A Plausible Explanation for Common Fractal Temporal-Spectral Slopes of Drainage Flows and Chemistries at Full-Scale Mining Operations

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Two Helpful Quotations about the Earth and Electricity

- "It has been known for over two centuries that the solid and liquid Earth and its atmosphere are almost permanently electrified." (National Research Council, 1986)

- "EMFs (electrical and magnetic fields) are all around us, occurring naturally in every atom of matter. The surface of the Earth is covered with a natural electric field, created by electrical charges in the upper atmosphere. Similarly, a powerful electric field is required to keep the cells of living organisms alive." (Hydro Québec, 2011)

A Minesite Has Many Components

A minesite is often composed of one or more large-scale open-system components like: open pits.

A Minesite Has Many Components

A minesite is often composed of one or more large-scale open-system components like: underground workings.

A Minesite Has Many Components

A minesite is often composed of one or more large-scale open-system components like: waste-rock piles and ore stockpiles.

A Minesite Has Many Components

A minesite is often composed of one or more large-scale open-system components like: tailings impoundments.

Objectives

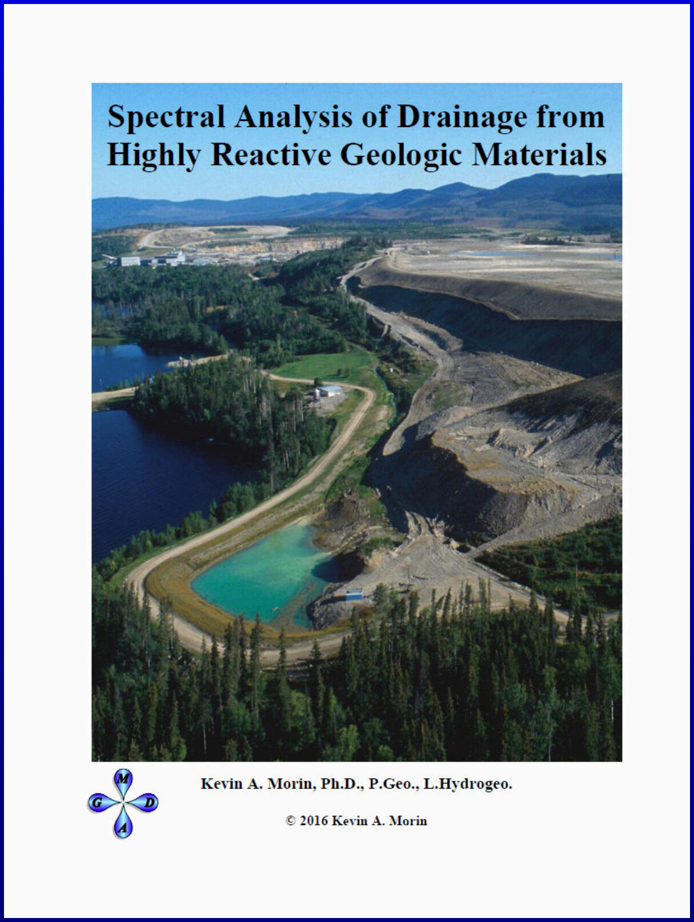
- To answer two questions.
  - *1) What mechanisms and processes can introduce periodicity into minesite-drainage chemistry and flow? In other words, why do flow and chemistry "pulsate" at many wavelengths? This effect can be more "ubiquitous" in non-mining catchments (J.W. Kirchner, ETH Zürich).*
  - *2) How do these mechanisms apparently "self organize" so that their amplitudes and spectral powers generally decrease with decreasing wavelength, often forming fractal spectral slopes? This includes the very common yet mysterious "1-over-f" with a spectral fractal slope of 1.0, which should not appear and should not persist according to mathematics.*

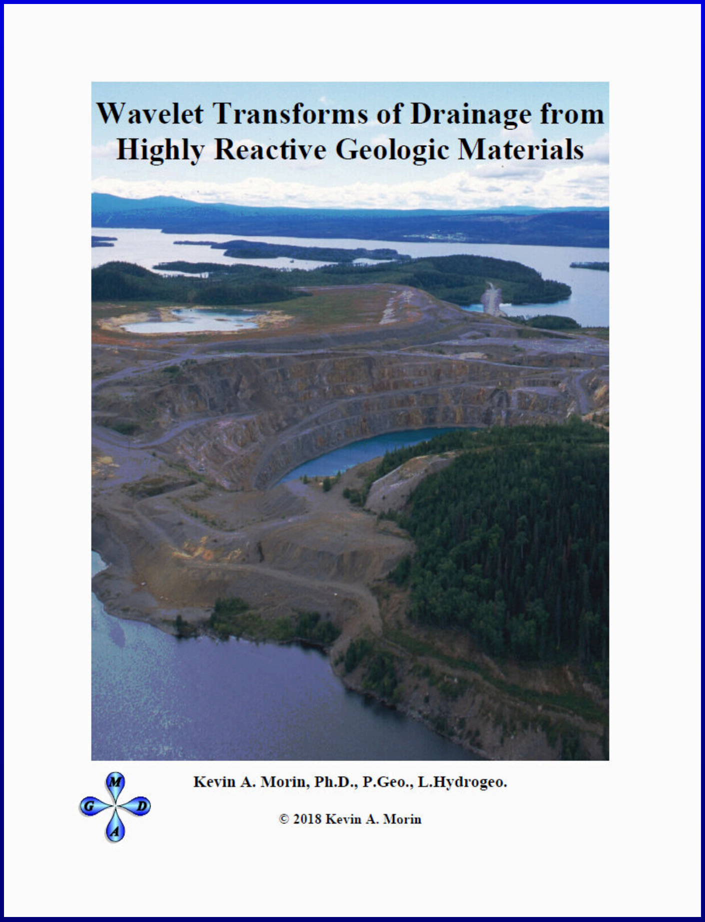
Free MDAG Books on Periodicity, Spectral Analysis, and Wavelet Transforms

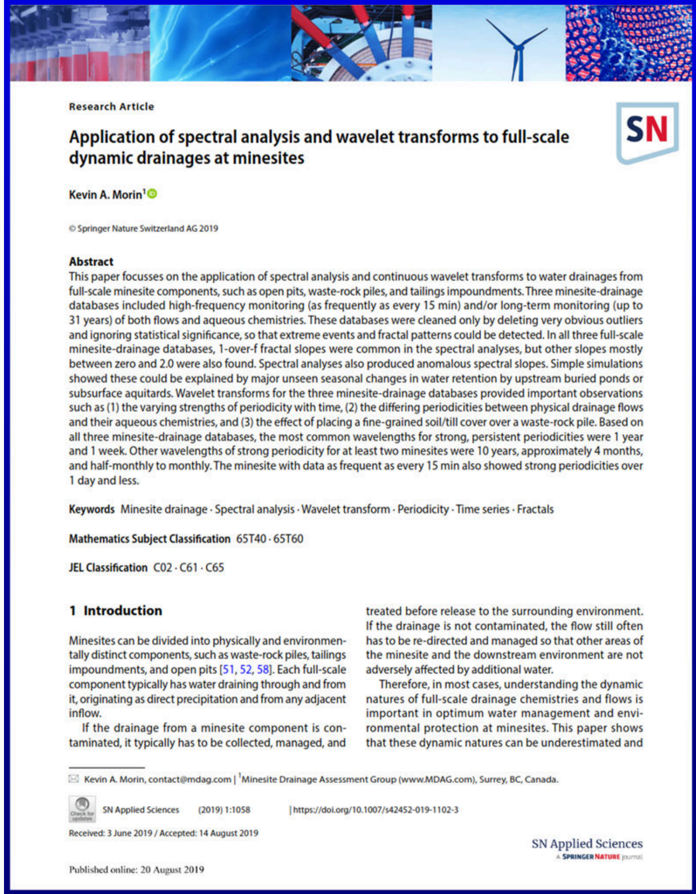
What you are about to hear is based on the books and related publications below and on case studies like:

Morin, K.A. 2020. MDAG-com Case Study 64 - Minesite components as large physical analogues of first-order low-pass signal filters, explaining 1-over-f and other fractal spectral slopes for flows and chemistries. MDAG Internet Case Study #64, www.mdag.com/case_studies.html.

Morin, K.A. 2019. Application of Spectral Analysis and Wavelet Transforms to Full-Scale Dynamic Drainages at Minesites. Springer Nature (SN) Applied Sciences 1:1058, published online August 2019. DOI: 10.1007/s42452-019-1102-3







Research Article

Application of spectral analysis and wavelet transforms to full-scale dynamic drainages at minesites

Kevin A. Morin[1]

Abstract
This paper focusses on the application of spectral analysis and continuous wavelet transforms to water drainages from full-scale minesite components, such as open pits, waste-rock piles, and tailings impoundments. Three minesite-drainage databases included high-frequency monitoring (as frequently as every 15 min) and/or long-term monitoring (up to 31 years) of both flows and aqueous chemistries. These databases were cleaned only by deleting very obvious outliers and ignoring statistical significance, so that extreme events and fractal patterns could be detected. In all three full-scale minesite-drainage databases, 1-over-f fractal slopes were common in the spectral analyses, but other slopes mostly between zero and 2.0 were also found. Spectral analyses also produced anomalous spectral slopes. Simple simulations showed these could be explained by major unseen seasonal changes in water retention by upstream buried ponds or subsurface aquitards. Wavelet transforms for the three minesite-drainage databases provided important observations such as (1) the varying strengths of periodicity with time, (2) the differing periodicities between physical drainage flows and their aqueous chemistries, and (3) the effect of placing a fine-grained soil/till cover over a waste-rock pile. Based on all three minesite-drainage databases, the most common wavelengths for strong, persistent periodicities were 1 year and 1 week. Other wavelengths of strong periodicity for at least two minesites were 10 years, approximately 4 months, and half-monthly to monthly. The minesite with data as frequent as every 15 min also showed strong periodicities over 1 day and less.

Keywords Minesite drainage · Spectral analysis · Wavelet transform · Periodicity · Time series · Fractals

Mathematics Subject Classification 65T40 · 65T60

JEL Classification C02 · C61 · C65

1 Introduction

Minesites can be divided into physically and environmentally distinct components, such as waste-rock piles, tailings impoundments, and open pits [51, 52, 58]. Each full-scale component typically has water draining through and from it, originating as direct precipitation and from any adjacent inflow.

If the drainage from a minesite component is contaminated, it typically has to be collected, managed, and treated before release to the surrounding environment. If the drainage is not contaminated, the flow still often has to be re-directed and managed so that other areas of the minesite and the downstream environment are not adversely affected by additional water.

Therefore, in most cases, understanding the dynamic natures of full-scale drainage chemistries and flows is important in optimum water management and environmental protection at minesites. This paper shows that these dynamic natures can be underestimated and

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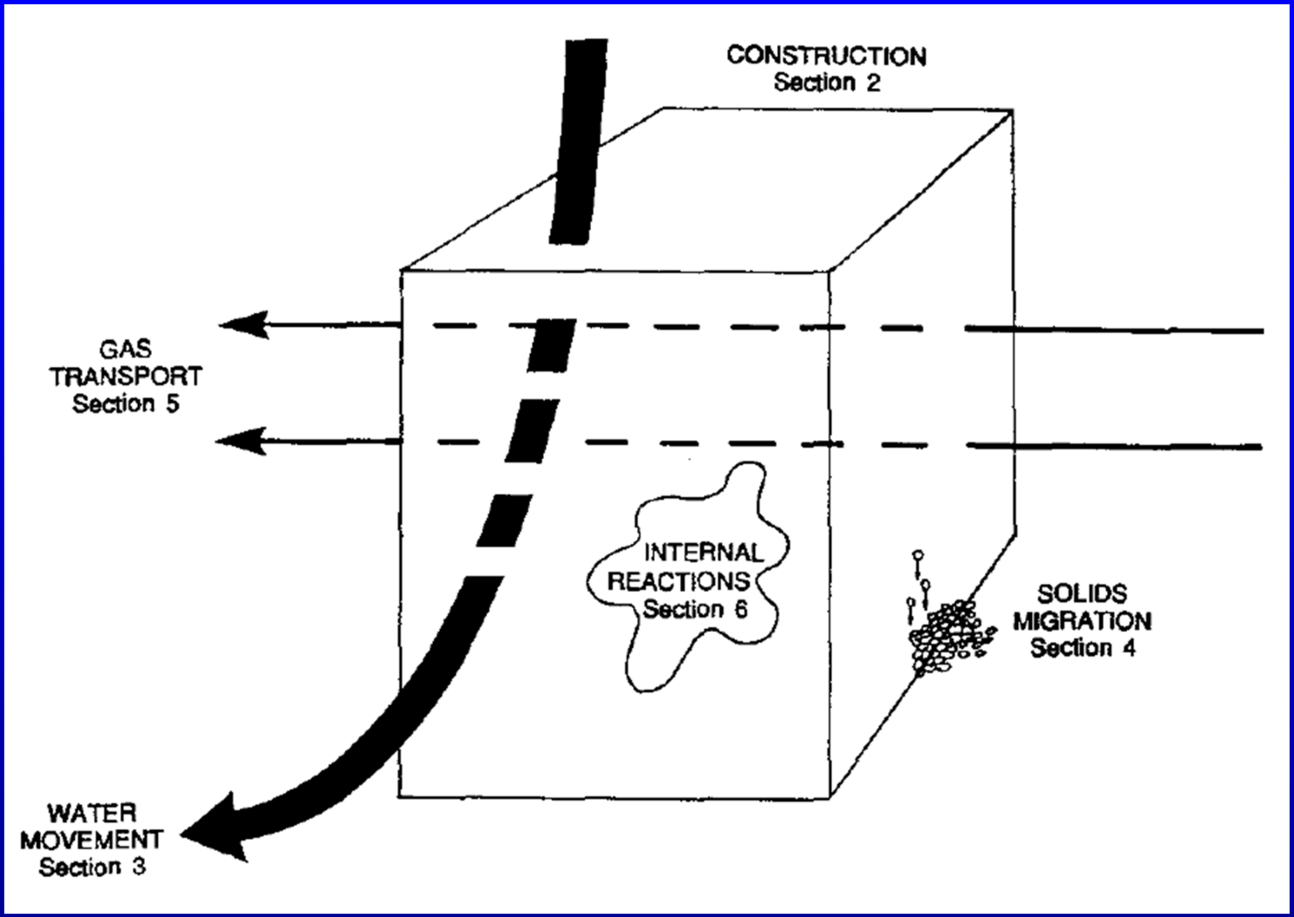
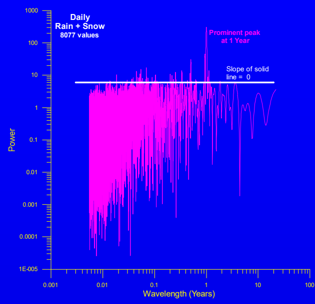
A Waste-Rock Pile, or Any Minesite Component, as a Simple Conceptual "Open" System



from Morin et al., 1991

Minesite components like waste-rock piles, tailings impoundments, and open pits are "open" environmental systems. They experience in inflow, transit, and then outflow ("drainage") of water, other mass like air and fine particles, and many forms of energy.

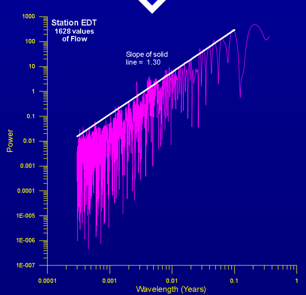
Signal Filters and Signal Generators



Spectral plot of Input

Minesite Component as a Signal Filter

Spectral plot of Output



At most minesites, the myriad physical, geochemical, and biological processes affecting drainage through time are not necessarily known.

Spectral analysis can help in this by looking at each minesite component as a *signal filter* and/or a *signal generator*.

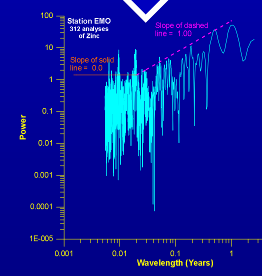
What Goes In ≠ What Comes Out

Therefore, the minesite component is changing the strengths of the periodicities ("pulsations") as water passes through.

No significant Input (e.g., Cu)

Minesite Component as a Signal Generator

Spectral plot of Output



The Energy Balance and Conservation for an Environmentally Open Minesite Component

$E_t = TS + Vp + \sum \mu_i N_i + q\varphi + m\Psi + \frac{1}{2} mv^2 + \ldots$ (Equation 2-2)

where:

- E_t = total energy, in joules
- V = volume, in $meter^3$
- p = pressure, in pascal ($joules/meter^3$)
- μ_i = chemical potential of the ith species, in joules/mole
- N_i = number of moles (particles) of the ith species, in moles
- φ = electrical potential in volts
- q = electrical charge, in coulombs
- Ψ = gravitation potential, in joules/kg
- m = mass, in kg
- v = velocity, in meter/second
- (note: positive and negative signs can sometimes shift with parameter and methodology)

- Other terms can be added to Equation 2-2, such as radiation and biological energy. Therefore, Equation 2-2 is not exhaustive and complete, but is a good example of Earth-System Science linking many aspects of the Earth into one interactive open system.

The Energy Balance and Conservation for an Environmentally Open Minesite Component

- When we are tracking a change in total energy ($dE_t \neq 0$) with time and/or distance, we can delete terms, or ignore terms, or consider certain terms constant in Equation 2-2 above. This leads to many common equations. For example:

- Gibbs Free Energy: $dE_t = Vdp - SdT + \sum \mu_i dN_i$ (Equation 2-3)

- Physical Movement of Subsurface Groundwater: $dE_t = Vdp + md\Psi$ (Equation 2-4), which reduces to:
  - $dh = d\upsilon + dz$
  - where:
  - h = hydraulic or piezometric head, in meters, measured as the elevation of groundwater level in a piezometer
  - υ = pressure head, in meters, measured as the height of the water column inside a piezometer
  - z = elevation, in meters, of the piezometer intake screen.

- Aqueous Geochemistry: $dE_t = \sum \mu_i dN_i$ (Equation 2-7)

- Electrochemistry: $dE_t = \sum \mu_i dN_i + qd\varphi$ (Equation 2-8)

Periodicity in One Energy Term, Like Electrical Potential, Can Cause Periodicity in Other Terms Like Flow and Aqueous Chemistry

- In our previous publications, major links of planetary electricity (including ground and atmosphere) were shown with aqueous chemistry and physical flow. These were related to periodicities in electrical fields due to principles in electrohydrodynamics, electrochemistry, thermogalvanic processes, etc.

- As a result, periodicity in any one term in Equation 2-2, such as in electrical potential, can create periodicity in one or more other terms like aqueous concentrations and flows.

General Energy Balance for an Environmentally Open Minesite Component

In January 2022, the EGU Blog GeoLog had an article discussing such large-scale linkages of open-system energies, “What if a tsunami’s magnetic field could predict the height of the wave?”

Thus, the variation in one form of earth energy can cause variations in other forms.

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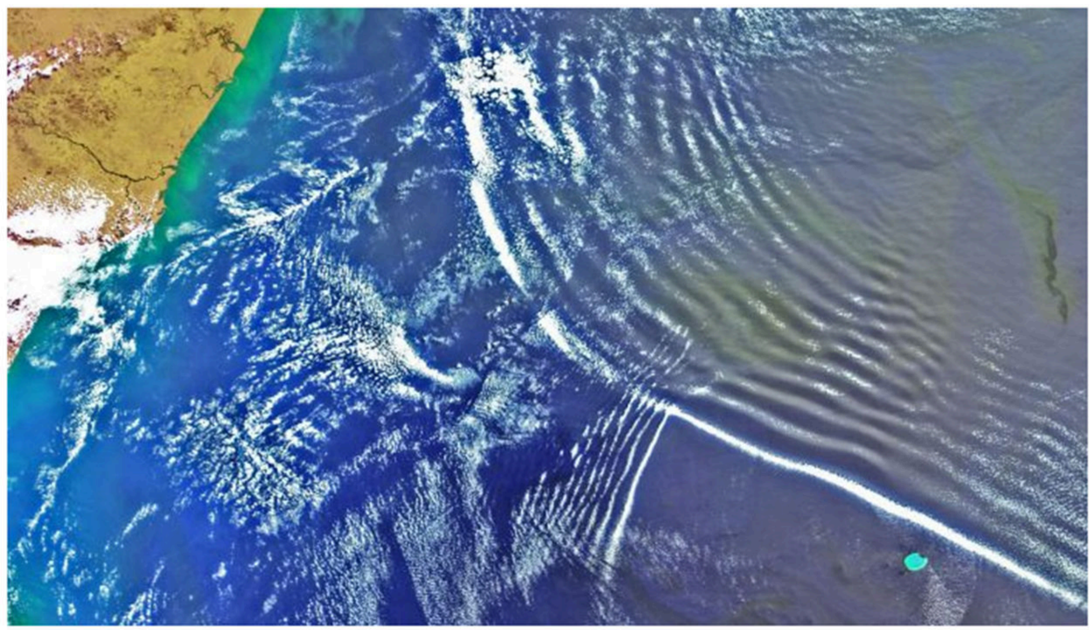
EGU Blogs » GeoLog » What if a tsunami’s magnetic field could predict the height of the wave?

What if a tsunami’s magnetic field could predict the height of the wave?

Gillian D'Souza · January 12, 2022 · Earth Magnetism and Rock Physics, Natural Hazards, News · 1 Comment



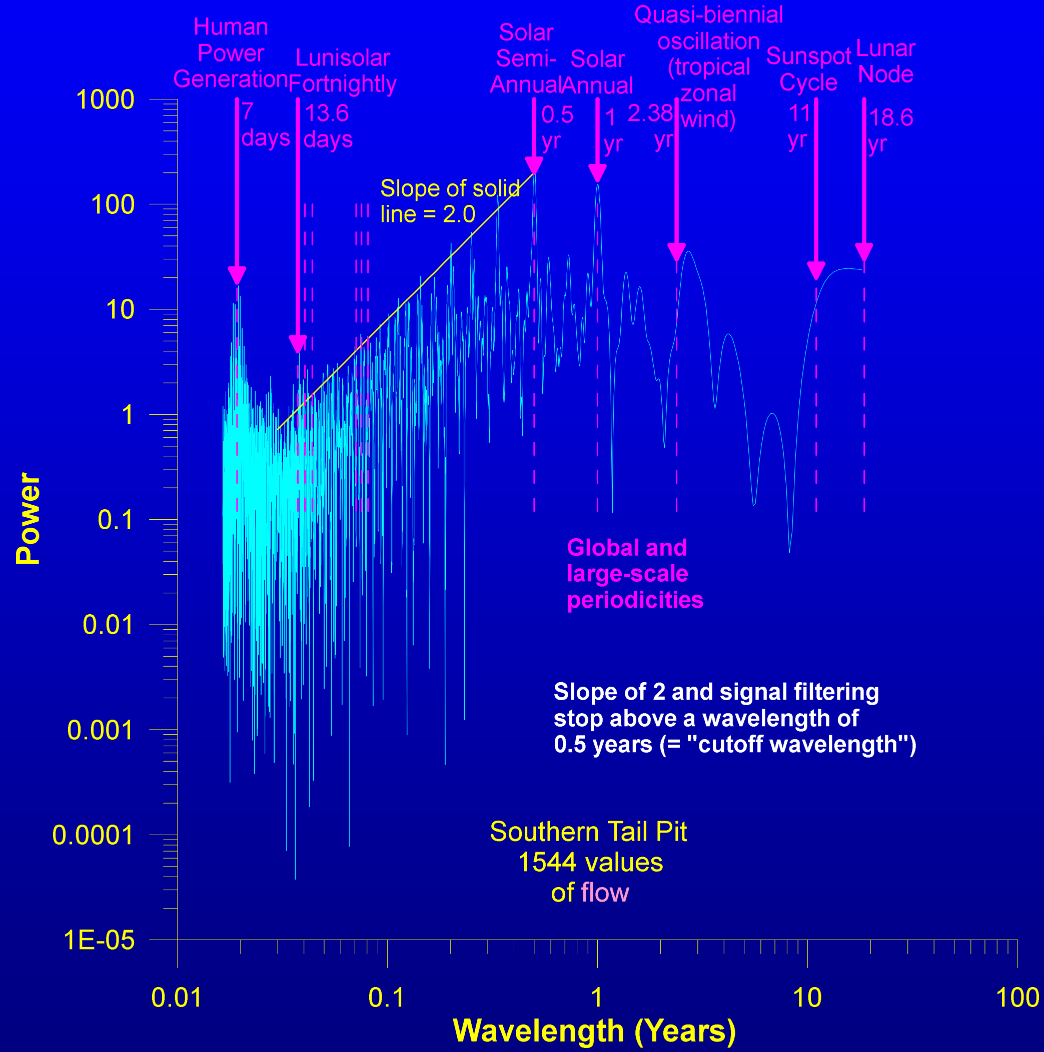
Atmospheric gravity waves . Credit: Jorge Magalhaes and Jose da Silva (distributed via imaggeo.egu.eu)

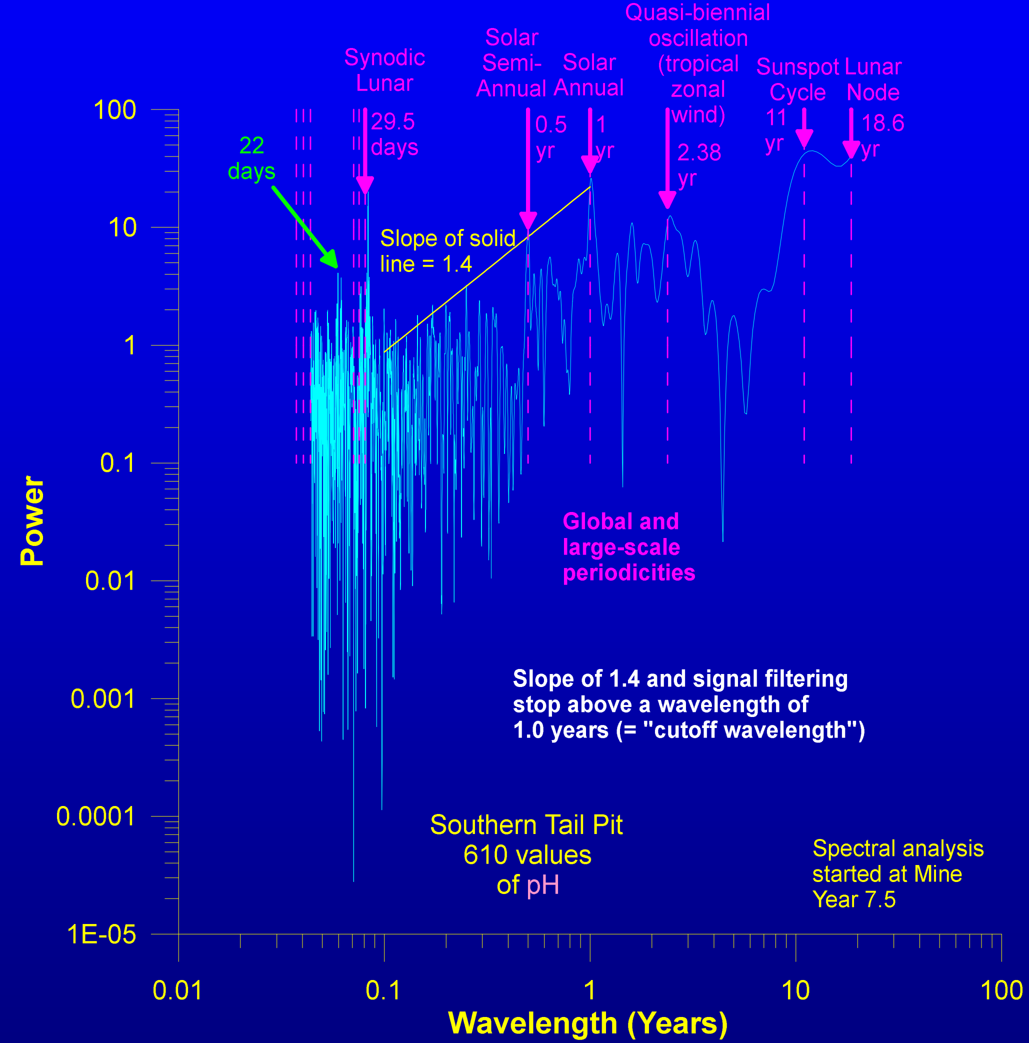
It’s been well established that tsunamis generate magnetic fields as they move seawater (which is conductive unlike freshwater) through the Earth’s magnetic field. Although researchers previously *predicted* that the tsunami’s magnetic field would arrive before a change in sea level, they lacked the means to simultaneously measure magnetics and sea level to confirm this phenomenon.

Periodicity in One Energy Term, Like Electrical Potential, Can Cause Periodicity in Other Terms Like Flow and Aqueous Chemistry

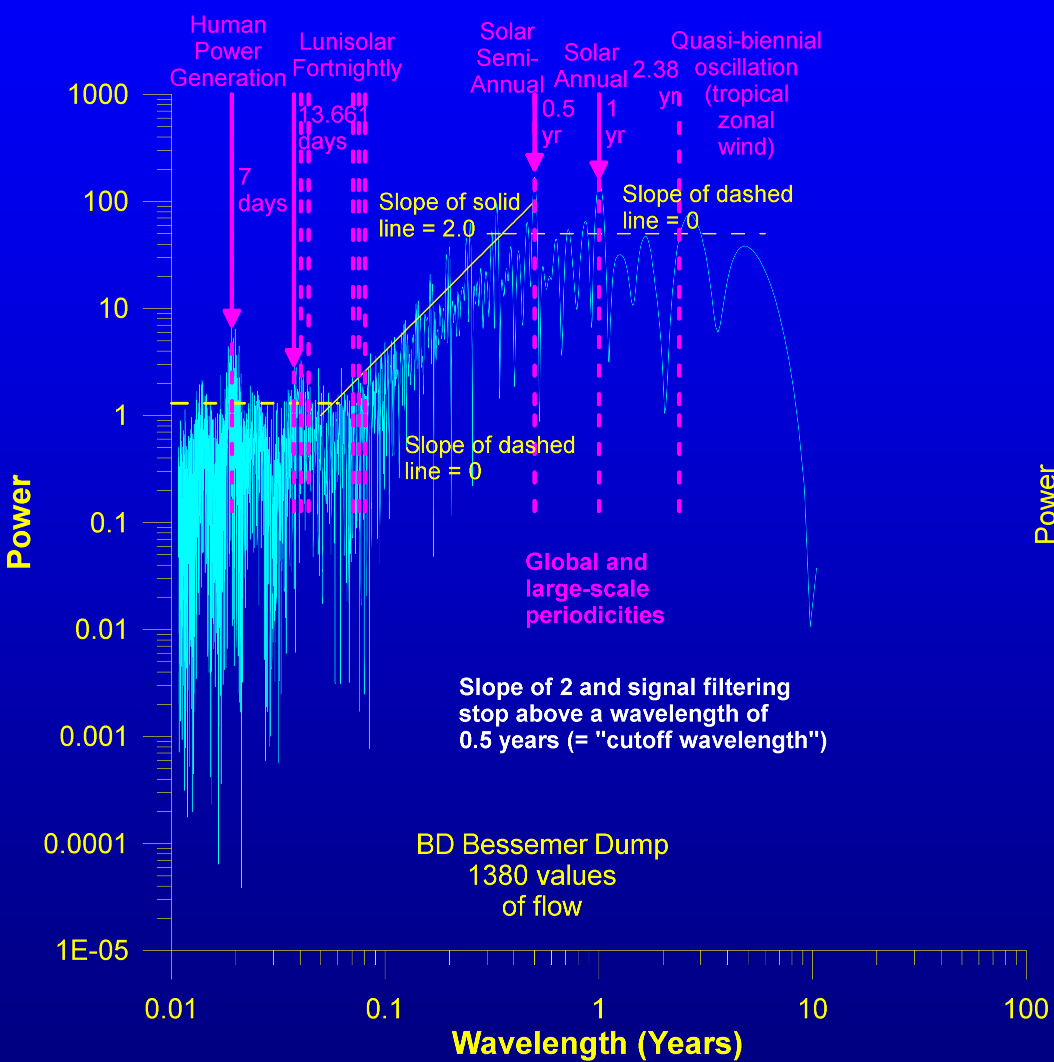
The following two slides contain some examples of periodicities in physical flow and aqueous chemistry caused by various large-scale processes such as the 11-yr sunspot cycle, the 2.38-yr quasi-biennial oscillation in tropical zonal winds, rotational gravity waves, and various tides driven by motions of the moon and sun relative to the earth.

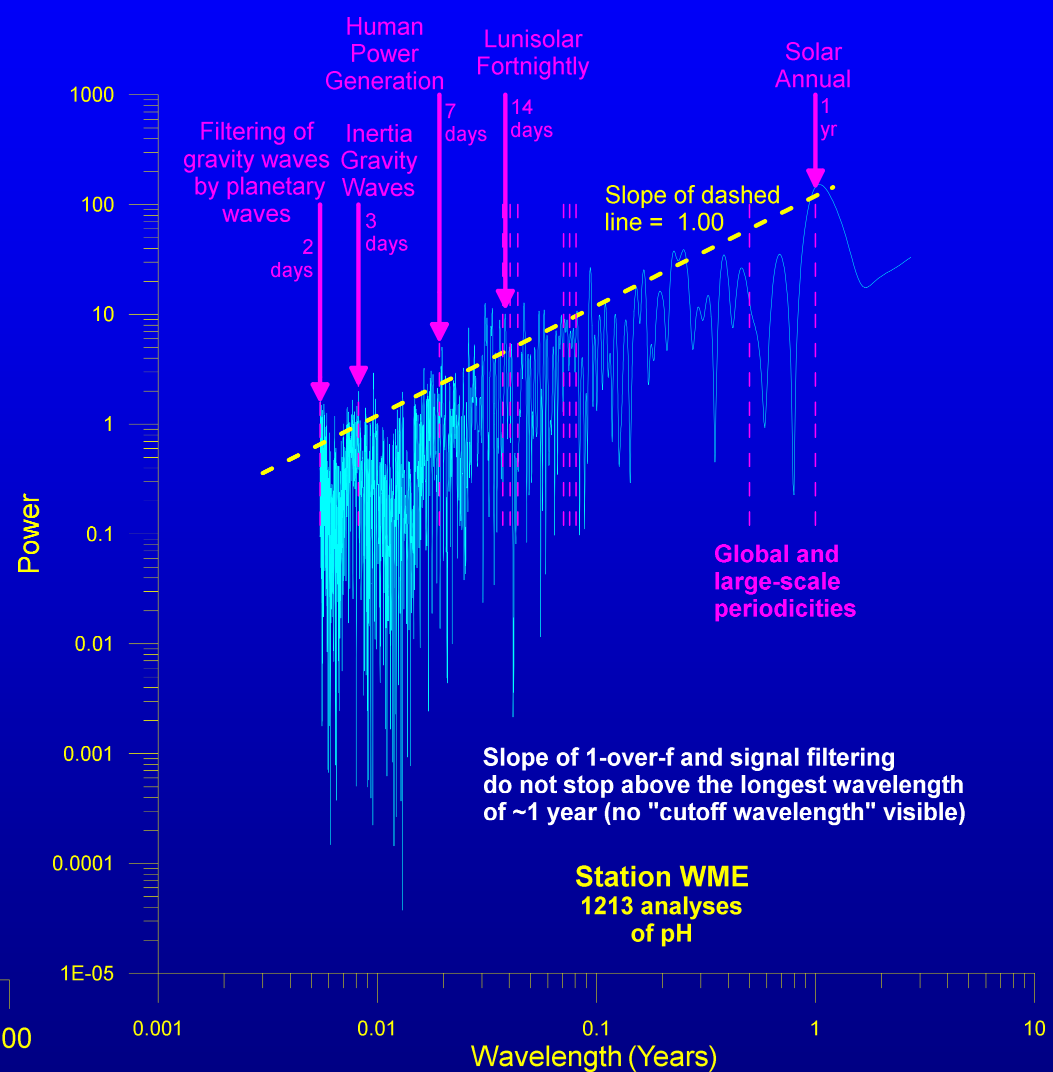
Periodicity in Flow and Aqueous Chemistry Caused by Other Periodicities





Periodicity in Flow and Aqueous Chemistry Caused by Other Periodicities





Objectives

- To answer two questions.
  - 1) What mechanisms and processes can introduce periodicity into minesite-drainage chemistry and flow? In other words, why do flow and chemistry "pulsate" at many wavelengths? This effect is more "ubiquitous" in non-mining catchments.
  - *Answer: Based on "Equation 2-2", the oscillation in any energy term can produce periodicity in one or more other energy terms. This includes the 11-yr sunspot cycle, the 2.38-yr quasi-biennial oscillation in tropical zonal winds, rotational gravity waves, and various tides driven by motions of the moon and sun relative to the earth. These appear to be linked to flow and aqueous concentrations primarily through oscillations in large-scale electrical fields based on electrodynamics, electrochemistry, thermogalvanic processes, etc.*

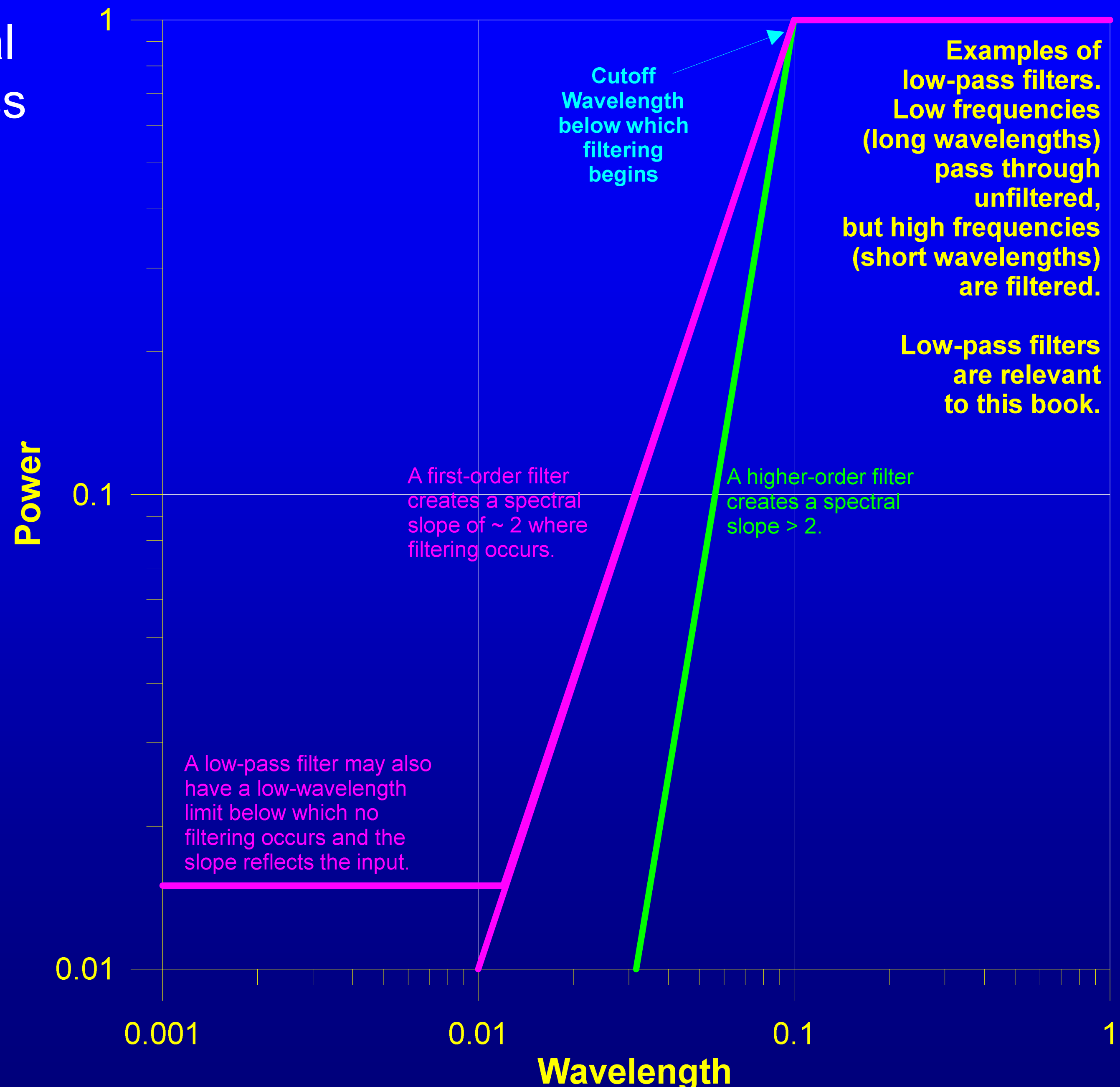
NEXT:

  - 2) How do these mechanisms apparently "self organize" so that their amplitudes and spectral powers generally decrease with decreasing wavelength, often forming fractal spectral slopes? This includes the very common yet mysterious "1-over-f" with a spectral fractal slope of 1.0, which should not appear and should not persist according to mathematics.

First-Order Low-Pass Filters

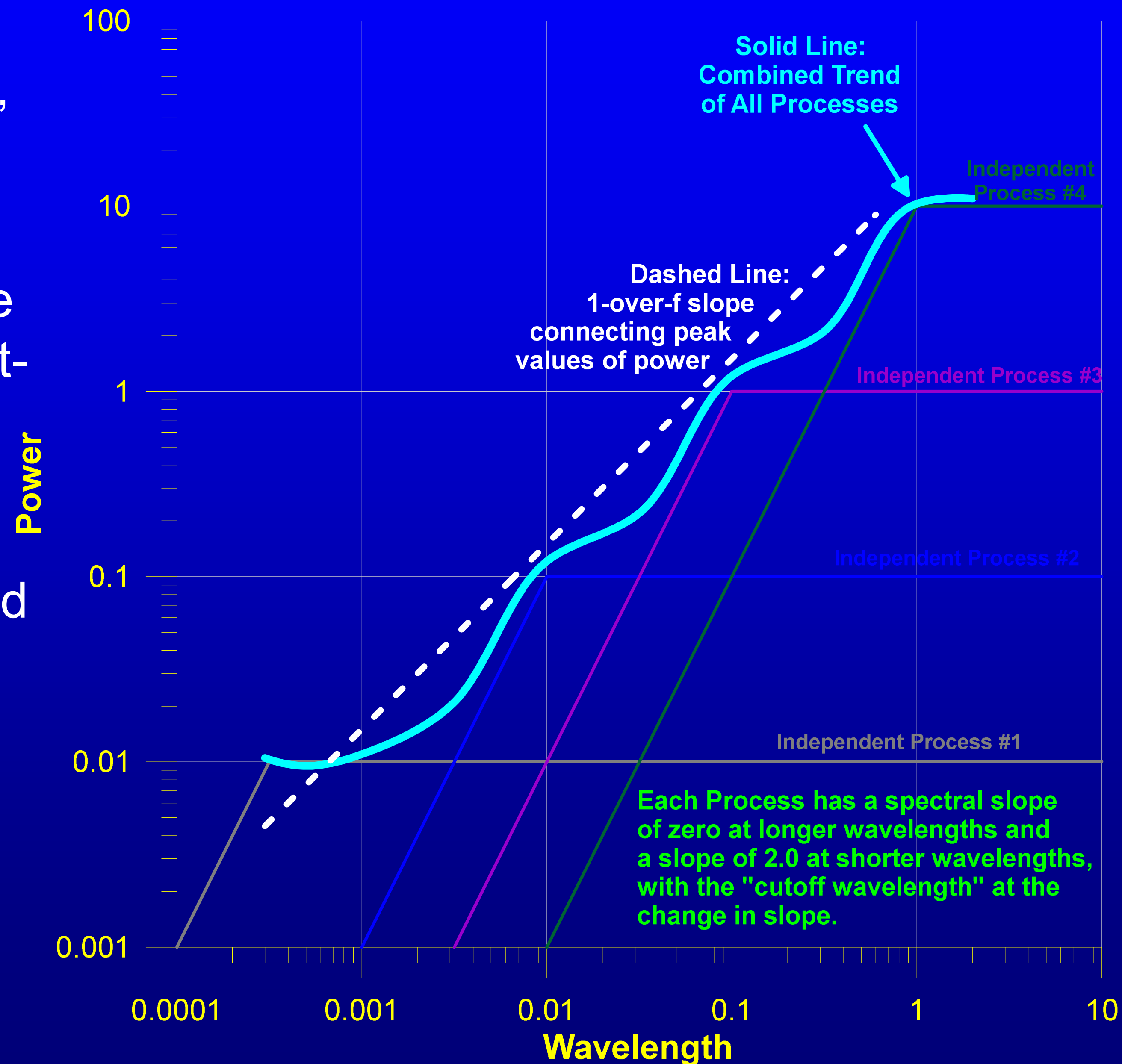
A common type of signal filter is called a “low-pass filter”. At wavelengths longer than the “cutoff wavelength”, there is no filtering. The cutoff wavelength is important as explained below.

At shorter wavelengths, a first-order low-pass filter reduces spectral power on a fractal slope of 2. Please note: a fractal slope of 2 for power is a fractal slope of 1 for amplitude.



First-Order Low-Pass Filters

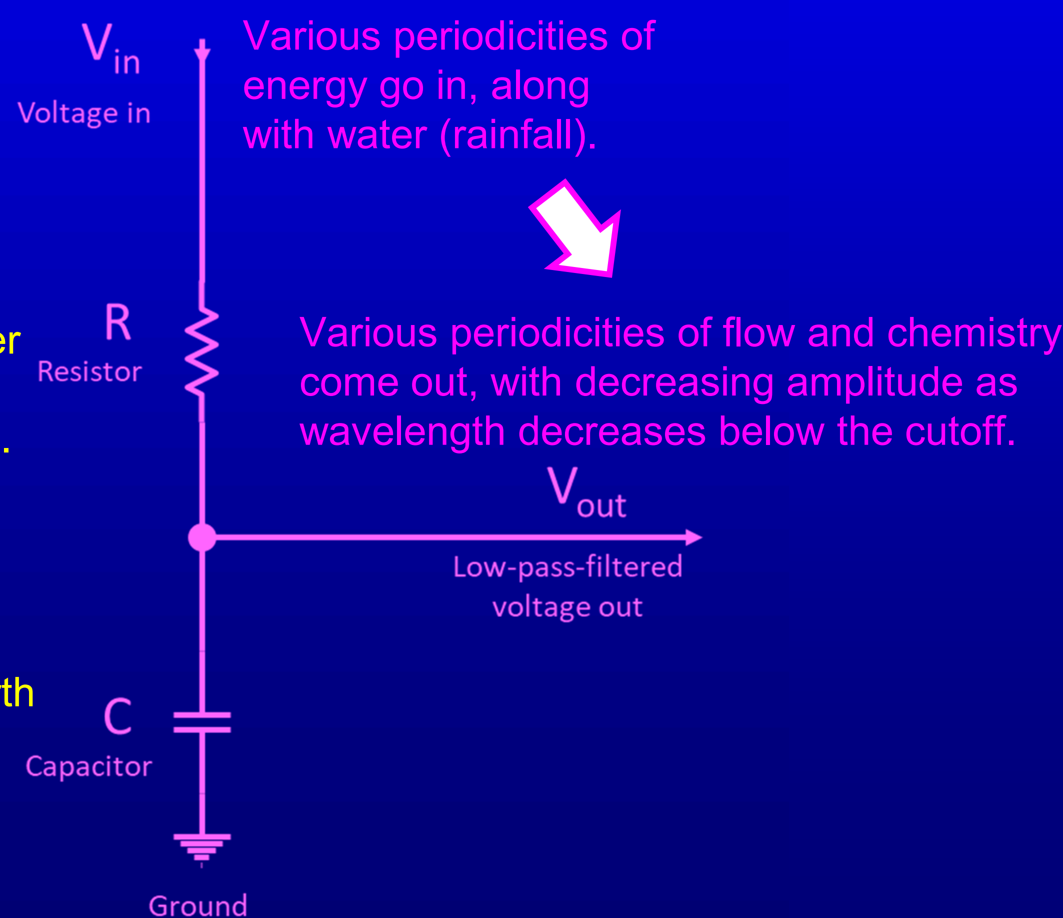
Fractal power slopes of 1 (1-over-f) are “mysterious” and found in many sciences and arts. One explanation for them is the superposition of many first-order low-pass filters operating at one time. This can include many physical, geochemical, and biological processes operating at one time inside a minesite component.



First-Order Low-Pass Filters

- A first-order low-pass "RC" filter is a relatively simple electrical circuit containing one resistor and one capacitor. At wavelengths shorter than the cutoff wavelength, this combination reduces the amplitudes of the inputs as wavelengths decrease, with a fractal slope of 2 for power and of 1 for amplitude. At wavelengths longer than the cutoff, there is no filtering.

Schematic Diagram of a First-Order Low-Pass Filter



At minesites, the rock, its minerals, and the interstitial water create spatial and temporal variations in electrical resistance.

The largest capacitor on earth is the earth itself and its atmosphere. The capacitance (C) of the earth has been calculated at 0.0007 farads.

Minesite Components as First-Order Low-Pass Filters

- If we can show that minesite components can be physical analogues of low-pass filters, then spectral slopes of 2 should be expected and other slopes including 1-over-f slopes can be expected when many low-pass-filtered processes operate at the same time.

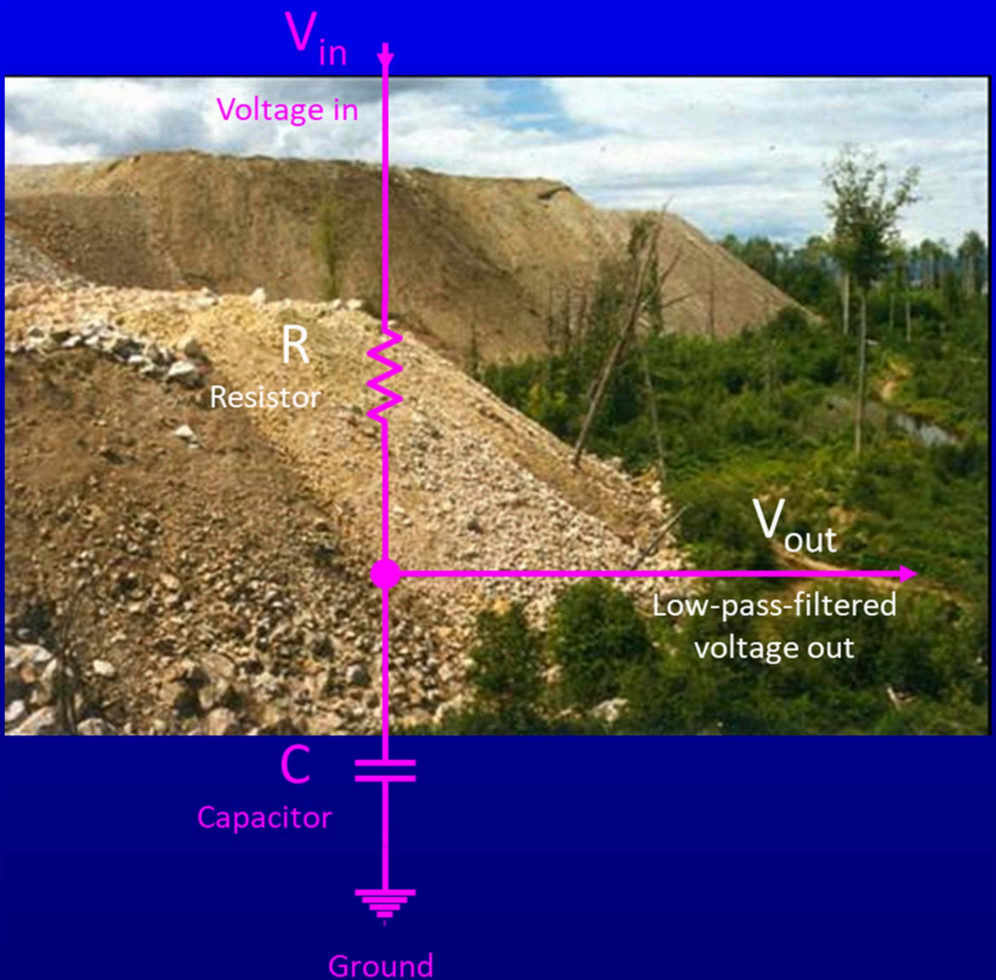
- The first step in showing this is the realization that many minesite components are well "grounded" to the earth. For geotechnical stability, vegetation, loose soil, and broken rock are often removed, and then the component is built in contact with intact rock.

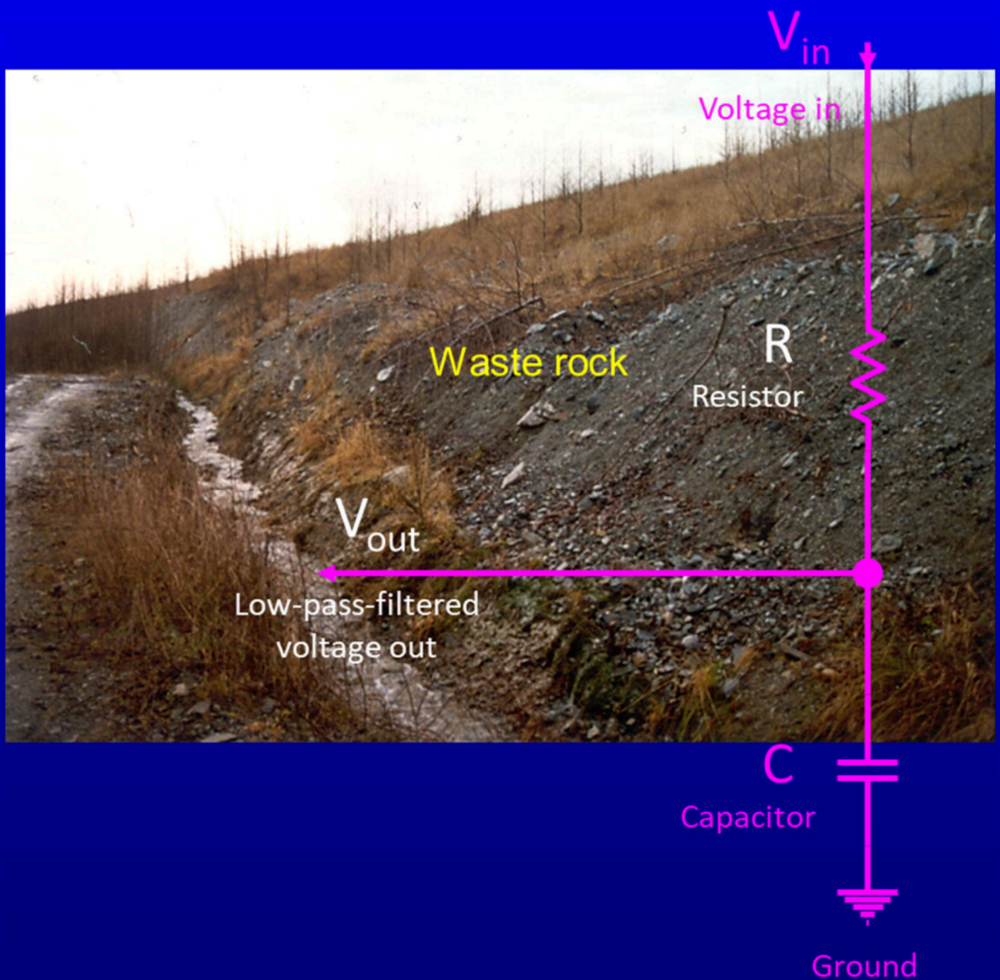
- The second step is recognizing that the largest capacitor on earth is the earth itself and its atmosphere. The capacitance (C) of the earth has been calculated at 0.0007 farads.

- The third and last step is recognizing that rock and tailings have relatively large, finite resistances and thus act as large electrical resistors.

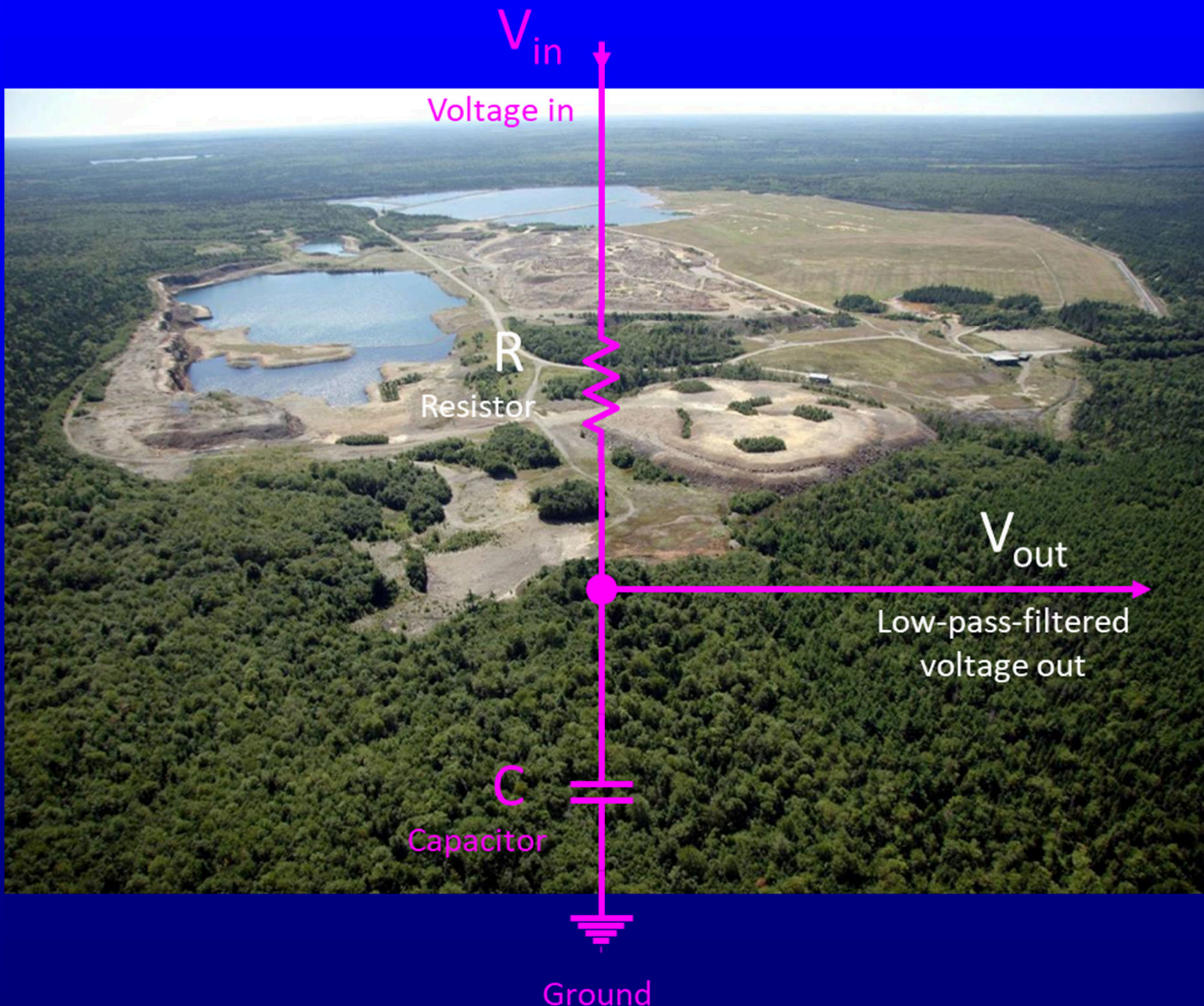
- Therefore, here is evidence of the first step:

Minesite Components as First-Order Low-Pass Filters





Minesite Components as First-Order Low-Pass Filters



Calculating the Resistance of a Minesite Component

- There is a simple equation relating the cutoff wavelength to the resistance of a minesite component.

$w_{c,sec} = 2 \pi R C$ (Equation 3-1)

where:

$w_{c,sec}$ = cutoff wavelength, in seconds

R = resistance, in ohms = 1/siemens = (volts*seconds)/coulomb

C = capacitance, in farads = coulomb/volt

- Replacing C with the earth's capacitance of 0.0007 farads:

$w_{c,sec} = 0.00440 * R$

Or

$w_{c,yr} = 1.40 \times 10^{-10} * R$

where:

w_c = cutoff wavelength, in years

Calculating the Resistance of a Minesite Component

- For example, some spectral periodograms shown above had a cutoff wavelength of ~0.5 years for one full-scale example of waste-rock-pile drainage flow and of pH. Thus, the calculated R is 3.94×10^9 ohms or siemens^{-1} for this waste-rock pile.

- The resistivity (r) is related to resistance (R) by:

$$R = r*L/A \qquad \text{(Equation 3-2)}$$

where:

R = resistance, in ohms = 1/siemens = siemens^{-1} = (volts*seconds)/coulomb

r = resistivity, in ohm·meter = meter/siemen

L = length of system, in meters

A = cross-sectional area of system in meter^2

Calculating the Resistivity of a Minesite Materials

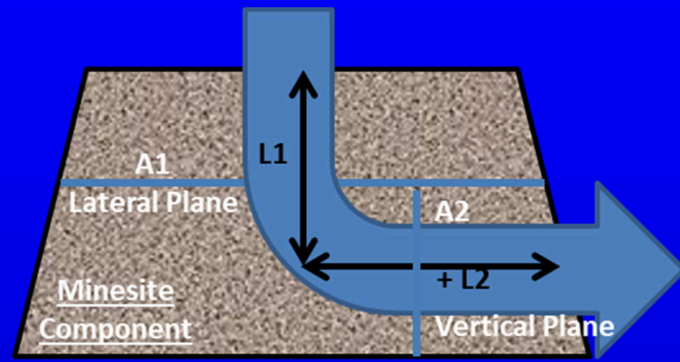
- As examples of relevant resistivities,
  - for dry solid quartz, r ~ 10^{+12} to 10^{+14} meter/siemen (equivalent to the old units of ohm·meter) depending on direction of measurement relative to crystal axis;
  - for sulphide minerals and graphite, r ~ 10^{-5} to 1 meter/siemen;
  - for groundwater with hundreds to thousands of mg/L typical of minesite drainage, r ~ 10 - 15 meter/siemen; and
  - for air, r ~ 10^{+9} to 10^{+15} meter/siemen.

- If L/A = 1.0, the r of this example's waste rock would be 3.94×10^9 ohm·meters or meters/siemens. This value is typical of, for example, relatively dry metamorphic and igneous rocks as found at this minesite. This supports the plausible explanation of low-pass filtering presented here.

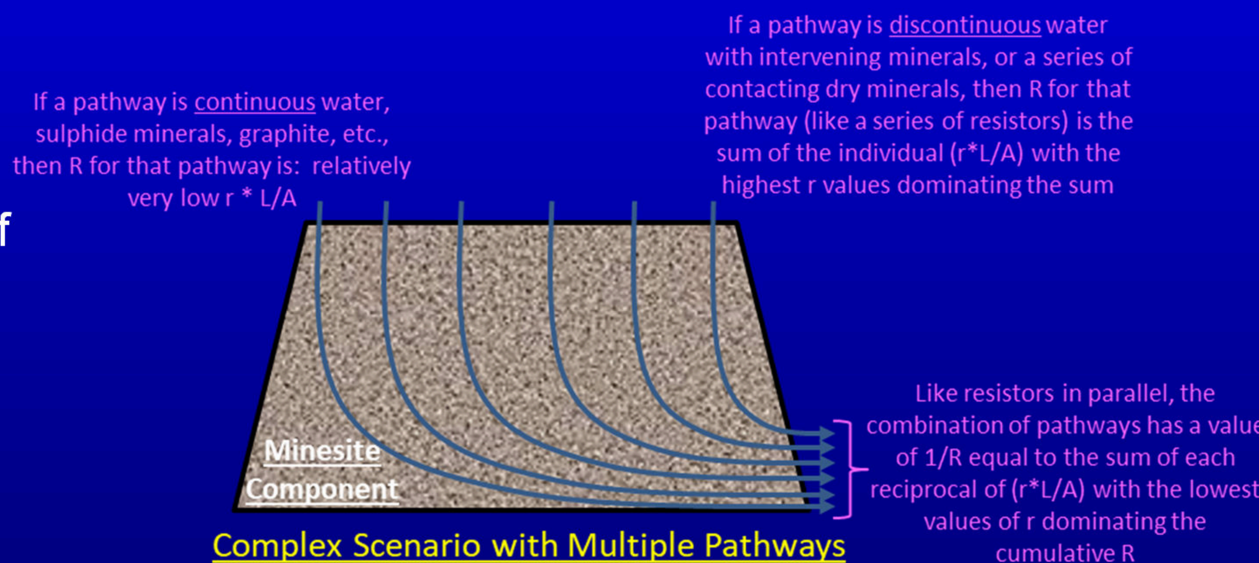
- But is L/A = 1.0?

Calculating the Resistivity of Minesite Materials

- The practical difficulty is obtaining values for L/A.
- In the relatively simple scenario (upper right), L/A would be much less than 1.0. Thus, r >> R and in the example above r >> 3.94×10^9 meters/siemens, typical of relatively dry quartz-rich rock.
- In the complex scenario (lower right), each pathway has a resistance R equal to the sum of its (r*L/A) like a series of resistors. The higher values of individual R dominate that pathway's R. However, at the exit, the combination of pathways reflects resistors in parallel, with the cumulative R for the minesite component reflecting the lower values of R.



Relatively Simple Scenario of the Entire Minesite Component:
Using units of meters, L/A typically << 1.0



Complex Scenario with Multiple Pathways Each with a Different Resistance:
Using units of meters, L/A >> 1.0 for each individual long narrow pathway but not the sum

Calculating the Resistivity of a Minesite Materials

- The preceding complex scenario showed several flowpaths in parallel entering and exiting a minesite component.

- Each flowpath consisted of a series of resistors reflecting spatial variations in the geological materials and their degree of water saturation. As a result, the highest value of resistivity (r) along the flowpath dominates the cumulative resistance (R) of that particular flowpath. Due to the relatively small cross-sectional area (A) of each flowpath, L/A is relatively high, increasing the R for that flowpath even further.

- At the exit, all flowpaths come together like resistors in parallel. Thus, the cumulative R for all flowpaths mixed together (the minesite component) mostly reflects the lower R values among the flowpaths.

Calculating the Resistance of a Minesite Component

- In general, the resistance R and the cutoff wavelength above which no fractal filtering occurs decreases with:
  - decreasing resistivity r, such as due to abundant interstitial water and electrically conductivity minerals like pyrite,
  - decreasing length of flowpath L, such as smaller-scale testing,
  - increasing cross-sectional area A.

- Therefore, fractal spectral slopes caused by low-pass filtering, which are only visible at times shorter than the cutoff wavelength, may only be detected with ultra-high-frequency monitoring:
  - in some smaller-scale tests with lower L/A values,
  - in geological materials containing highly conductivity minerals or abundant interstitial water with lower r values.

Answers

- 1) What mechanisms and processes can introduce periodicity into minesite-drainage chemistry and flow? In other words, why do flow and chemistry "pulsate" at many wavelengths? This effect is more "ubiquitous" in non-mining catchments.
  - *Answer: Based on "Equation 2-2", the oscillation in any energy term can produce periodicity in one or more other energy terms. This includes the 11-yr sunspot cycle, the 2.38-yr quasi-biennial oscillation in tropical zonal winds, rotational gravity waves, and various tides driven by motions of the moon and sun relative to the earth. These appear to be linked to flow and aqueous concentrations primarily through oscillations in large-scale electrical fields based on electrodynamics, electrochemistry, thermogalvanic processes, etc.*

Answers

2) How do these mechanisms apparently "self organize" so that their amplitudes and spectral powers generally decrease with decreasing wavelength, often forming fractal spectral slopes? This includes the very common yet mysterious "1-over-f" with a spectral fractal slope of 1.0, which should not appear and should not persist according to mathematics.

– *Answer: Minesite components are open systems in the surficial environment well grounded to the earth that behaves like a capacitor. Thus, relatively large components can act as first-order low-pass filters. These filters cause the spectral powers of various periodicities entering them to (1) decrease along a fractal slope of 2 at wavelengths shorter than the "cutoff wavelength" and (2) remain unfiltered at longer wavelengths. When several mechanisms are simultaneously acting as low-pass filters, various fractal slopes including 1-over-f can appear.*

Conclusion

- Therefore, based on large-scale low-pass filtering, fractal spectral slopes should be common in full-scale minesite drainage and in large non-mining catchments.

- And they are indeed found to be common to ubiquitous in high-frequency and long-duration monitoring.

- Thus, fractal spectral slopes in large-scale natural water flows and chemistries are not mysterious and unexplainable.

- At smaller scales with lower L/A values (such as in a laboratory), the cutoff wavelength can decrease to less than one day or one hour. Thus, their signal filtering and fractal spectral slopes would not be detected except at very short wavelengths by very-high-frequency monitoring.

THE END