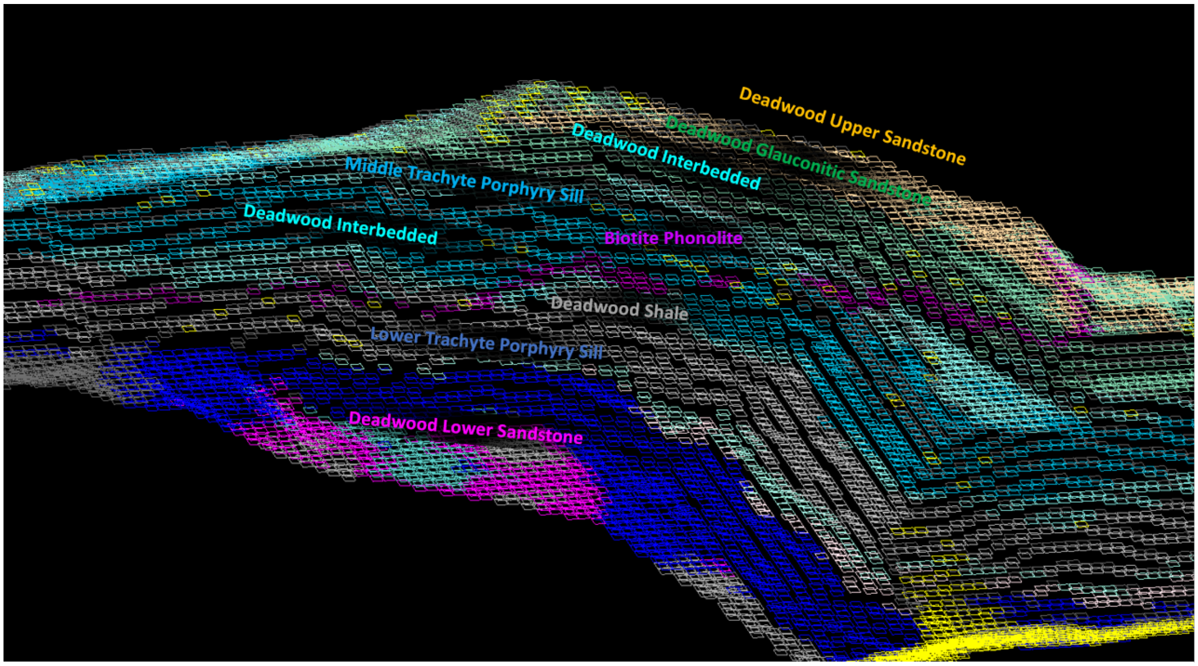


Figure 4-3. Isometric View of the South and West Walls of the Current Green Mountain Pit Showing Wharf's Block Model.

4.1.3 ROCK MASS PROPERTIES

Most of the rock mass properties used for the Phase 1 stability evaluation were sourced directly from the Excel workbook ("Rock Test Data.xlsx") used in RESPEC's most recent stability evaluations at the Site [Nopola and Roberts, 2011; 2013]. RESPEC reviewed the data contained in the spreadsheet for consistency and assessed the data's validity based on experience and the geological model provided by Wharf. The cross sections provided by Wharf contained greater detail in terms of identifiable geologic units than the Excel file. The upper, middle, and lower Deadwood sandstone units were not differentiated in previous studies; all units were assigned the Deadwood sandstone parameters included in the Excel file. Similarly, the three porphyry units in geologic cross sections were assigned "tertiary intrusive" parameters included in the Excel file. Because strength data for the Icebox Shale unit were lacking, the unit weight and UCS were assumed to be the same as the Deadwood Shale. Strength and material properties were not available for the Phonolite and Biotite Phonolite units in Wharf's geological model. Based on observations made during RESPEC's site visits, the Phonolite was assumed to have approximately 85 percent strength of the porphyry while the unit weight remained the same as the porphyry. Similarly, the Biotite Phonolite was assumed to have 50 percent of the intact rock strength of the porphyry but the same unit weight. Table 4-2 is a summary of the geotechnical material properties that were assigned to the units in Wharf's geological model.

The latest version of the Hoek-Brown failure criterion [Hoek and Brown, 2018] was used for the LE global stability models. According to this method, a rock mass disturbance (*D*) factor should be applied to the slopes when building and solving stability models. The *D* factor accounts for the effects of blast damage in open-pit mine slopes and ranges between 0 and 1; higher values reduce the rock mass strength more and indicate more significant blast damage.

Table 4-2. Hoek-Brown Strength Parameters for Geological Units Found in the Portland and Green Mountain Pits

Geologic Unit	Unit Weight (pcf)	UCS (ksf)	GSI	m_i
Phonolite	170	857	39	17
Icebox Shale	135	326	46	6
Deadwood Upper Sandstone	145	1,440	52	17
Deadwood Glauconitic Sandstone	145	1,440	52	17
Biotite Phonolite (thin low-angle dike)	170	504	23	10
Deadwood Interbedded Upper	145	1,440	52	8
Middle Trachyte Porphyry Sill	170	1,008	46	20
Deadwood Middle Shale	145	326	46	6
Trachyte Porphyry Other	170	1,008	46	20
Deadwood Interbedded Lower	145	1,440	52	8
Deadwood Lower Sandstone	145	1,440	52	17
Phonolite Other	170	857	39	17
Lower Trachyte Porphyry	170	1,008	46	20
Precambrian	145	1,656	60	12

pcf = pounds per cubic foot
ksf = thousands of pounds per square foot
GSI = Geological Strength Index.

Hoek and Brown [2018] recommend that the *D* factor be set to 1 at the surface and graded down to 0 at some distance into the slope from the highwall face. Industry standard-of-practice for slopes that do not use controlled blasting techniques such as pre-splitting is to apply the *D* factor as a 1 to gradient from the surface to a distance into the slope equal to 30 percent of the total height of the slope. This standard was selected for the current study because the Site is not currently using controlled blasting methods. An example of a graded *D* factor in a 2D LE slope stability model is shown in Figure 4-4.

4.1.4 HYDROGEOLOGY

RESPEC reviewed publicly available hydrology data for the Site and conferred with RESPEC personnel who have been involved with hydrogeologic studies at the Wharf Mine for several years. The 2018 potentiometric surface map in Figure 4-5 indicates the current water elevations range between 5,900 ft and 6,200 ft along the southern wall of the Portland Pit. The planned Ultimate Pit bottom is at an elevation of 5,920 ft.

The potentiometric surface shown in Figure 4-5 is inconsistent with RESPEC's field observations and conversations with Wharf personnel. The slopes in the current pits are generally dry, and recent exploration drilling in the area indicates that the water table elevation is several hundred feet below ground surface. Furthermore, the potentiometric surface shown in Figure 4-5 is a sub-regional model based on data from widely spaced monitoring wells, and the depressurizing effects of the pit

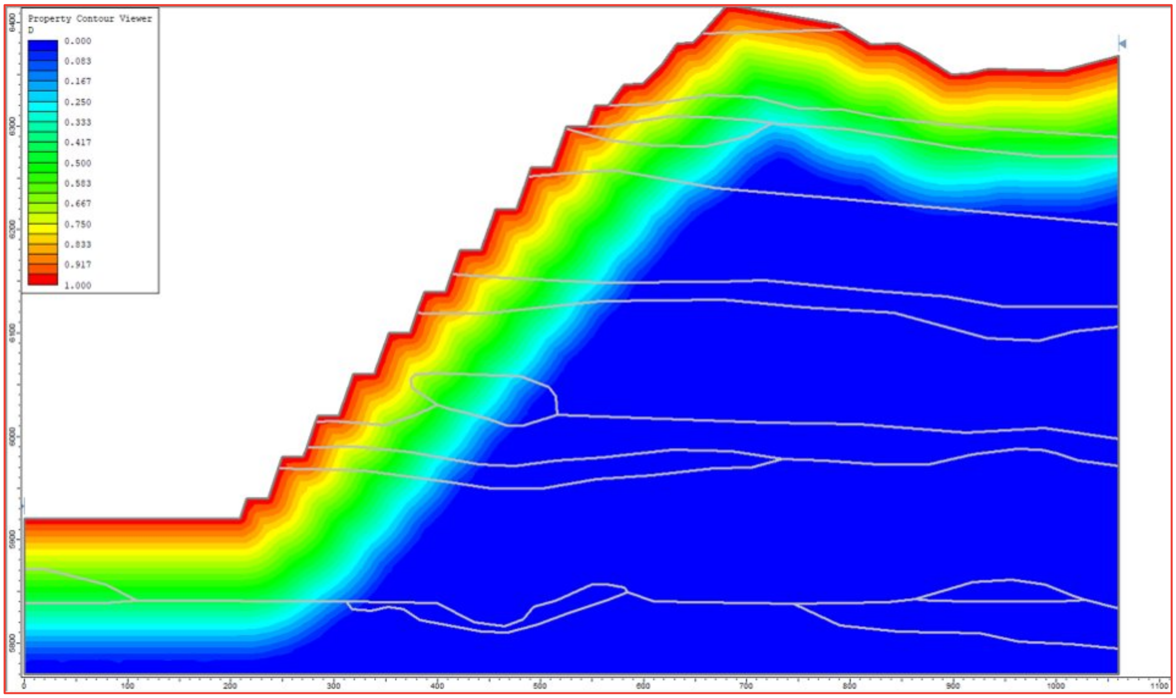


Figure 4-4. Example of a Graded Disturbance (D) Factor Where Red Represents Maximum Blast Damage (D = 1) and Blue Represents No Blast Damage (D = 0).

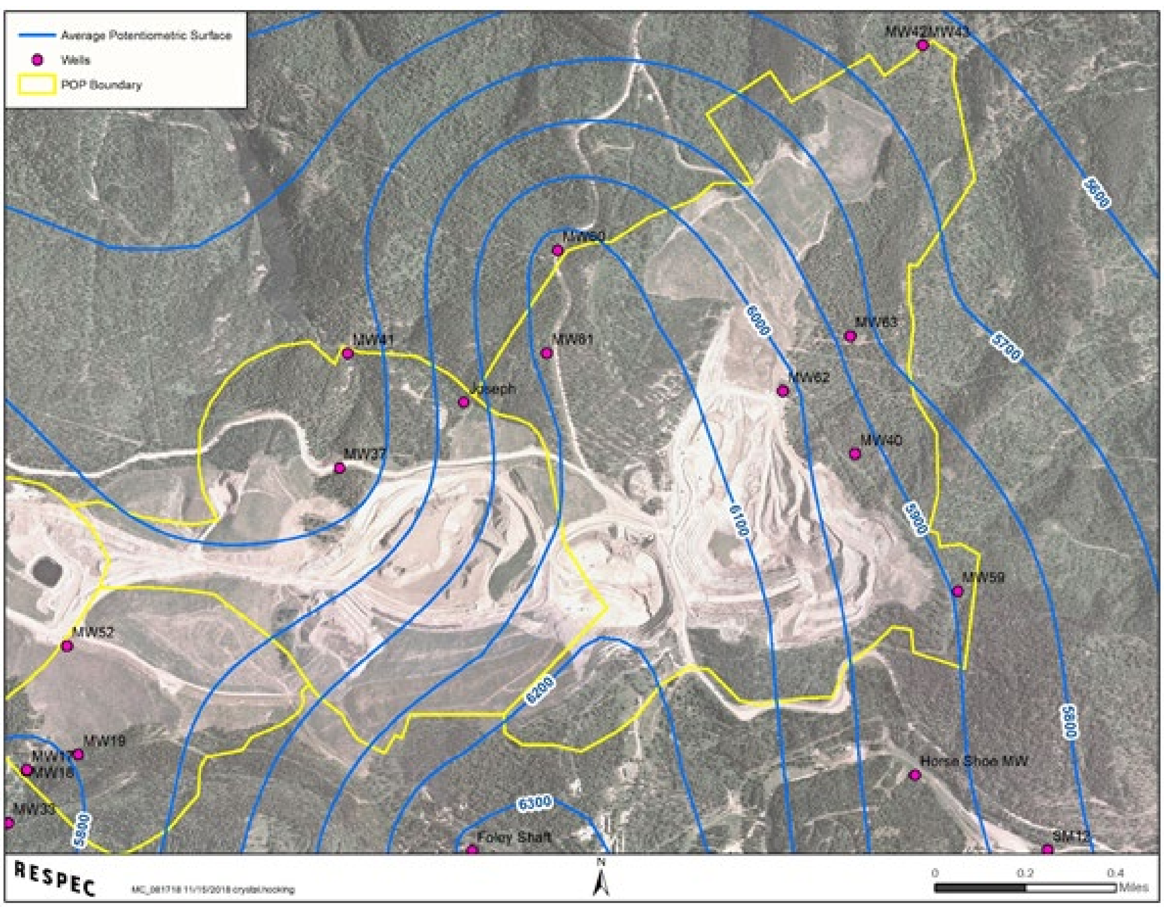


Figure 4-5. Potentiometric Surface Map of the Wharf Mine From April 2018.

excavations do not appear to be accounted for. For these reasons and in the absence of a more refined hydrogeologic model for the Portland and Green Mountain Pits, the modeled pit slopes were assumed to be dry. This assumption is also consistent with industry practice in semiarid and arid environments where pit slopes are expected to depressurize quickly because of blast damage and fracture networks that allow water to flow freely to the highwall.

4.1.5 SEISMICITY

The South Dakota Department of Public Safety's *Multi-Hazard Mitigation Plan* categorizes geologic hazards for the Site (including earthquakes) as "limited" and indicates that the primary and secondary impacts will be "negligible" and "limited," respectively. According to the U.S. Geological Survey (USGS) interactive hazard map, the 2,500-year, 5.5-magnitude earthquake's Peak Ground Acceleration (PGA) is 0.066 gravity (g). Because of the low seismic hazard and small PGA at the Site, seismic loading was not included in the current slope stability evaluation.

4.1.6 HISTORICAL SLOPE PERFORMANCE

In addition to the documents and information provided by Wharf, RESPEC visited the Site on two occasions to observe highwall conditions, evaluate rock mass characteristics, and collect laser-scan point cloud data. Information gathered during the site visits was used to qualitatively evaluate the performance of the current pit-slope designs. Other than toppling rockfall, few historical slope instabilities have occurred at the Site. An incipient failure of the east highwall of the old East Liberty Pit was discovered and mitigated in 1994 [Nopola and Roberts, 2013]. Whether or not the failure could have been managed operationally is unclear, but the primary motivation for mitigating instead of managing the failure appears to be because of the presence of a historical cemetery immediately to the east of the highwall. Blankenship and Osnes [1994] attributed the instability to a near-vertical dike that was striking nearly parallel to the highwall face. The dike was thought to have acted as a release structure that allowed the weak Deadwood Shale unit to slide. Surface-water inflow in open tension cracks was also thought to be contributing to the instability.

Other than the reported instability in the old East Liberty Pit and common toppling rockfalls, no significant slope instabilities are known to RESPEC. Nopola and Roberts [2013] mention an internal memorandum in which Wharf (then Golden Reward Mining Company) documented all slope stability issues at the mine through 1996 [Zeihen, 1996]. The memorandum was not available for the current study, but its existence implies that other significant instabilities have occurred. However, based on RESPEC's conversations with Wharf personnel, the East Liberty instability and some or all the previous slope failures were associated with steeply dipping faults and other structures that are not present in the current study area.

Bench-scale and sub-bench-scale wedge, planar sliding, and toppling rockfall events have occurred in the current Green Mountain and Portland Pits. These rockfall events have resulted in limited backbreak of catch-bench crests. Except where material has been pushed over the top of the pits, much of the available rockfall catchment remains in long-term highwalls. Toppling events are common in blocky, moderately to highly fractured rock conditions such as those found at the Site. These conditions have historically presented some minor challenges to operations but are not considered a major stability concern.

4.2 KINEMATIC STABILITY ANALYSES

Kinematic slope stability analysis is the process of systematically evaluating the likelihood that structurally controlled slope failures will occur in a slope. Generally, the parameters affecting the stability of a slope during a kinematic analysis are the friction angles and cohesions of discontinuity surfaces, slope dip direction (i.e., azimuth), and slope dip (i.e., angle from horizontal). If friction angles and cohesions along the discontinuity planes and a statistically significant number of discontinuity measurements are available (typically > 30 per discontinuity set), the probability that a given type of slope failure will occur for a given slope orientation can be calculated. Alternatively, mean discontinuity sets can be used to calculate FS values for sliding, toppling, and wedge failures.

The main advantage to using the probability of failure (PF) approach is that PF values can be incorporated into a geotechnical risk-management program and they better account for noise in orientation measurements and spatial variability in joint set orientations. For these reasons, probabilistic methods were used for this study. The typical PF and FS acceptance criteria for open-pit mines that have implemented slope performance monitoring methods are shown in Table 4-3. Read and Stacey [2009] provide additional information regarding kinematic analyses theory and FS and PF acceptance criteria.

Table 4-3. Probability of Failure Acceptance Criteria for Bench-Face and Inter-Ramp Angles Used With Slope Performance Monitoring (From Read and Stacey [2009])

Slope Scale	Consequence of Failure	FS Values for Static Loading	FS Values for Seismic Loading	PF (%)
Bench	Low-High	1.1	—	25–50
Inter-Ramp Angles	Low	1.15–1.2	1.0	25
	Medium	1.2	1.0	20
	High	1.2–1.3	1.1	10

Rocscience's DIPS software [Rocscience, 2021] was used to perform the kinematic stability analyses. A total of 1,228 discontinuity orientations were measured from photogrammetric and laser-scan point clouds and plotted as poles on lower-hemisphere, equal-angle stereonets. Pole plots of the discontinuities grouped by geologic unit type and source location are shown in Figures 4-6 and 4-7, respectively. The poles located near the outer edge of the stereonet are representative of steeply dipping discontinuities, while the poles nearer the center of the plot represent shallowly dipping features such as bedding planes. The stereonets in Figures 4-6 and 4-7 illustrate the location and material biases of the data used. The discontinuity measurements from the Flossie Pit were from a unit (Quartz Trachyte) not present in Wharf's current geological model for the Portland and Green Mountain Pits. Discontinuity measurements in the Quartz Trachyte included in the stability assessment because the unit's full extent and expected exposure in the Ultimate Pit is not known.

The results of multiple runs of probabilistic kinematic models and a sensitivity analysis were used to develop recommendations for IRAs and BFAs using the acceptance criteria in Table 4-3. Mean discontinuity set orientations were developed from RESPEC's entire discontinuity database to compare with the results of historical studies.

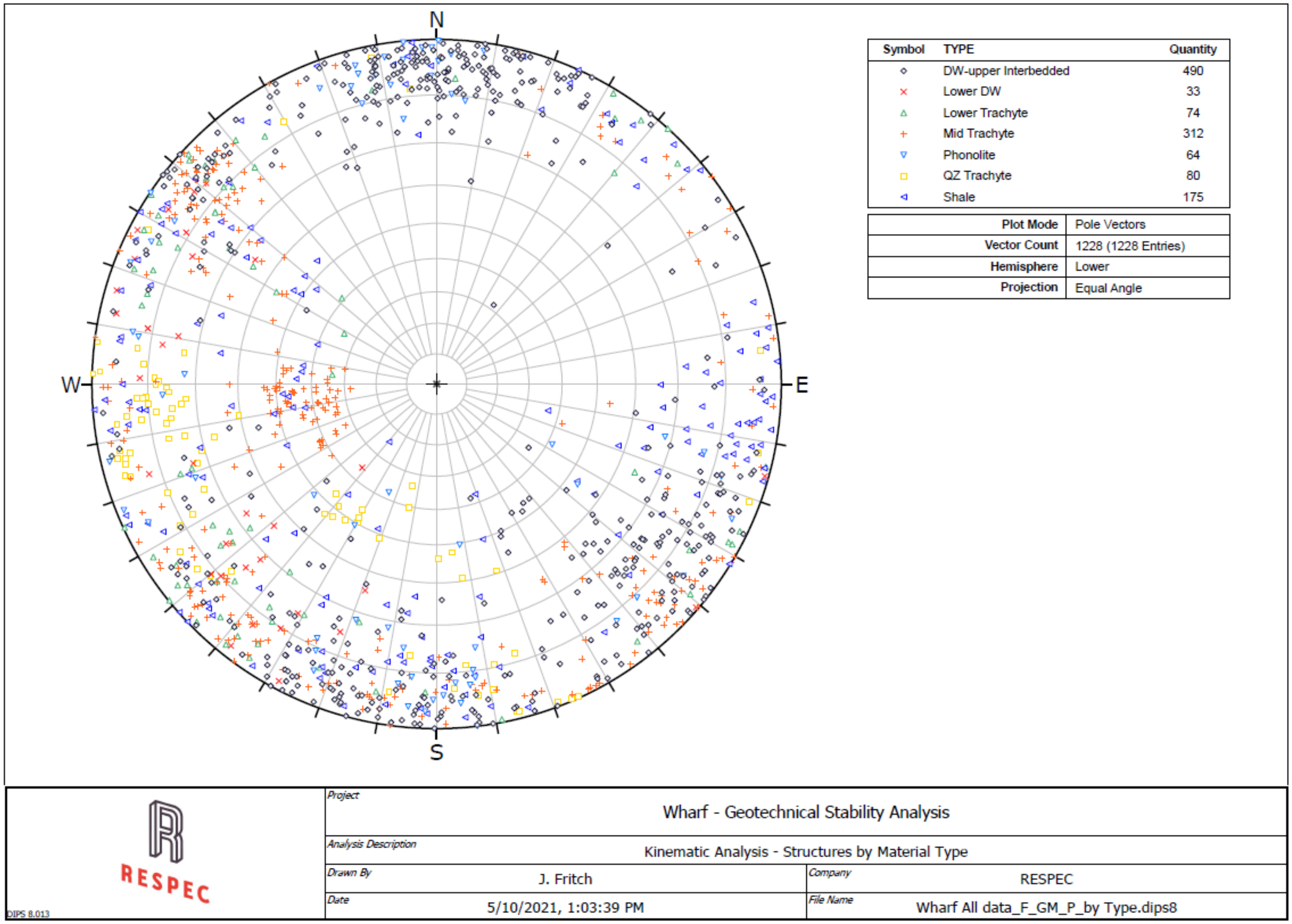
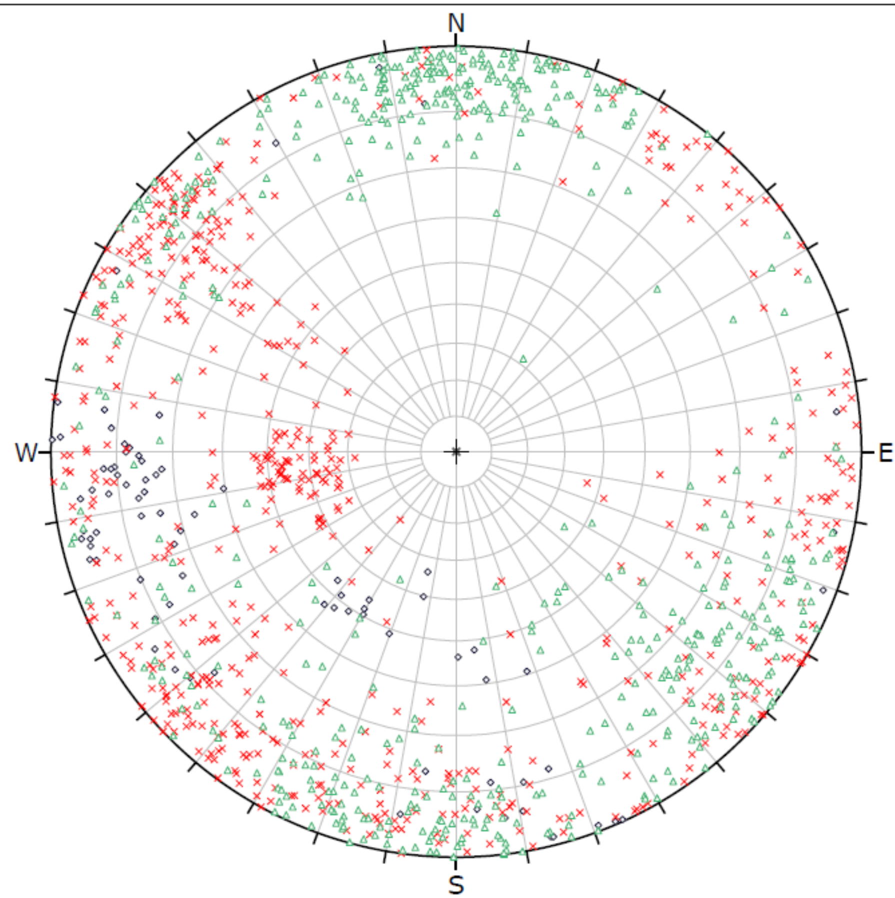


Figure 4-6. Stereonet Pole Plot of RESPEC's Discontinuity Orientation Measurements Grouped by Geologic Unit.



Symbol	SOURCE	Quantity
◇	Flossie	80
×	Green Mountain	604
△	Portland	544

Plot Mode	Pole Vectors
Vector Count	1228 (1228 Entries)
Hemisphere	Lower
Projection	Equal Angle

RESPEC	*Project* Wharf - Geotechnical Stability Analysis		
	Analysis Description Kinematic Analysis - Structural Data by Source Location		
	Drawn By J. Fritch	*Company* RESPEC	
DIPS 8.013	*Date* 5/10/2021, 1:03:39 PM	*File Name* Wharf All data_F_GM_P_by Type.dips8	

Figure 4-7. Stereonet Pole Plot of RESPEC's Discontinuity Orientation Measurements Grouped by Source Location.

4.2.1 DISCONTINUITY SETS

To compare RESPEC's discontinuity measurements with historical data, mean joint set orientations were selected using pole-density contours and engineering judgment. The mean joint set orientations are also useful for determining the most geotechnically unfavorable slope orientations and dominant kinematic failure modes (i.e., planar sliding, wedge sliding, or toppling).

4.2.2 GENERAL EVALUATION OF INTER-RAMP ANGLES

For each cross section, the 49-degree current design IRA and 60-degee maximum IRA as recommended by Kliche [2007] were initially evaluated using RESPEC's entire database of joint set orientations. To validate current practices and historical recommendations, the slope dip directions listed in Table 4-1 were used to calculate the PF values for sliding, wedge, direct toppling, and flexural toppling at both IRAs.

Historical studies have consistently identified the glauconitic siltstone, Icebox Shale, and Deadwood Shale as being the most problematic geologic units at the Site. Friction angle values from historical direct shear tests on siltstones and shales at the Site range from 22 to 50 degrees. Direct shear tests on a weak dolomite unit near the Site yielded a much lower friction angle of 13.5 degrees [Kliche et al., 1987]. Nopola and Roberts [2013] also included rock mass friction angles that were empirically derived from their rock mass classifications. Although estimated rock mass friction angles are not necessarily representative of the friction angle of discontinuities, the empirically derived friction angle for the Deadwood Shale that was in the "Rock Test Summary.xlsx" workbook was 32.7 degrees. This value is slightly less than the mean of the friction angle of 34.1 degrees that was measured using direct shear tests. All the historical direct shear friction angles are summarized in Table 4-4.

Table 4-4. Historical Friction Angle Measurements From Direct Shear Tests

Rock Type	Strength Type	Data Source	Friction Angle (ϕ)
Shale 1	Peak	Rock Test Summary.xlsx	44.9
	Residual		45.0
Shale 2	Peak	Hladysz [1996]	50.0
	Residual		22.0
Schist	Peak	Rock Test Summary.xlsx	36.7
	Residual		28.8
Siltstone	Peak	Smith and Kliche [1988]	36.2
	Residual		30.1
Dolomite	Unknown	Kliche et al. [1987]	13.5
Mean Friction Angle			34.1

Because the shales were expected to be the controlling factor in the kinematic stability evaluation and little additional information about the historical direct shear test samples was available (e.g., exact rock unit, sample depth, and sample location), a discontinuity friction angle of 33 degrees was selected for the general evaluation of IRAs. Kliche [2007] used a friction angle of 30 degrees.

4.2.3 SENSITIVITY ANALYSIS

A sensitivity analysis of kinematic stability was performed to explore the possibility of steepening the current design BFAs (approximately 70 degrees) and IRAs. Using the same 33-degree friction angle as in the general kinematic IRA evaluation (refer to Section 4.2.2) and the entire discontinuity database, the least geotechnically favorable slope dip direction was selected by plotting wedge and planar failure PF values in a circular diagram and finding the slope dip azimuth with the maximum PF. After selecting the least favorable slope dip direction, PFs were calculated for a range of BFAs between 40 and 90 degrees. The critical PF thresholds from Table 4-3 were then compared to the sensitivity plots to provide recommendations regarding Wharf's design IRAs and BFAs and the recommendations made by Kliche [2007].

4.3 LIMIT-EQUILIBRIUM STABILITY ANALYSES

To evaluate the likelihood of global slope instabilities caused by rock mass failures (as opposed to kinematically controlled failures), deterministic 2D LE slope stability simulations were run. The geological cross sections described in Section 4.1.1 were imported into Rocscience's Slide2 software [Rocscience, 2021]. Based on historical geotechnical data, RESPEC's recent field observations, and conversations with Wharf personnel, Hoek-Brown material properties were assigned to each geological unit in the cross sections. Voids from historical mine workings were not considered in the 2D LE models because their locations and sizes are difficult to predict, and no void maps were available at the time of the study. In all of the models, the Cuckoo method [Wu, 2012] was used to iteratively search for noncircular failure surfaces. The limits defining the search boundaries of where the failure surfaces could daylight in the slope were initially set to the maximum lateral extents of the slopes and then adjusted as needed to adequately evaluate IRAs.

To evaluate the importance of the estimated intact rock strength on global slope stability and account for uncertainties in currently available data, a sensitivity analysis of UCS values were performed for each cross section. FS values were plotted against the range of UCS values for each geological unit. The results of the 2D LE modeling effort were used to develop recommendations regarding design IRAs and those recommended by Kliche [2007]. Geological units, associated Hoek-Brown properties, and overall slope heights in the 2D LE models are shown in Figures 4-8 through 4-11. Additional information regarding the theory of LE slope stability analysis can be found in Read and Stacey [2009].

4.3.1 DETERMINISTIC ANALYSIS

Deterministic global minimum FS values were computed in the 2D LE models using the Spencer [1967] method. Noncircular slip surfaces were evaluated because they generally provide more realistic failure planes in stratified deposits with isolated weak units. The Hoek-Brown material strength properties used by Nopola and Roberts [2013] and included in Table 4-2 were used. Without performance monitoring, the industry standard is to use a minimum acceptable FS value between 1.4 and 1.5 for deterministic 2D LE models of long-term slopes under static loads (i.e., no significant seismic hazards). If performance monitoring is performed, reducing the acceptable FS values to between 1.2 and 1.3 is common, as shown in Table 4-3. Because performance monitoring is currently limited at the Site, and may not be used in the future, a critical FS criterion of 1.4 was used for all of the 2D LE models.

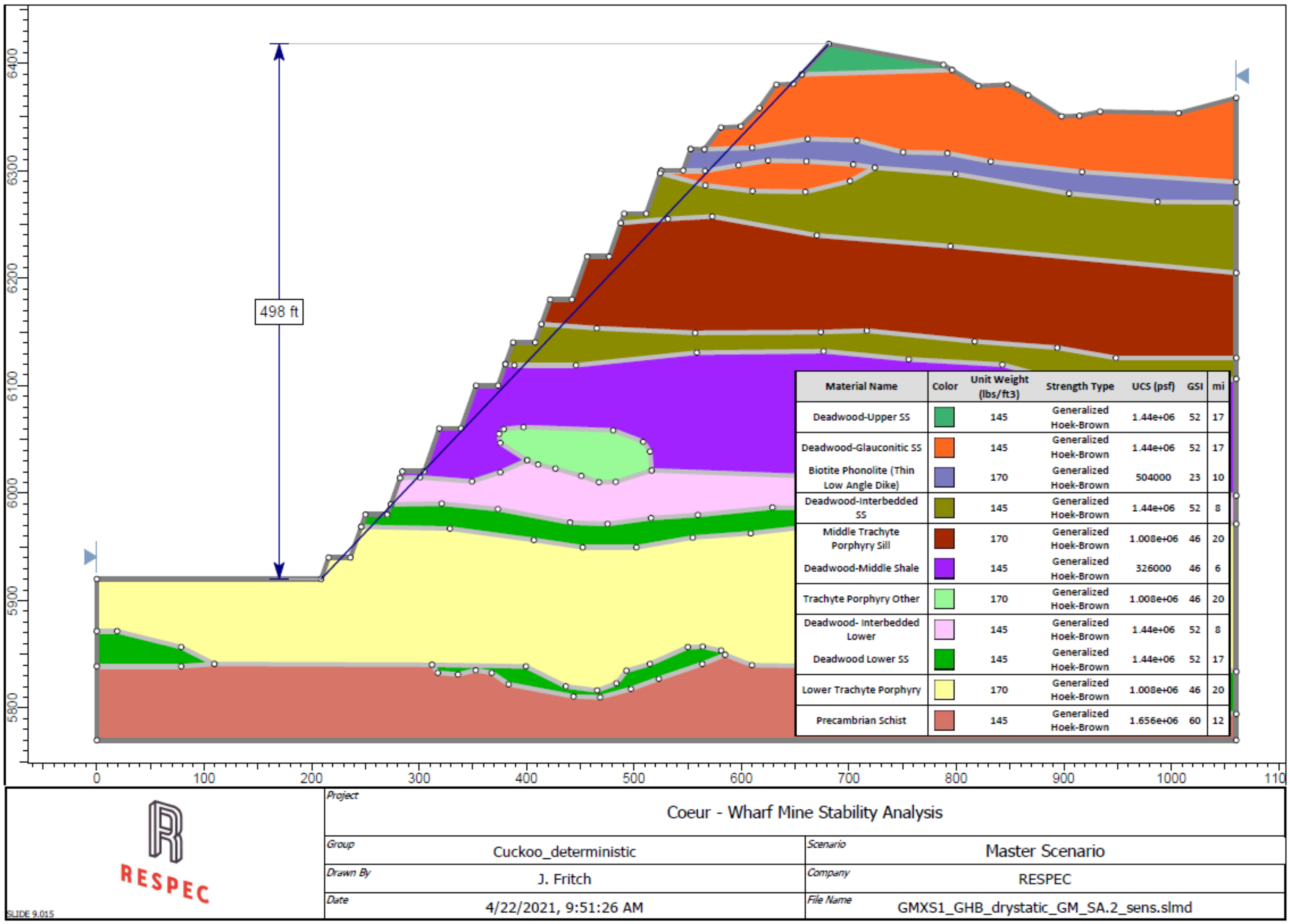


Figure 4-8. Geological Units, Overall Slope Height, and Materials Properties Used for Stability Modeling in Cross Section GM-1.

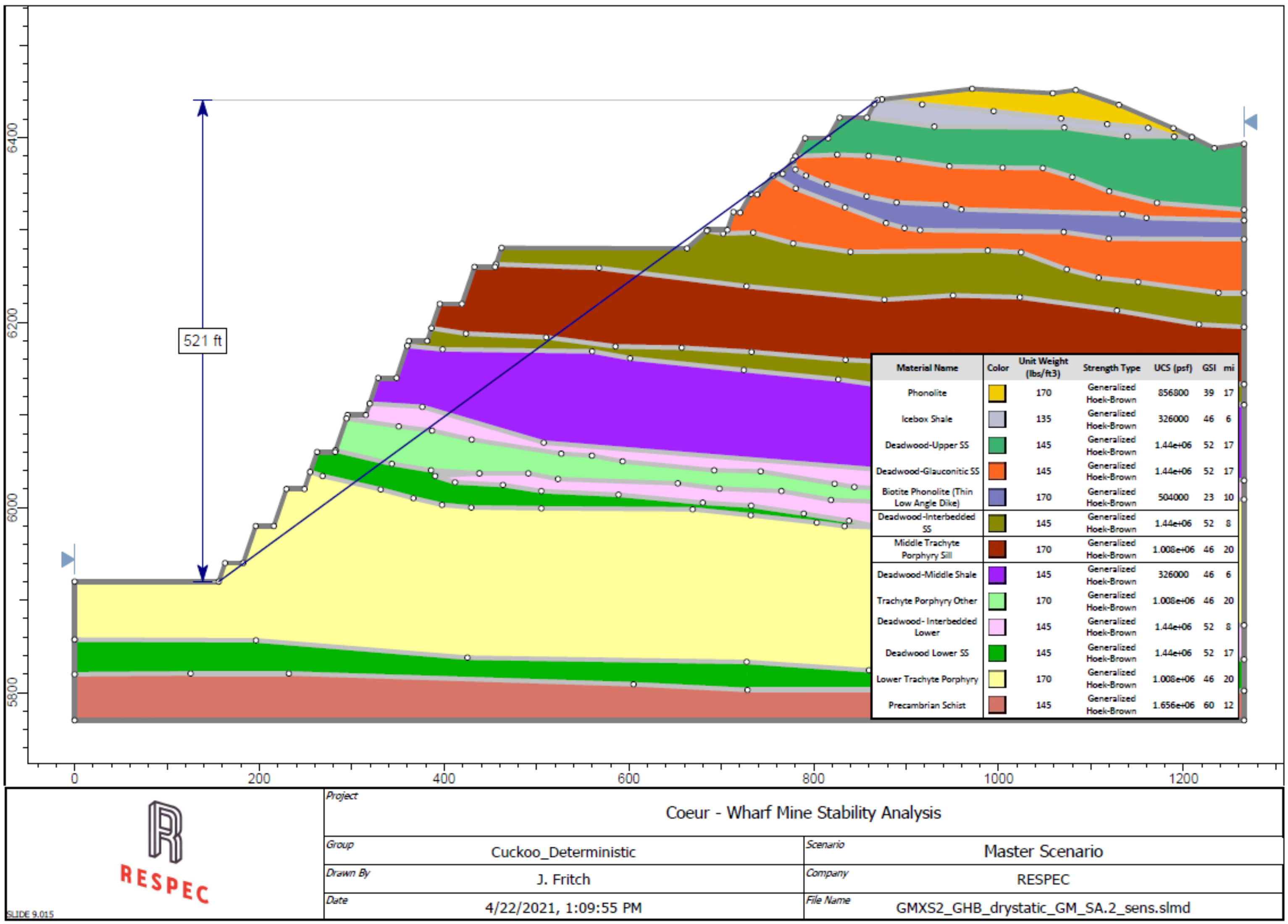
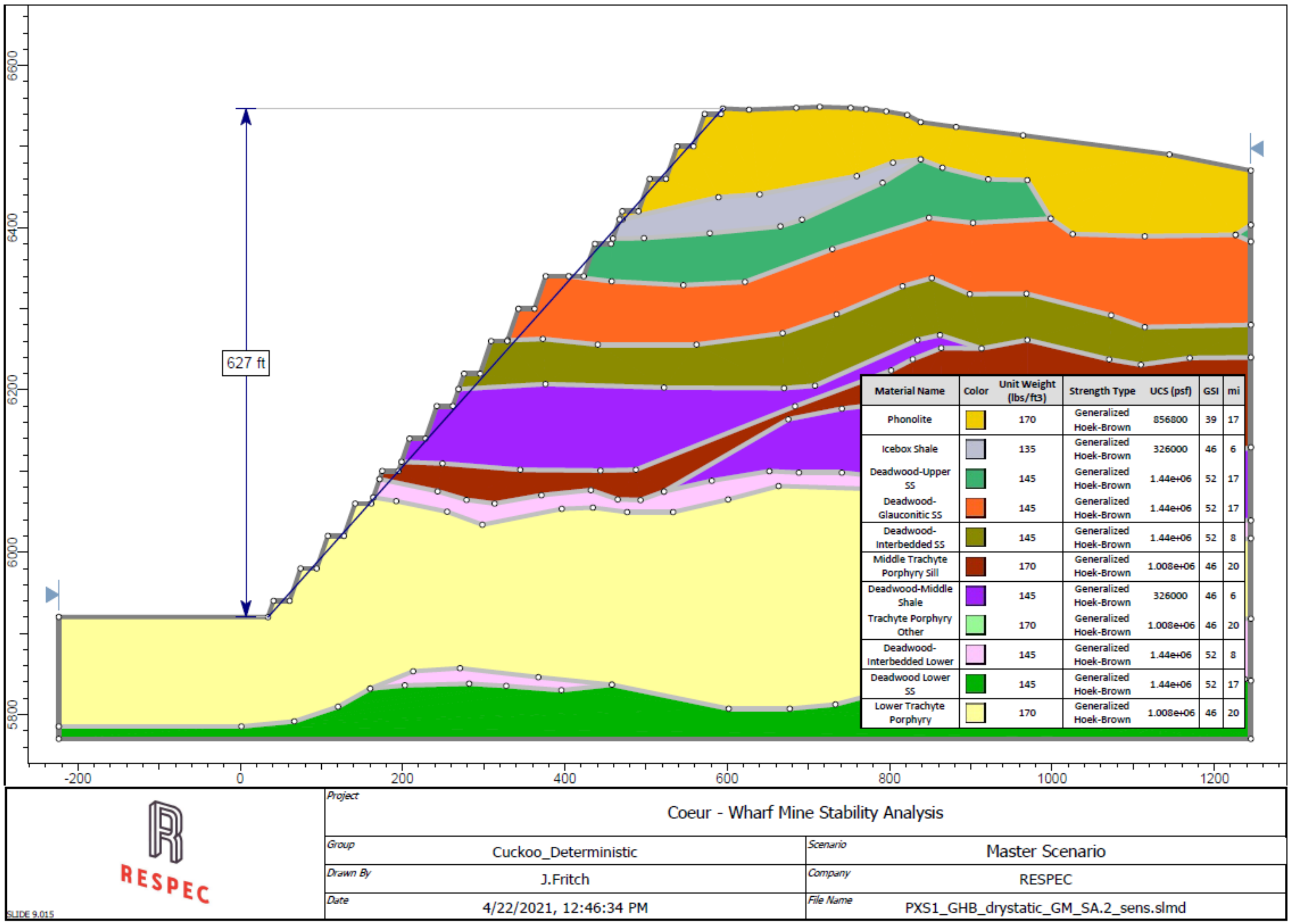
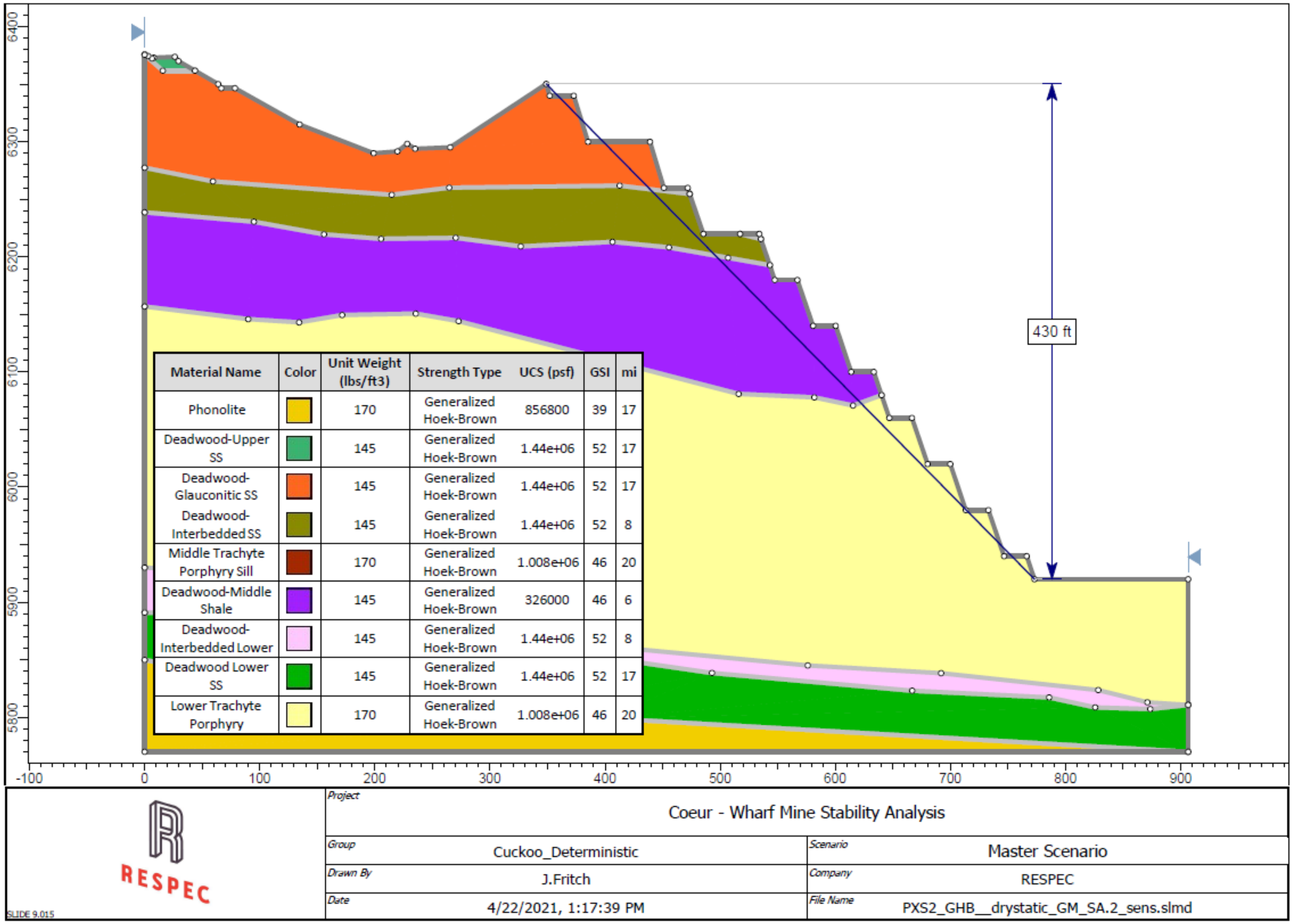


Figure 4-9. Geological Units, Overall Slope Height, and Materials Properties Used for Stability Modeling in Cross Section GM-2.



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	UCS (psf)	GSI	mi
Phonolite		170	Generalized Hoek-Brown	856800	39	17
Icebox Shale		135	Generalized Hoek-Brown	326000	46	6
Deadwood-Upper SS		145	Generalized Hoek-Brown	1.44e+06	52	17
Deadwood-Glauconitic SS		145	Generalized Hoek-Brown	1.44e+06	52	17
Deadwood-Interbedded SS		145	Generalized Hoek-Brown	1.44e+06	52	8
Middle Trachyte Porphyry Sill		170	Generalized Hoek-Brown	1.008e+06	46	20
Deadwood-Middle Shale		145	Generalized Hoek-Brown	326000	46	6
Trachyte Porphyry Other		170	Generalized Hoek-Brown	1.008e+06	46	20
Deadwood-Interbedded Lower		145	Generalized Hoek-Brown	1.44e+06	52	8
Deadwood Lower SS		145	Generalized Hoek-Brown	1.44e+06	52	17
Lower Trachyte Porphyry		170	Generalized Hoek-Brown	1.008e+06	46	20

Figure 4-10. Geological Units, Overall Slope Height, and Materials Properties Used for Stability Modeling in Cross Section PORT-1.



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	UCS (psf)	GSI	mi
Phonolite		170	Generalized Hoek-Brown	856800	39	17
Deadwood-Upper SS		145	Generalized Hoek-Brown	1.44e+06	52	17
Deadwood-Glauconitic SS		145	Generalized Hoek-Brown	1.44e+06	52	17
Deadwood-Interbedded SS		145	Generalized Hoek-Brown	1.44e+06	52	8
Middle Trachyte Porphyry Sill		170	Generalized Hoek-Brown	1.008e+06	46	20
Deadwood-Middle Shale		145	Generalized Hoek-Brown	326000	46	6
Deadwood-Interbedded Lower		145	Generalized Hoek-Brown	1.44e+06	52	8
Deadwood Lower SS		145	Generalized Hoek-Brown	1.44e+06	52	17
Lower Trachyte Porphyry		170	Generalized Hoek-Brown	1.008e+06	46	20

Figure 4-11. Geological Units, Overall Slope Height, and Materials Properties Used for Stability Modeling in Cross Section PORT-2.

4.3.2 UNCONFINED COMPRESSIVE STRENGTH SENSITIVITY ANALYSIS

Because of the limited amount of site-specific geotechnical data available for this study, RESPEC performed a sensitivity analysis of intact rock UCS values. Global minimum FS values were calculated 500 times where for each geologic unit, the UCS value was randomly selected from uniform probability distribution of ±20 percent of a central value. Although uniform distributions of geotechnical properties are sometimes unrealistic, an insufficient quantity of strength data were available to justify using a more sophisticated distribution (e.g., Gaussian) of UCS values. The relationship between FS and UCS values were plotted for each geologic unit in each cross section. The range of material properties used in the sensitivity analysis are shown in Table 4-5.

Table 4-5. Intact Rock Unconfined Compressive Strength Values Used in the Two-Dimensional, Limit-Equilibrium Global Stability Models

Geologic Unit	Central UCS Value (ksf)	Minimum UCS Value (ksf)	Maximum UCS Value (ksf)
Phonolite	856.8	685.8	1,027
Icebox Shale	326	261	391
Deadwood Upper Sandstone	1,440	1,152	1,728
Deadwood Glauconitic Sandstone	1,440	1,152	1,728
Biotite Phonolite (Thin Low-Angle Dike)	504	403	605
Deadwood Interbedded Sandstone	1,440	1,152	1,728
Middle Trachyte Porphyry Sill	1,008	806	1,210
Deadwood Middle Shale	326	261	391
Trachyte Porphyry Other	1,008	806	1,210
Deadwood- Interbedded Lower	1,440	1,152	1,728
Deadwood Lower Sandstone	1,440	1,152	1,728
Lower Trachyte Porphyry	1,008	806	1,210
Precambrian Schist	1,656	1,325	1,987

5.0 RESULTS AND CONCLUSIONS

5.1 KINEMATIC STABILITY ANALYSES

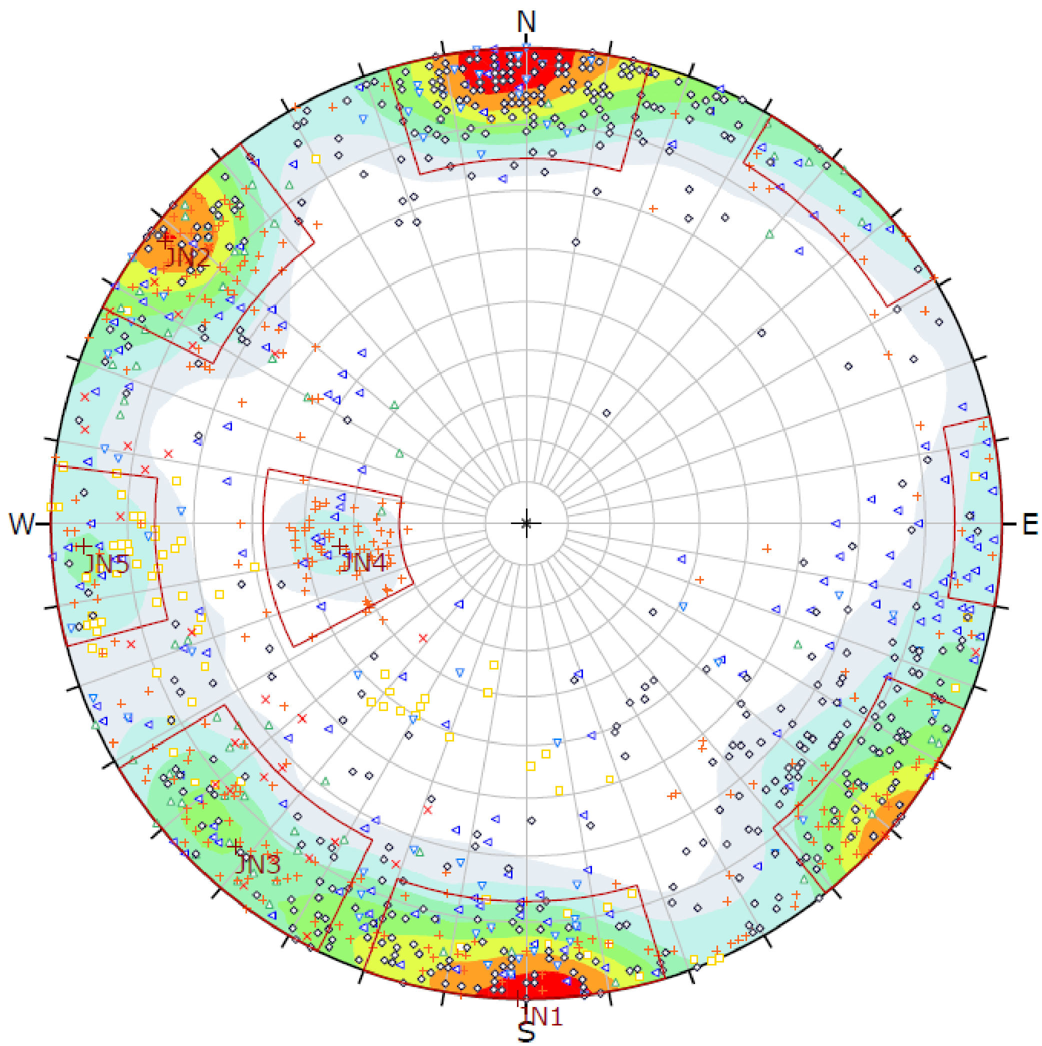
Five joint sets were identified from the discontinuity orientation data obtained by RESPEC. The sets were numbered from one to five based on pole-density concentration, where higher concentrations are assigned lower numbers (i.e., JN1 had the highest pole density). Table 5-1 is a summary of the mean joint set orientations in comparison with sets reported by Kliche [2007]. A stereonet plot of all RESPEC's discontinuity poles with pole densities and joint sets is shown in Figure 5-1. Further descriptions of each set are as follows:

- JN1 has a near-vertical dip to the north/south and is most strongly expressed in the Deadwood Formation.
- JN2 has a near-vertical dip to the northwest/southeast and is most strongly expressed in the Deadwood Formation with some expression in the trachyte units.
- JN3 has a near-vertical dip to the northeast/southwest and has a substantially lower pole-density concentration than JN1 or JN2.
- JN4 has the flattest dip of any of the identified joint sets and consists almost entirely of discontinuities in the trachyte units found in the current Portland and Green Mountain Pits.
- JN5 has a near-vertical dip in approximately the same direction as JN4 (east) but largely consists of trachyte discontinuities from the Flossie Pit.

Table 5-1. Five Predominant Mean Set Orientations Compared to Kliche [2007] and Kliche and Hladysz [1997] Studies

2021 Study			2007 Study		
Set Name	Dip (degrees)	Dip Direction (degrees)	Set Name	Dip (degrees)	Dip Direction (degrees)
JN1	90	1	Set 3	87	182
JN2	88	128	Set 2	87	135
JN3	85	42	Set 1	88	45
JN4	43	83	Set 5	6	240
JN5	86	87	Set 4	86	286

Like Kliche [2007] and Kliche and Hladysz [1997], RESPEC identified four near-vertically dipping joint sets and one low-angle joint set. Among the near-vertical sets, JN1 was nearly identical to Kliche's [2007] Set 3, JN2 was nearly identical to Set 2, and JN3 was nearly identical to Set 1. Set JN4 is not found in Kliche's [2007] analysis. Set JN5 loosely correlates with Kliche's [2007] Set 4 but is unclear if or how these sets might be related. Kliche's [2007] Set 5 is associated with bedding planes in the Deadwood Formation that could not be measured with the point cloud data and was not included in the current stability assessment. Figure 5-2 shows a side-by-side comparison of pole-density plots from Kliche [2007] and the current study.



Symbol	TYPE	Quantity
◇	DW-upper Interbedded	490
×	Lower DW	33
△	Lower Trachyte	74
+	Mid Trachyte	312
▽	Phonolite	64
□	QZ Trachyte	80
◁	Shale	175

Color	Density Concentrations
	0.00 - 1.00
	1.00 - 2.00
	2.00 - 3.00
	3.00 - 4.00
	4.00 - 5.00
	5.00 - 6.00
	6.00 - 7.00
	7.00 - 8.00

Contour Data	Pole Vectors
Maximum Density	7.96%
Contour Distribution	Fisher
Counting Circle Size	1.0%

	Color	Dip	Dip Direction	Label
Mean Set Planes				
6m		90	1	JN1
7m		43	83	JN4
8m		88	128	JN2
9m		86	87	JN5
10m		85	42	JN3

Plot Mode	Pole Vectors
Vector Count	1228 (1228 Entries)
Hemisphere	Lower
Projection	Equal Angle

Figure 5-1. Pole-Density Density Plot of All Measured Discontinuities, by Rock Type and Showing Mean Joint Sets.

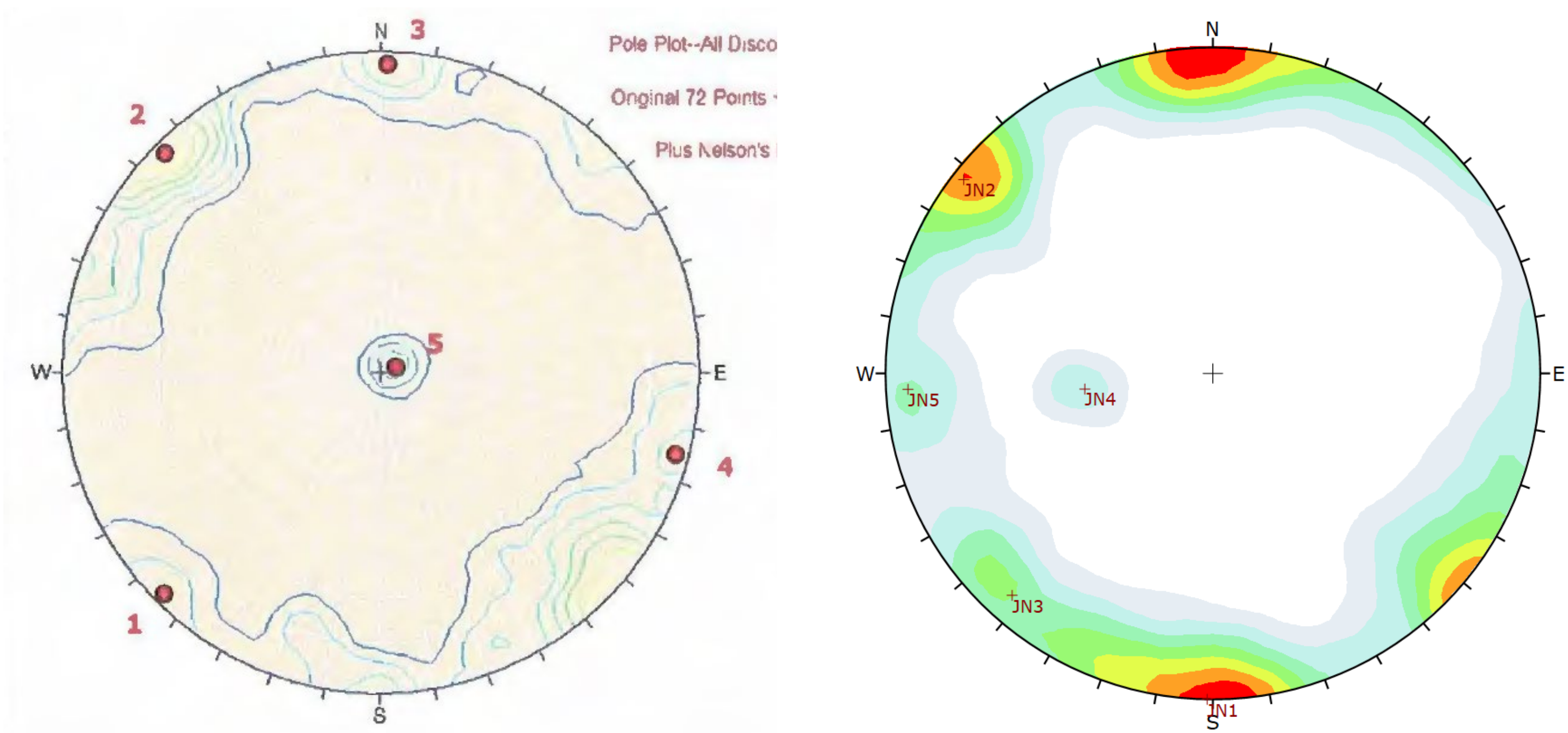


Figure 5-2. Side-by-Side Pole-Density Plots of Mean Joint Sets From Kliche [2007] (Left) and the Current Study (Right).

In terms of kinematic slope stability, the key differences between Kliche's [2007] and RESPEC's analyses are the presence JN4 and the lack of bedding planes. Because of its dip and dip direction, JN4 poses the highest risk of planar and wedge sliding failures on east-facing slopes. This risk is consistent with historical slope performance information from the Green Mountain Pit but was not a risk identified by Kliche [2007], likely because his analysis was based on data from other pit areas. The lack of bedding planes in RESPEC's analysis means that the risk of the toppling failure mode is likely underreported by probabilistic kinematic assessment.

5.1.1 GEOLOGIC CONTROLS

The steeply dipping joint sets (i.e., JN1, JN2, JN3, and JN5) generally occur in the igneous and sedimentary rocks exposed in the Portland, Green Mountain, and Flossie Pit walls. As can be seen in Figure 5-1, low-angle joint orientations are rare in the Deadwood Formation, and toppling is the controlling kinematic failure mode in the sedimentary rocks. A similar toppling risk also occurs in the igneous units, likely because of regional structure. These findings are consistent with the Site's slope performance history and RESPEC's field observations.

Unlike the steeply dipping joints, JN4 primarily occurs in trachyte and Phonolite units but was not apparent in the Quartz Trachyte unit exposed in the Flossie Pit (see Figure 5-1). Instead, the Quartz Trachyte has a somewhat scattered set of discontinuity measurements, most of which either were oriented close to the mean JN5 orientation or had a similar dip to JN4 but a more northerly dip direction. These measurements imply that there is a structural change between the current Portland and Flossie Pits, or the Quartz Trachyte has different dominant joint sets than the other trachytes evaluated. Because the western portion of the Ultimate Pit shell is between the current Portland and Flossie Pits. evaluating whether or not a structural change occurs in the area or the Quartz Trachyte has unique joint set orientations will be an important consideration in geotechnical studies at the Site.

5.1.2 GENERAL EVALUATION OF INTER-RAMP ANGLES

For each cross-section slope direction, PF values were calculated for at 49- and 60-degree IRAs. Tables 5-2 and 5-3 summarize the results of the general kinematic analysis. For both IRAs, the PF values generally met the acceptance criteria suggested by Read and Stacey [2009] (Table 4-3). Flexural toppling had the highest PF value in every cross section. Direct toppling had the second highest PF value in every cross section but because bedding planes were not included in the current assessment, direct toppling may actually be a more dominant failure mode than flexural toppling.

The maximum PF value for 49-degree slopes was 14.37 percent and occurred along the PORT-1 slope direction. In the same direction, the maximum PF value for 60-degree slopes increased slightly to 14.81 percent. Both these values fall below the 20-percent critical PF for medium-risk inter-ramp slopes. Among the 32 PF results listed in Tables 5-2 and 5-3, only 4 were greater than the 10 percent suggested by Read and Stacey [2009] for high-risk inter-ramp slopes. These results are consistent with previous work, and the recommendations provided by Kliche [2007] and current pit-slope design practices are considered reasonable. Figures 5-3 through 5-6 show the kinematic analysis stereonet plots of the most critical cross-section directions. A more detailed evaluation of acceptable IRAs is provided in Section 5.1.3.

Table 5-2. General Kinematic Analysis Results for an Inter-Ramp Angle of 49 Degrees

Slope Dip: 49°		Discontinuity Friction Angle: 33°			
Cross Section	Slope Dip Direction (degrees)	Probability of Failure (%)			
		Planar Sliding	Wedge Sliding	Flexural Toppling (All)	Direct Toppling (Intersection)
GM-1	028	0.35	4.38	6.62	5.76
GM-2	338	0.52	1.89	8.80	4.12
PORT-1	002	0.09	3.01	14.37	3.99
PORT-2	128	0.44	4.53	10.63	7.24

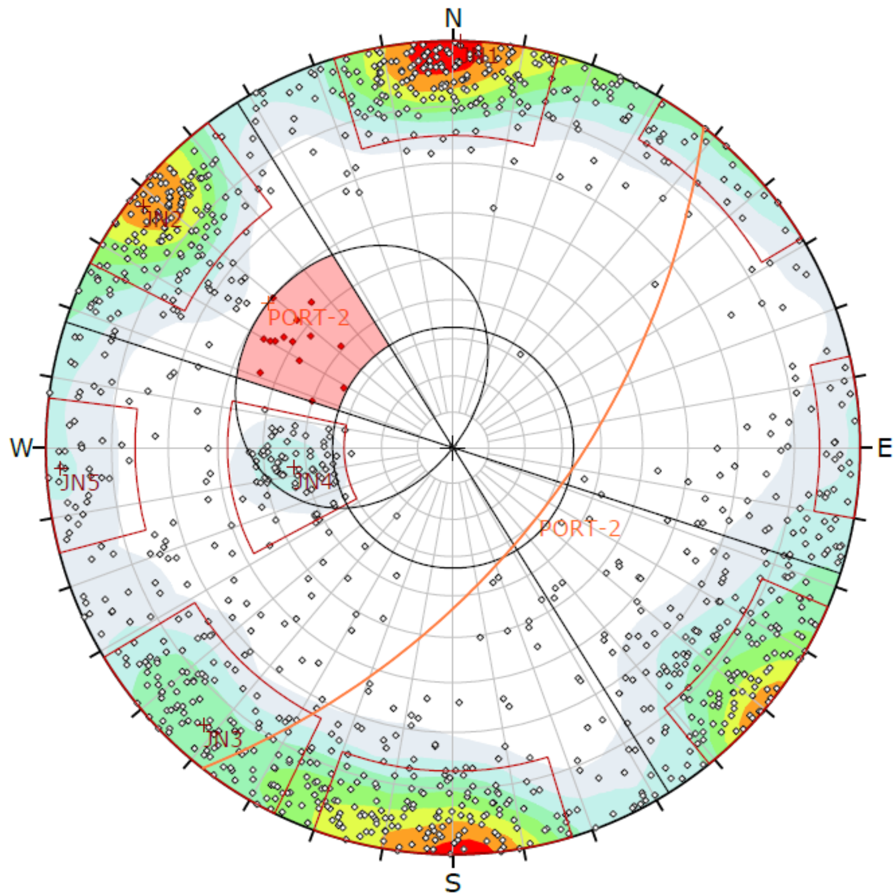
Table 5-3. General Kinematic Analysis Results for an Inter-Ramp Angle of 60 Degrees

Slope Dip: 60°		Discontinuity Friction Angle: 33°			
Cross Section	Slope Dip Direction (degrees)	Probability of Occurrence (%)			
		Planar Sliding	Wedge Sliding	Flexural Toppling (All)	Direct Toppling (Intersection)
GM-1	028	0.70	8.95	6.86	6.43
GM-2	338	0.96	5.55	9.32	4.39
PORT-1	002	0.26	6.40	14.81	4.22
PORT-2	128	1.22	9.61	13.15	7.65

5.1.3 SENSITIVITY ANALYSIS

Critical BFA and IRA values were evaluated by selecting the least geotechnically favorable slope direction and iteratively varying the slope angle. Figures 5-7 through 5-10 are plots of PF values for slope dip directions between 0- and 359-degree azimuth, and Figures 5-11 through 5-14 show PF values for each failure mode in the most critical slope dip direction for a range of slope dips between 40 and 90 degrees. These values encompass a wide range of potential IRAs and BFAs. As in the general IRA investigation, RESPEC found that the current design BFAs and IRAs are reasonable but could potentially be steepened.

The probability of wedge sliding failures is most sensitive to slope dip (Figure 5-12). Wedge sliding PF values range between approximately 3 percent for a 40-degree slope to approximately 55 percent for a 90-degree slope. If a critical PF for a medium-consequence inter-ramp slope of 20 percent is used as an acceptance criterion, IRAs less than 65 degrees would have an acceptable level of risk for all kinematic failure modes. Based on these results, IRAs even steeper than those recommended by Kliche [2007] may be achievable. The current 70-degree BFA design criterion results in critical PF values of between approximately 7 percent for planar sliding and 23 percent for wedge sliding. If a critical PF acceptance criterion between 30 and 40 percent is selected, BFAs of 75 to 85 degrees could be safely achievable.



Symbol	Feature
◇	Pole Vectors
◆	Critical Vectors

Color	Density Concentrations
	0.00 - 1.10
	1.10 - 2.20
	2.20 - 3.30
	3.30 - 4.40
	4.40 - 5.50
	5.50 - 6.60
	6.60 - 7.70
	7.70 - 8.80

Contour Data	Pole Vectors
Maximum Density	8.33%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Kinematic Analysis	Planar Sliding
Slope Dip	60
Slope Dip Direction	128
Friction Angle	33°
Lateral Limits	20°

	Critical	Total	%
Planar Sliding (All)	14	1148	1.22%

	Color	Dip	Dip Direction	Label
User Planes				
1		60	128	PORT-2
Mean Set Planes				
6m		90	181	JN1
7m		43	83	JN4
8m		88	128	JN2
9m		88	87	JN5
10m		85	42	JN3

Plot Mode	Pole Vectors
Vector Count	1148 (1148 Entries)
Hemisphere	Lower
Projection	Equal Angle

RESPEC	*Project* Wharf - Geotechnical Stability Analysis		
	Analysis Description PORT-2 - Kinematic Analysis - Planar Sliding		
	Drawn By J. Fritch	*Company* RESPEC	
DIPS 8.013	*Date* 5/10/2021, 1:03:39 PM	*File Name* Wharf All data_GM_P_PORT2.dips8	

Figure 5-3. Planar Sliding Kinematic Analysis in the Direction of Cross Section PORT-2.

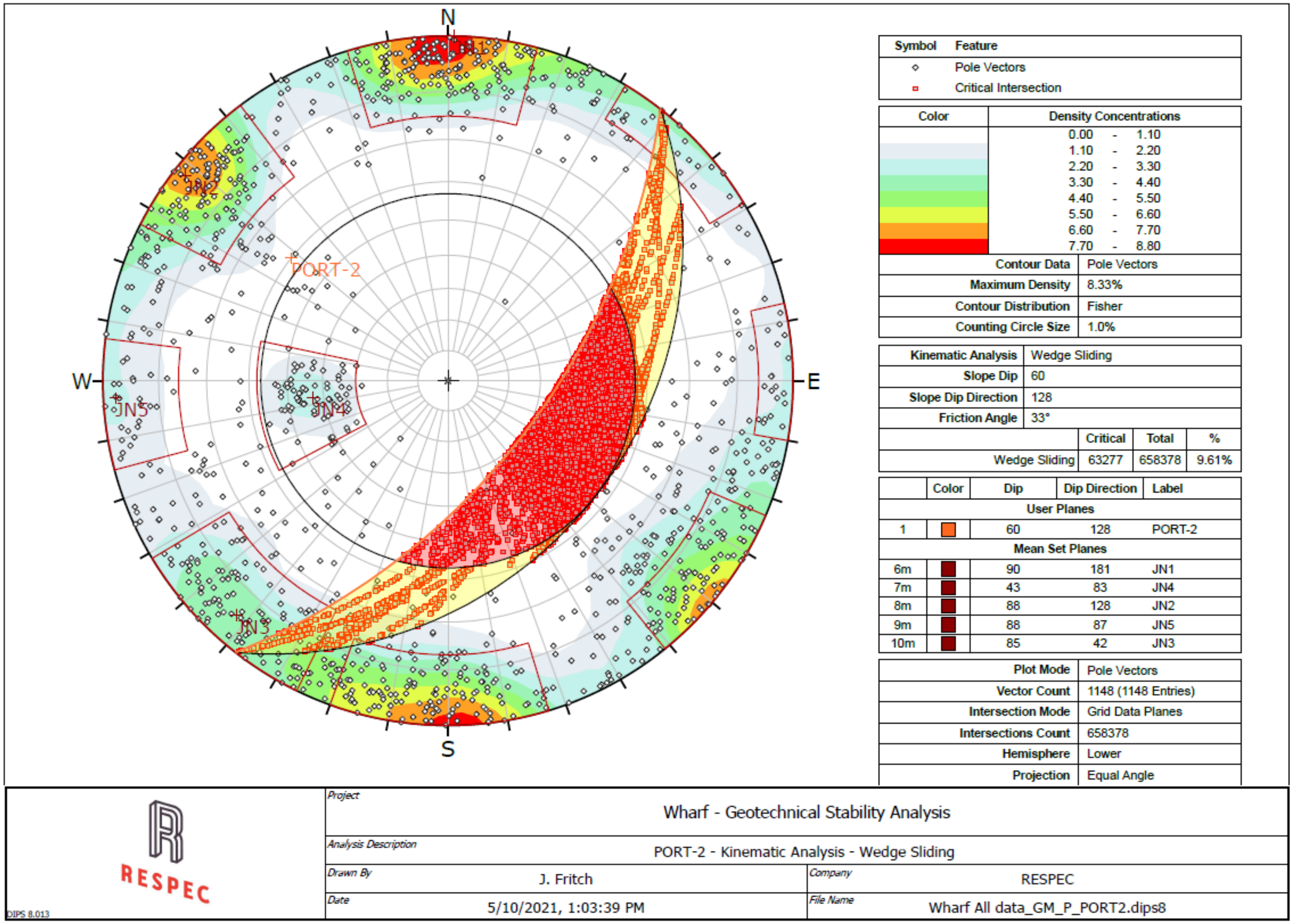
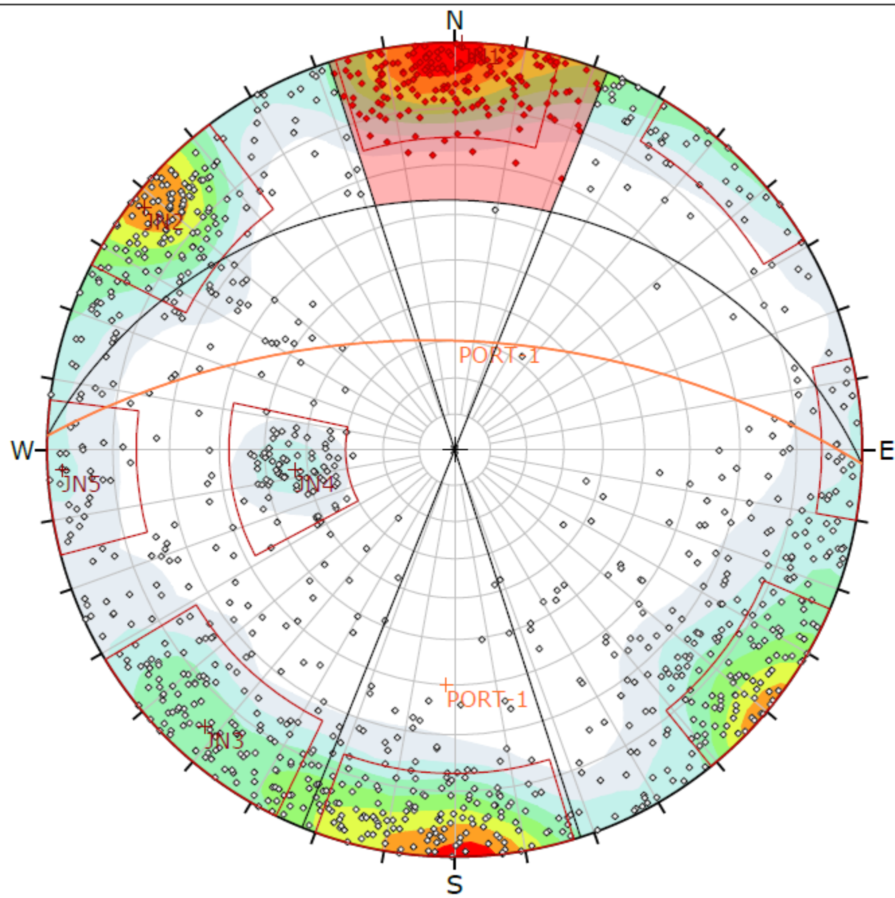


Figure 5-4. Wedge Sliding Kinematic Analysis in the Direction of Cross Section PORT-2.



Symbol	Feature
◇	Pole Vectors
◆	Critical Vectors

Color	Density Concentrations
	0.00 - 1.10
	1.10 - 2.20
	2.20 - 3.30
	3.30 - 4.40
	4.40 - 5.50
	5.50 - 6.60
	6.60 - 7.70
	7.70 - 8.80
Contour Data	Pole Vectors
Maximum Density	8.33%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Kinematic Analysis	Flexural Toppling
Slope Dip	60
Slope Dip Direction	2
Friction Angle	33°
Lateral Limits	20°

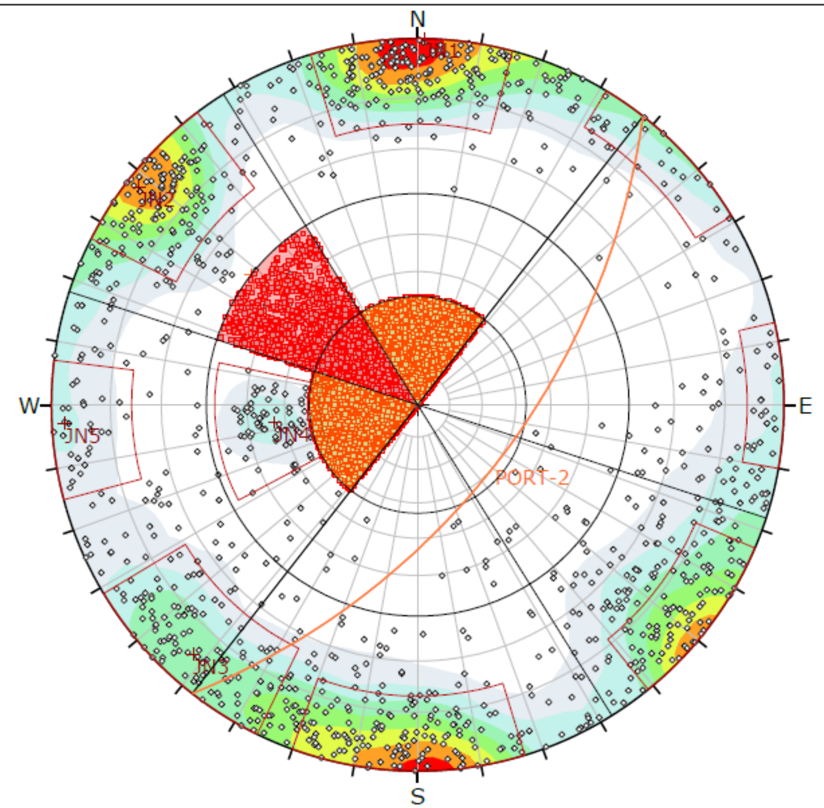
	Critical	Total	%
Flexural Toppling (All)	170	1148	14.81%
Flexural Toppling (Set 6: JN1)	150	275	54.55%

	Color	Dip	Dip Direction	Label
User Planes				
1		60	2	PORT-1
Mean Set Planes				
6m		90	181	JN1
7m		43	83	JN4
8m		88	128	JN2
9m		88	87	JN5
10m		85	42	JN3

Plot Mode	Pole Vectors
Vector Count	1148 (1148 Entries)
Hemisphere	Lower
Projection	Equal Angle

RESPEC	*Project* Wharf - Geotechnical Stability Analysis	
	Analysis Description PORT-1 - Kinematic Analysis - Flexural Toppling	
	Drawn By J. Fritch	*Company* RESPEC
DIPS 8.013	*Date* 5/10/2021, 1:03:39 PM	*File Name* Wharf All data_GM_P_PORT1.dips8

Figure 5-5. Flexural Toppling Kinematic Analysis in the Direction of Cross Section PORT-1.



Symbol	Feature
◇	Pole Vectors
▫	Critical Intersection

Color	Density Concentrations
	0.00 - 1.10
	1.10 - 2.20
	2.20 - 3.30
	3.30 - 4.40
	4.40 - 5.50
	5.50 - 6.60
	6.60 - 7.70
	7.70 - 8.80
Contour Data	Pole Vectors
Maximum Density	8.33%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Kinematic Analysis	Direct Toppling		
Slope Dip	60		
Slope Dip Direction	128		
Friction Angle	33°		
Lateral Limits	20°		
	Critical	Total	%
Direct Toppling (Intersection)	50353	658378	7.65%
Oblique Toppling (Intersection)	152810	658378	23.21%
Base Plane (All)	20	1148	1.74%
Base Plane (Set 7: JN4)	3	73	4.11%

	Color	Dip	Dip Direction	Label
User Planes				
1		60	128	PORT-2
Mean Set Planes				
6m		90	181	JN1
7m		43	83	JN4
8m		88	128	JN2
9m		88	87	JN5
10m		85	42	JN3

Plot Mode	Pole Vectors
Vector Count	1148 (1148 Entries)
Intersection Mode	Grid Data Planes
Intersections Count	658378
Hemisphere	Lower
Projection	Equal Angle

RESPEC	*Project* Wharf - Geotechnical Stability Analysis	
	Analysis Description PORT-2 - Kinematic Analysis - Direct Toppling	
	Drawn By J. Fritch	*Company* RESPEC
DIPS 8.013	*Date* 5/10/2021, 1:03:39 PM	*File Name* Wharf All data_GM_P_PORT2.dips8

Figure 5-6. Direct Toppling Kinematic Analysis in the Direction of Cross Section PORT-2.

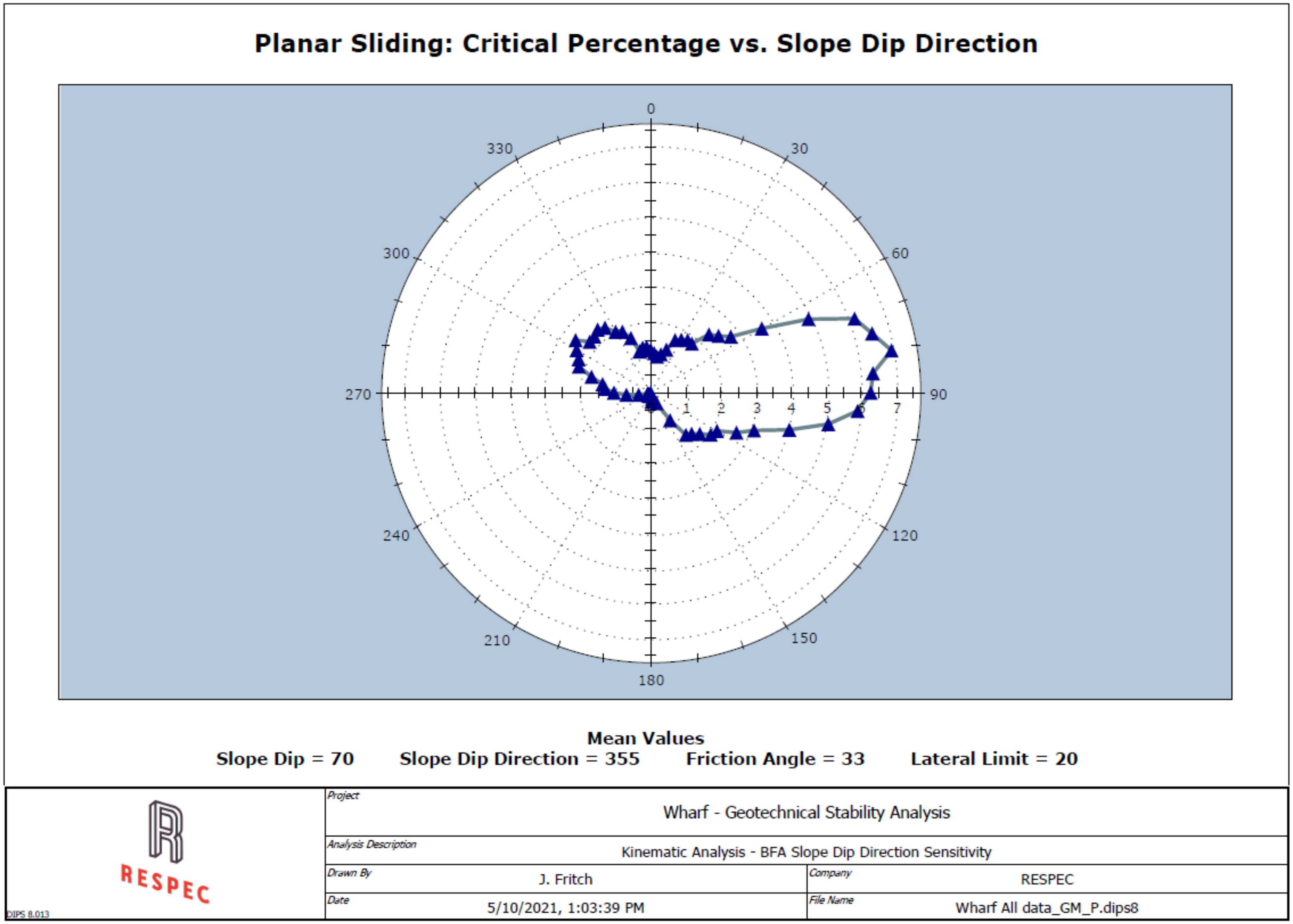


Figure 5-7. Probability of Failure Values for Planar Sliding Failures Versus Slope Azimuth.

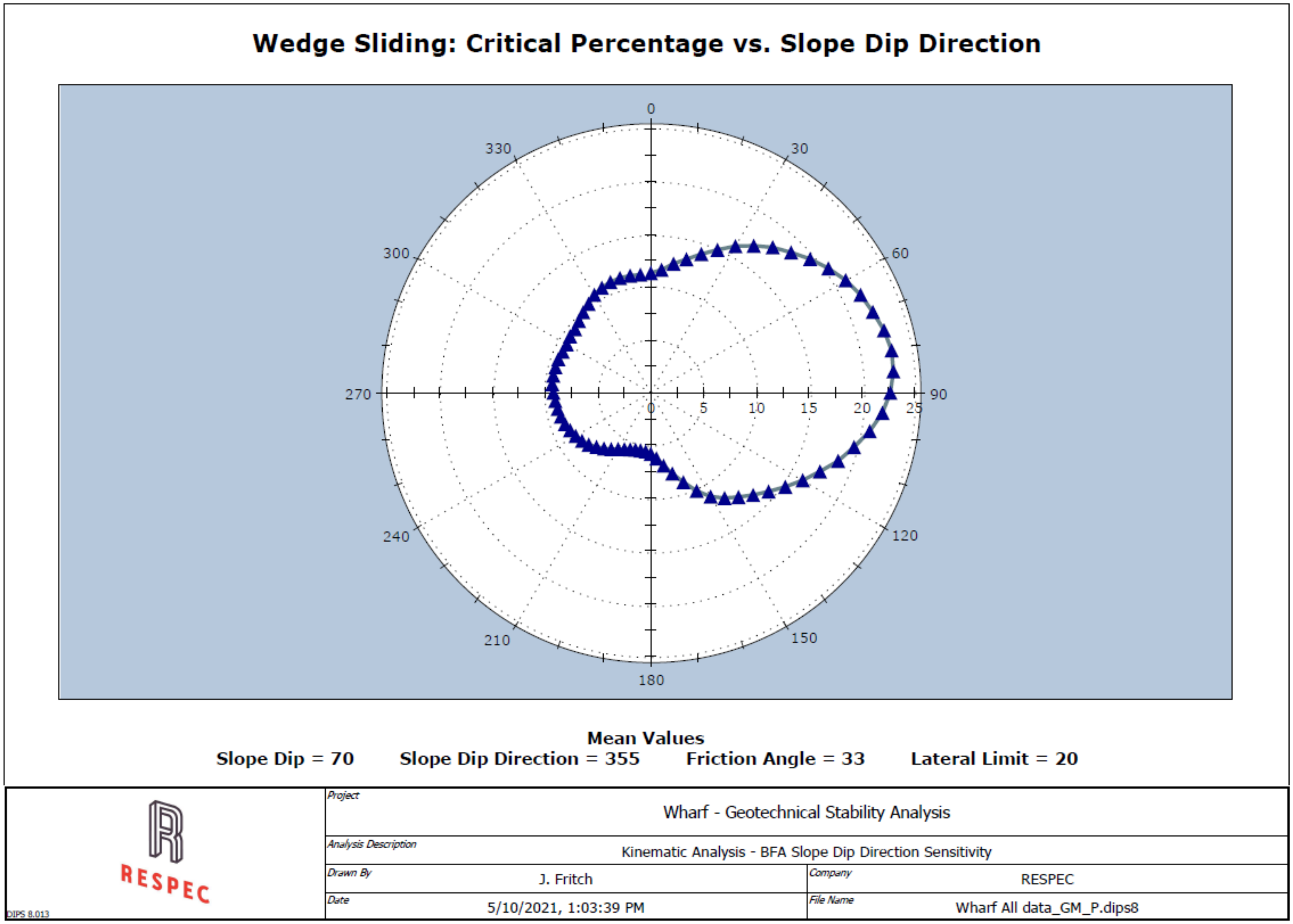


Figure 5-8. Probability of Failure Values for Wedge Sliding Failures Versus Slope Azimuth.

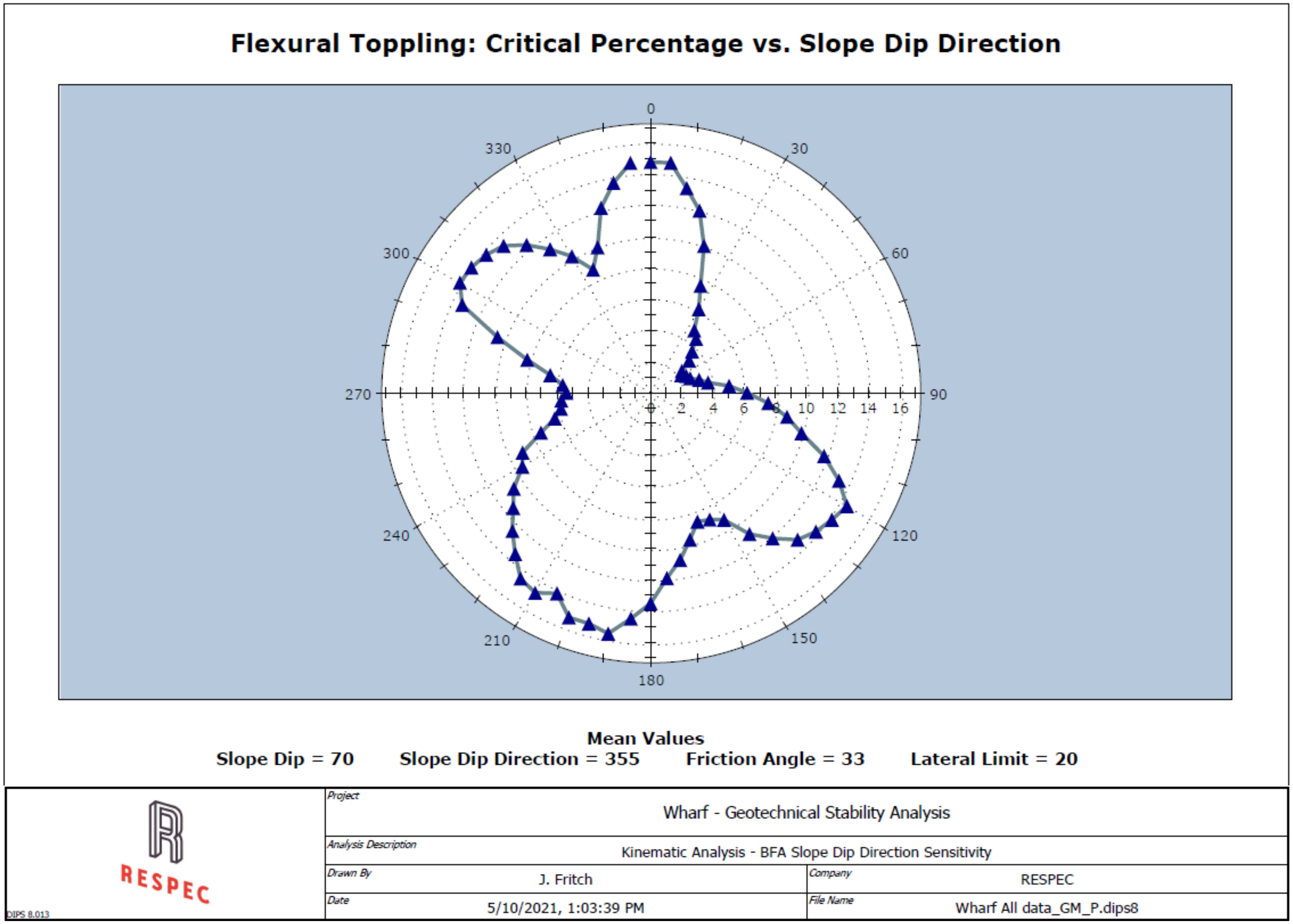


Figure 5-9. Probability of Failure Values for Flexural Toppling Failures Versus Slope Azimuth.

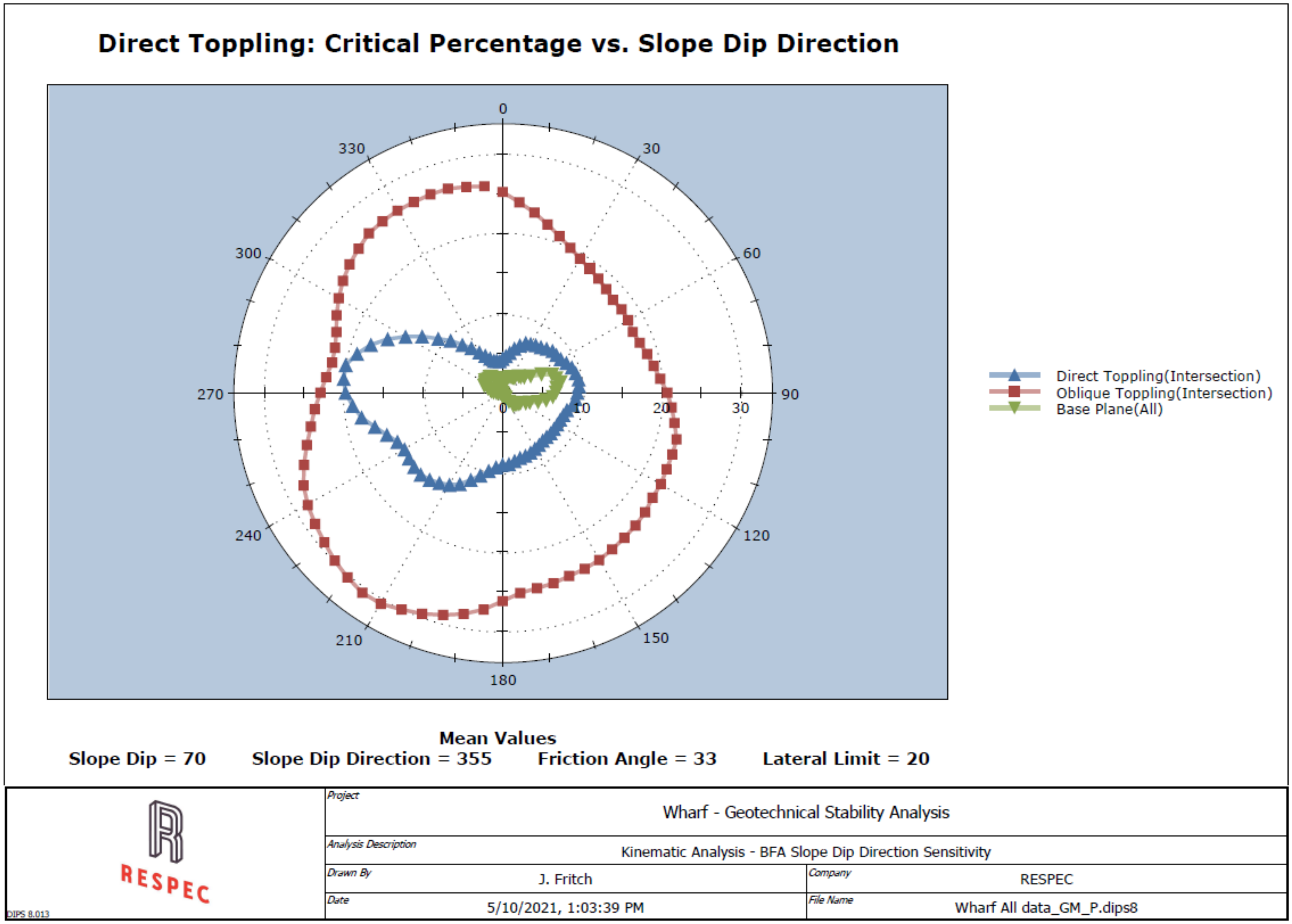


Figure 5-10. Probability of Failure Values for Direct Toppling Failures Versus Slope Azimuth.

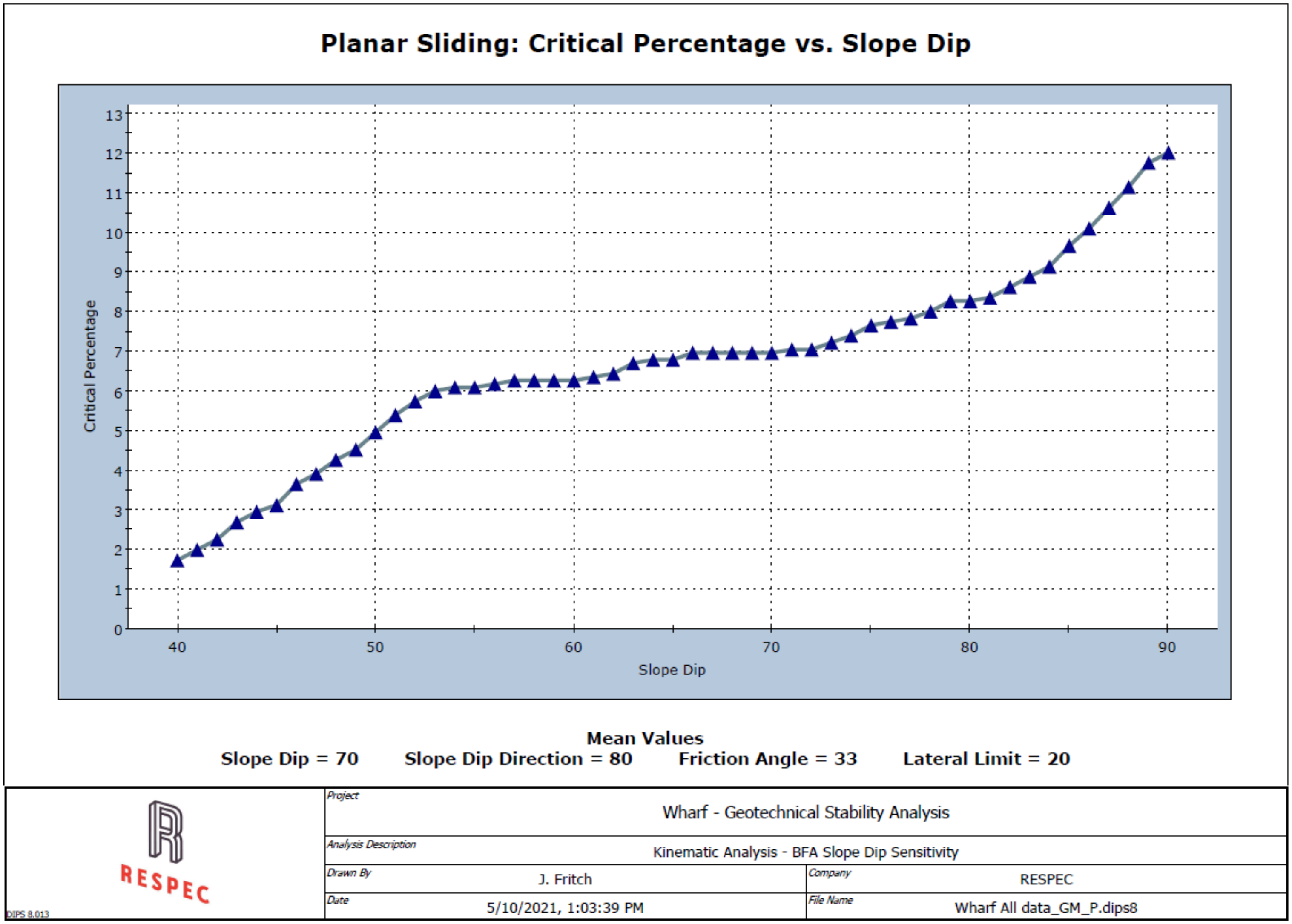


Figure 5-11. Probability of Failure Sensitivity Analysis for Planar Sliding Failures at Various Slope Dips.

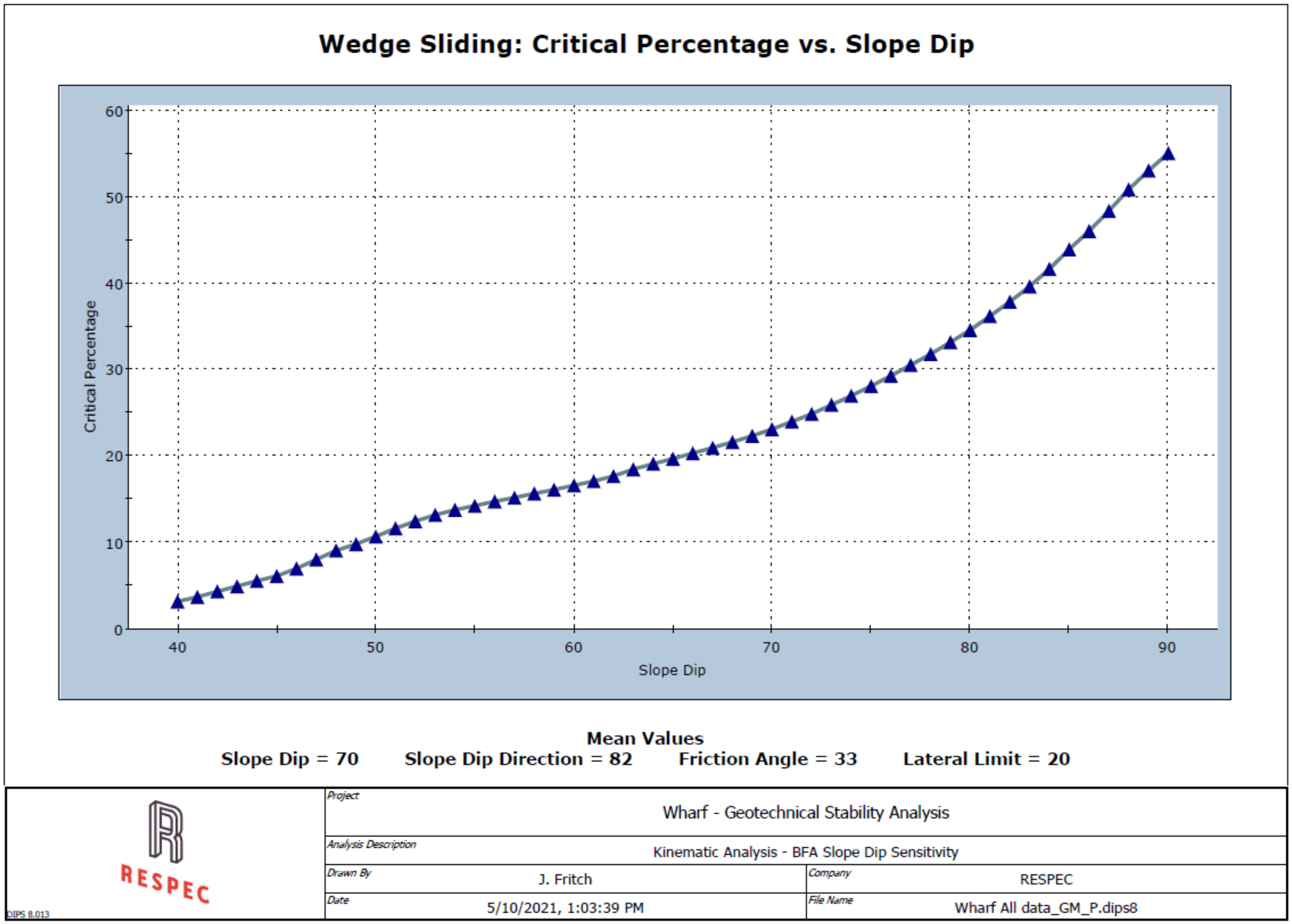


Figure 5-12. Probability of Failure Sensitivity Analysis for Wedge Failures at Various Slope Dips.

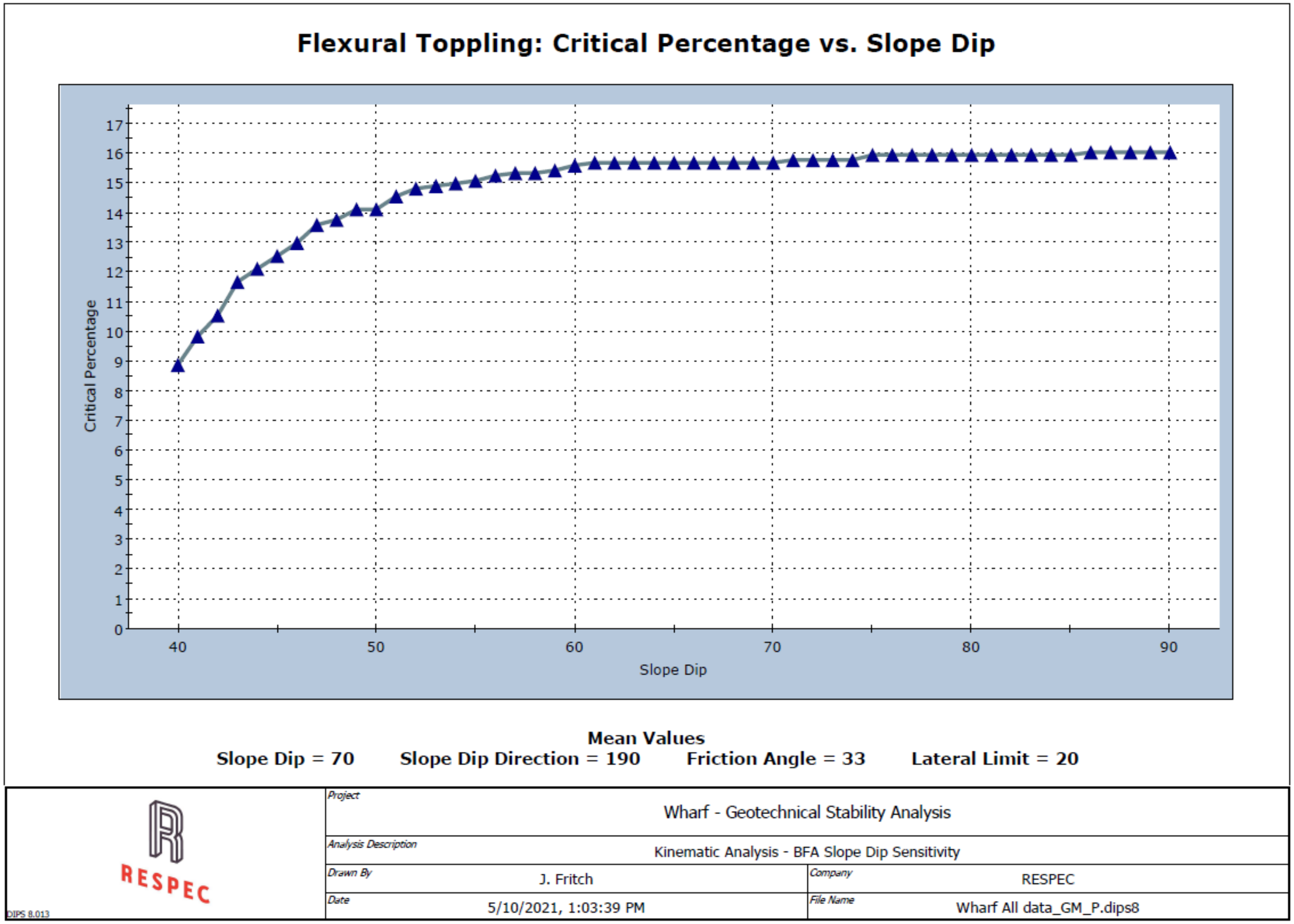
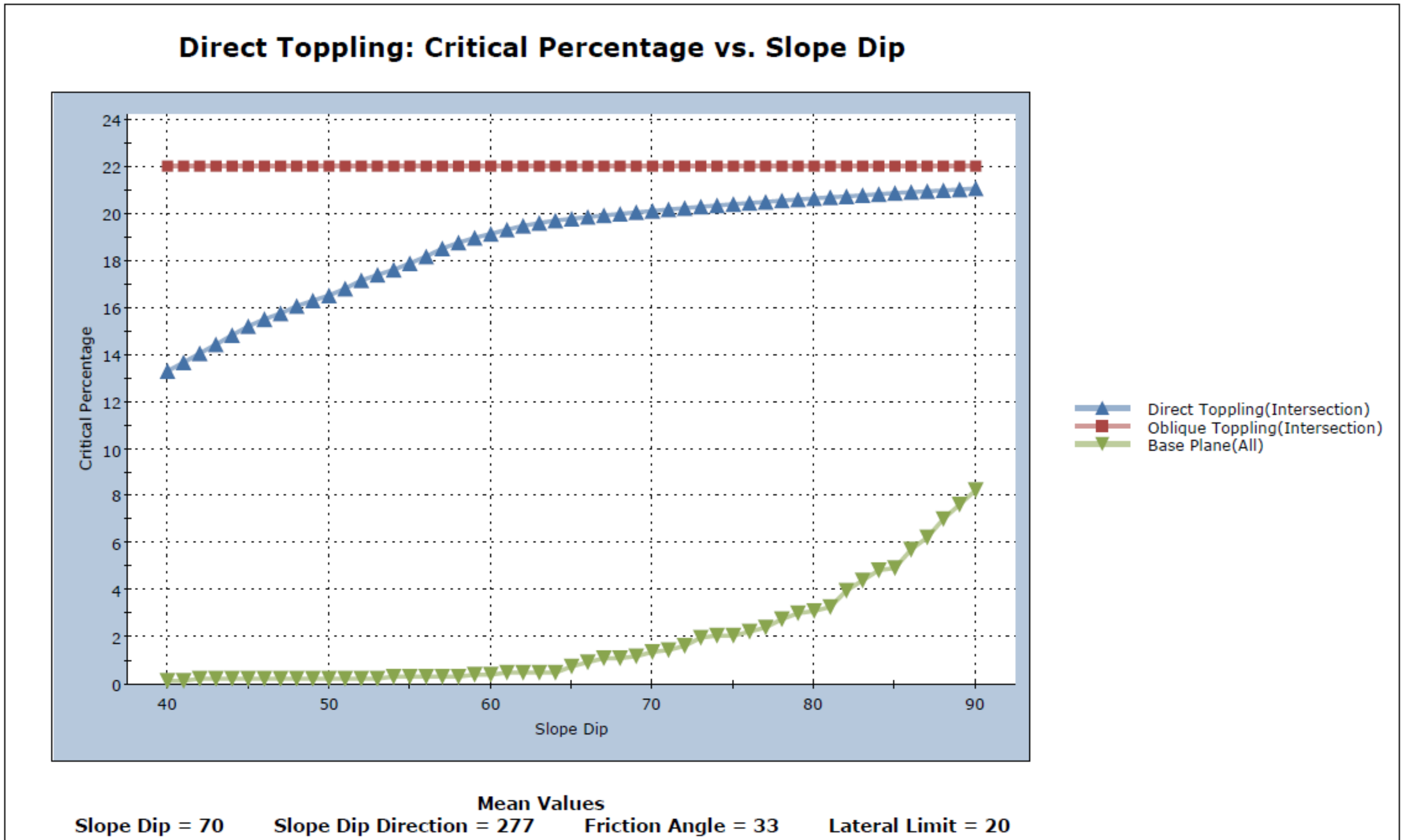


Figure 5-13. Probability of Failure Sensitivity Analysis for Flexural Toppling Failures at Various Slope Dips.



RESPEC	Project	Wharf - Geotechnical Stability Analysis	
	Analysis Description	Kinematic Analysis - BFA Slope Dip Sensitivity	
	Drawn By: J. Fritch	Company	RESPEC
DIPS 8.013	Date: 5/10/2021, 1:03:39 PM	File Name	Wharf All data_GM_P.dips8

Figure 5-14. Probability of Failure Sensitivity Analysis for Direct Toppling Failures at Various Slope Dips.

5.2 LIMIT-EQUILIBRIUM STABILITY ANALYSES

The 2D LE stability analysis confirmed that the shales in the Portland and Green Mountain Pits are expected to control rock mass failures and multi-bench failures are unlikely if the planned slope configurations in the Ultimate Pit shell are used. Results and conclusions specific to the deterministic stability analysis and UCS sensitivity study are described in more detail in the following sections.

5.2.1 DETERMINISTIC ANALYSIS

During the initial deterministic stability analysis, all of the simulated minimum FS failure surfaces daylighted in shale units. The failure surface in PORT-1 runs from near the top of the slope to a point in the Icebox Shale at the toe of the fourth bench. The failure surface in PORT-2 starts and ends in the Deadwood Shale and encompasses two benches. Initially, a small, localized minimum FS failure surface was found in GM-1 that comprised only a corner of the upper portion of a bench in the Biotite Phonolite unit. Although this surface had a minimum FS value of 0.92, it was not considered representative of inter-ramp stability and the slip limits of the model were narrowed to select a more representative failure surface. The selected GM-1 multi-bench failure surface began in the Deadwood Interbedded unit and daylighted three benches below in the Deadwood Shale. Similar to GM-1, the GM-2 failure surface initiated in the Deadwood Interbedded and daylighted in the Deadwood Shale. The deterministic minimum FS values for each cross section are shown in Table 5-4. The 2D-LE stability model results are shown in Figures 5-15 through 5-18.

All global minimum FS values for inter-ramp failure surfaces exceeded RESPEC's acceptance criterion of 1.4. The lowest FS value was 1.49 for Cross Section PORT-2. The primary units of concern are the Deadwood Shale, Deadwood Interbedded, Icebox Shale, and Biotite Phonolite. These findings are consistent with previous work, indicate that current IRA design practices are reasonable, and suggest that steeper design IRAs could be used if site-specific materials properties data are collected and found to be similar to those used in the 2D LE models. Furthermore, because the global minimum FS values in the models exceeded the criterion recommended by Read and Stacey [2009] (FS = 1.3) by an even larger margin, if slope performance monitoring is implemented there is an additional opportunity to steepen the Ultimate Pit IRAs.

Table 5-4. Deterministic Factor-of-Safety Values Along the Four Cross Sections

Item	Cross Section			
	GM-1	GM-2	PORT-1	PORT-2
Global Minimum FS	1.59[a]	1.68	1.52	1.49
Failure Surface Daylight Material	DW-Shale[a]	DW-Shale	Icebox Shale	DW-Shale

(a) A small bench-scale failure surface completely within Phonolite had a factor of safety of 0.92.

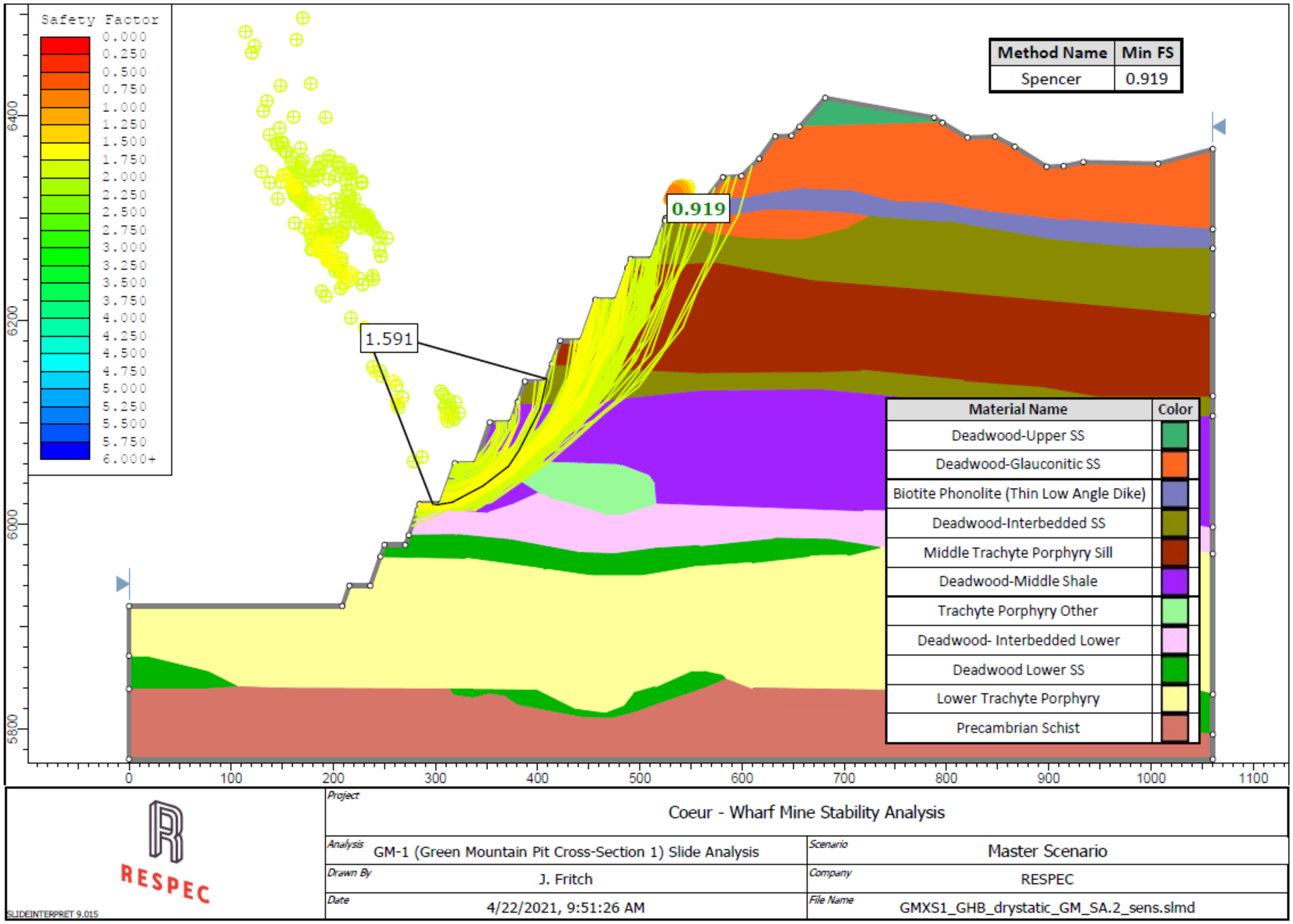


Figure 5-15. Deterministic Two-Dimensional, Limit-Equilibrium Stability Analysis Results for Cross Section GM-1.

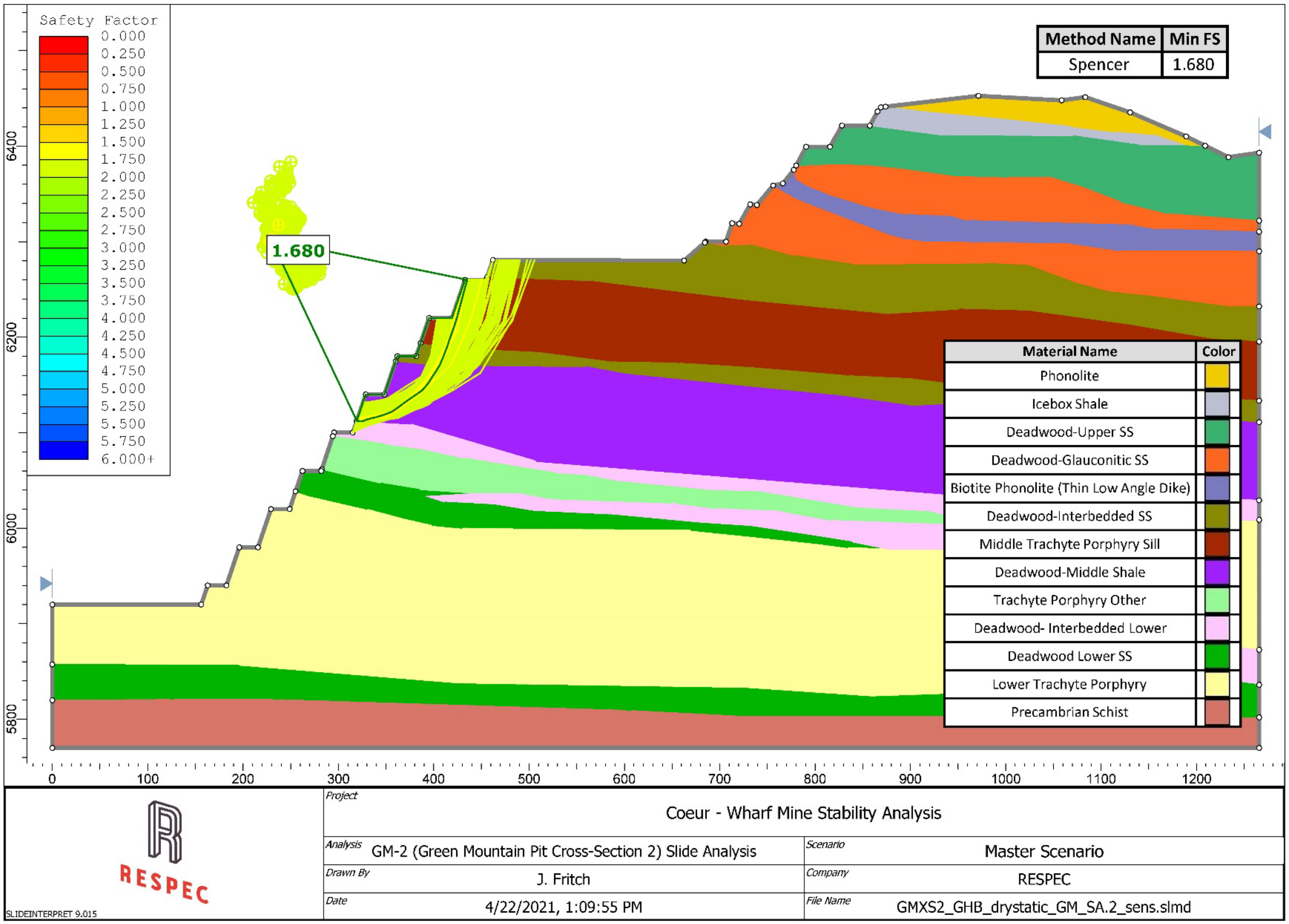


Figure 5-16. Deterministic Two-Dimensional, Limit-Equilibrium Stability Analysis Results for Cross Section GM-2.

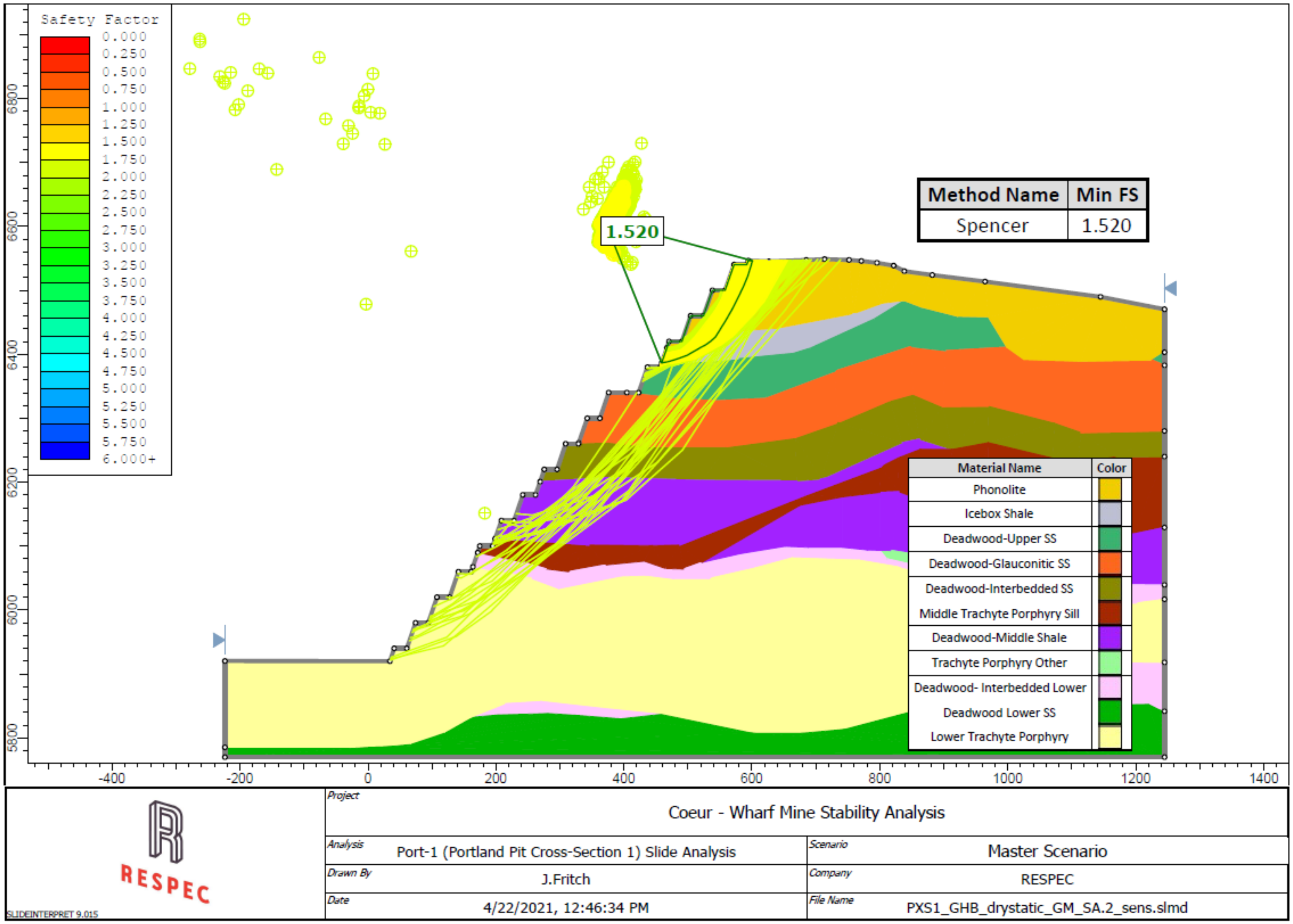


Figure 5-17. Deterministic Two-Dimensional, Limit-Equilibrium Stability Analysis Results for Cross Section PORT-1.

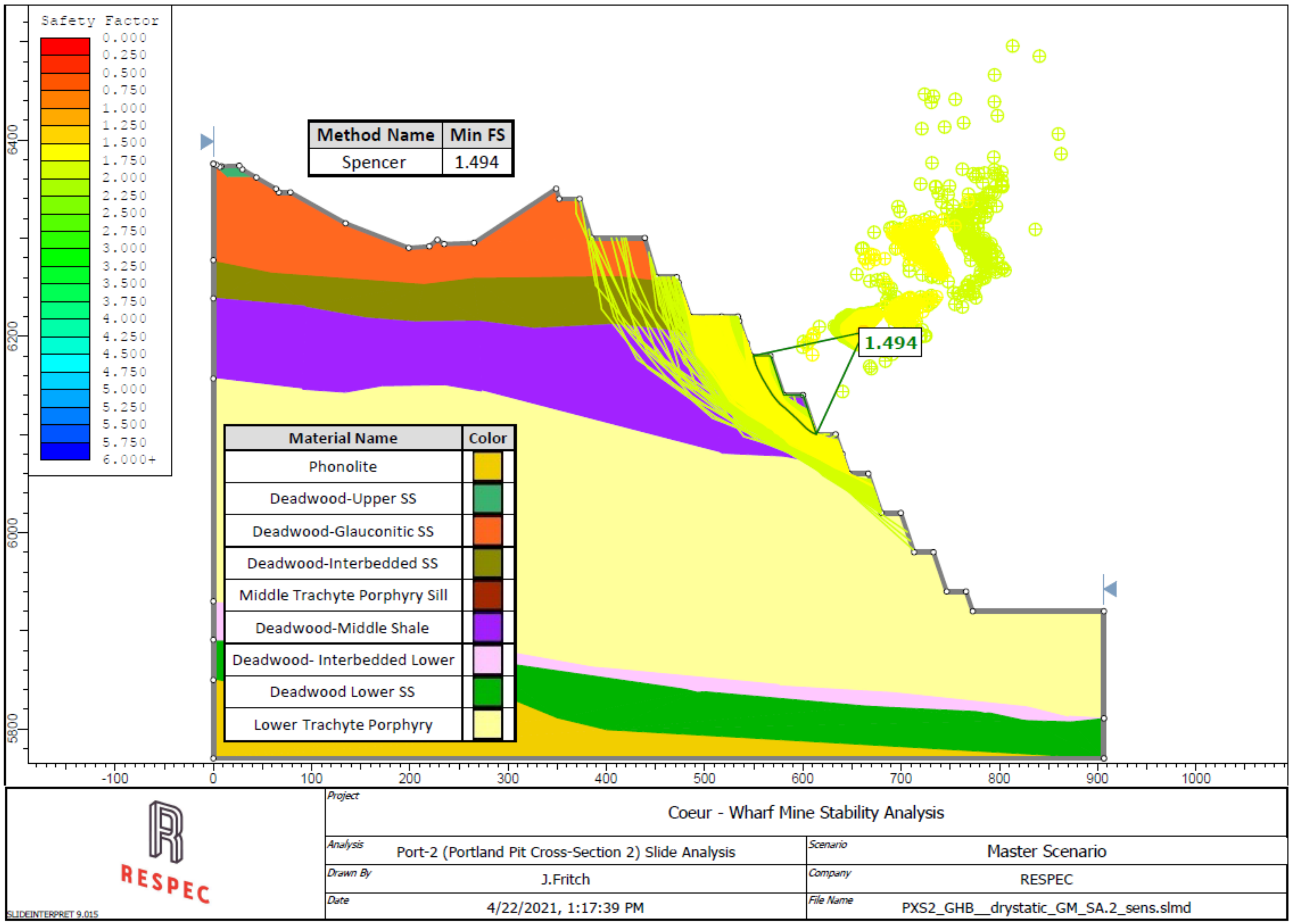


Figure 5-18. Deterministic Two-Dimensional, Limit-Equilibrium Stability Analysis Results for Cross Section PORT-2.

5.2.2 UNCONFINED COMPRESSIVE STRENGTH SENSITIVITY ANALYSIS

Two plots of FS values versus relative UCS values for cross section GM-1 are shown in Figures 5-19 and 5-20: the first for the bench-scale failure surface in GM-1 that had a deterministic FS of 0.92 (Figure 5-19); and the second for the multi-bench failure surface that is more representative of inter-ramp stability (Figure 5-20). Plots of FS versus UCS values for cross sections GM-2, PORT-1, and PORT-2 are shown in Figures 5-21, 5-22, and 5-23, respectively.

The FS values of the critical failure surfaces found during the deterministic 2D LE stability analysis are highly sensitive to the UCS values of the Phonolite, Biotite Phonolite, and Deadwood Shale units. This result is consistent with historical slope performance information and previous stability evaluations. If during future work any of these units are found to be stronger than was assumed for the current study, it may be possible to increase the Ultimate Pit design IRAs.

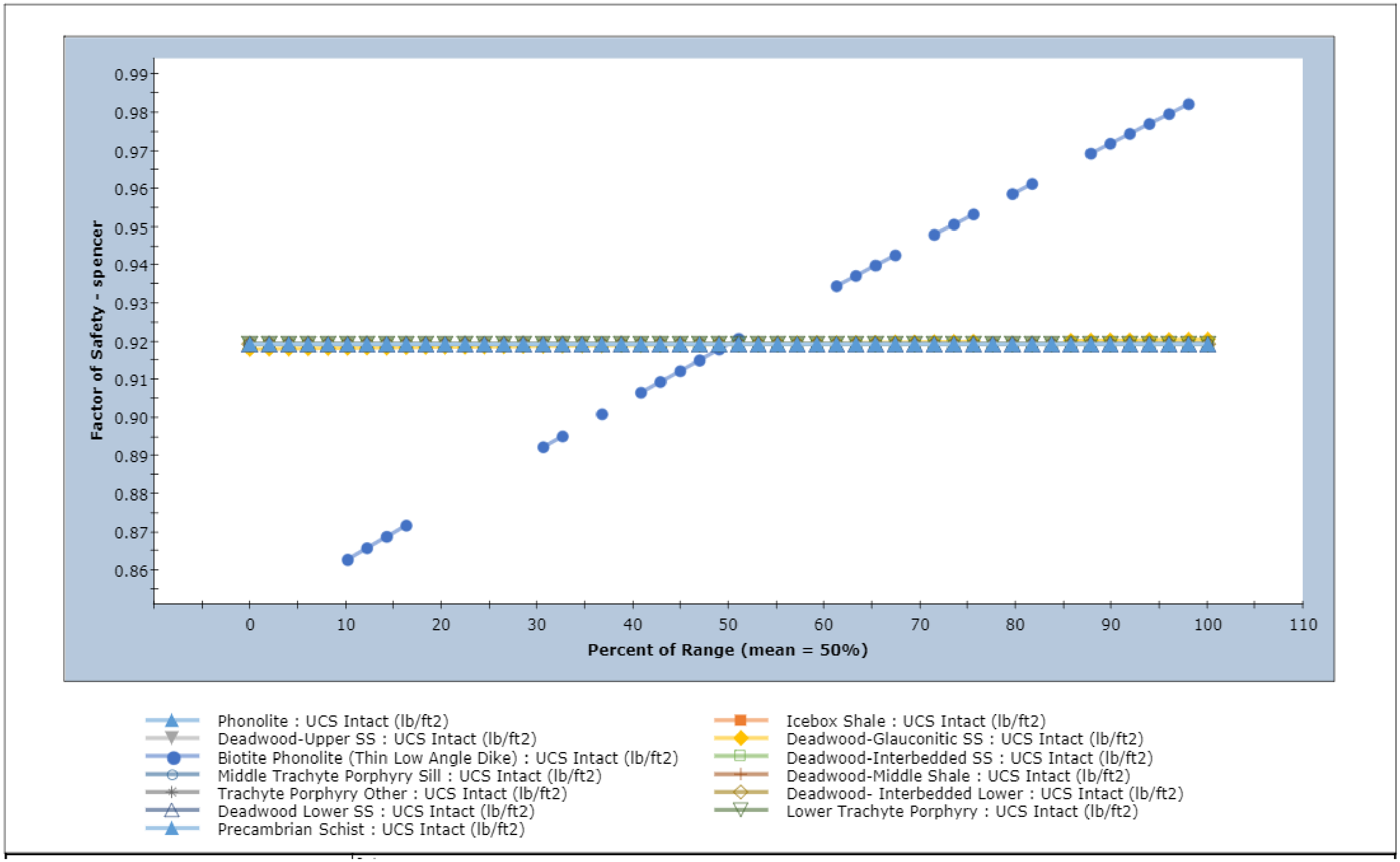


Figure 5-19. Sensitivity of Factor of Safety to Unconfined Compressive Strength Values for the Bench-Scale Global Minimum Failure Surface Identified in Cross Section GM-1.

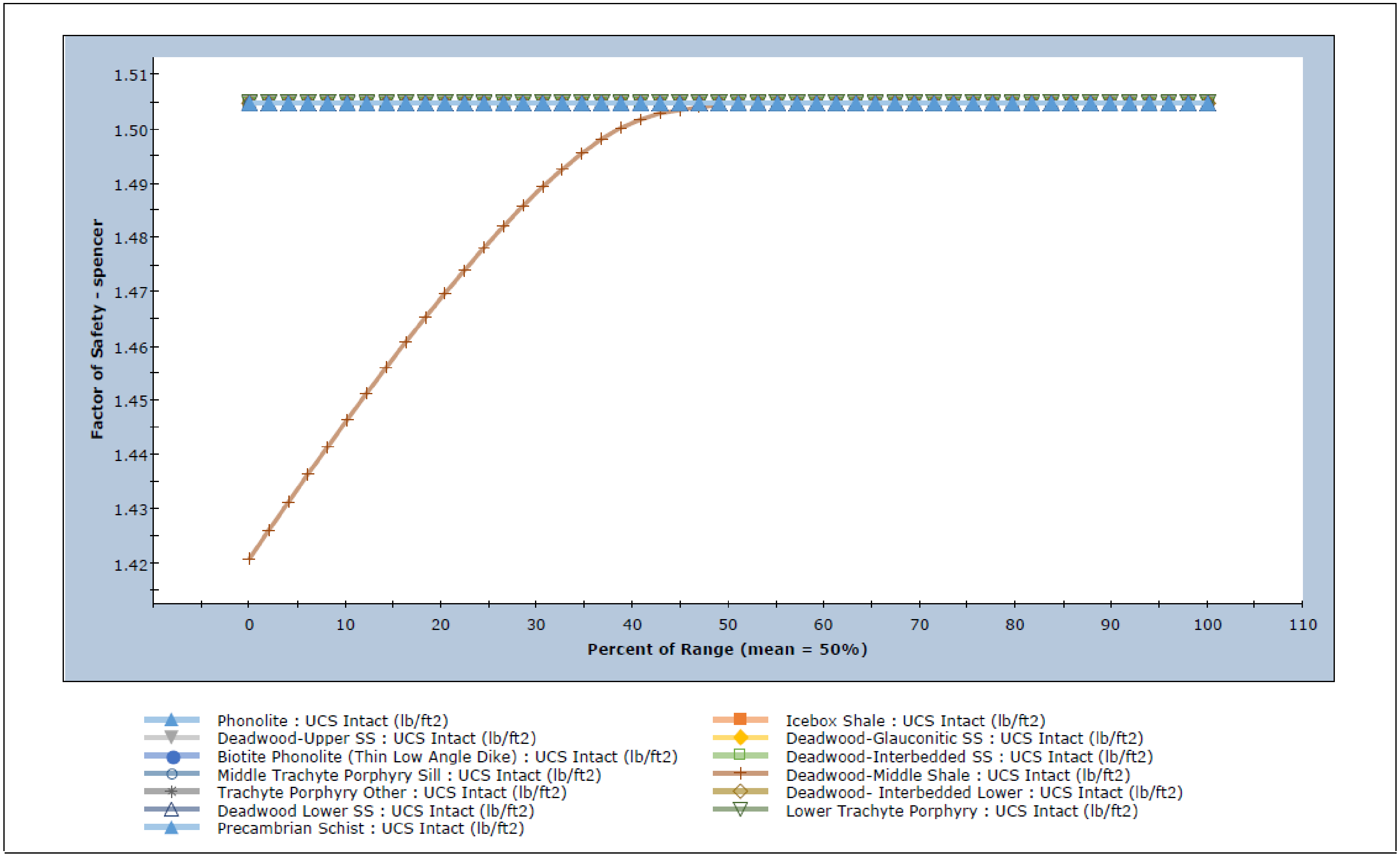


Figure 5-20. Sensitivity of Factor of Safety to Unconfined Compressive Strength Values for the Multi-Bench Global Minimum Failure Surface Identified in Cross Section GM-1.

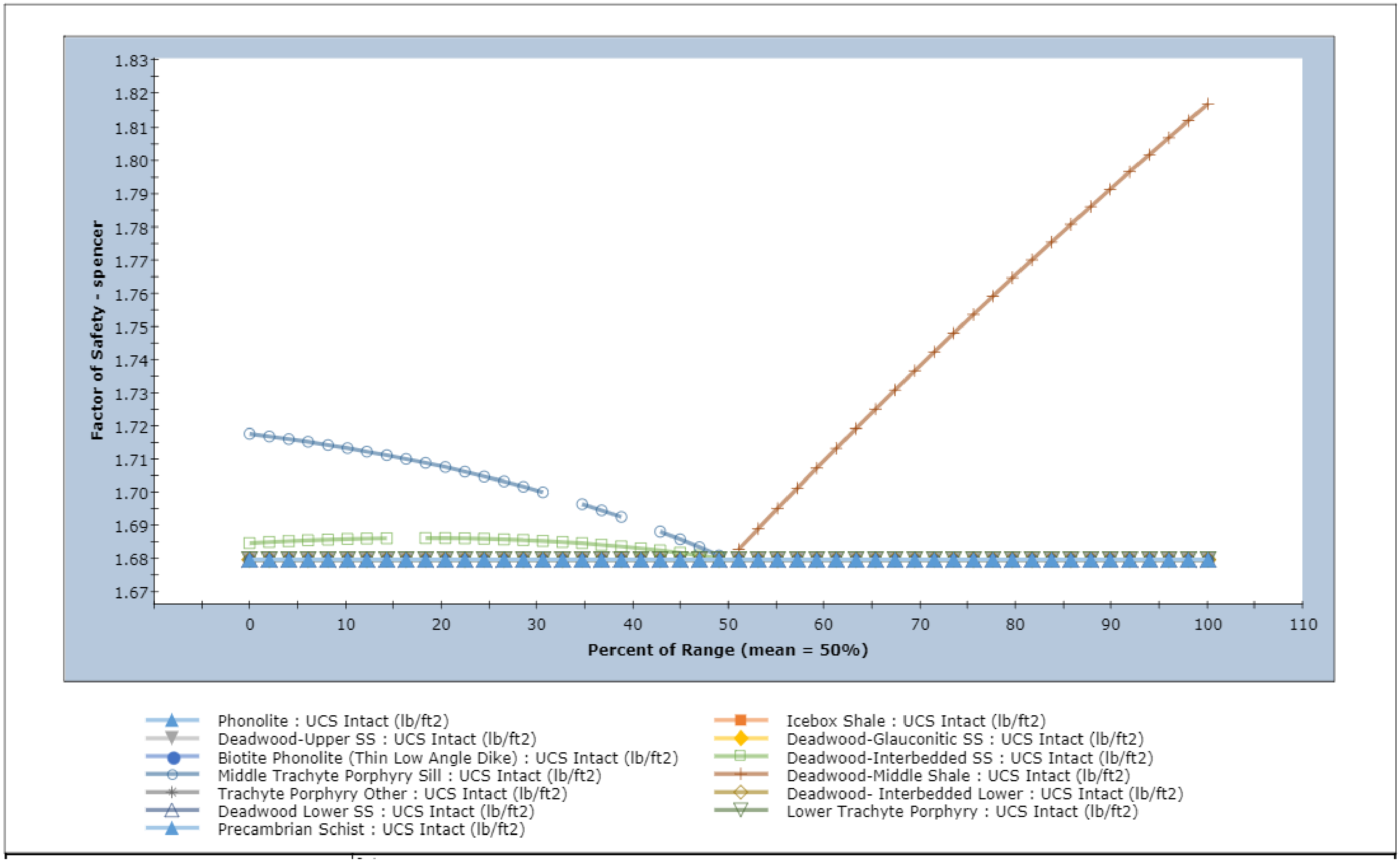


Figure 5-21. Sensitivity of Factor of Safety to Unconfined Compressive Strength Values for the Global Minimum Failure Surface Identified in Cross Section GM-2.

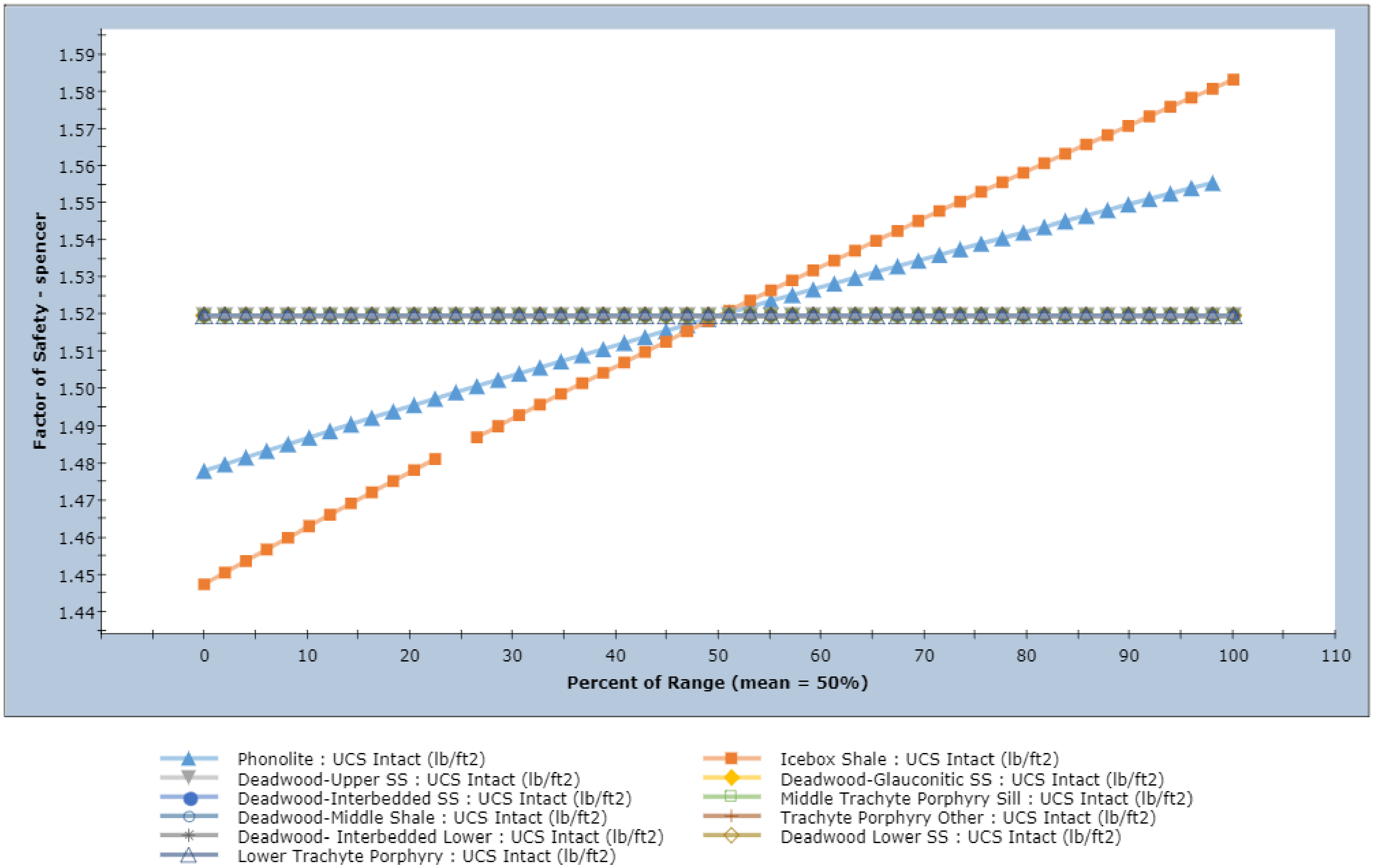


Figure 5-22. Sensitivity of Factor of Safety to Unconfined Compressive Strength Values for the Global Minimum Failure Surface Identified in Cross Section PORT-1.

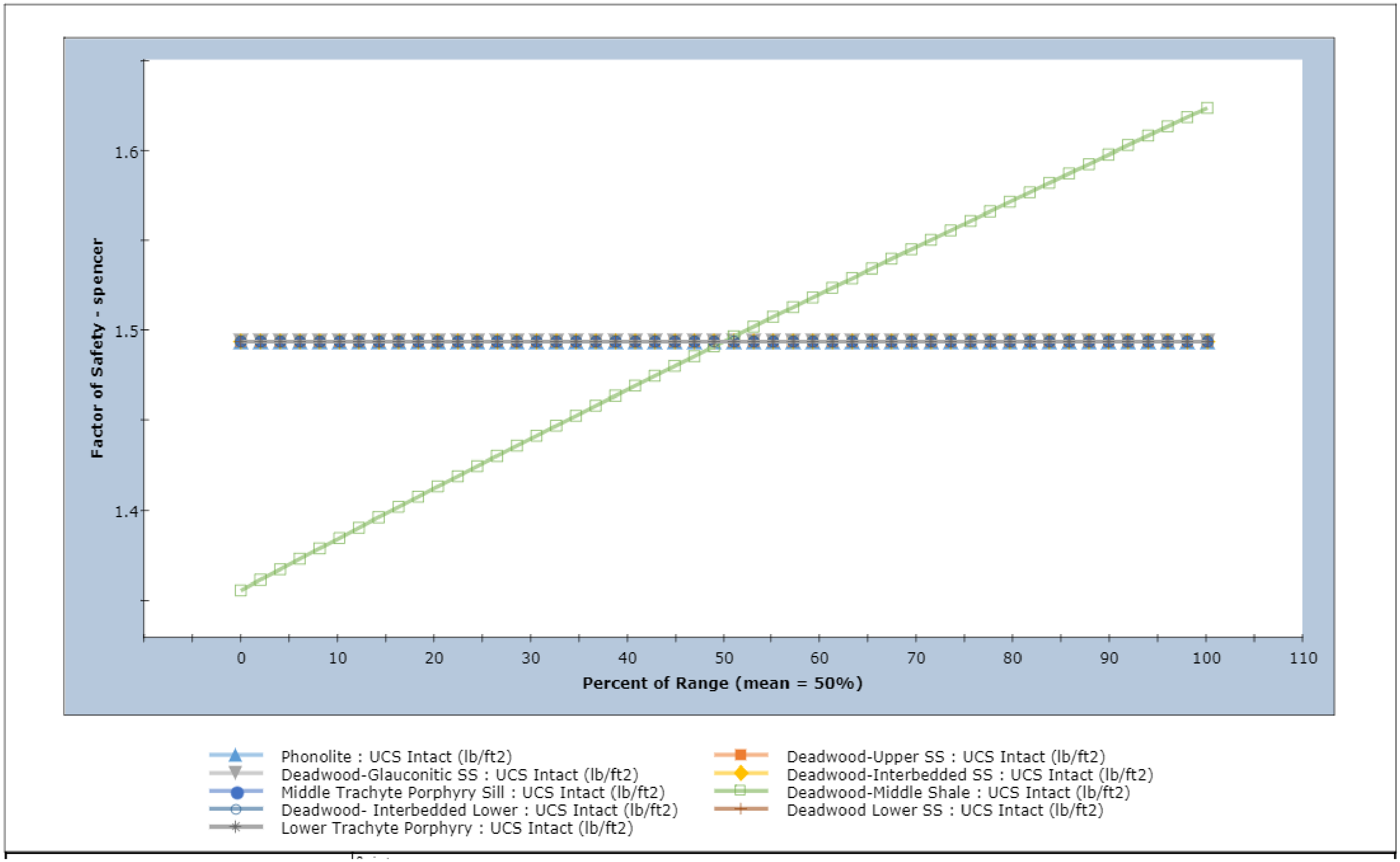


Figure 5-23. Sensitivity of Factor of Safety to Unconfined Compressive Strength Values for the Global Minimum Failure Surface Identified in Cross Section PORT-2.

6.0 DISCUSSION AND RECOMMENDATIONS

Based on RESPEC's Phase 1 stability analyses, the current design configurations for Wharf's Ultimate Pit appear to be appropriate, but there is an opportunity to design the Ultimate Pit with steeper IRAs and BFAs if the Phase 2 slope optimization study is performed. Phase 2 would include a geotechnical drilling and core logging program, laboratory testing, and additional stability analyses designed to optimize the slope configurations of the Ultimate Pit. Phase 2 would also include the identification of critical slope performance monitoring areas and recommendations for what monitoring equipment and monitoring methods are appropriate. Additional information regarding the identified data gaps and material properties identified during the Phase 1 study, discussions of slope performance monitoring and blasting practices, and a recommended scope for Phase 2 are included in this chapter.

6.1 DATA GAPS AND MATERIAL PROPERTIES

Inter-ramp highwall stability at the Site is expected to be controlled by rock mass strengths. The PF and FS values presented in this report are highly dependent on the accuracy of historical data, and RESPEC's kinematic and 2D LE slope stability models indicate that design IRAs could be steepened if more geotechnically favorable site-specific material properties are measured. Although stratigraphic relationships are generally consistent between the current study area and other areas at the Site where slope stability evaluations have been performed, evidence exists that the geotechnical properties of rock materials in the Portland and Green Mountain Pits are different than those used in the previous studies. RESPEC believes that two specific areas lend an opportunity to use less-conservative material properties used in the current study: intact UCS values and discontinuity shear strengths of the shales and phonolites.

Intact UCS values are a critical factor in determining appropriate IRAs when multi-bench failures are expected to be controlled by rock mass properties rather than structural (i.e., kinematic) failures. The available UCS test data for the units that control the inter-ramp stability of the Green Mountain and Portland Pits are limited in number and from areas outside the Ultimate Pit boundary. RESPEC highly recommends additional UCS testing on the controlling geologic units (i.e., shales and phonolites). Confirmatory UCS testing on samples from the other geologic units are also recommended because they will improve the accuracy of future stability assessments.

The discontinuity shear strength data used to perform the kinematic stability analyses are dated and limited in terms of rock type. The location and source of the data are also not entirely clear. Important information such as joint infilling amount and type, joint aperture, and joint roughness are not readily available for many of the test results, and an insufficient number of tests have been performed to accurately estimate the friction angles of joints in most of the units present in the Portland and Green Mountain Pits. For these reasons, RESPEC believes an opportunity exists to increase the estimates of joint friction angles and likewise increase the IRAs and BFAs that Wharf uses in its pit designs. Furthermore, rock-type-specific IRA and BFA improvements could be made if additional detailed characterization and direct shear testing of discontinuities are performed.

Because historical strength data for the phonolites included in Wharf's geologic model of the Portland and Green Mountain Pits were not available, RESPEC made some simplifying assumptions during this study. For this reason, the recommended Phase 2 UCS and direct shear testing should include samples from the phonolites and geotechnical drilling and core logging should be performed to characterize the rock mass of all of the units expected to be exposed in the Ultimate Pit shell. Special attention should be paid to the phonolites and shales that will control the stability of the pit highwalls. To improve the accuracy and reliability of the results presented in this Phase 1 report, the geotechnical data gathered in Phase 2 should be compared with historical data and material-property estimates used in Phase 1.

In addition to the outstanding questions regarding intact rock and discontinuity strengths, some questions remain regarding the influence of historical mine workings on the stability of the Ultimate Pit. Depending on their size, depth, and location relative to the highwalls, voids caused by historical mining can have a significant influence on slope stability. RESPEC recommends that Wharf evaluate the known void locations relative to the highwalls maps and cross sections of voids near the Ultimate Pit shell for use during Phase 2 of the project.

6.2 SLOPE PERFORMANCE MONITORING

Read and Stacey [2009] recommend that the critical PF and FS values Table 4-3 only be used in conjunction with slope performance monitoring. If slope monitoring is not performed, higher critical PF and FS values may be appropriate, and there will be less opportunity to steepen the Ultimate Pit slopes. RESPEC therefore recommends that Wharf investigate and implement a slope performance monitoring program during Phase 2. Such programs generally consist of automated sensors, physical highwall inspection protocols, and action response plans.

6.3 BLASTING PRACTICES

Wharf is not currently using pre-splitting or other controlled blasting techniques. These techniques are known to improve bench-scale and inter-ramp highwall stability. If controlled blasting is implemented at the Site, the frequency of rockfall events and likelihood of kinematic slope instabilities can be reduced. Controlled blasting also reduces backbreak and becomes more critical to achieving the highwall design as BFAs and IRAs become steeper. RESPEC recommends that Wharf explore adding controlled blasting to their blast designs immediately; if controlled blasting methods are implemented and documented before Phase 2 of the project, a more favorable gradation of the blast damage factor (D) can be used in the 2D LE models, which offers additional opportunity to steepen the IRAs.

6.4 PROPOSED PHASE 2 SCOPE

In Phase 2, RESPEC proposes that four HQ-size geotechnical core holes be drilled to depths between 400 and 600 ft. Rock core will be logged and sampled for geology and geotechnical properties by RESPEC personnel, and appropriate samples will be collected and tested for UCS and direct shear strengths in RESPEC's laboratory in Rapid City, South Dakota. The material properties used in the Phase 1 stability analyses will be updated and steeper IRA and BFA slope configurations will be evaluated based on geology and practical mining considerations (e.g., blast-hole drill rig capabilities).

Void maps and current blasting practices will be included in the stability evaluation. RESPEC will also evaluate options for slope performance monitoring and provided recommendations for appropriate equipment and monitoring practices.

The proposed Phase 2 core holes would be selected to ensure that the extent and material properties of the trachyte, Phonolite, and shale units expected to be exposed in the Ultimate Pit are adequately characterized. The core holes would also be used in conjunction with field inspections to identify if and where a structural transition may be occurring between the current Portland Pit and the Flossie Pit to the southwest. Additional discontinuity data from down-hole optical or acoustic televiewer surveys would be used to augment the discontinuity measurements made in Phase 1, thereby reducing the underrepresentation of low-angle discontinuities identified by Kliche [2007] and increasing the reliability of the Phase 2 kinematic stability assessment.

At this time, RESPEC's original Phase 2 budget estimate of $212,732 from October 2020 is still considered valid but needs to be reviewed. A more detailed budget and scope for Phase 2 will be provided following the delivery of this Phase 1 report and at Wharf's request.

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