Monitored Natural Attenuation at a Municipal Solid Waste Landfill Near Sulphide Bearing Mine Tailings

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Introduction

- Case History
  - Five Year Hydrogeology Review
- Evaluation of Sub-Surface Conditions
  - Water level and temperature monitoring
  - Biogeochemical cycling
    - Biogenic gases
  - Sampling and analytical limitations
    - Sulphide, arsenic, dissolved oxygen

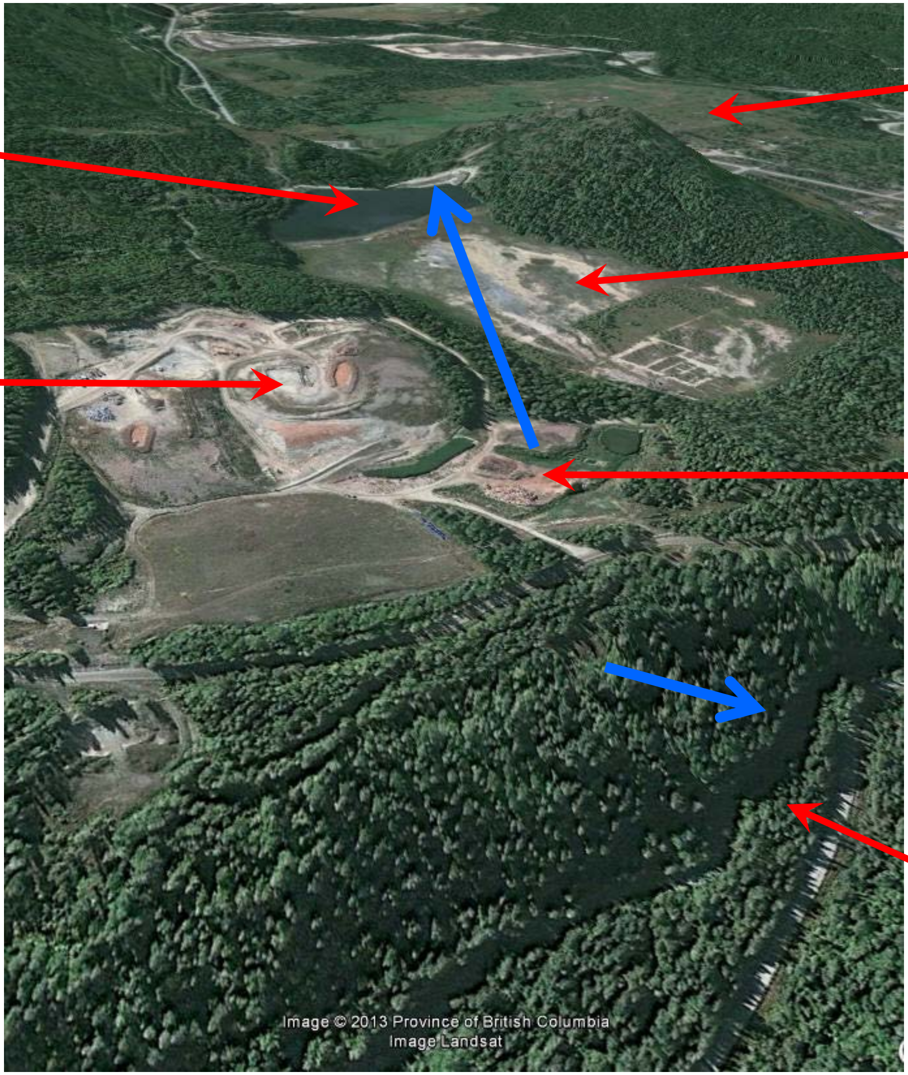
Site Location and History

- Landfill operated by the Regional District
  - Municipal Solid Waste
  - Septage (1,000 m^3/year)
  - Serves approximately 100,000 people
  - Started in 1983
  - First hydrogeology study in 1999
- Mine
  - Operated from 1912 to 1978
  - Pb, Zn, Ag, Cd, Au, and talc
  - 30 hectares (over 70 acres) of tailings

Oblique View of Site

Tailings Pond and Dam

Landfill



Valley Bottom

Tailings

Septage

Creek and Road

Hydrogeology

- Generally coarse grained sediments over bedrock
  - Up to 18 m of sand and gravel
  - Bedrock (phyllite, or metasediment)
- Depth to groundwater varies
  - Above ground surface (i.e. artesian well)
  - Maximum DTW of about 19 m below grade
- Previous interpretations assumed unfractured bedrock with all groundwater flow being through sand and gravel

Chloride

- Total ion concentrations in groundwater are low
- Minor amounts of chloride in groundwater

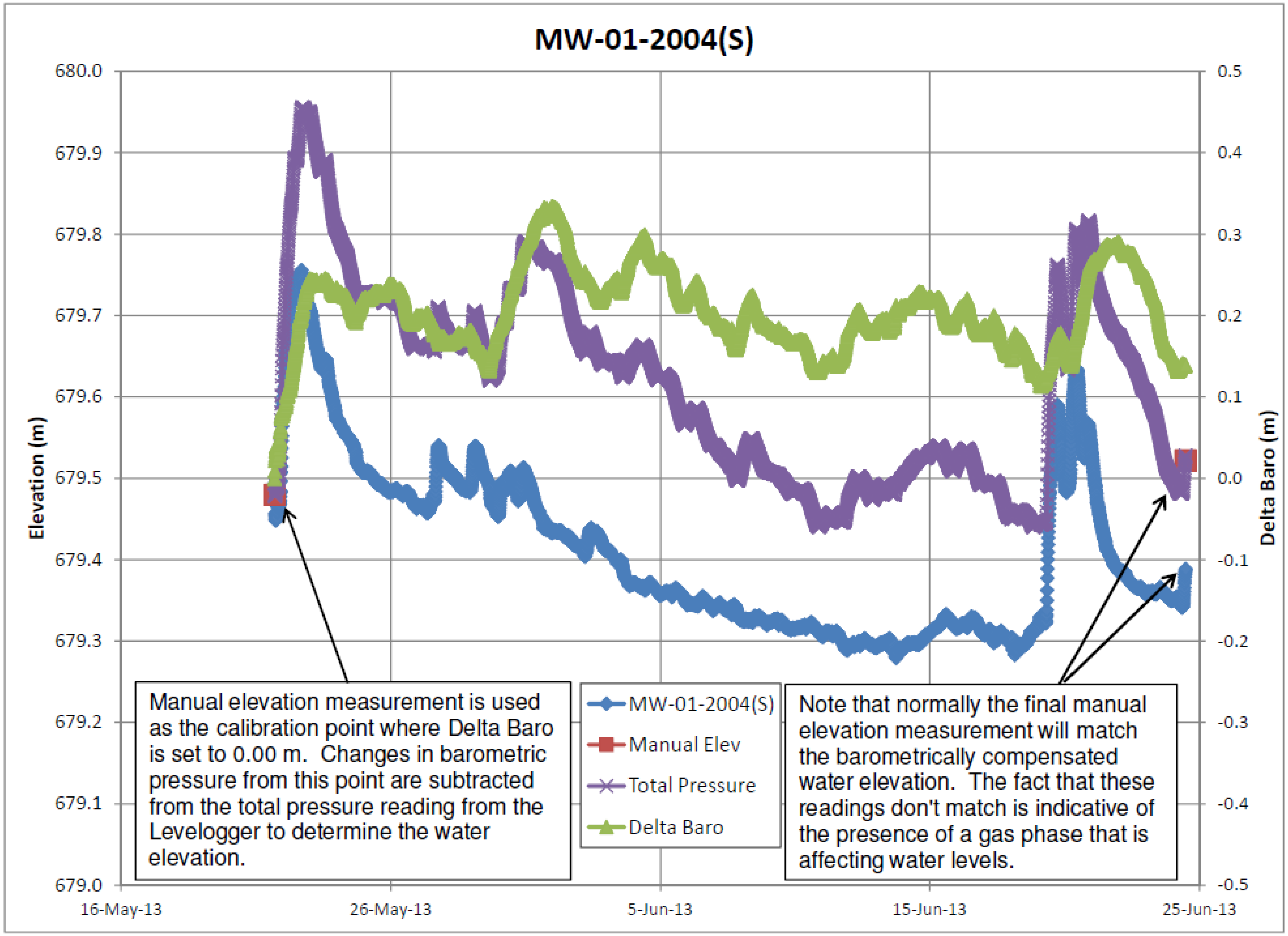
  - Chloride is normally considered a conservative tracer
    - Moves at speed of groundwater flow and is unaffected by biological or chemical reactions
  - Historically, contaminant hydrogeologists and landfill engineers have viewed this as an iron clad assumption

    No chloride = No leachate = No problem
  - More recently, this assumption has been called into question
    - Landfill gas can affect groundwater without chloride
    - Korom and Seaman, *When Conservative Anionic Tracers Aren't*, Groundwater, Nov/Dec 2012

Water Level Monitoring

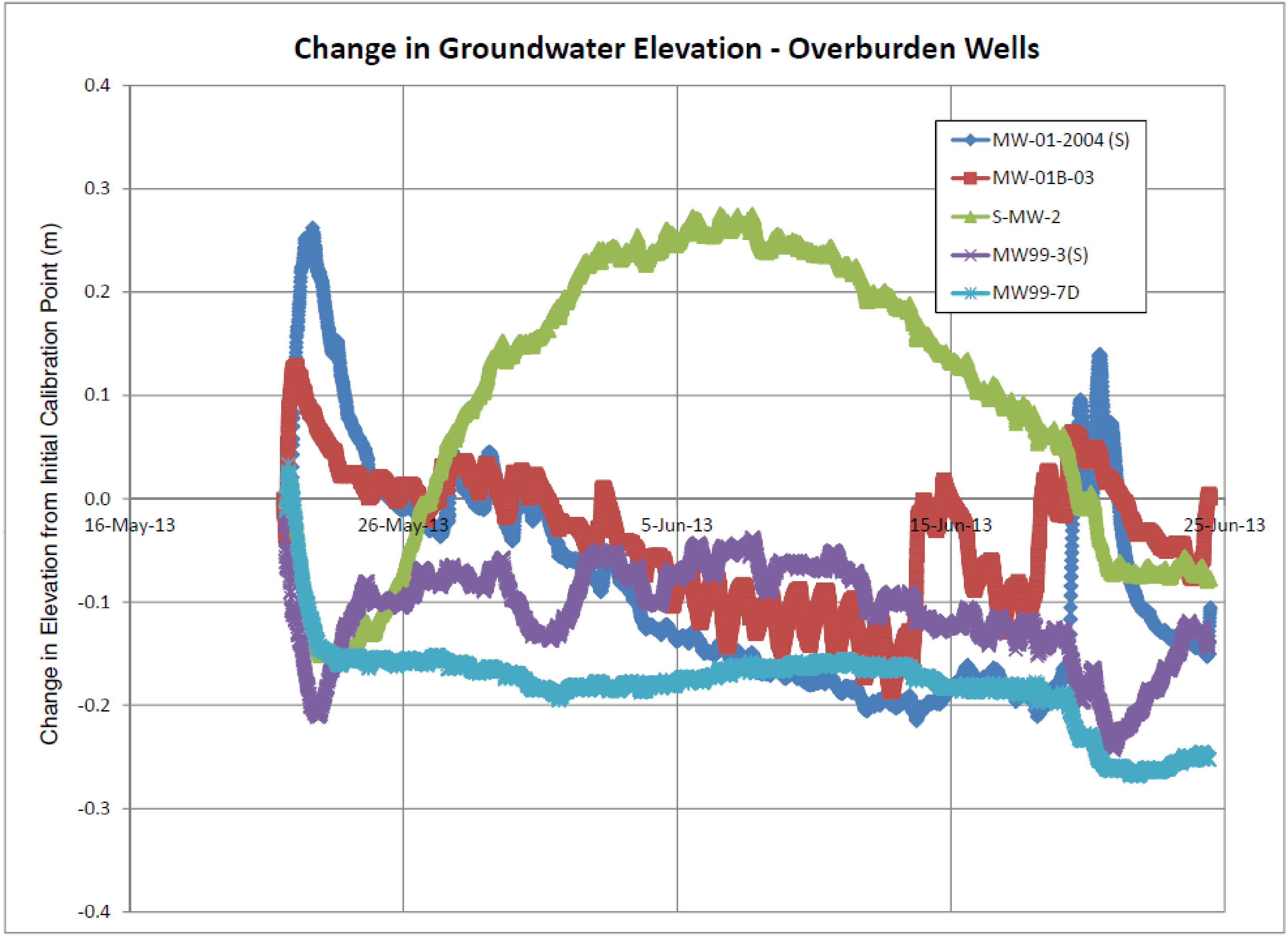
- Monitor water level changes to evaluate potential hydraulic connections between monitoring wells
  - Barometric pumping
  - Like a groundwater pumping test
  - Easiest way to evaluate wells completed in fractured bedrock
- Data loggers measure:
  - Time
  - Temperature
  - Total Pressure
- Manual DTW measurements to scale response to elevation
- Compensate for fluctuations in barometric pressure
- These graphs show about 40 days of data at 10 minute intervals

Data Logger Barometric Compensation

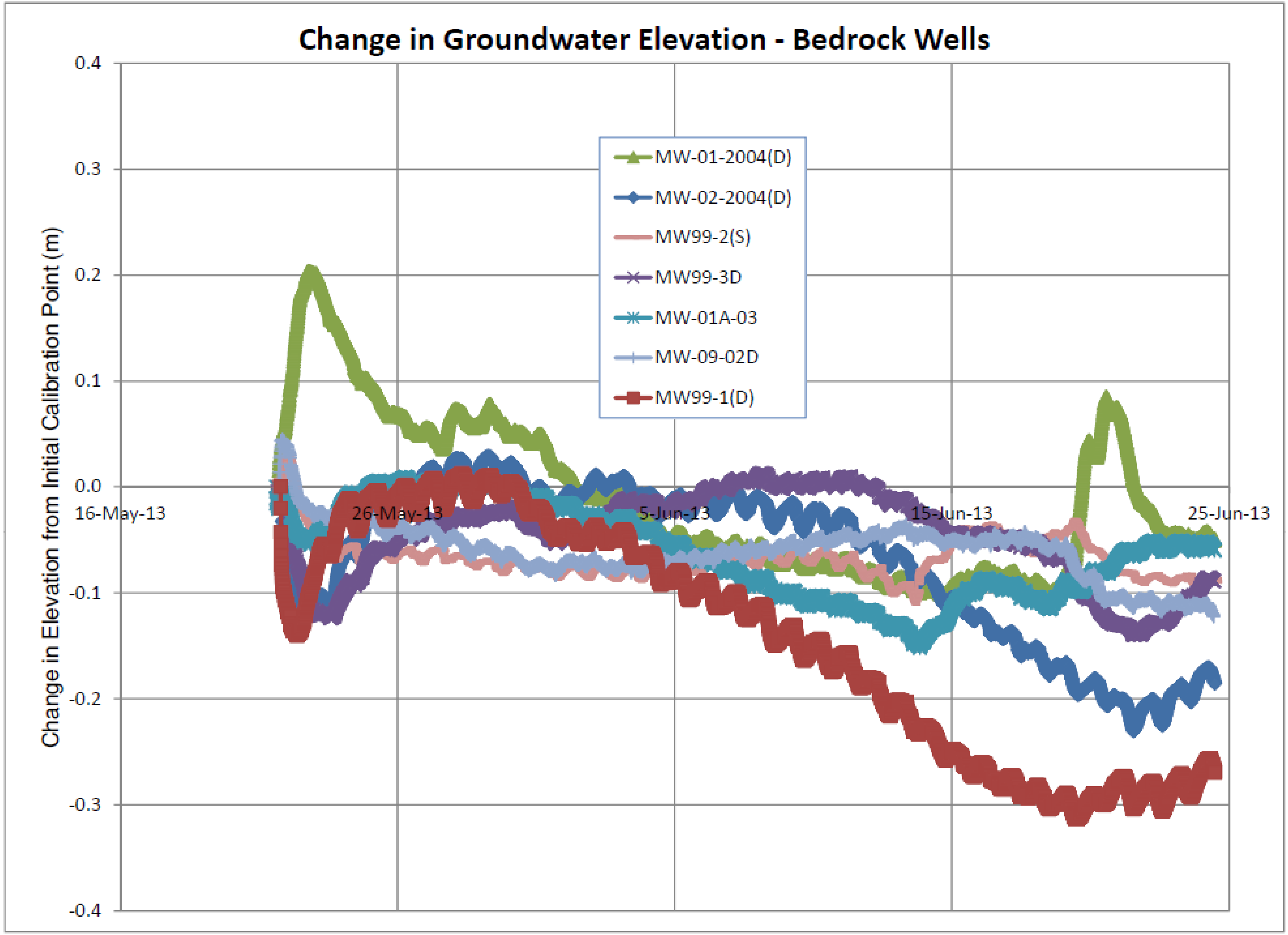


Difference in before and after manual readings versus barometrically compensated logger readings is considered indicative of a gas phase present in the groundwater.

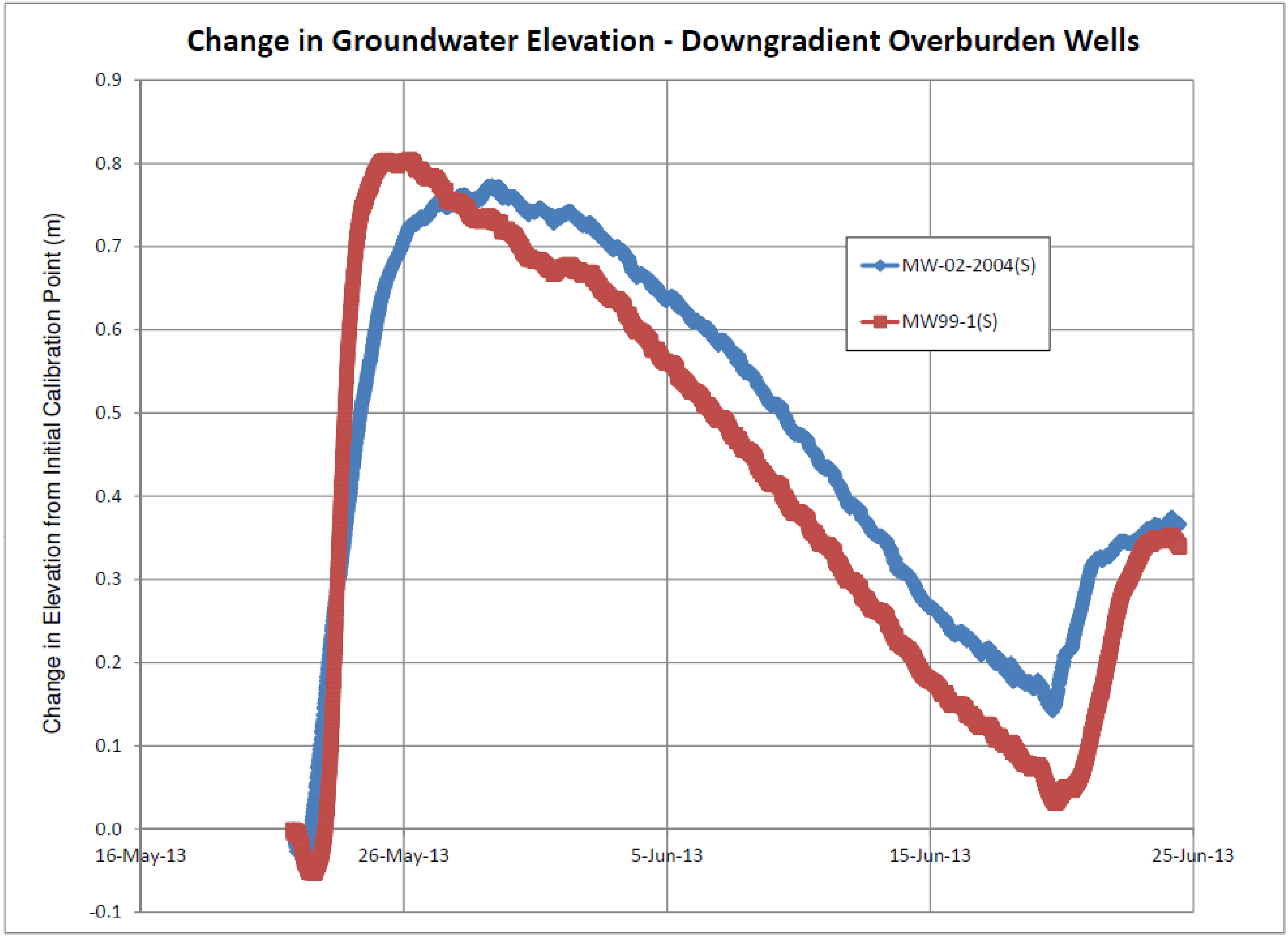
Change in Water Elevation - Overburden



Change in Water Elevation - Bedrock



Change in Water Elevation – Downgradient Bedrock Wells



Water Level Data

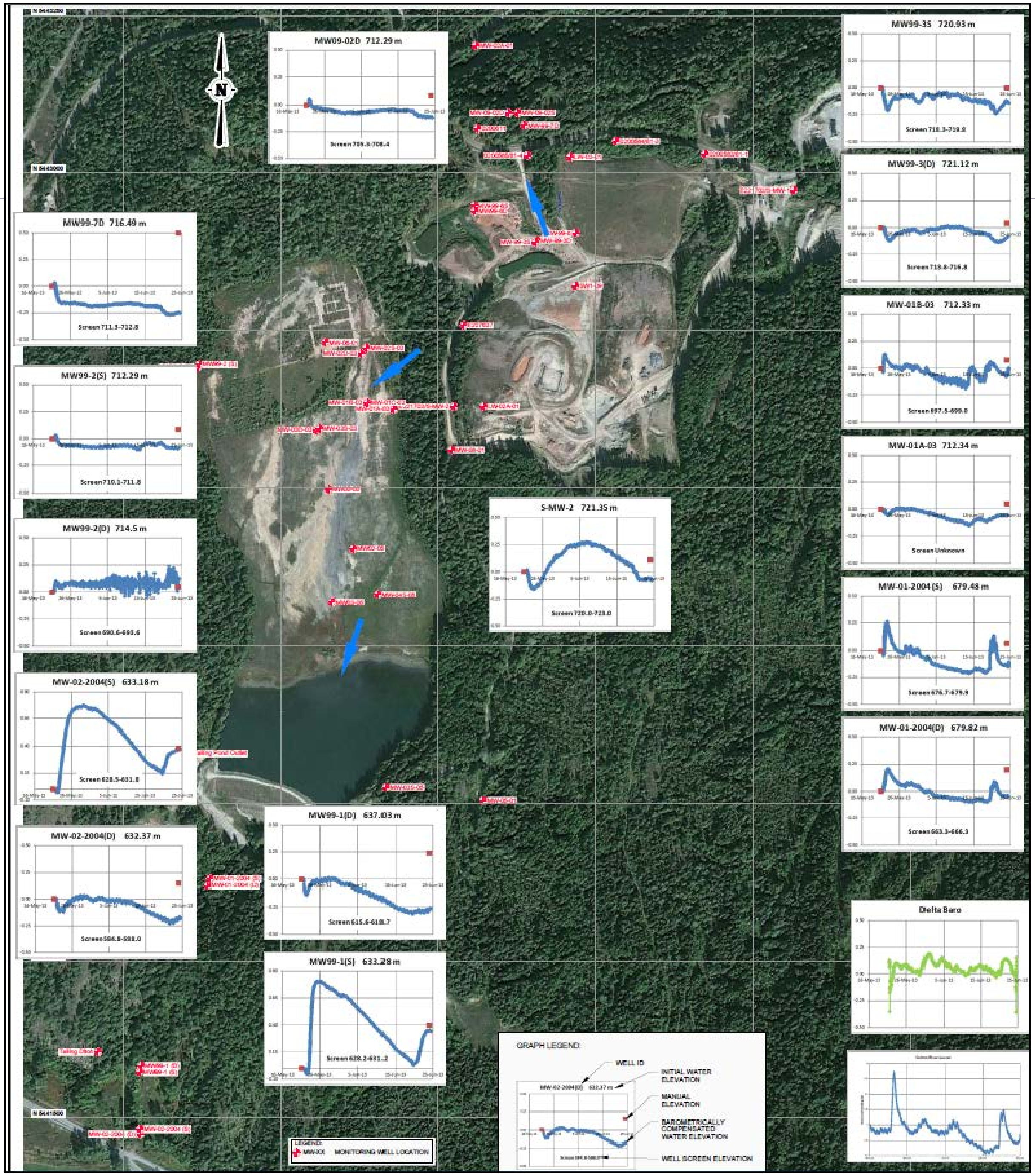
Large variation in water level responses.

Final manual DTW differed from barometrically compensated logger reading at most locations.

Two major storm events over this timeframe.

River elevation changes shown in lower right corner.

Horizontal grid 10 days. Vertical grid 0.25 m.



Summary of Water Level Observations

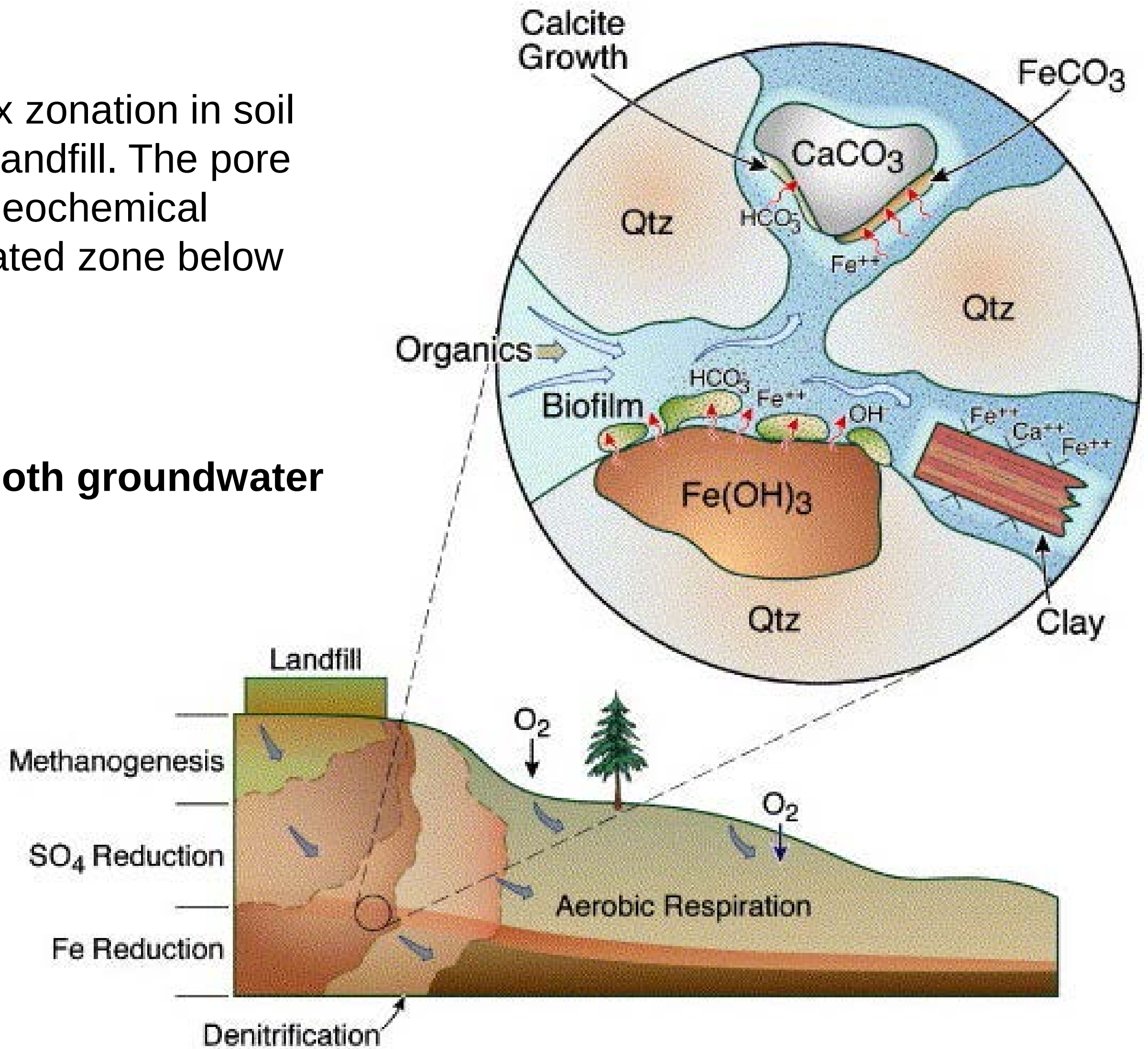
- Variety of water level responses
  - Logger readings calibrated to initial manual DTW reading
  - Difference between compensated logger reading and final DTW indicative of a separate gas phase below the water table
    - Dissolved gases don't affect water levels
    - Presence of bubbles in an aquifer can affect water levels
      - Bubbles can form when total dissolved gas pressure exceeds confining pressure
- Storm events had large changes in barometric pressure
  - Drop in confining pressure resulted in discharge of gas from aquifer
  - Most wells were under suction when J-plug was removed
- Gas phase in groundwater is starting to be acknowledged as an issue that hydrogeologists have historically ignored
  - Groundwater, July/August 2013
    - Focus on the Deep Subsurface and Gas in Groundwater

Landfill Redox Zonation

Schematic illustration of redox zonation in soil gas and groundwater near a landfill. The pore scale close-up illustrates biogeochemical processes active in the saturated zone below the water table.

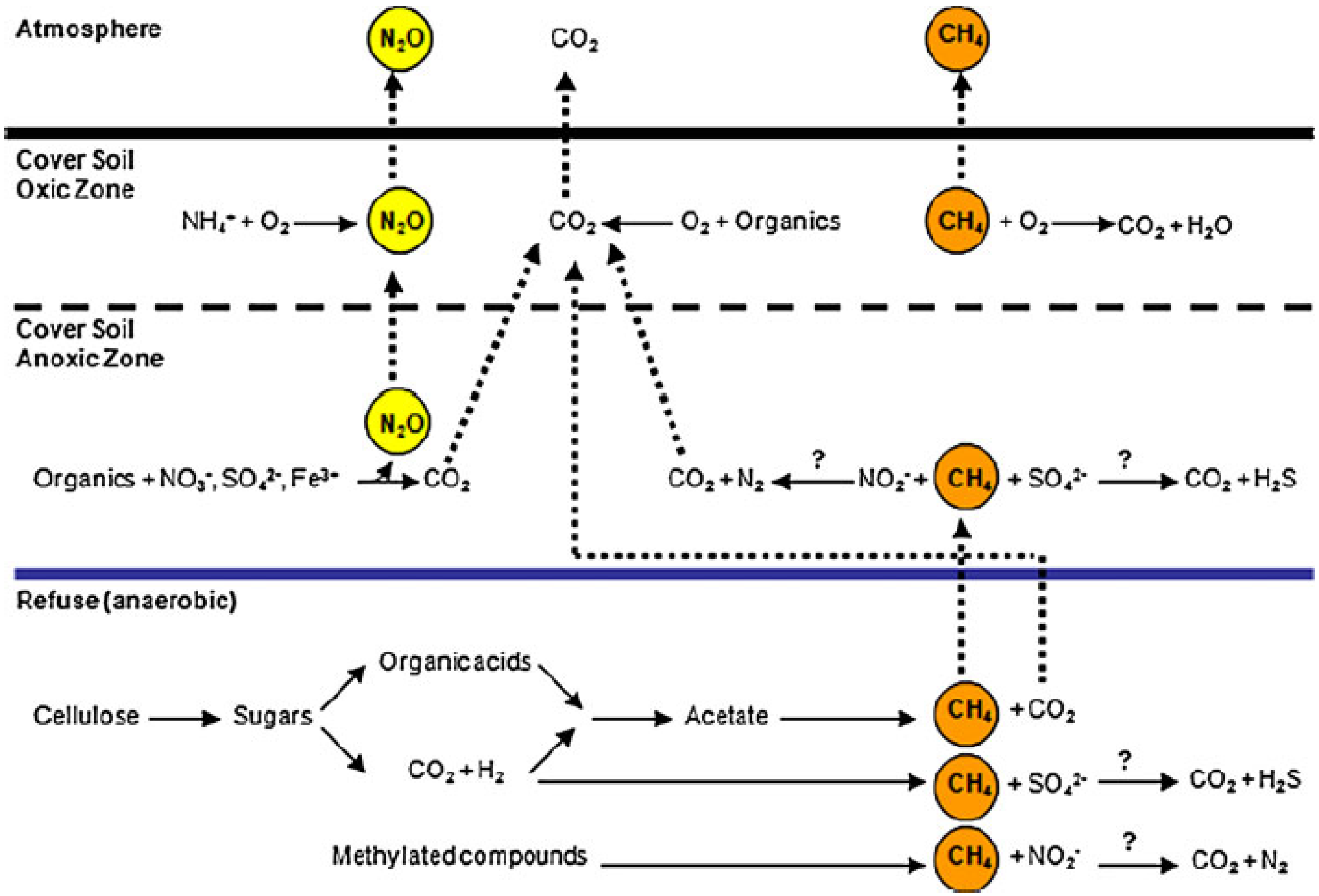
From C.I. Steefel, et al. (2005).

Redox zonation occurs in both groundwater and soil gas.



Landfill Gases (Biogenic Gases)

General pathways of methane, carbon dioxide, nitrous oxide, and nitrogen gas production and consumption in landfills. From Semrau, J.D. (2011).

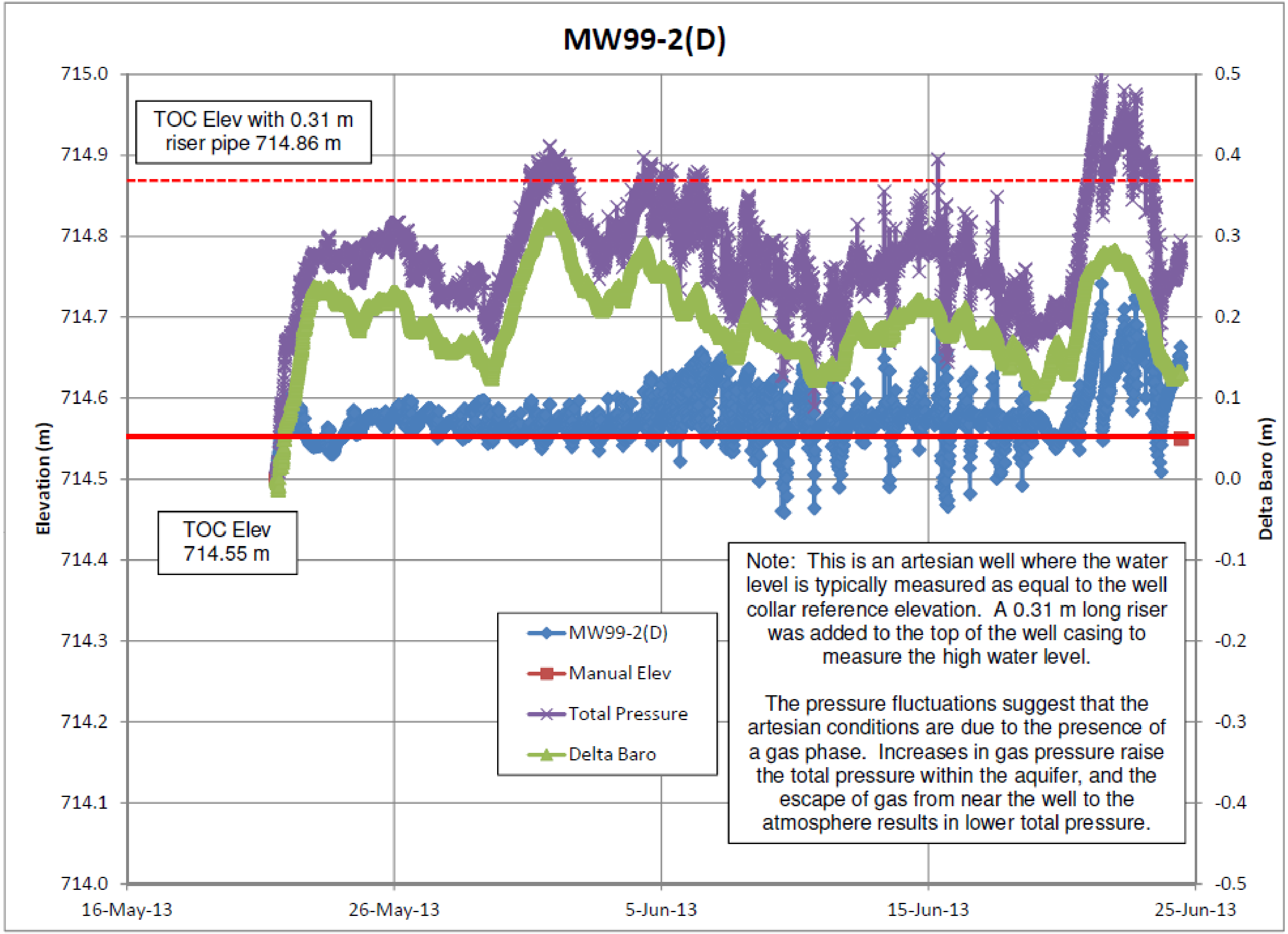


Gas Water Partitioning (Henry's Law)

Biogenic Gas		Henry's Law Constant L*atm/mol
Nitrogen Gas	N_2	1540
Methane	CH_4	770
Oxygen	O_2	770
Nitrous Oxide	NO_2	42
Carbon Dioxide	CO_2	29
Hydrogen Sulphide	H_2S	10

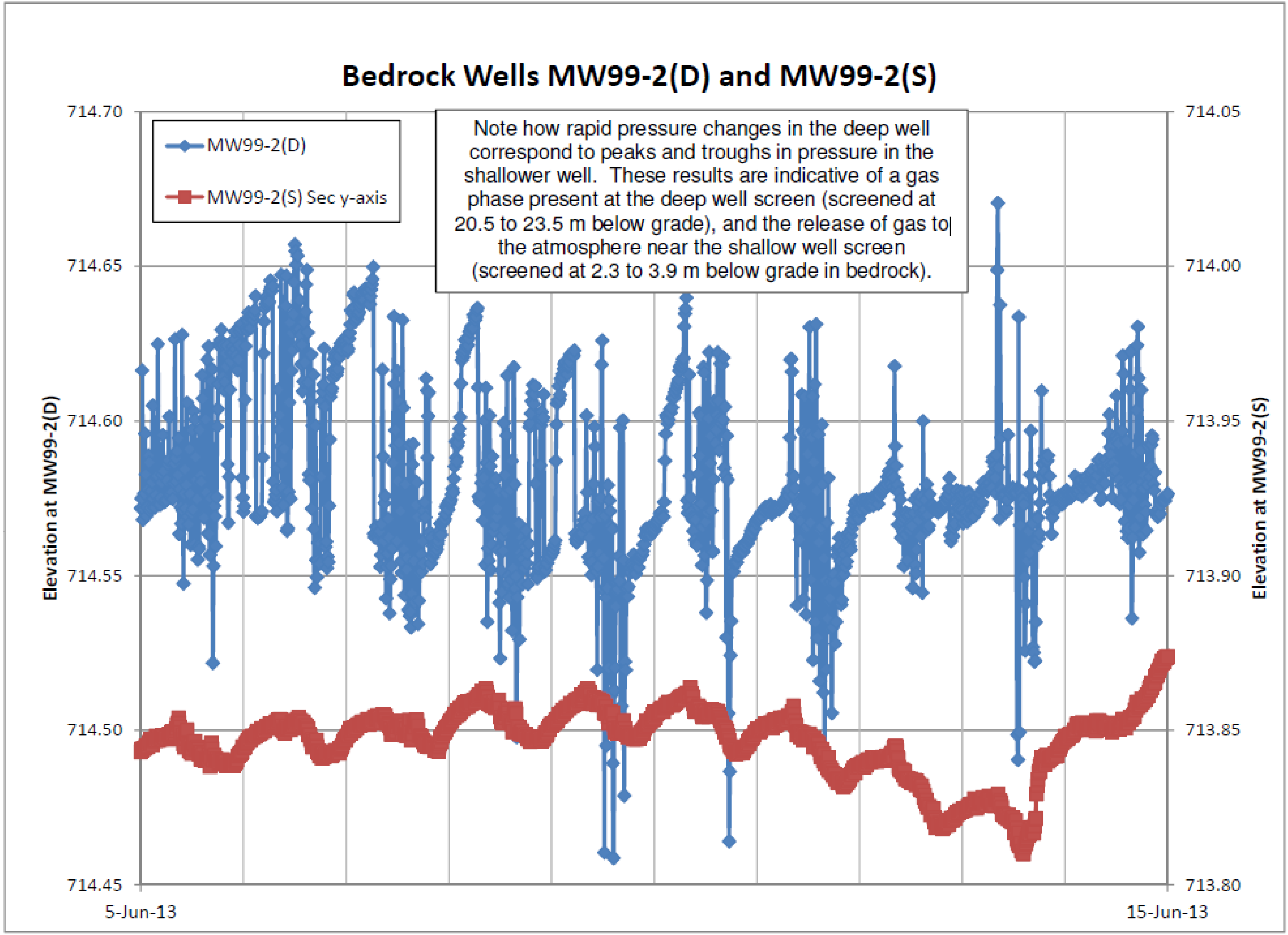
- Formation of N_2 creates high gas partial pressures
- Gas bubbles can form when total gas pressure > confining pressure
- Separate gas phase contributes to total pressure in aquifer

Artesian Well

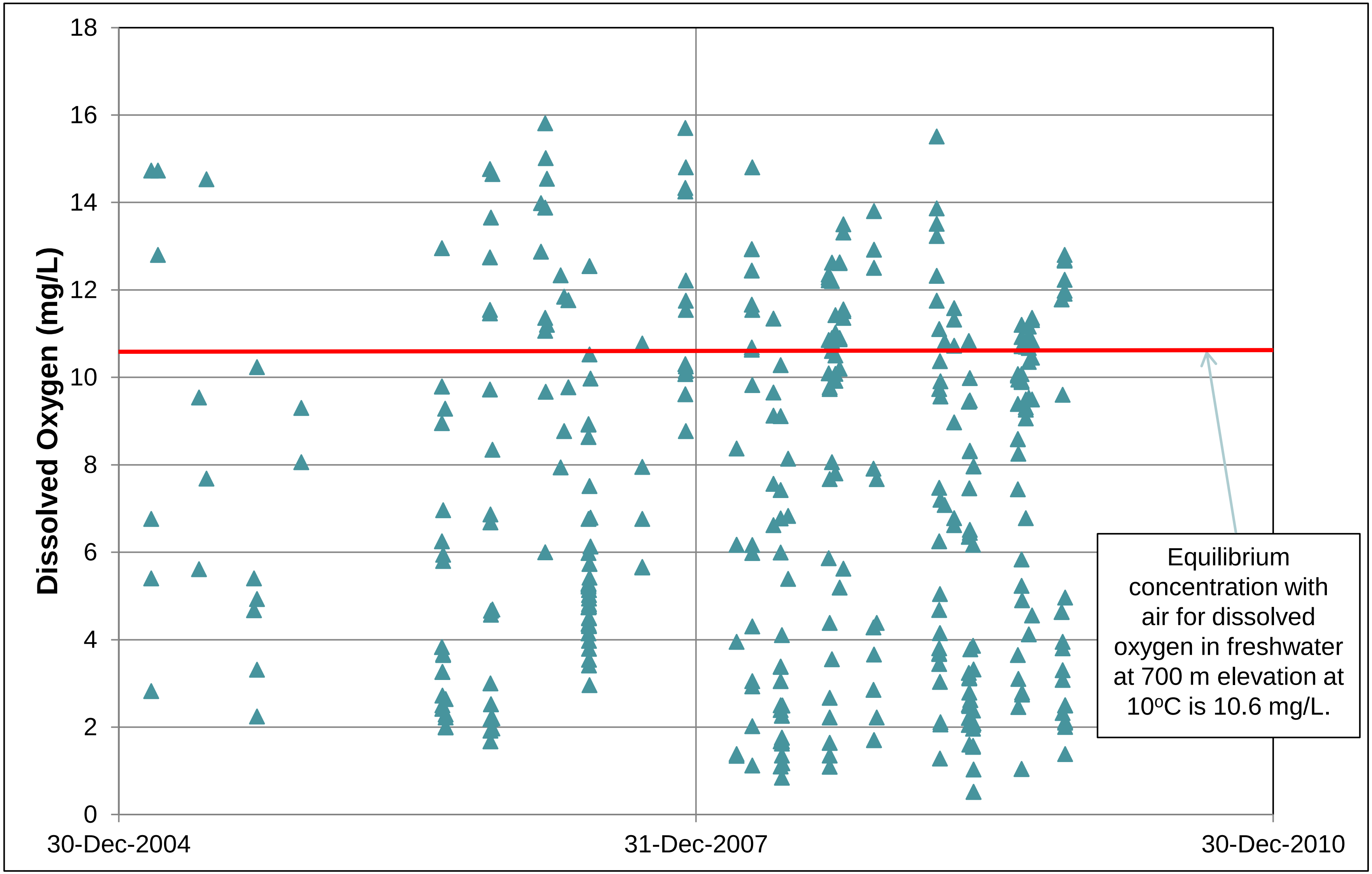


Artesian conditions (i.e. water level above ground surface) due to combination of physical setting and gas pressure.

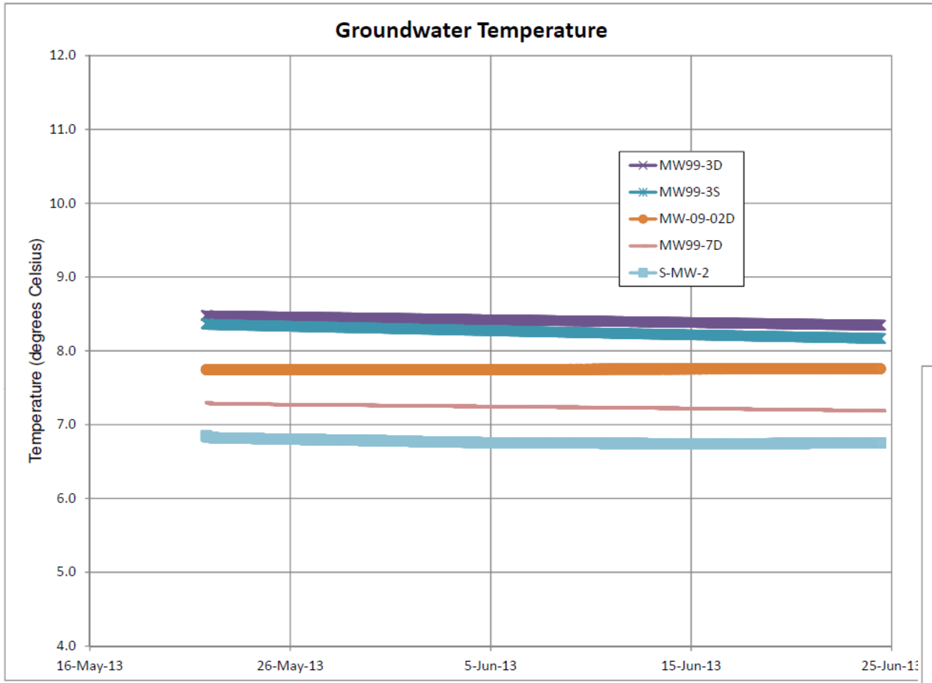
Artesian Well



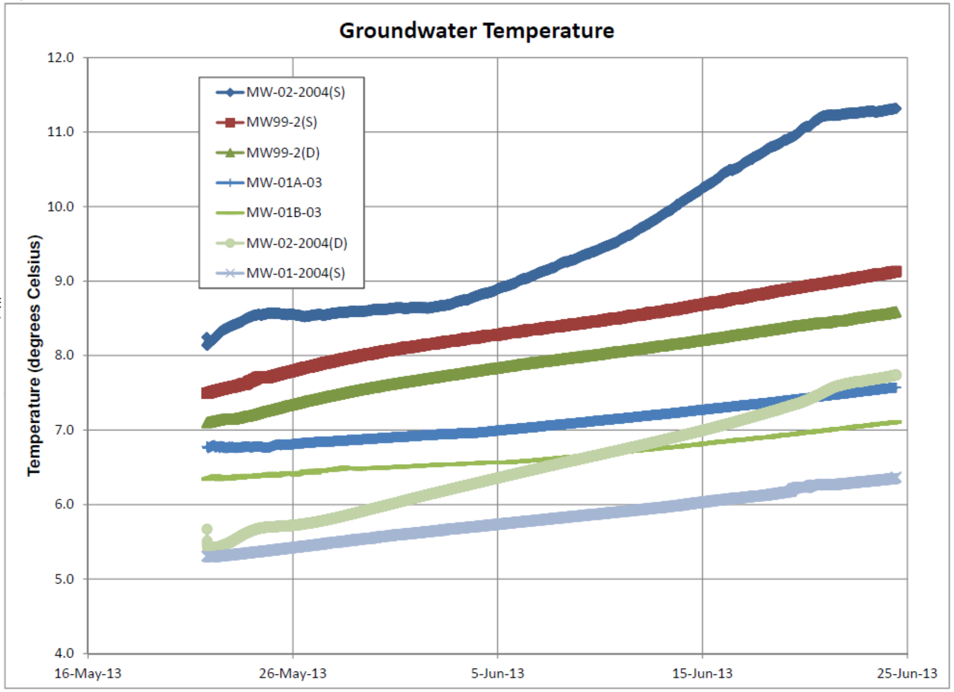
Dissolved Oxygen Readings



Temperature



Groundwater temperature is typically average ambient temperature



Wells downgradient of tailings increased by up to 3 degrees

Sulphide oxidation?

Sulphide and Arsenic

- Dissolved metals
  - Acidify with Nitric Acid
- When sulphide is present in water, most metals will precipitate at neutral pH as metal sulphides
  - Not arsenic
- Arsenic can precipitate from solution when nitric acid is added to sulphide rich water (Smieja & Wilkin, 2003)
- Collect and analyze unacidified metals samples to determine in-situ arsenic concentration when sulphide is present

Table 1 Final dissolved arsenic and sulfide concentrations (ppm) after treatment with HNO_3

H_2S	As(III)[a]	H_2S	As(III)[b]	H_2S	As(III)[c]
0	0.358 ± 0.011	0	1.94 ± 0.03	0	10.06 ± 0.02
0.28 ± 0.21	0.348 ± 0.010	0.50 ± 0.01	1.78 ± 0.01	0.23 ± 0.01	7.05 ± 0.04
1.18 ± 0.09	0.299 ± 0.002	1.04 ± 0.07	0.70 ± 0.03	0.33 ± 0.13	3.70 ± 0.05
2.52 ± 0.03	0.145 ± 0.006	3.1 ± 0.23	0.140 ± 0.004	2.20 ± 0.15	0.28 ± 0.02
4.67 ± 0.00	0.027 ± 0.001	6.44 ± 0.07	0.063 ± 0.006	9.09 ± 0.33	0.093 ± 0.005
10.74 ± 0.08	0.011 ± 0.001	13.00 ± 0.38	0.051 ± 0.016	17.45 ± 0.18	0.073 ± 0.002

The reported uncertainty is one standard deviation of replicate measurements.[a]Initial As(III) concentration = 0.35 ppm. [b]Initial As(III) concentration = 2.0 ppm [c]Initial As(III) concentration = 10.0 ppm

Follow Up Sampling Interpretation

- No sulphide present
  - Consistent with presence of dissolved oxygen
  - Reported arsenic results are correct
- Why did the temperature downgradient of tailings increase?
  - Exothermic chemical reaction
  - Organic acids present
    - Comparing Total Alkalinity versus Total Inorganic Carbon and Total Organic Carbon
- Possibly due to Serpentinization of bedrock
  - Low temperature, low pressure (retrograde metamorphosis)
- Could explain temperature increase and large extent of gas phase noted during water level monitoring
- Serpentinization as the explanation is just a hypothesis

Conclusions

- Landfills should be evaluated on more than just chloride and a few other indicator parameters
  - Landfill Gas
  - Landfill Leachate
- Water level monitoring is an effective way to evaluate hydraulic connections between wells
  - Barometric pumping
  - Better understanding of aquifer and flowpaths
- Presence of a gas phase can be identified using water levels in some situations
  - Biogenic gases
- Temperature increase is not due to sulphide oxidation
  - Possibly a regional scale metamorphic process