
## Types of slope instruments

- Displacement monitoring devices
  - Precise surveys
  - Differential global positioning systems (DGPS)
  - Space-borne and terrestrial SAR Interferometry
- Strain monitoring devices
  - Surface extensometers
  - Borehole extensometers
  - Borehole inclinometers
  - Tiltmeters
  - Time domain reflectometry (TDR)
- Pore-pressure measurements
  - Piezometers and monitoring wells
  - Tensiometers
  - TDR moisture gauges
- Microseismicity
  - Geophones

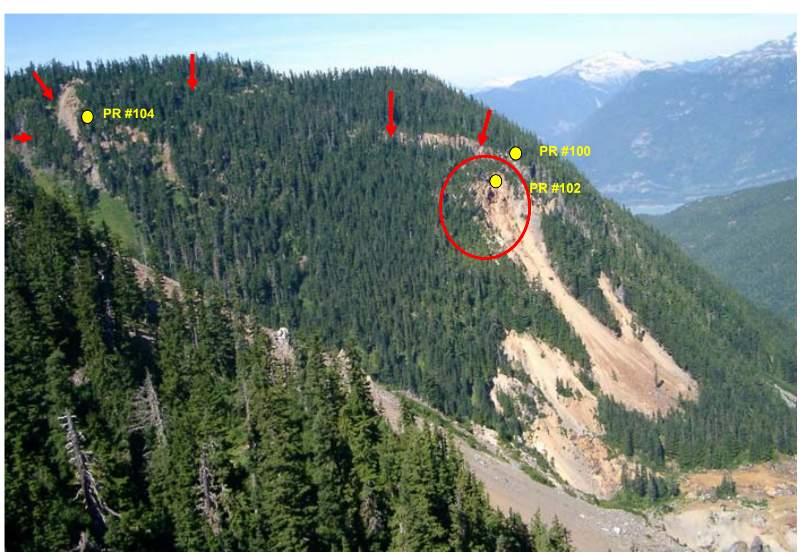
# Displacement monitoring

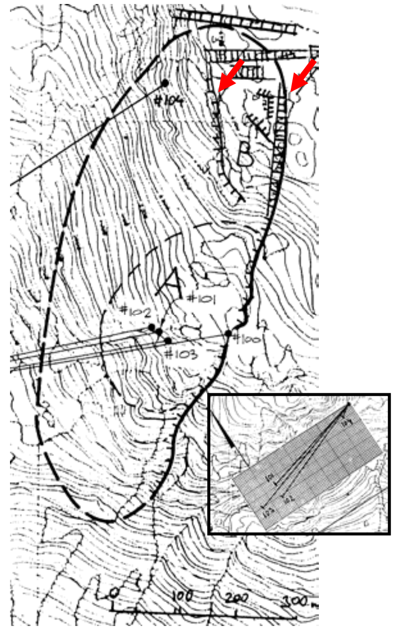
1) "Total Station": Electronic Distance Measurement ("EDM") + Theodolite

2) "DGPS" Differential Global Positioning System: Base station+measuring stations

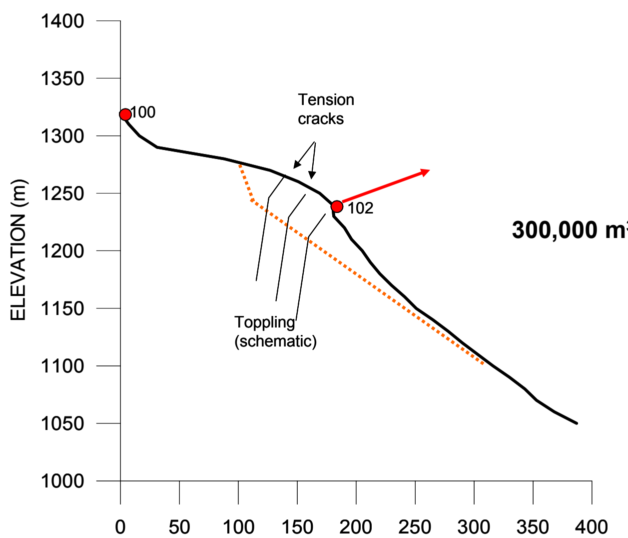
Target prism

# Britannia Mine, B.C. Disturbed Area

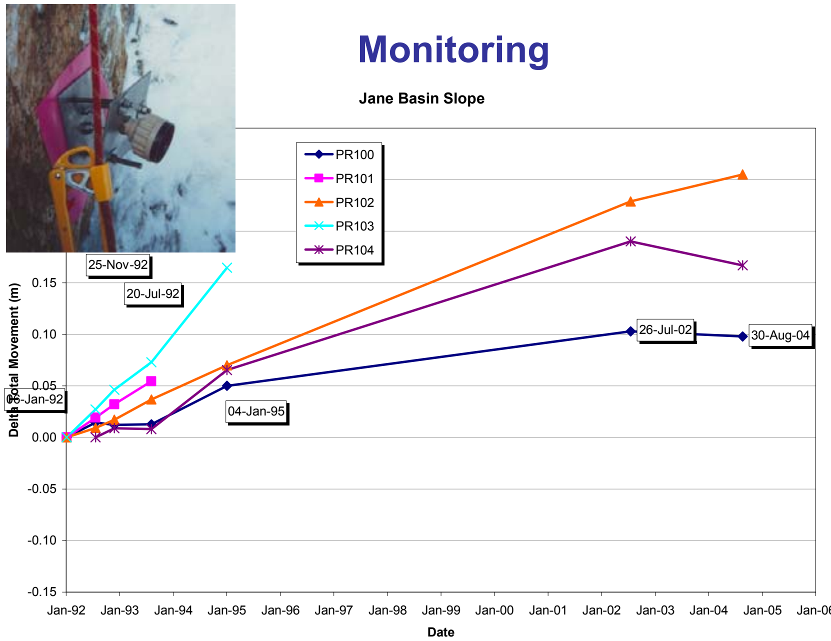



# East Block, failure model

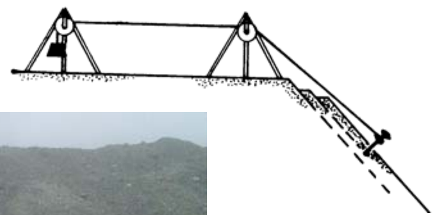


# Monitoring



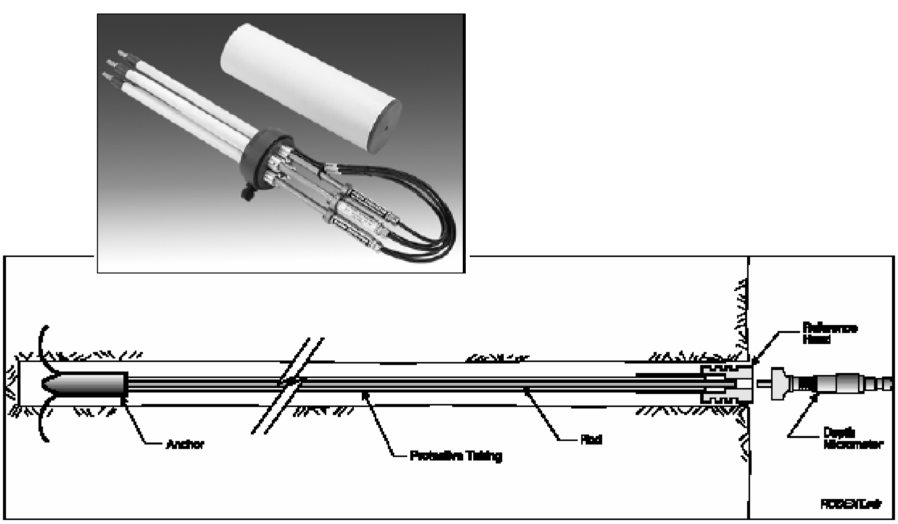

# Coal Mine Waste Dumps

# Wire extensometer

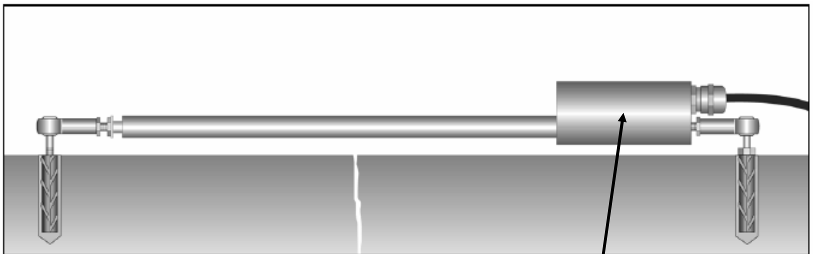


With data logger

# Borehole extensometer (Slope Indicator, Ltd.)

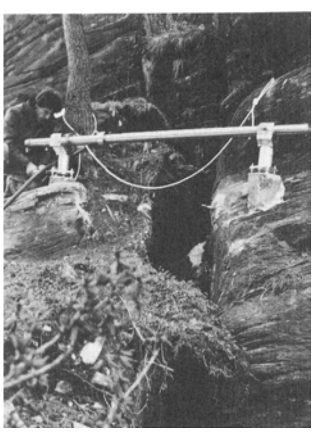


## Surface rod extensometer ("crackmeter")



Vibrating wire displacement gauge (or a vernier for manual readings or a linear transducer) accuracy <1mm

Tape extensometer

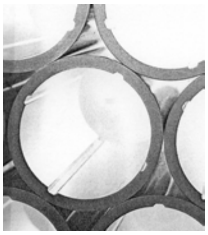


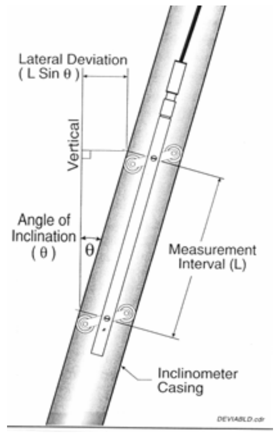
## Rod Extensometers

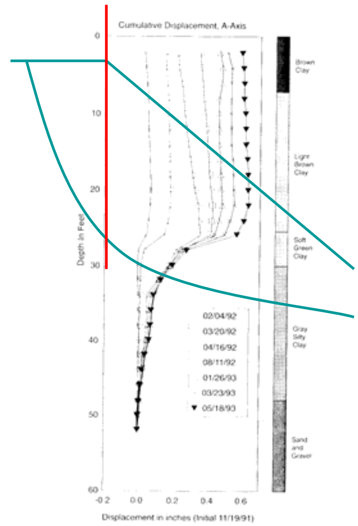
**ISMES, Valtellina, Italy**

**ETH, Switzerland**

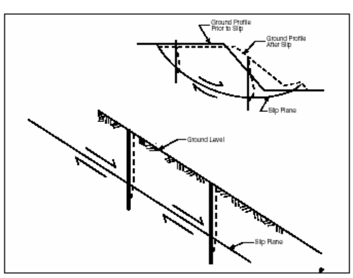
## Borehole inclinometer (“Slope Indicator”)

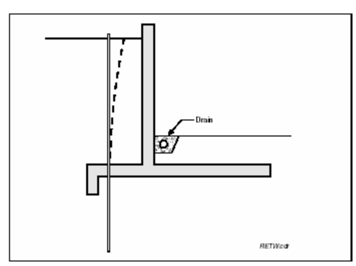


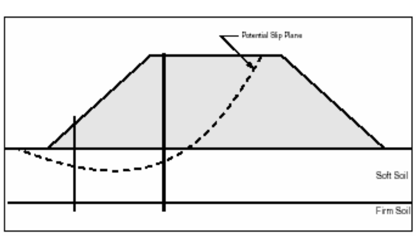


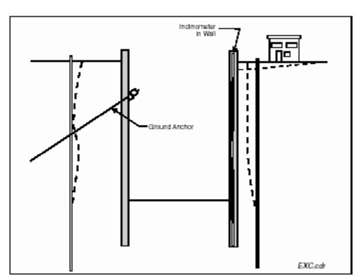




## Some inclinometer applications (Slope Indicator, Ltd.)

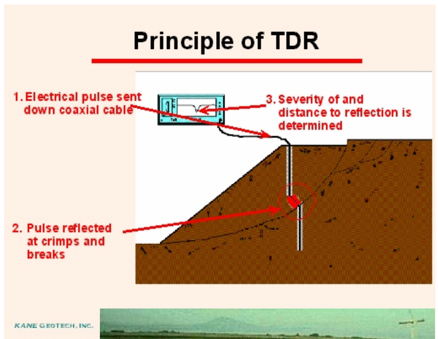


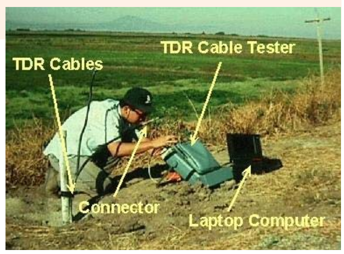



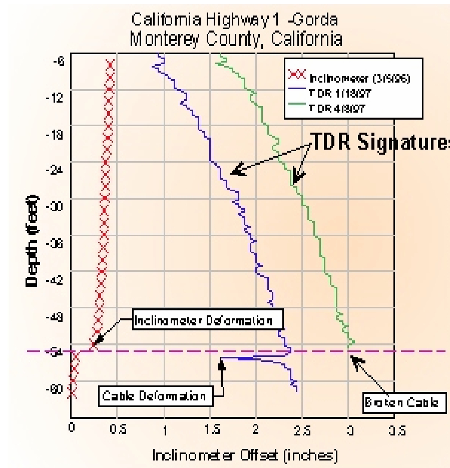



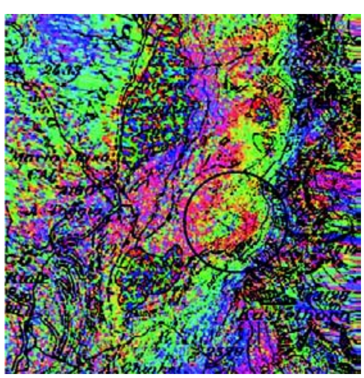
# Time domain reflectometry (TDR)



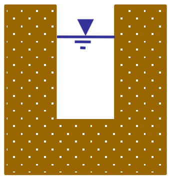




# Synthetic aperture radar interferometry (SAR)

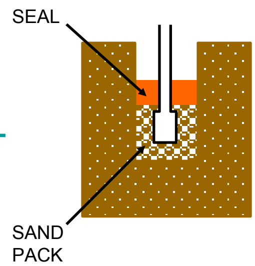


| Class | Description | Speed | Speed (m/s) | SAT DInSAR | GB DIn SAR |
|---|---|---|---|---|---|
| 1 | Extremely slow | 16 mm/year | $5\ 10^{-10}$ m/s | Yes | Partly |
| 2 | Very slow | 1.6 m/year | $5\ 10^{-8}$ m/s | Partly | Yes |
| 3 | Slow | 13 m/month | $5\ 10^{-6}$ m/s | No | Yes |
| 4 | Moderate | 1.8 m/h | $5\ 10^{-4}$ m/s | No | Partly |
| 5 | Rapid | 3 m/min | $5\ 10^{-2}$ m/s | No | No |
| 6 | Very rapid | 5 m/s | 5 m/s | No | No |
| 7 | Extremely rapid | | | No | No |

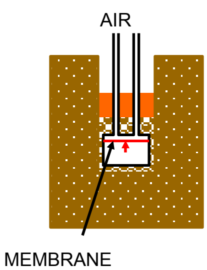
# Piezometers



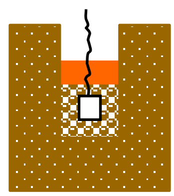
**1) Observation well (open) – not a piezometer**




**3) Standipe (Casagrande) piezometer**




**2) Pneumatic piezometer**

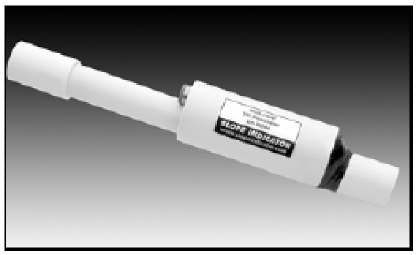


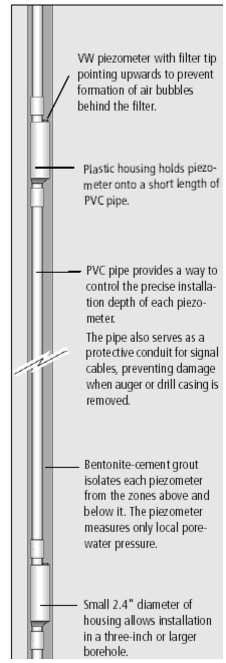
**4) Electric piezometer (Vibrating Wire)**

# Piezometer comparison

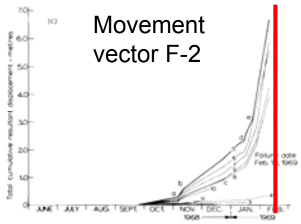
| | Standpipe | VW | Pneumatic |
|---|---|---|---|
| Range | Depth of standpipe | 50, 100, 250, 500 psi | 180 psi |
| Response Time* | Slow | Fast | Fast |
| Reading Time* | Minutes | Seconds | 5 minutes with 200 feet of tubing. Longer times with longer tubing. |
| Readout* | Water level indicator. Size and weight depend on reel capacity. | Portable readout. Lightest, smallest. | Portable readout. Large and heavy because of internal tank. |
| Remote Access* | No. Reading is obtained at top of standpipe. | Yes. Signal cable can be run to remote readout station. | Yes. Tubing can be run to remote read-out station |
| DataLog* | No | Yes | No |
| Main Advantages | Simplicity. Nothing to go wrong. | Easy to read. Simple grout-in installation. Remote access. | Remote access. Not affect by electri-cal transients. |
| Main Limitations | No remote access. | Long horizontal runs of cable should be protected from elec-trical transients. | Slow reading time |
| Main Cost of Installation | Borehole. Components are the least expensive of any type of piezo-meter. | Borehole. Components are more expensive than pneumatic or standpipe. | Borehole. Components are less expensive than VW piezometers. |

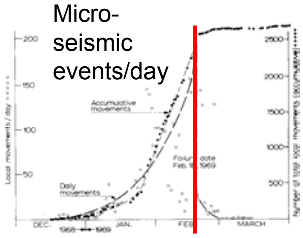
## Slope Indicator multi-point vibrating wire piezometer

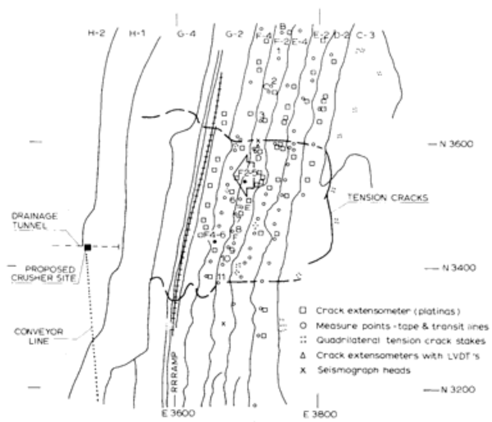


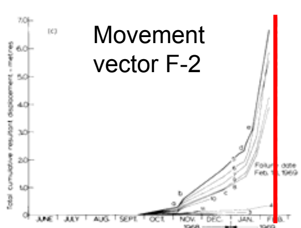

# Chuquicamata Mine, Chile, 1968

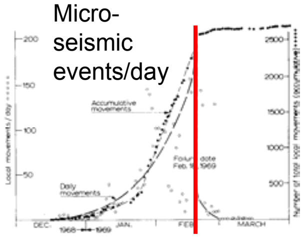


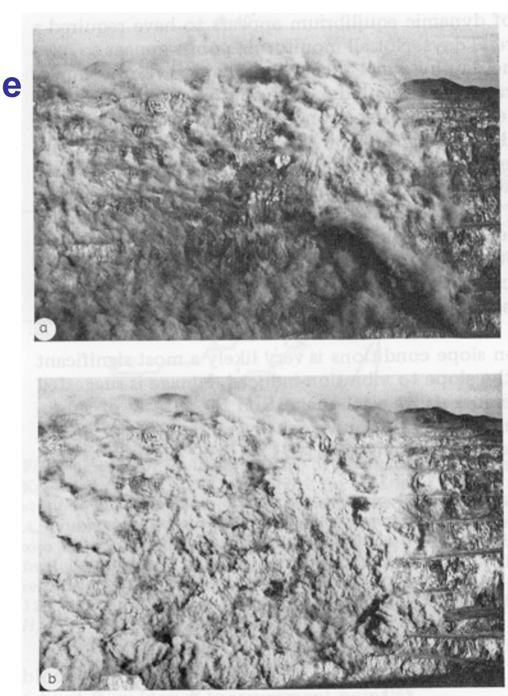



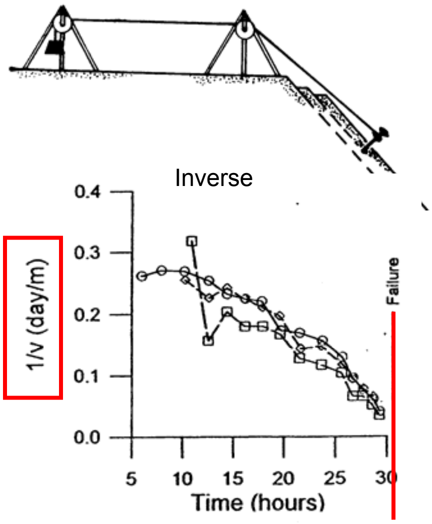

# Chuquicamata Mine

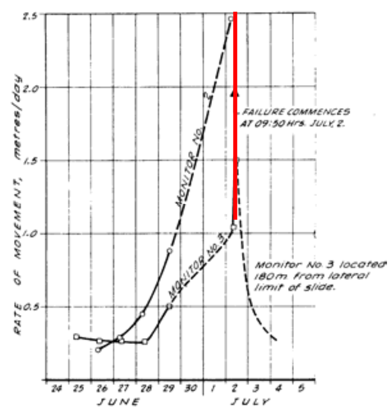


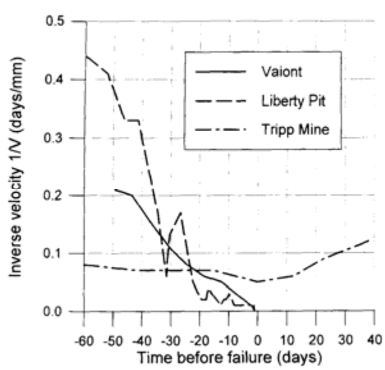



## Inverse Velocity Method (Fukuzono, 1985)

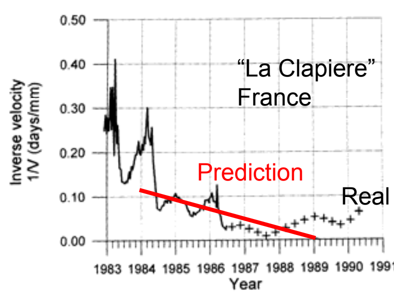


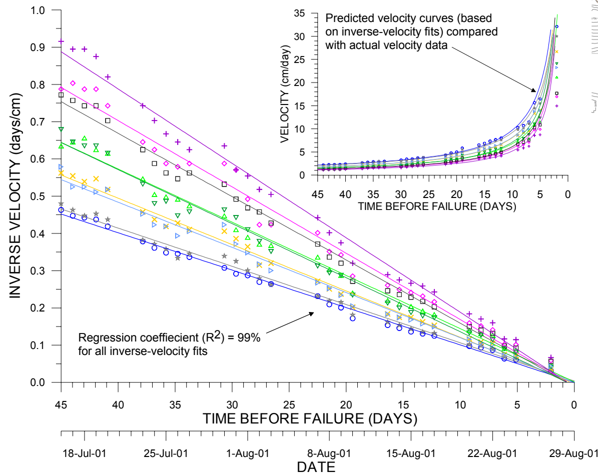

## Inverse Velocity Method, more examples

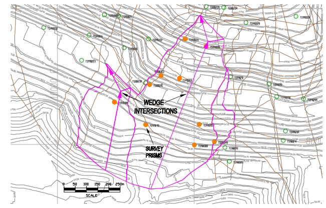



Tripp Mine: slow failure

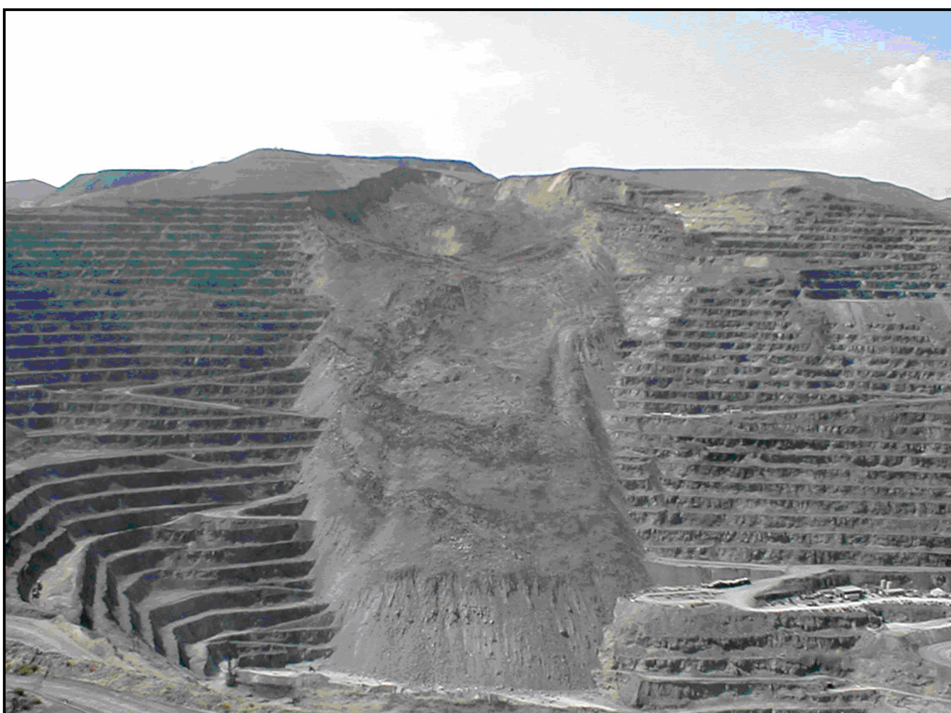



# Inverse Velocity Method, another example

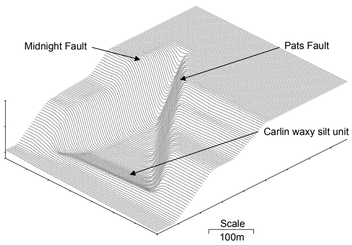


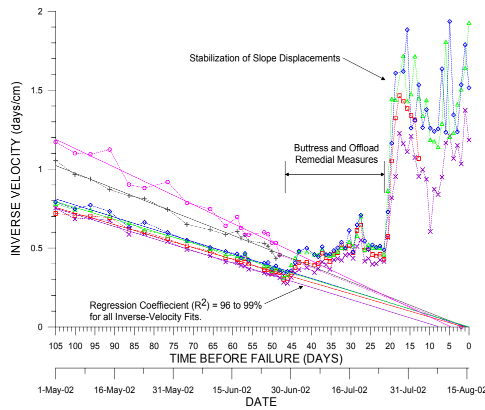
18 million $m^3$ pit slope failure prediction (Rose and Hungr, 2006)



## Use of inverse velocity to monitor stabilization progress (Rose and Hungr, 2006)

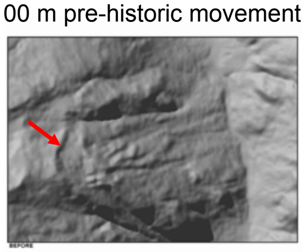


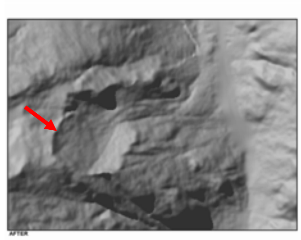

Two faults and a pre-sheared silt layer, 3 million $m^3$




## Total Displacement?

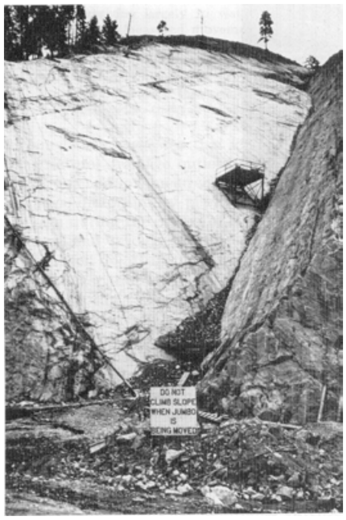
100 m pre-historic movement

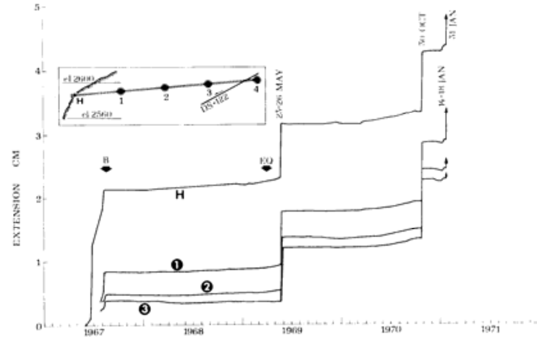



ValPola rock avalanche, 1986

# Small rock slides



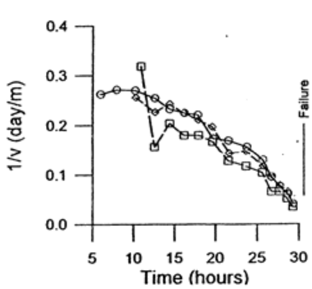




**Libby Dam, Montana, 1971**

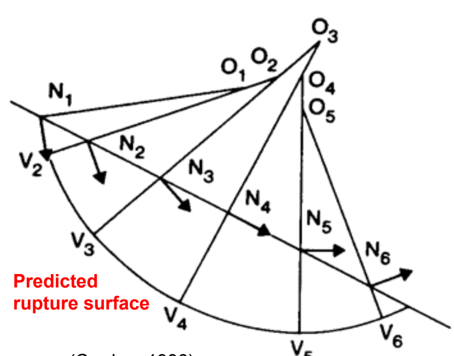
**Prediction not feasible**

# Purpose of monitoring

**1) Movement detection, failure prediction**




**2) Vector solutions, interpretation of failure mechanism**




(Cruden, 1986)