

A large yellow Caterpillar haul truck is shown in the process of dumping its load of material into a large pile. The truck is positioned on a dirt road at a mining site. The background shows a large pile of material and other mining equipment. The text "Environmental Hazards in Mineral Deposits: Considerations in Pre-Permitting Sampling at Hard-Rock Mines" is overlaid in blue on the image.

# Environmental Hazards in Mineral Deposits: Considerations in Pre-Permitting Sampling at Hard-Rock Mines

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# Hazards to Consider

1. Asbestiform Minerals
2. Acid Rock Drainage
3. Neutral Metal Drainage
4. Very Toxic Elements
5. Basic Rock Drainage





# 1. Asbestiform Minerals



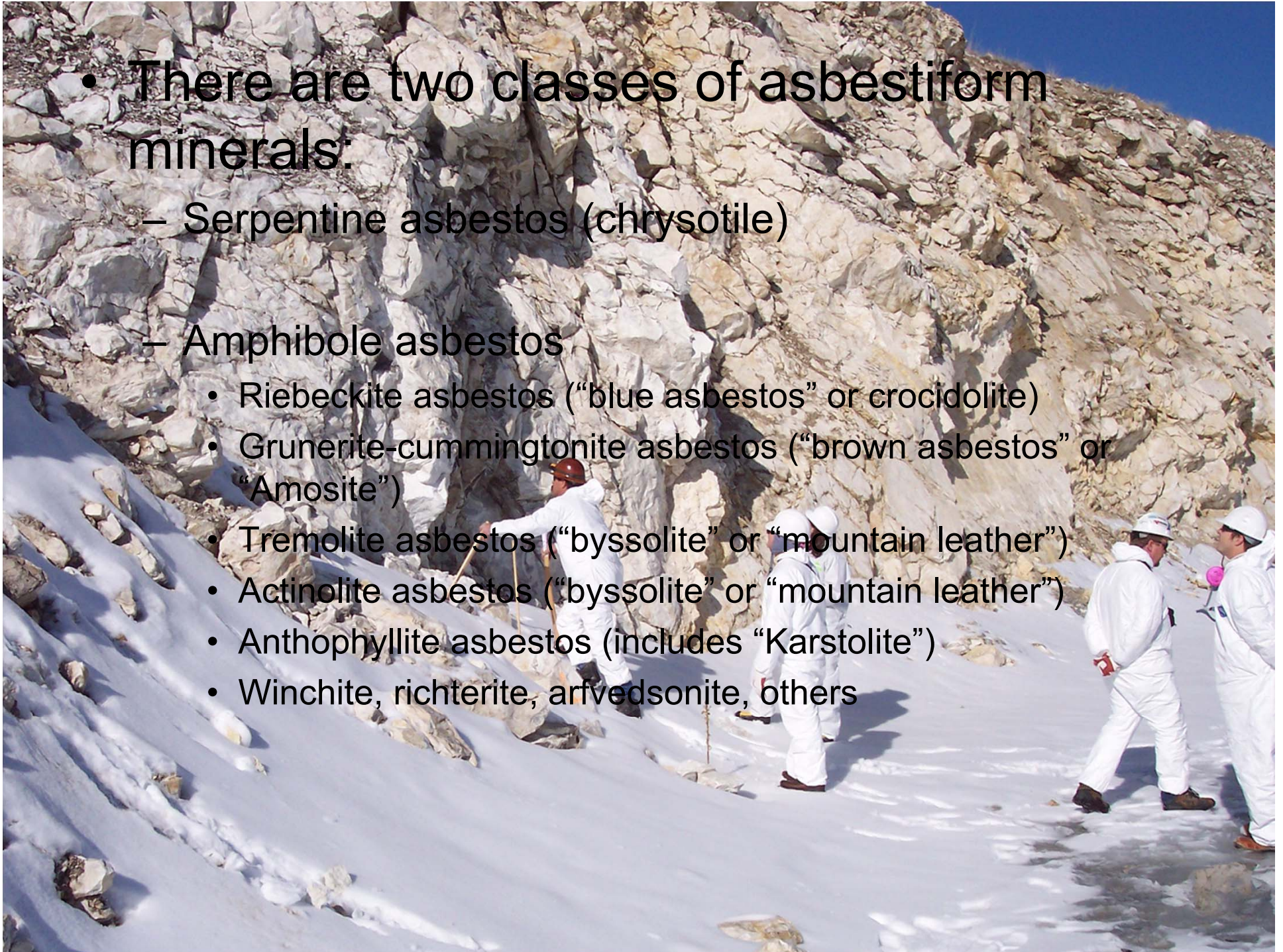


- There are two classes of asbestiform minerals:

- Serpentine asbestos (chrysotile)

- Amphibole asbestos

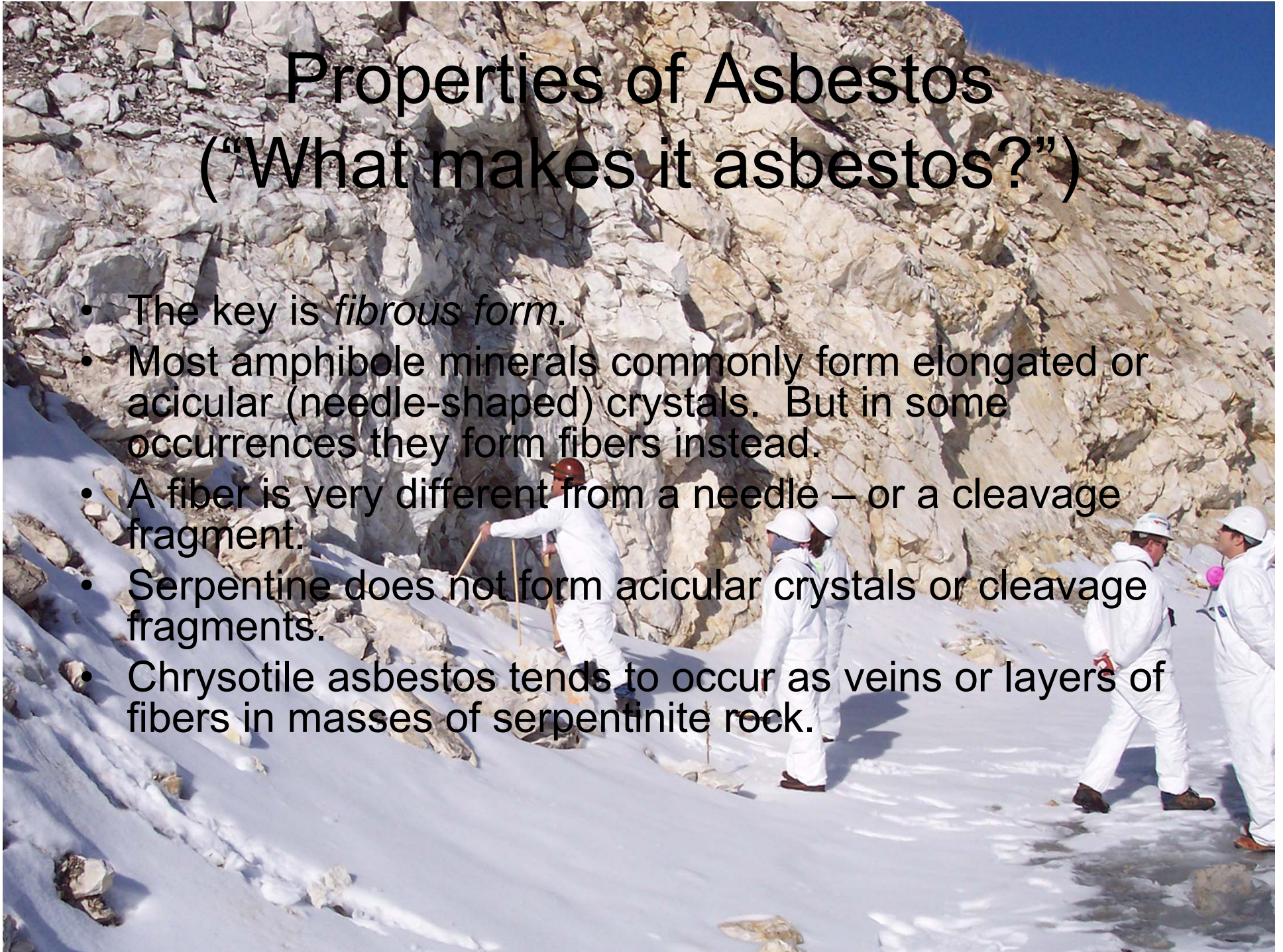
- Riebeckite asbestos (“blue asbestos” or crocidolite)
- Grunerite-cummingtonite asbestos (“brown asbestos” or “Amosite”)
- Tremolite asbestos (“byssolite” or “mountain leather”)
- Actinolite asbestos (“byssolite” or “mountain leather”)
- Anthophyllite asbestos (includes “Karstolite”)
- Winchite, richterite, arfvedsonite, others





# Properties of Asbestos ("What makes it asbestos?")

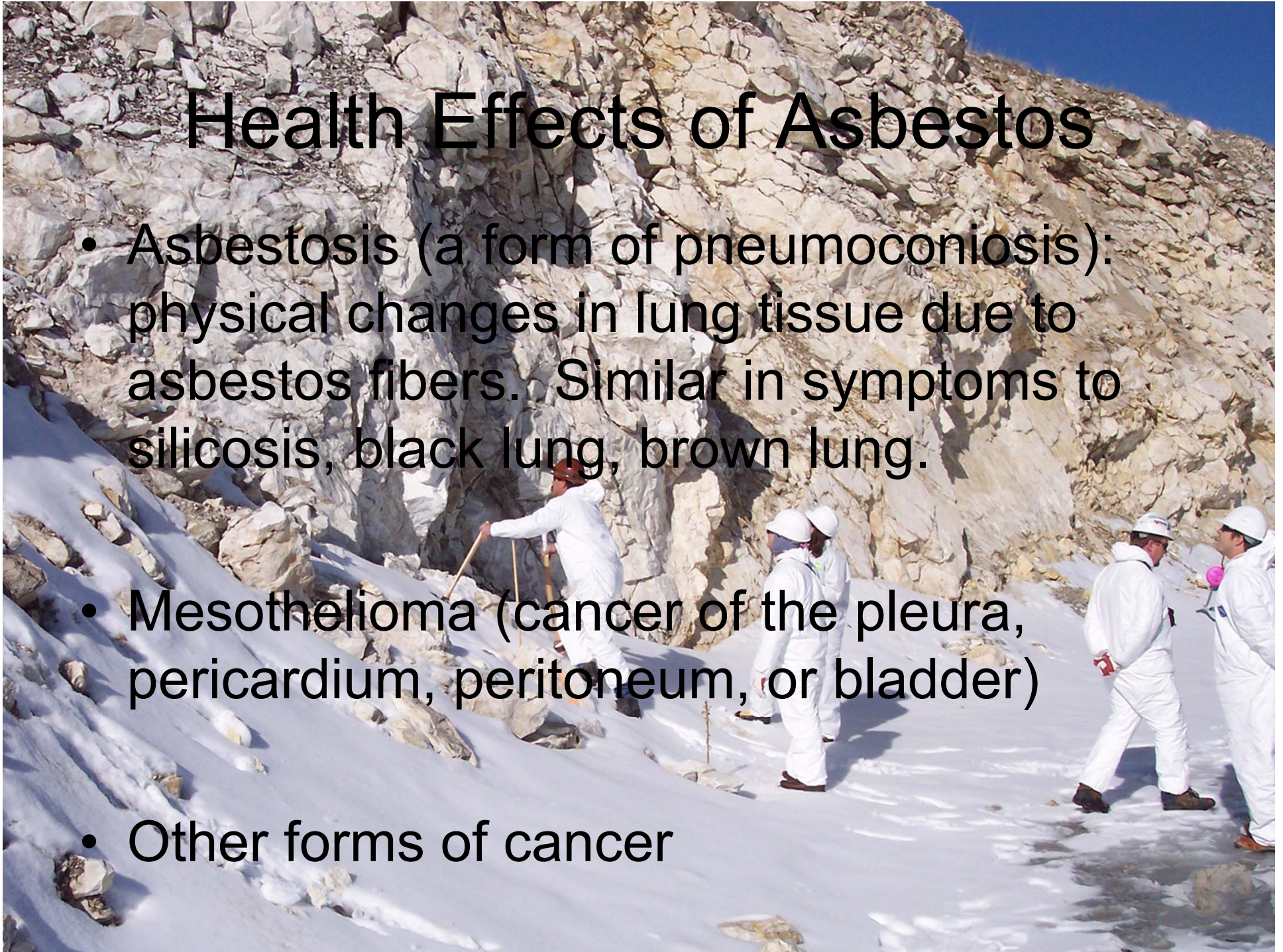
- The key is *fibrous form*.
- Most amphibole minerals commonly form elongated or acicular (needle-shaped) crystals. But in some occurrences they form fibers instead.
- A fiber is very different from a needle – or a cleavage fragment.
- Serpentine does not form acicular crystals or cleavage fragments.
- Chrysotile asbestos tends to occur as veins or layers of fibers in masses of serpentinite rock.





# Health Effects of Asbestos

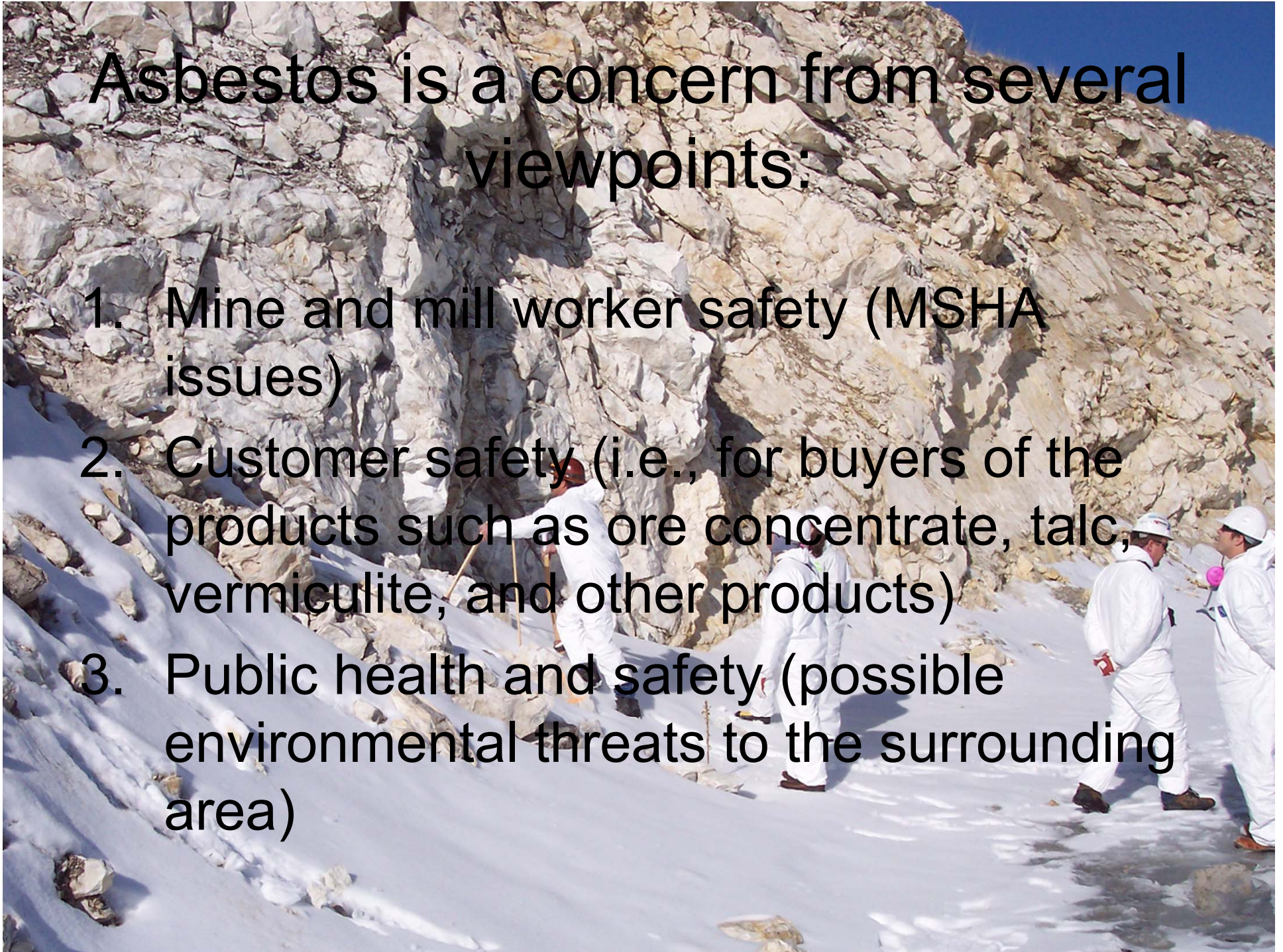
- Asbestosis (a form of pneumoconiosis): physical changes in lung tissue due to asbestos fibers. Similar in symptoms to silicosis, black lung, brown lung.
- Mesothelioma (cancer of the pleura, pericardium, peritoneum, or bladder)
- Other forms of cancer





# Asbestos is a concern from several viewpoints:

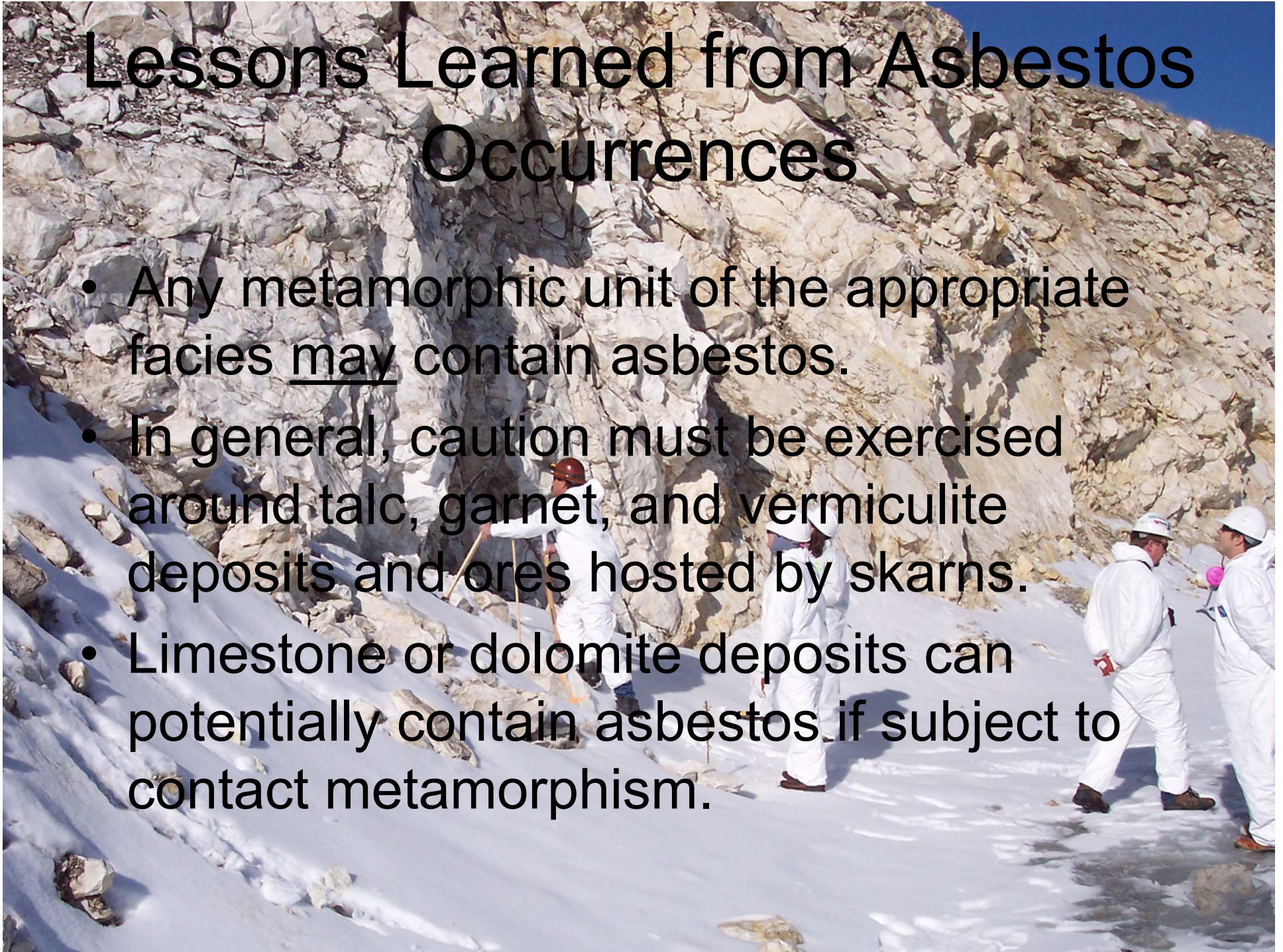
1. Mine and mill worker safety (MSHA issues)
2. Customer safety (i.e., for buyers of the products such as ore concentrate, talc, vermiculite, and other products)
3. Public health and safety (possible environmental threats to the surrounding area)





# Lessons Learned from Asbestos Occurrences

- Any metamorphic unit of the appropriate facies may contain asbestos.
- In general, caution must be exercised around talc, garnet, and vermiculite deposits and ores hosted by skarns.
- Limestone or dolomite deposits can potentially contain asbestos if subject to contact metamorphism.





# The Main Lesson Learned

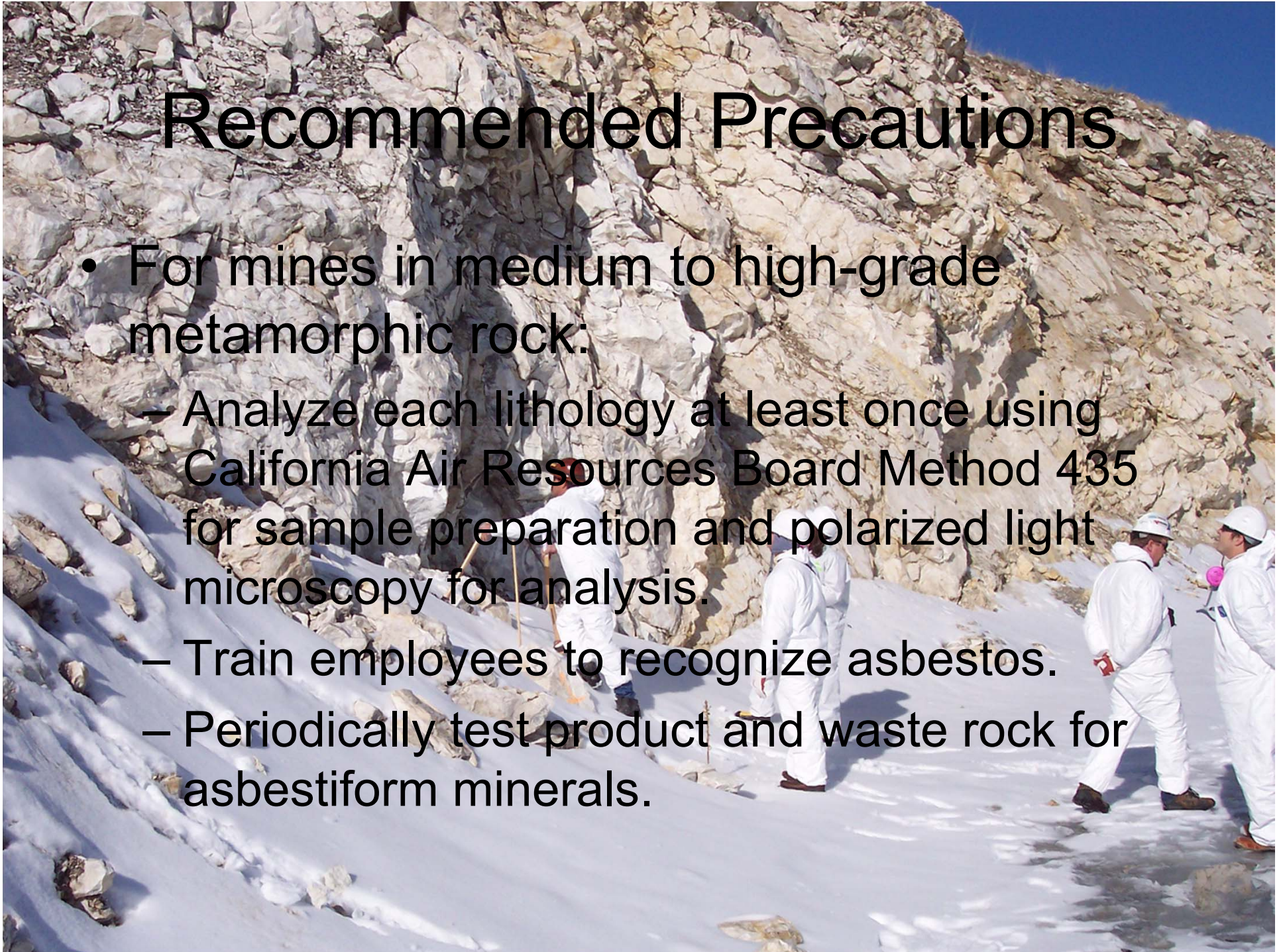
The time to sample for asbestos is *before* the start of mining.





# Recommended Precautions

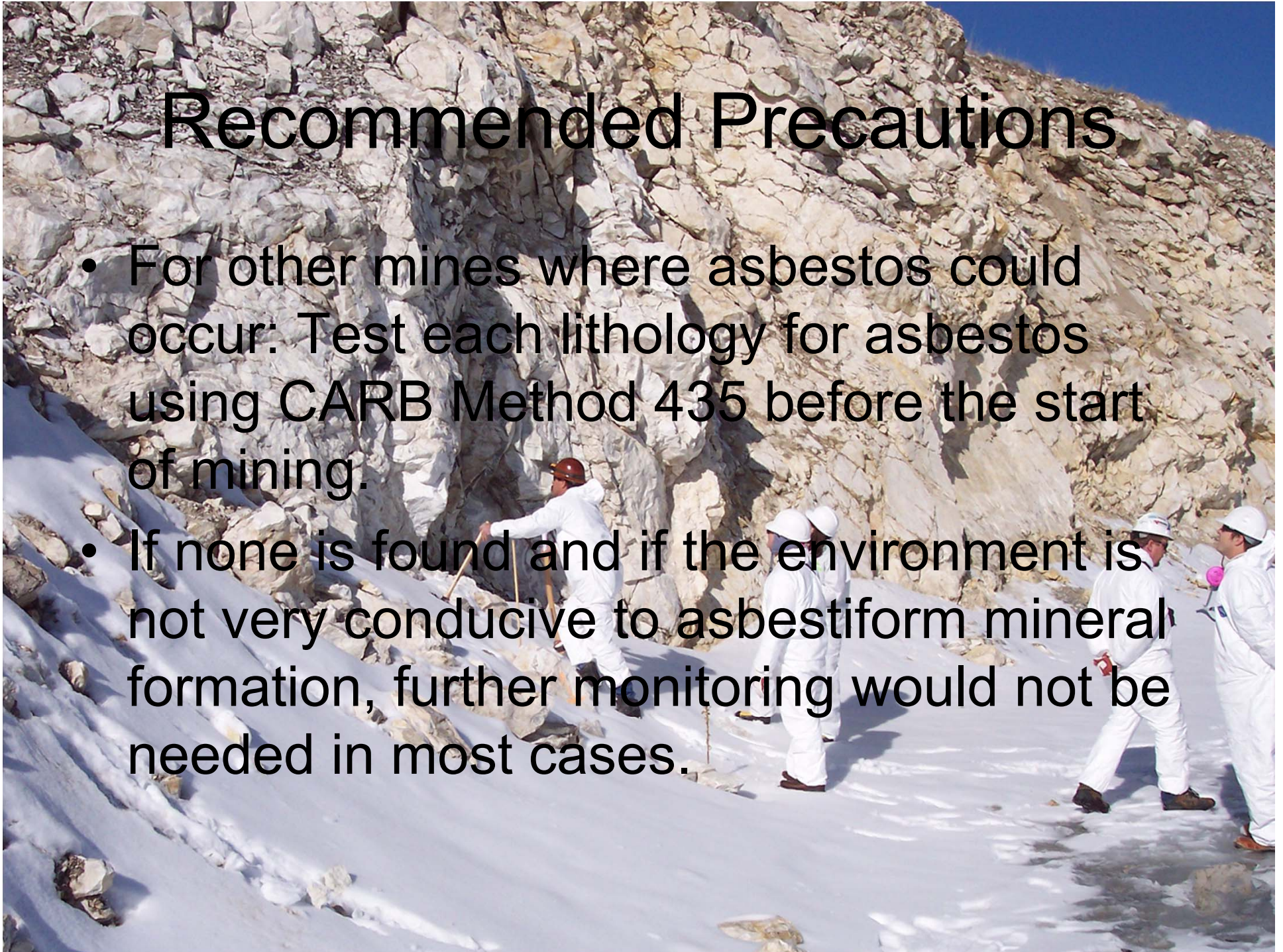
- For mines in medium to high-grade metamorphic rock:
  - Analyze each lithology at least once using California Air Resources Board Method 435 for sample preparation and polarized light microscopy for analysis.
  - Train employees to recognize asbestos.
  - Periodically test product and waste rock for asbestiform minerals.





# Recommended Precautions

- For other mines where asbestos could occur: Test each lithology for asbestos using CARB Method 435 before the start of mining.
- If none is found and if the environment is not very conducive to asbestiform mineral formation, further monitoring would not be needed in most cases.

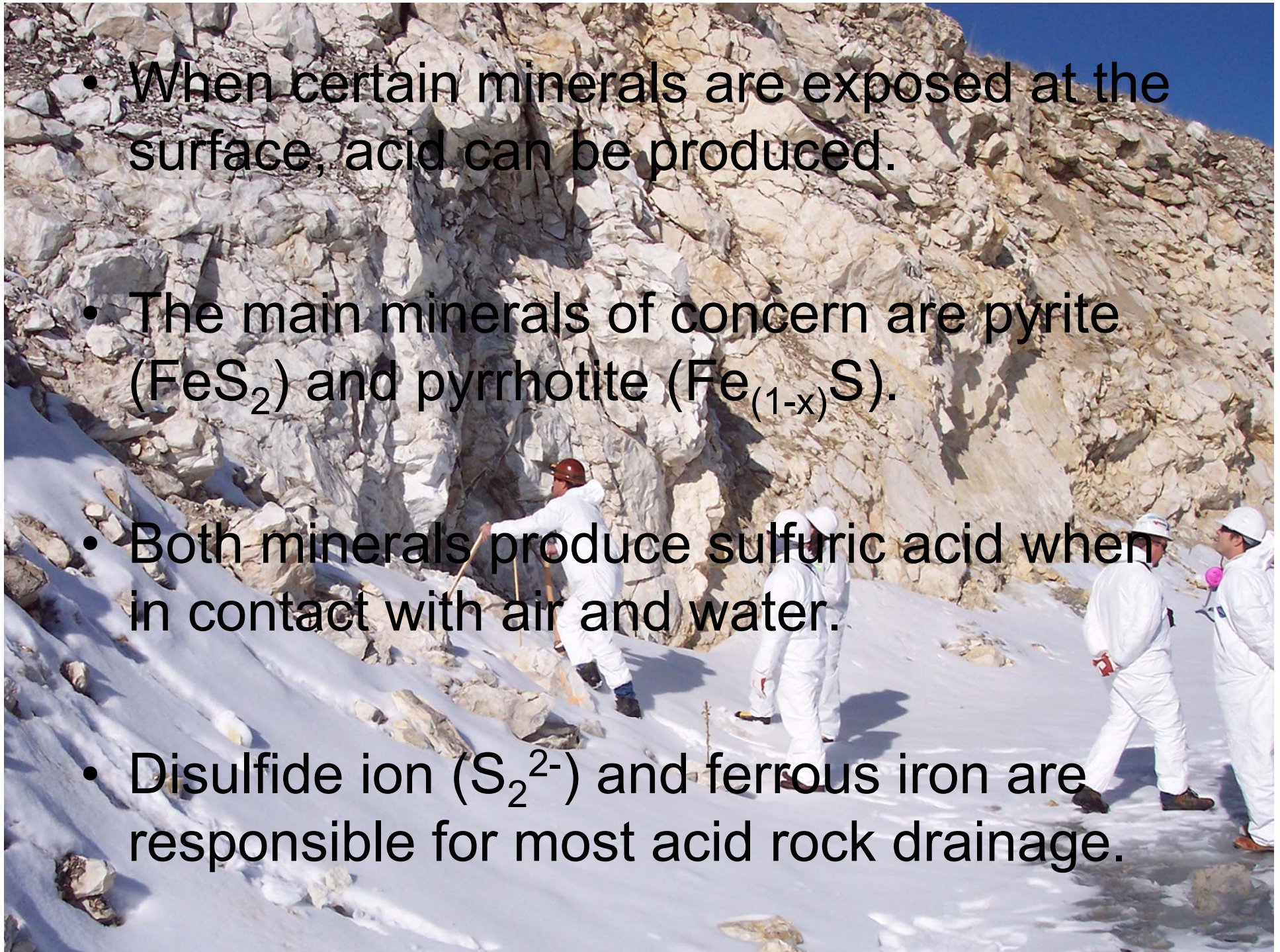




## 2. Acid-Generating Rock





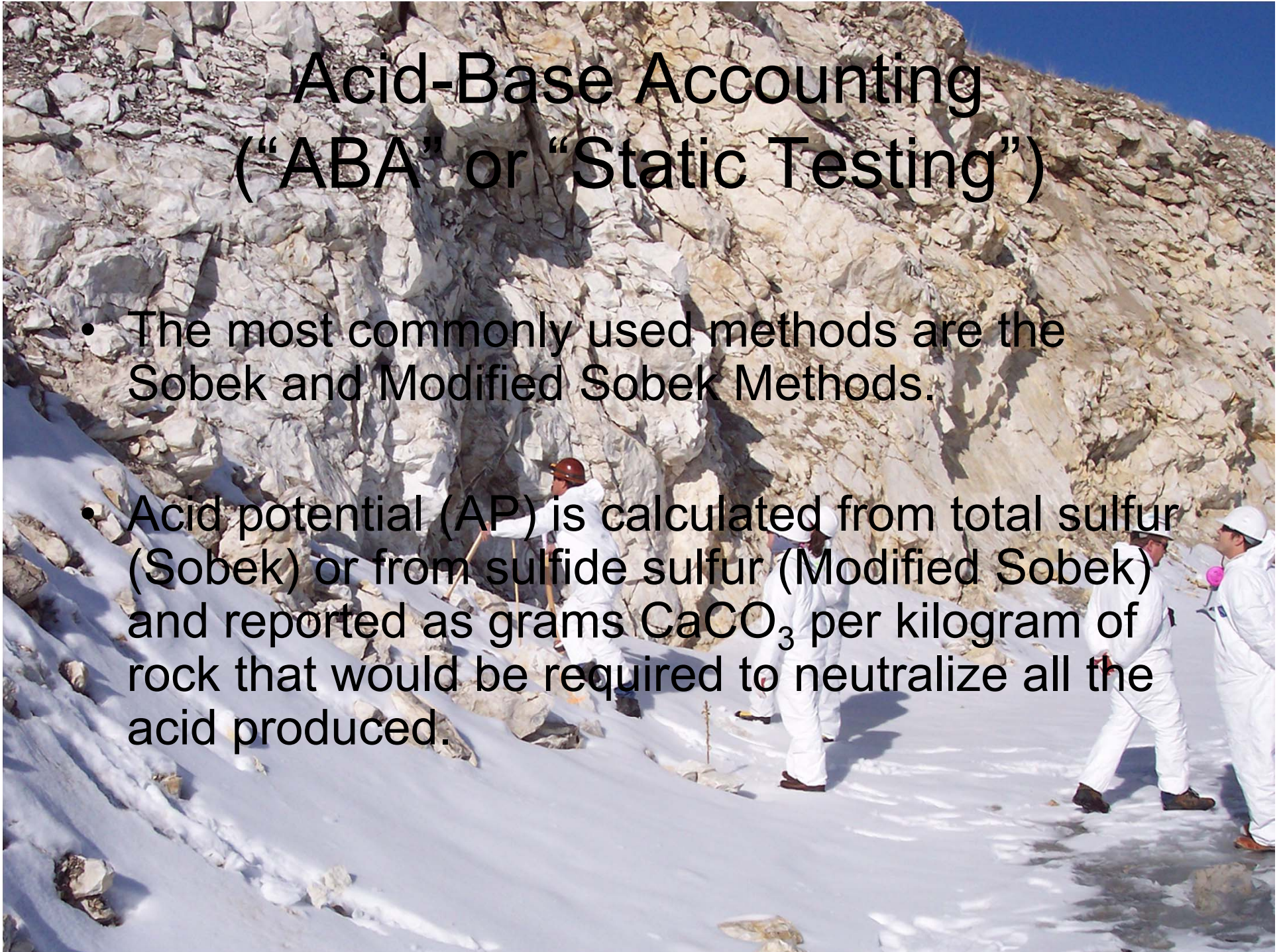


- When certain minerals are exposed at the surface, acid can be produced.
- The main minerals of concern are pyrite ( $\text{FeS}_2$ ) and pyrrhotite ( $\text{Fe}_{(1-x)}\text{S}$ ).
- Both minerals produce sulfuric acid when in contact with air and water.
- Disulfide ion ( $\text{S}_2^{2-}$ ) and ferrous iron are responsible for most acid rock drainage.



# Acid-Base Accounting ("ABA" or "Static Testing")

- The most commonly used methods are the Sobek and Modified Sobek Methods.
- Acid potential (AP) is calculated from total sulfur (Sobek) or from sulfide sulfur (Modified Sobek) and reported as grams  $\text{CaCO}_3$  per kilogram of rock that would be required to neutralize all the acid produced.



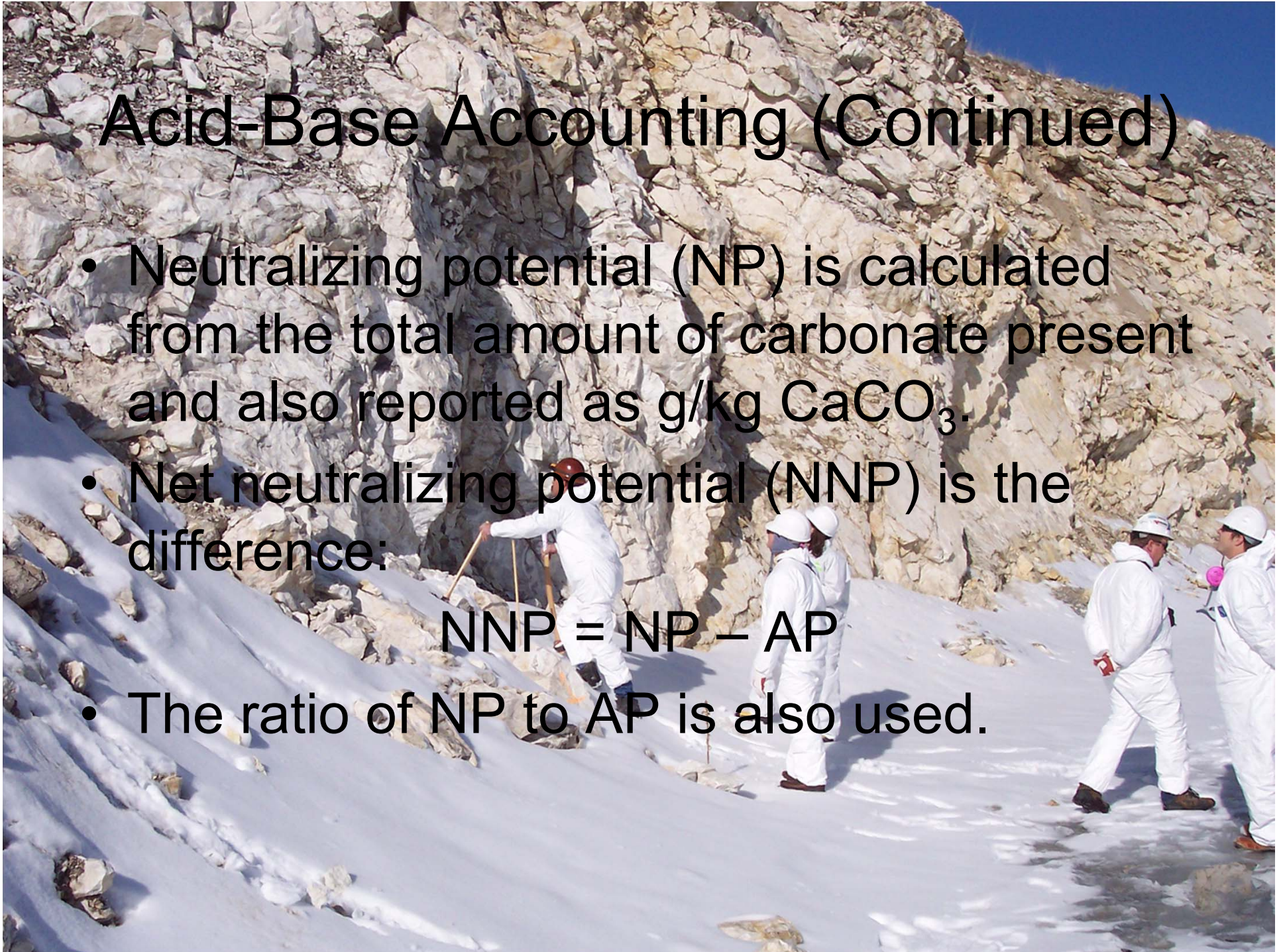


# Acid-Base Accounting (Continued)

- Neutralizing potential (NP) is calculated from the total amount of carbonate present and also reported as g/kg  $\text{CaCO}_3$ .
- Net neutralizing potential (NNP) is the difference:

$$\text{NNP} = \text{NP} - \text{AP}$$

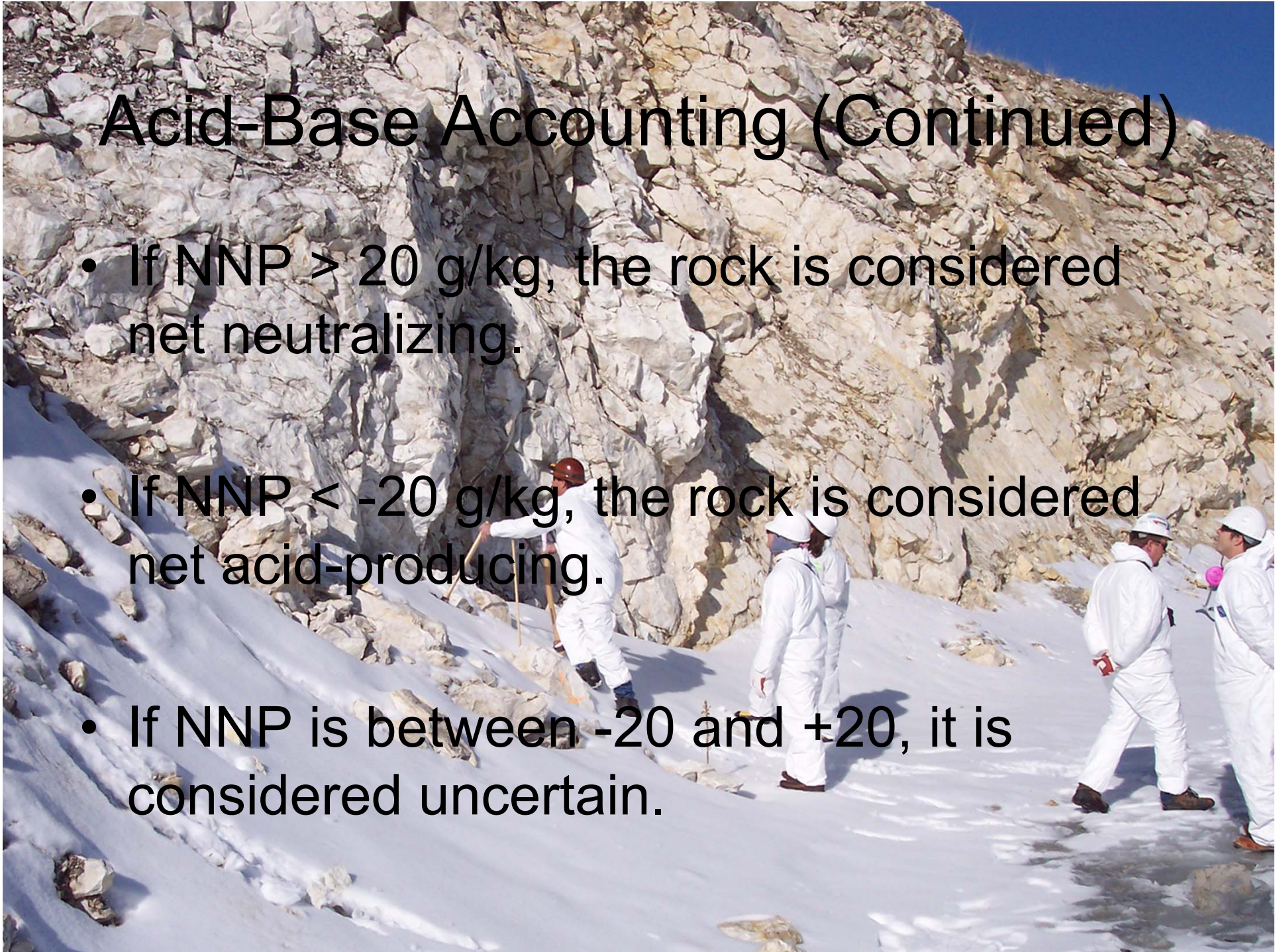
- The ratio of NP to AP is also used.





# Acid-Base Accounting (Continued)

- If  $NNP > 20$  g/kg, the rock is considered net neutralizing.
- If  $NNP < -20$  g/kg, the rock is considered net acid-producing.
- If  $NNP$  is between  $-20$  and  $+20$ , it is considered uncertain.

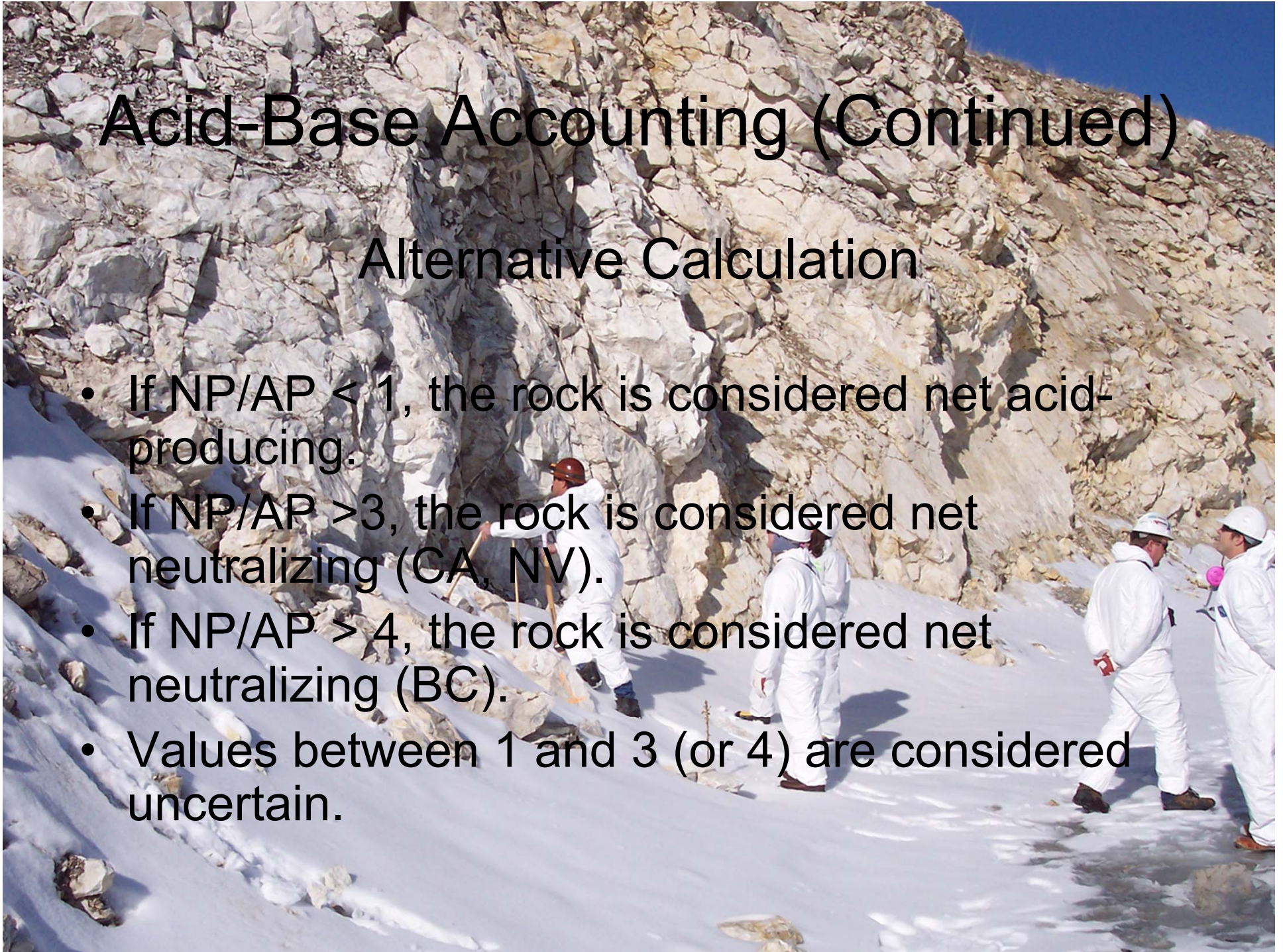




# Acid-Base Accounting (Continued)

## Alternative Calculation

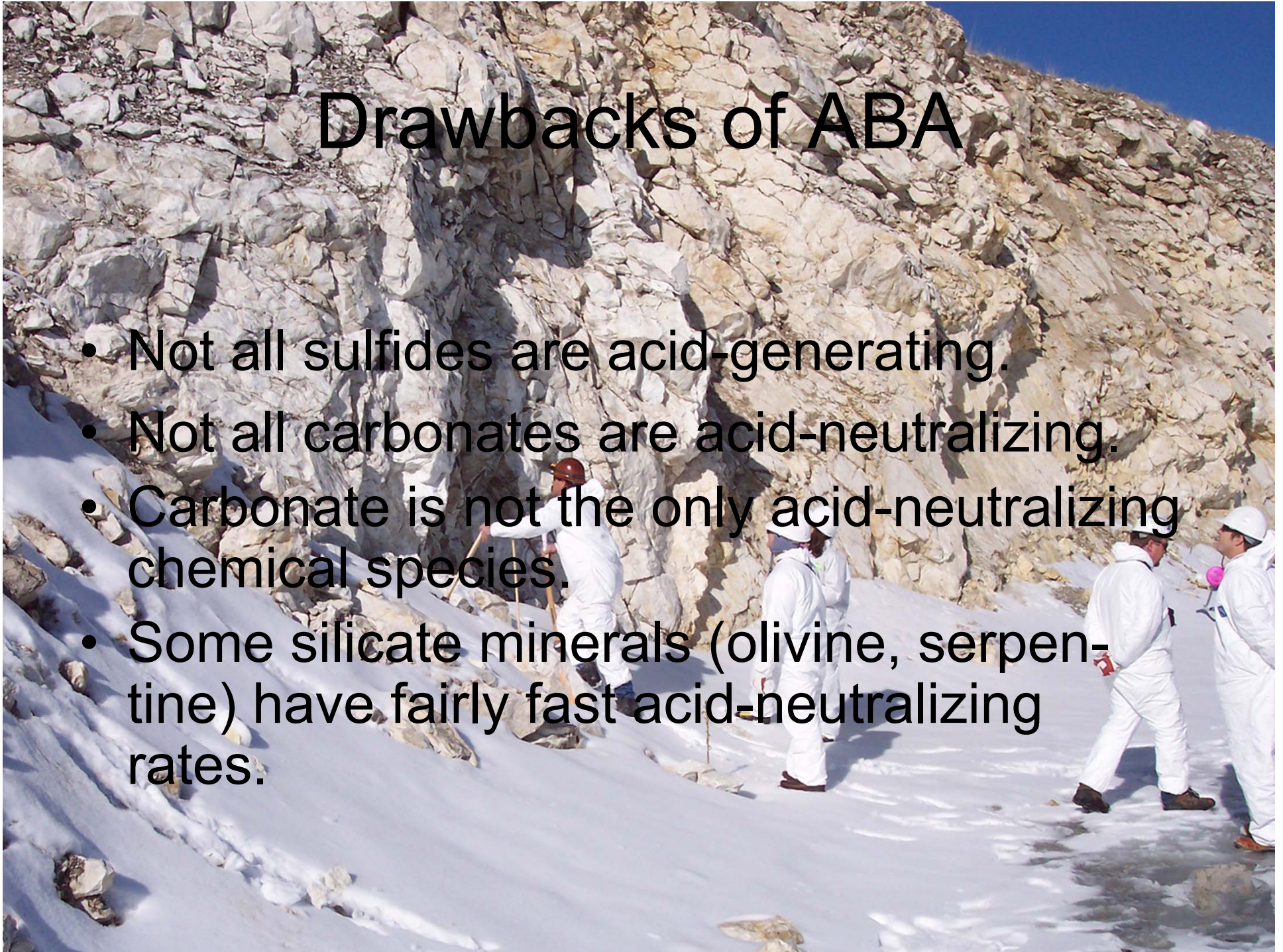
- If  $NP/AP < 1$ , the rock is considered net acid-producing.
- If  $NP/AP > 3$ , the rock is considered net neutralizing (CA, NV).
- If  $NP/AP > 4$ , the rock is considered net neutralizing (BC).
- Values between 1 and 3 (or 4) are considered uncertain.





# Drawbacks of ABA

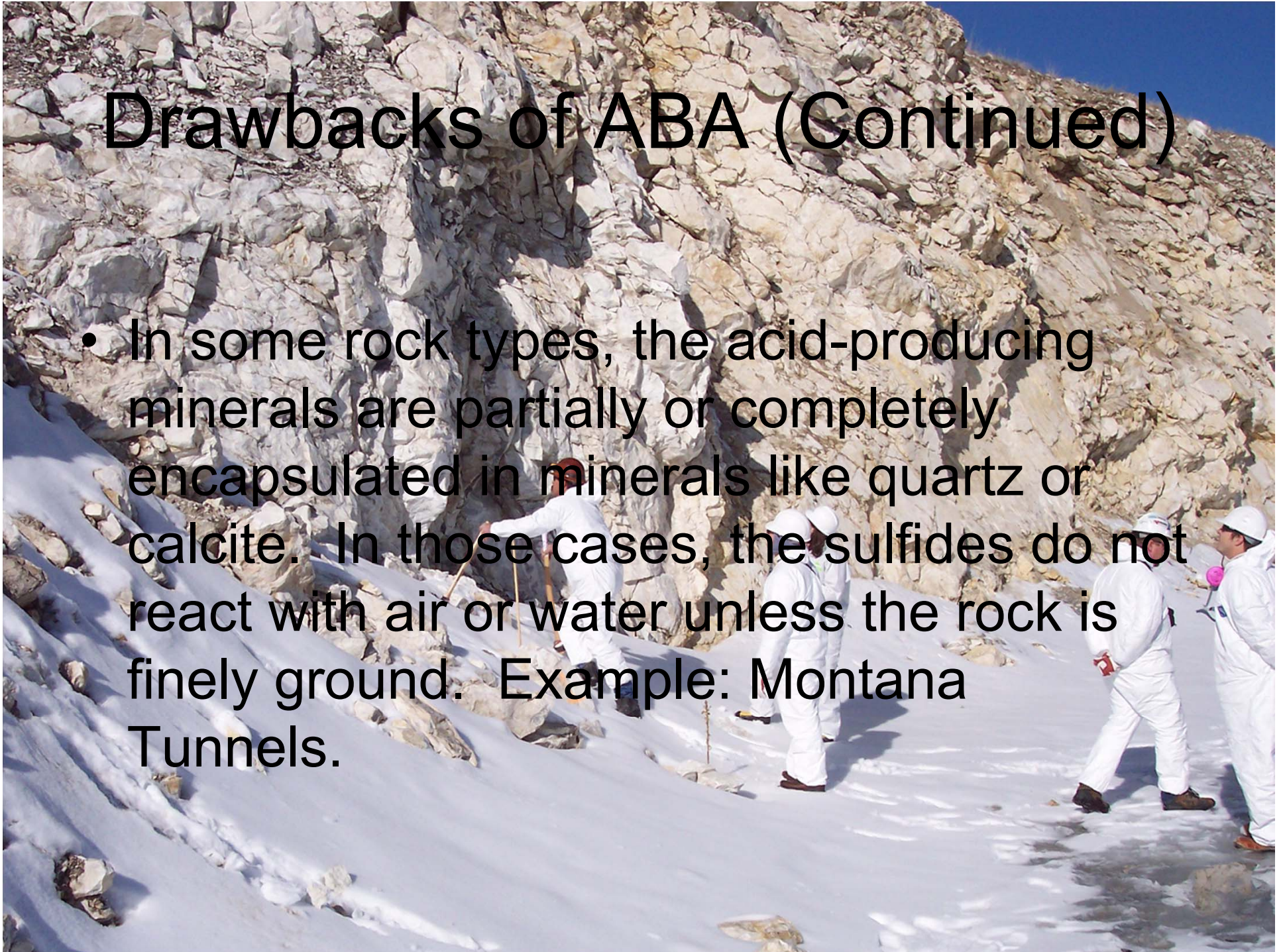
- Not all sulfides are acid-generating.
- Not all carbonates are acid-neutralizing.
- Carbonate is not the only acid-neutralizing chemical species.
- Some silicate minerals (olivine, serpentine) have fairly fast acid-neutralizing rates.





# Drawbacks of ABA (Continued)

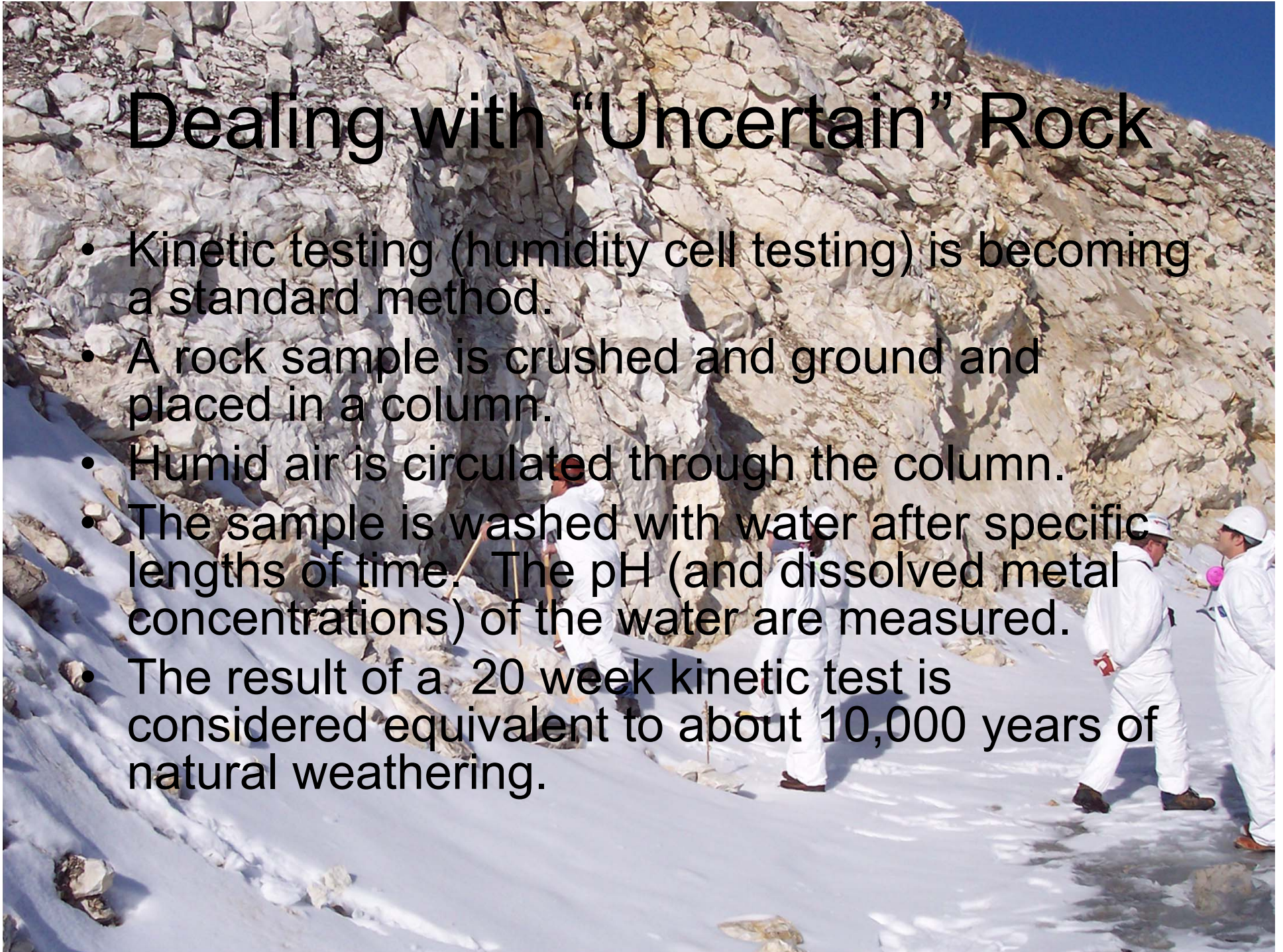
- In some rock types, the acid-producing minerals are partially or completely encapsulated in minerals like quartz or calcite. In those cases, the sulfides do not react with air or water unless the rock is finely ground. Example: Montana Tunnels.





# Dealing with “Uncertain” Rock

- Kinetic testing (humidity cell testing) is becoming a standard method.
- A rock sample is crushed and ground and placed in a column.
- Humid air is circulated through the column.
- The sample is washed with water after specific lengths of time. The pH (and dissolved metal concentrations) of the water are measured.
- The result of a 20 week kinetic test is considered equivalent to about 10,000 years of natural weathering.





# 3. Neutral Metal Drainage







- Even if rock is net neutralizing, metals may be mobilized. There are two reasons:

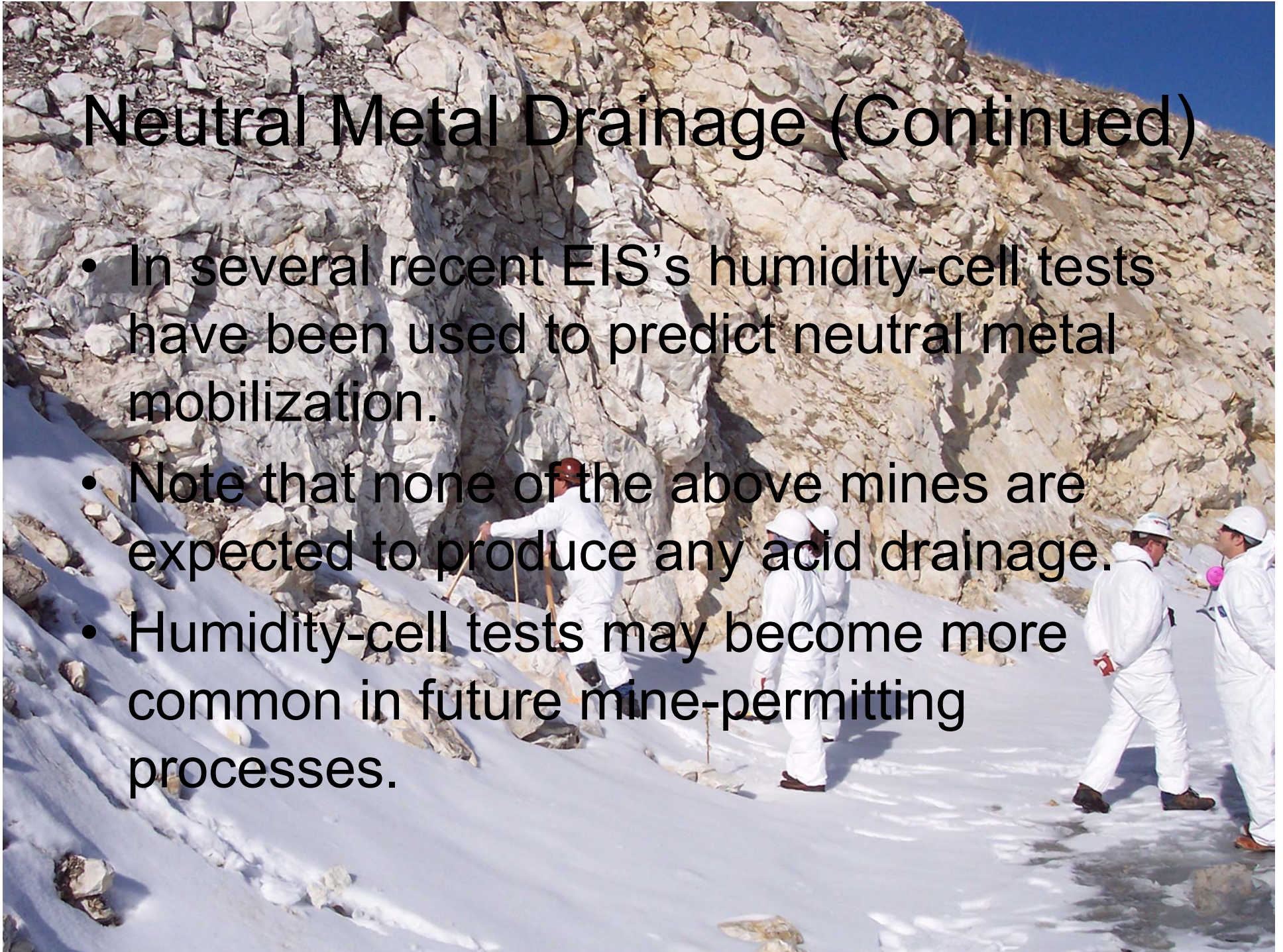
- Many heavy metals are soluble in neutral water at concentrations higher than their water-quality limits (e.g., Cu, Zn, and Pb). Once the metal sulfide ore minerals oxidize, acid is not necessary to mobilize the metals.

- Metalloids like As and Se, which form anions, are more soluble under neutral to basic conditions anyway.



## Neutral Metal Drainage (Continued)

- In several recent EIS's humidity-cell tests have been used to predict neutral metal mobilization.
- Note that none of the above mines are expected to produce any acid drainage.
- Humidity-cell tests may become more common in future mine-permitting processes.





# 4. Elements Toxic at Very Low Concentrations





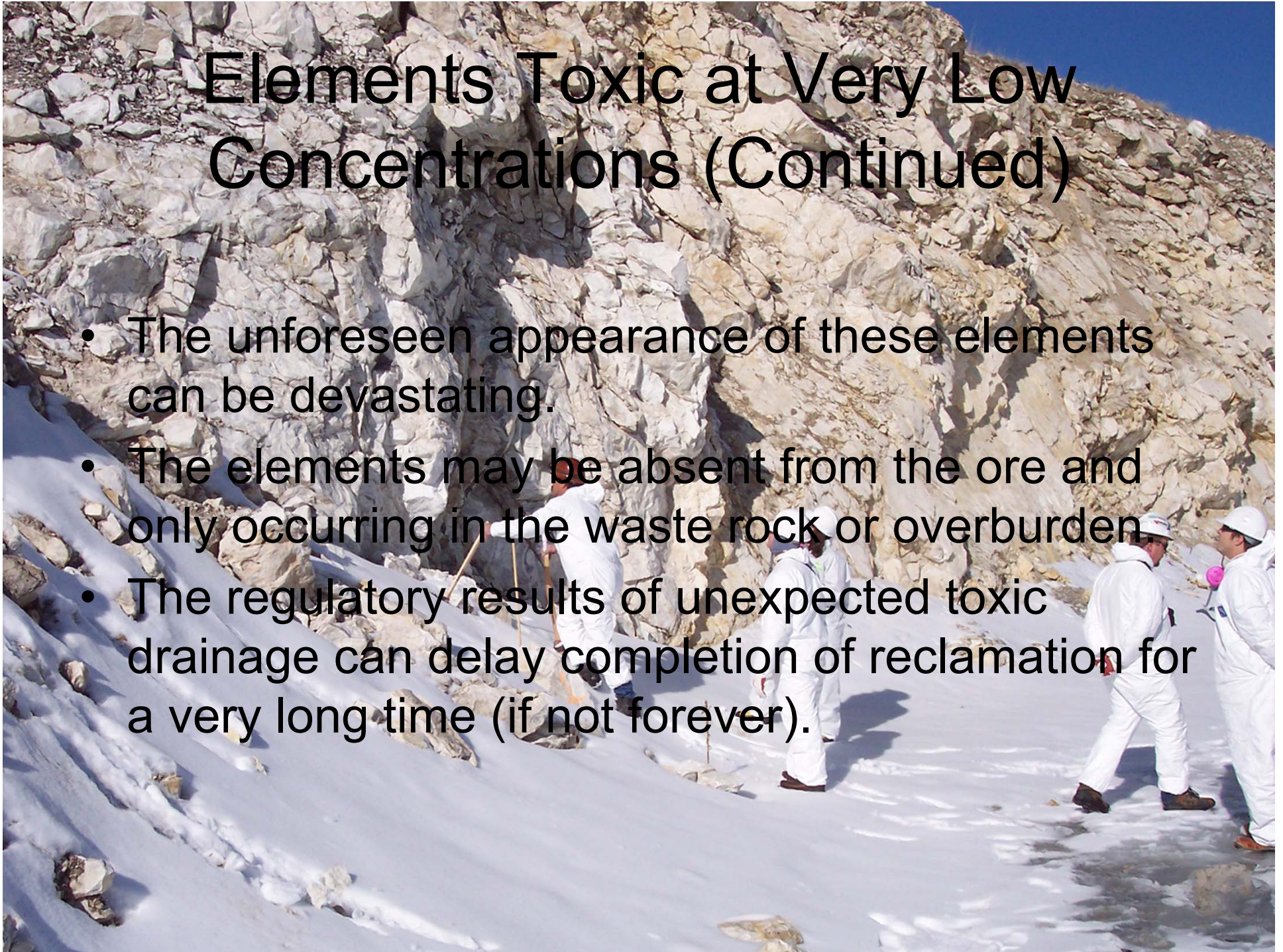
# Human Health Limits ( $\mu\text{g}/\text{L}$ )

Element	Surface Water	Groundwater
Antimony	5.6	6.0
Arsenic	10	10
Beryllium	4	4
Cadmium	5.0	5.0
Mercury	0.05	2.00
Thallium	0.24	2.0



## Elements Toxic at Very Low Concentrations (Continued)

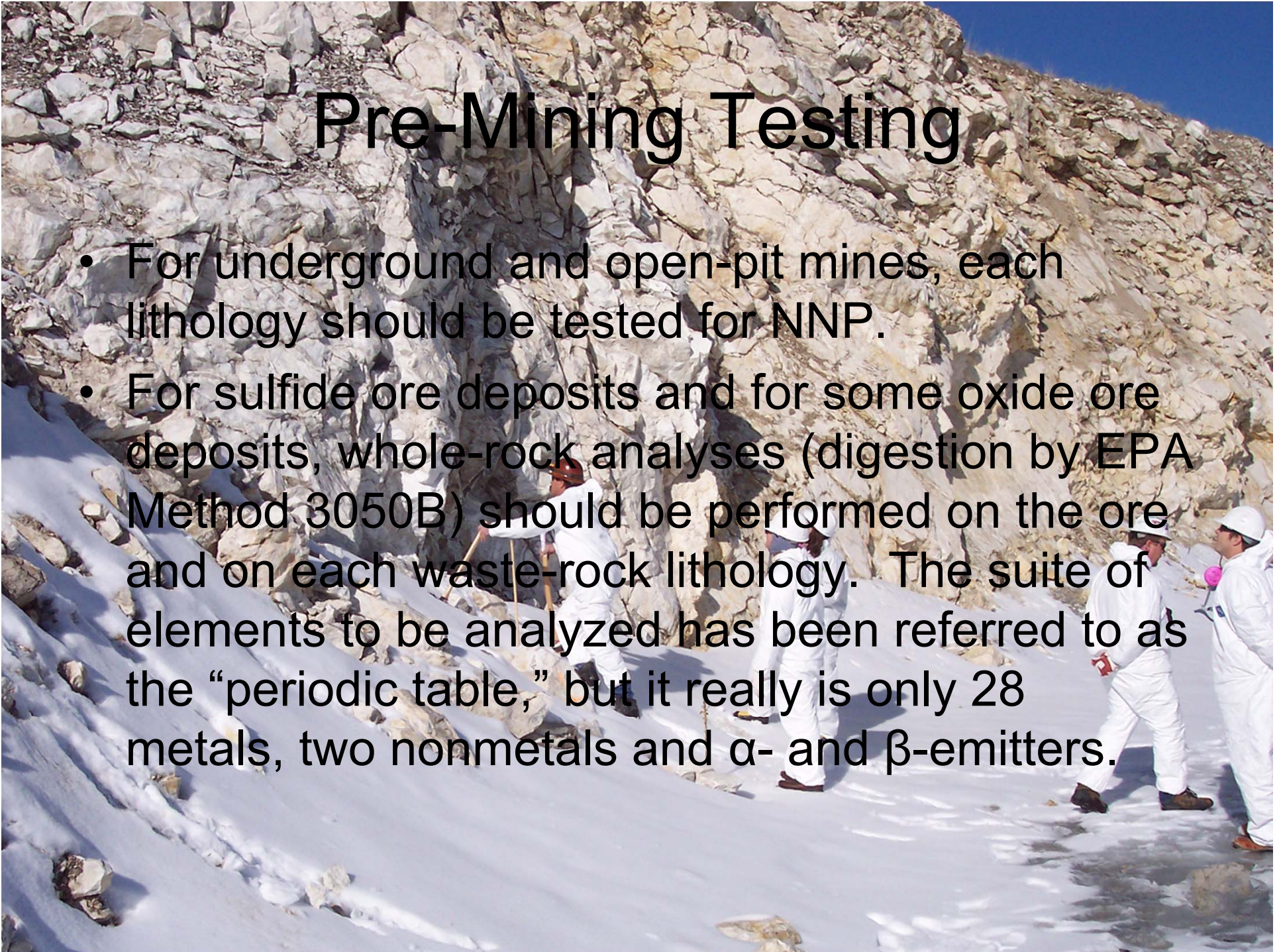
- The unforeseen appearance of these elements can be devastating.
- The elements may be absent from the ore and only occurring in the waste rock or overburden.
- The regulatory results of unexpected toxic drainage can delay completion of reclamation for a very long time (if not forever).





# Pre-Mining Testing

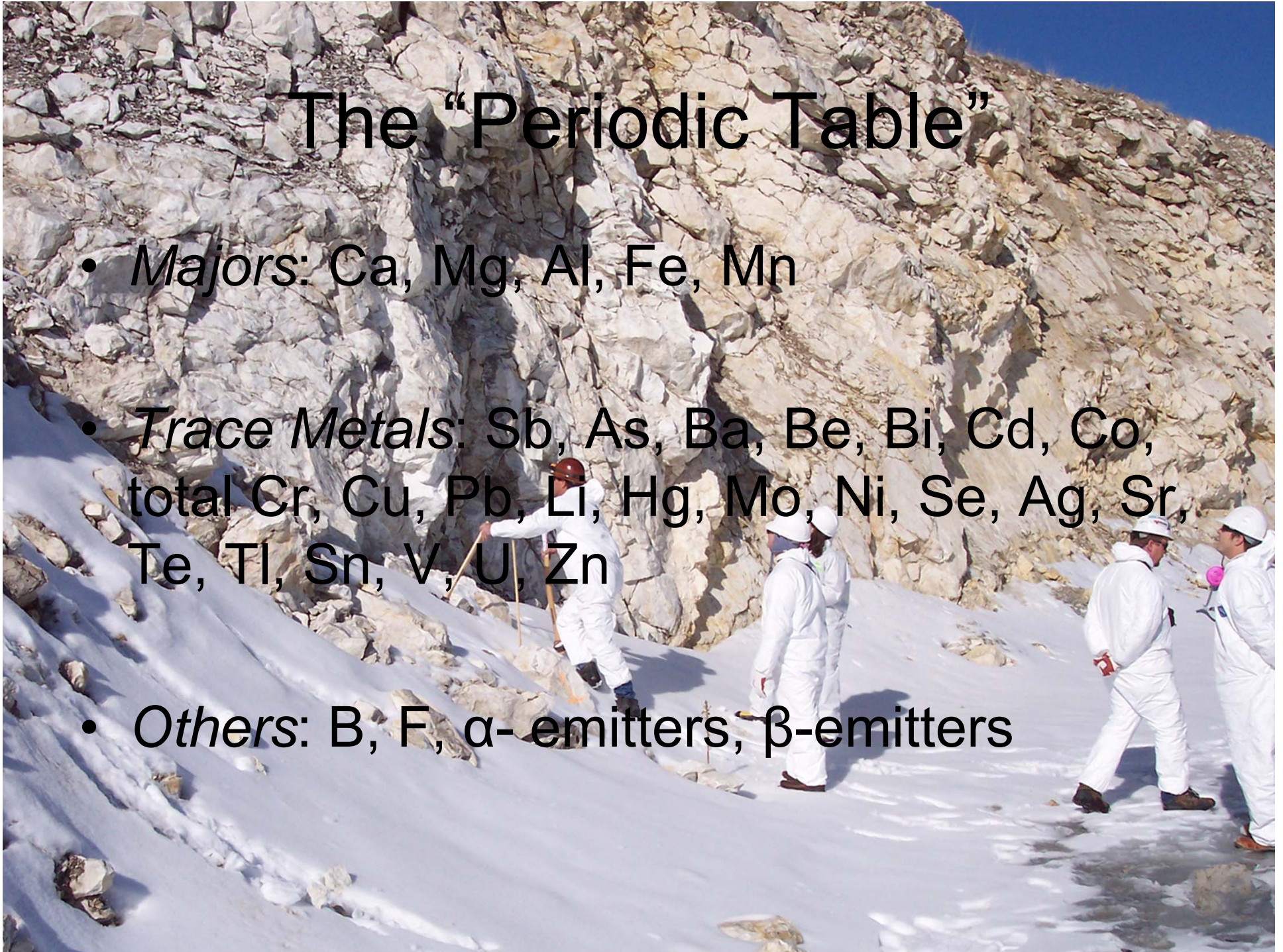
- For underground and open-pit mines, each lithology should be tested for NNP.
- For sulfide ore deposits and for some oxide ore deposits, whole-rock analyses (digestion by EPA Method 3050B) should be performed on the ore and on each waste-rock lithology. The suite of elements to be analyzed has been referred to as the “periodic table,” but it really is only 28 metals, two nonmetals and  $\alpha$ - and  $\beta$ -emitters.





# The “Periodic Table”

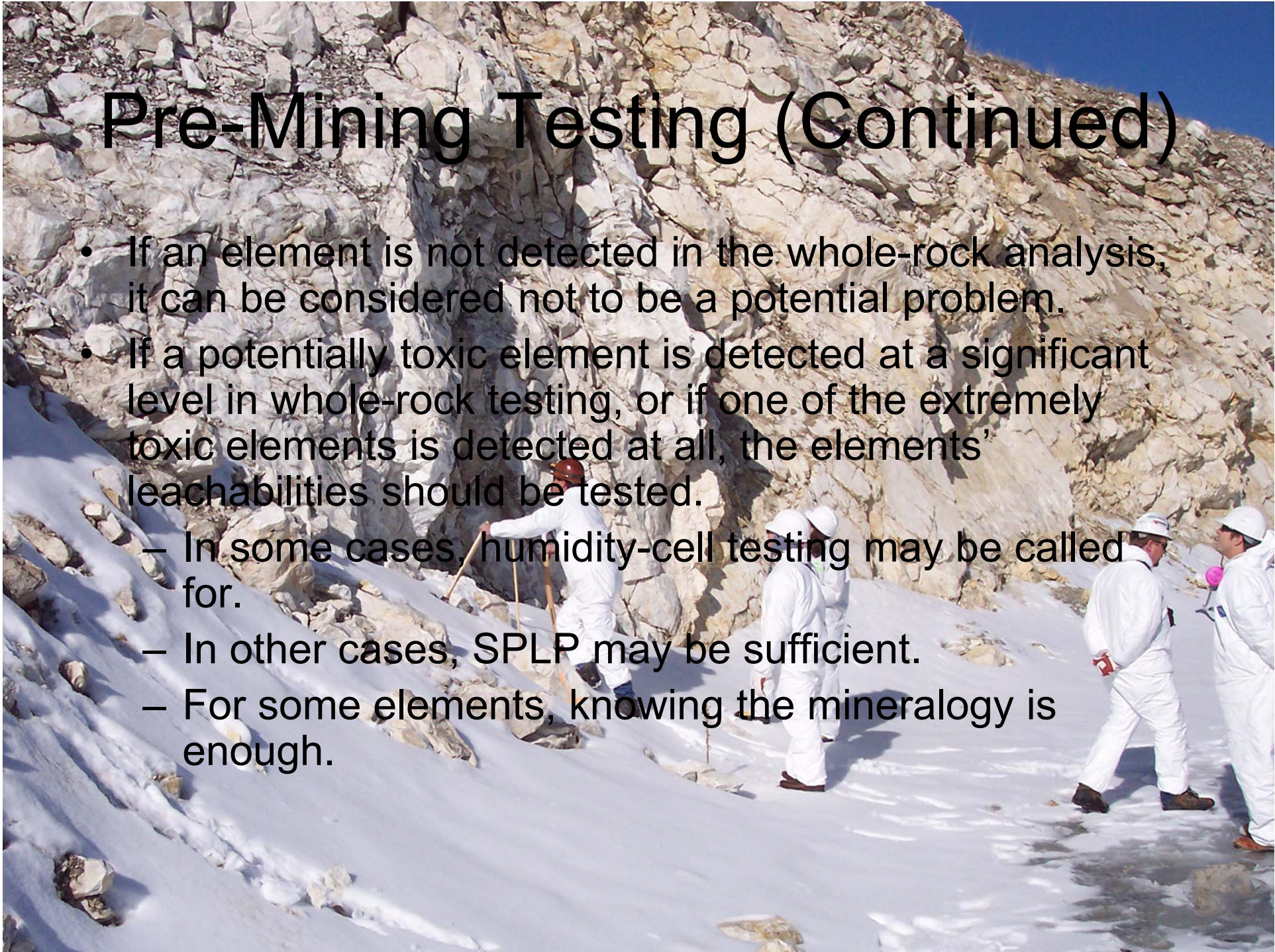
- *Majors*: Ca, Mg, Al, Fe, Mn
- *Trace Metals*: Sb, As, Ba, Be, Bi, Cd, Co, total Cr, Cu, Pb, Li, Hg, Mo, Ni, Se, Ag, Sr, Te, Tl, Sn, V, U, Zn
- *Others*: B, F,  $\alpha$ -emitters,  $\beta$ -emitters





# Pre-Mining Testing (Continued)

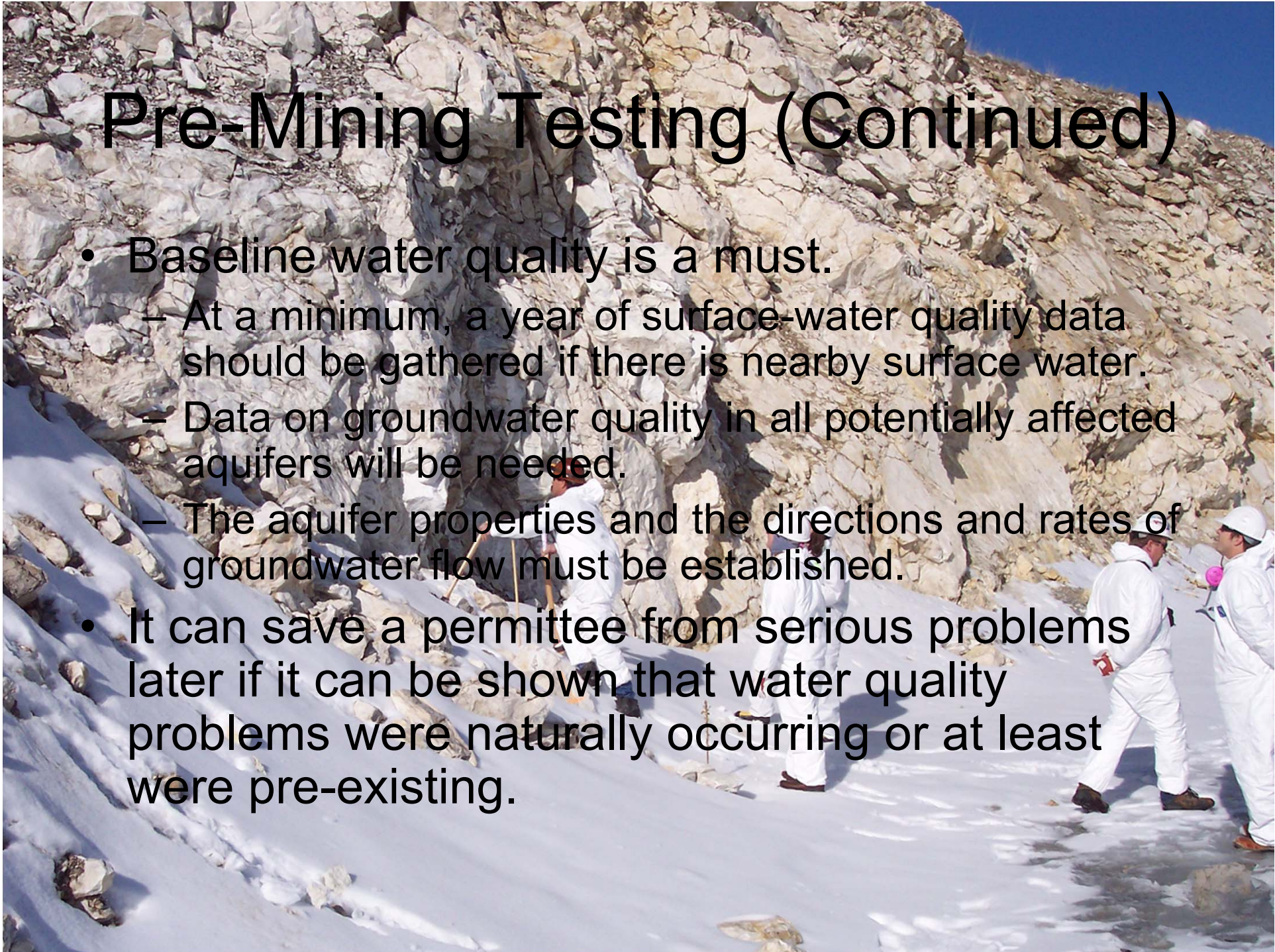
- If an element is not detected in the whole-rock analysis, it can be considered not to be a potential problem.
- If a potentially toxic element is detected at a significant level in whole-rock testing, or if one of the extremely toxic elements is detected at all, the elements' leachabilities should be tested.
  - In some cases, humidity-cell testing may be called for.
  - In other cases, SPLP may be sufficient.
  - For some elements, knowing the mineralogy is enough.





# Pre-Mining Testing (Continued)

- Baseline water quality is a must.
  - At a minimum, a year of surface-water quality data should be gathered if there is nearby surface water.
  - Data on groundwater quality in all potentially affected aquifers will be needed.
  - The aquifer properties and the directions and rates of groundwater flow must be established.
- It can save a permittee from serious problems later if it can be shown that water quality problems were naturally occurring or at least were pre-existing.

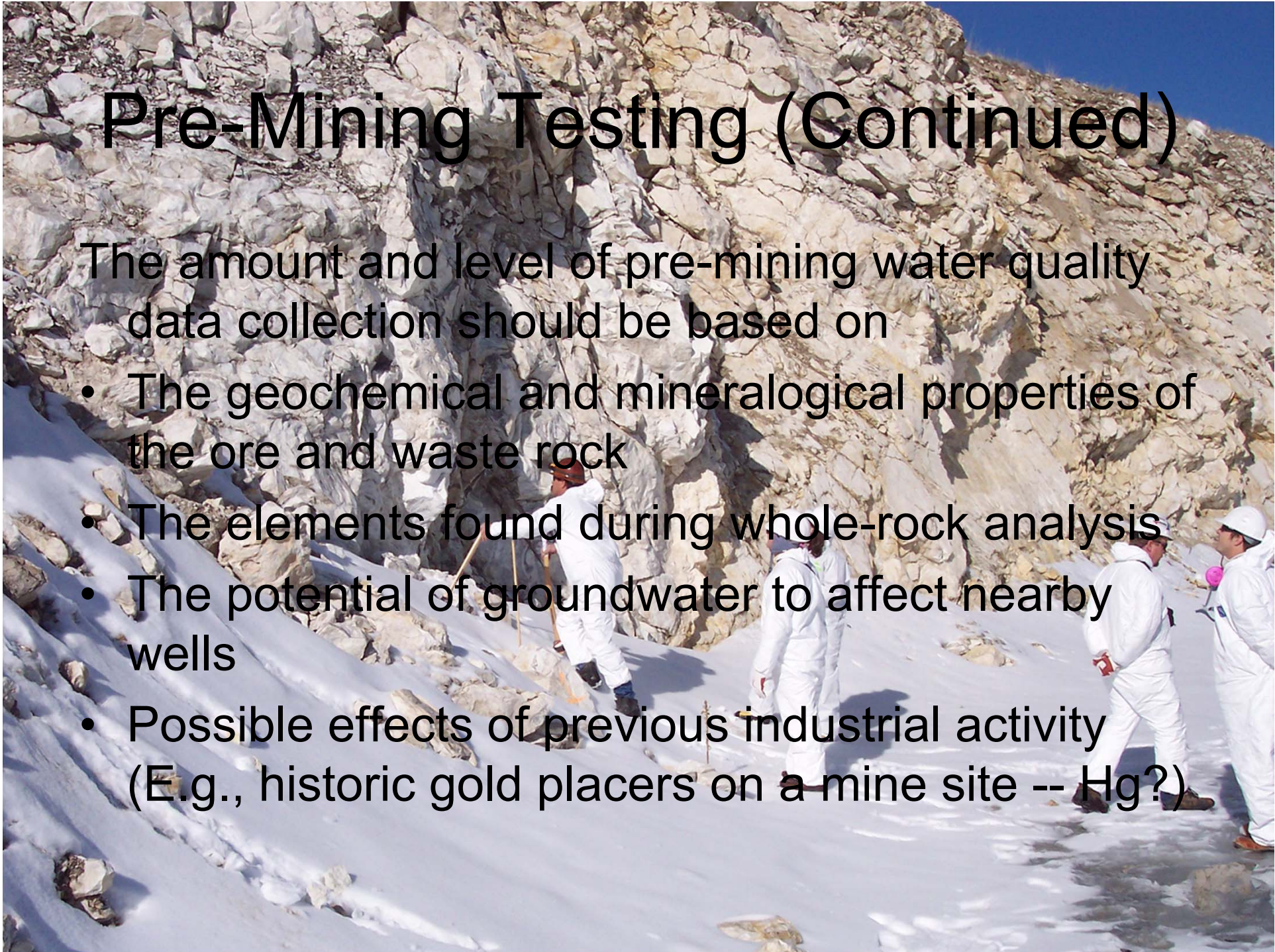




# Pre-Mining Testing (Continued)

The amount and level of pre-mining water quality data collection should be based on

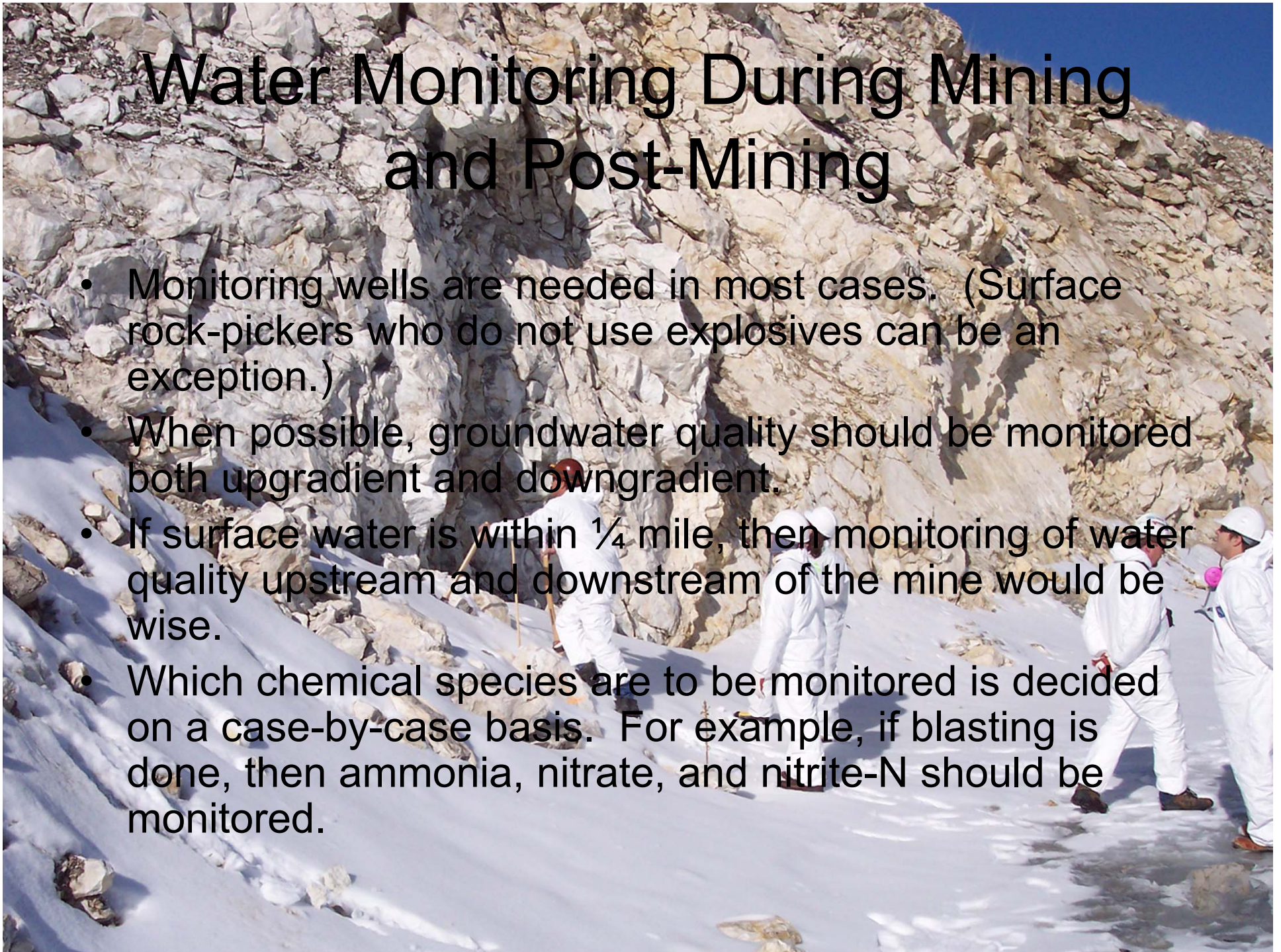
- The geochemical and mineralogical properties of the ore and waste rock
- The elements found during whole-rock analysis
- The potential of groundwater to affect nearby wells
- Possible effects of previous industrial activity (E.g., historic gold placers on a mine site -- Hg?)





# Water Monitoring During Mining and Post-Mining

- Monitoring wells are needed in most cases. (Surface rock-pickers who do not use explosives can be an exception.)
- When possible, groundwater quality should be monitored both upgradient and downgradient.
- If surface water is within  $\frac{1}{4}$  mile, then monitoring of water quality upstream and downstream of the mine would be wise.
- Which chemical species are to be monitored is decided on a case-by-case basis. For example, if blasting is done, then ammonia, nitrate, and nitrite-N should be monitored.

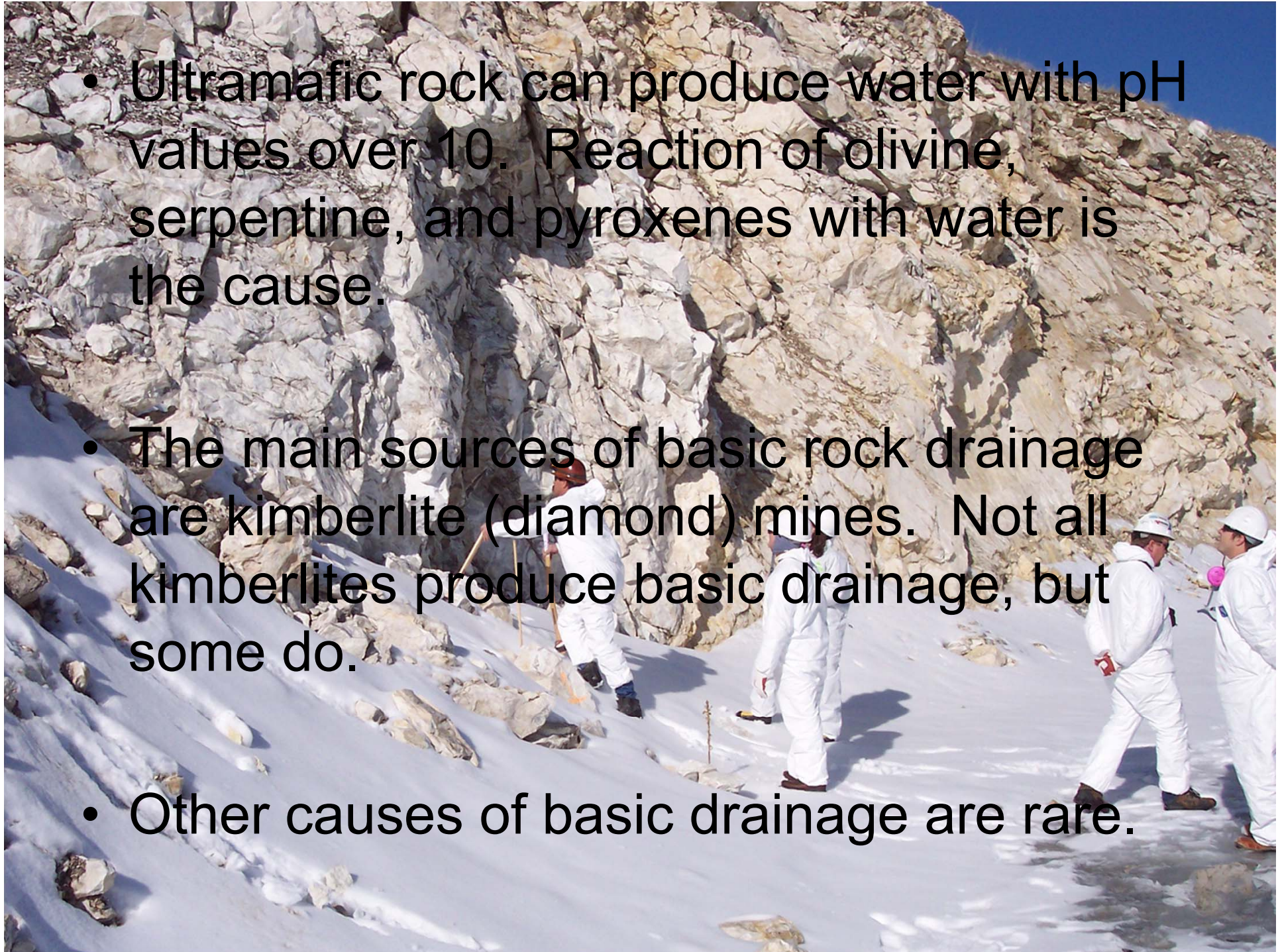




# 5. Basic Rock Drainage







- Ultramafic rock can produce water with pH values over 10. Reaction of olivine, serpentine, and pyroxenes with water is the cause.
- The main sources of basic rock drainage are kimberlite (diamond) mines. Not all kimberlites produce basic drainage, but some do.
- Other causes of basic drainage are rare.



# Questions ?

