Soils and weathering – and why it is important for acidification and sustainable forestry

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Litterature

The first part of the chapter “Preliminaries to Erosion: Weathering and Mass wasting” (the part about denudation and weathering)

The chapter “Soils”
From rocks to soils to elements (e.g. Ca, P, K): Weathering - one of the denudation processes

**Weathering:** Mechanical, chemical and biological breaking down of rocks

**Mass wasting:** Short-distance downslope movement of broken rock material

**Erosion:** Removal, transportation and deposition of fragmented rock material over wider areas (wind/water/ice)

*(From Hess, 2013)*
Weathering and mass movements in “Fjällen” (the Swedish mountains)

(Photo: Cecilia Akselsson)
Joints – where the weathering begins

Weathering occurs where atmosphere and litosphere meet. Microscopic openings, joints, faults, lava vesicles and solution cavities cause weathering not only on the surface.

(From Hess, 2013)
Different types of weathering

**Mechanical weathering:** Breaking of rock material without any chemical changes

**Chemical weathering:** Decomposition of rock or soils by the chemical alteration of the material

**Biological weathering, according to the book:** E.g. Plant roots penetrating cracks, lichens drawing minerals from rock through ion exchange, burrowing by animals

**Biological weathering, in my research community:** The impact of vegetation and fungi on weathering of mineral soils, e.g. through altering the chemical conditions in the soils (closely connected to chemical weathering)
Mechanical weathering – frost wedging (frostsprängning)

Freezing of water in cracks leads to expansion. Continuously freezing and thawing causes frost wedging. Occurs in many scales. Most common in high latitudes and on high elevations.

(From Hess, 2013)
Mechanical weathering – salt wedging (saltsprängning)

Salt crystallize when water evaporates. Crystals grow with time. In areas with dry climate and along ocean coast lines.

(From Hess, 2013)
Mechanical weathering – temperature changes

- Fluctuation of temperature from day to night and summer to winter can lead to expansion and contraction.
- Weakens and eventually cracks the rock.
- The same process but much faster at forest fires.
Mechanical weathering – exfoliation

Theory: Removal of weight, unloading, causes cracks, curved layers peel off

(From Hess, 2013)
Chemical weathering - Important for tree nutrition (P and base cations: Ca, Mg, K) and recovery from acidification.
Chemical weathering

Mechanical weathering creates surfaces for chemical weathering. Chemical weathering can lead to release of different ions, e.g. Ca, Mg, K and P. Different types of chemical weathering:

- Hydrolysis (Reaction with H₂O)
- Carbonation (Reaction with CO₂)
- Strong acids (Reaction with H⁺)
- Reaction with organic acids
- Oxidation (Reaction with O₂)
Oxidation

“Rusting”: \(4\text{Fe} + 3\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3\)
Hydrolysis

Reaction with water, example olivine:
\[ \text{Mg}_2\text{SiO}_4 + 4 \text{H}^+ + 4 \text{OH}^- \rightleftharpoons 2 \text{Mg}^{2+} + 4 \text{OH}^- + \text{H}_4\text{SiO}_4 \]

Carbonation

Reaction with carbonic acid, example calcium carbonate:
\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \]
\[ \text{H}_2\text{CO}_3 + \text{CaCO}_3 \rightarrow \text{Ca}^{2+} 2\text{HCO}_3^- \]

Strong acids

Reaction with strong acids, example K-feldspar
\[ 3 \text{KAlSi}_3\text{O}_8 + 2\text{H}^+ + 12 \text{H}_2\text{O} \rightarrow \text{KAl}_3\text{Si}_3\text{O}_{10} (\text{OH})_2 + 6 \text{H}_4\text{SiO}_4 + 2 \text{K}^+ \]
Important factors affecting chemical weathering rates

Presence of weathering agents:

- Water (H₂O)
- Carbon dioxide (CO₂)
- Hydrogen ions (H⁺)
- Organic acids
- Oxygen (O₂)
Important factors affecting chemical weathering rates

Hardness and composition of material

3. CALCITE
6. FELDSPAR
7. QUARTZ

Reduced weathering rates
Important factors affecting chemical weathering rates

Total surface area

Total surface area = 24 m²
(4 m² per face and there are six faces)

Total surface area = 48 m²

Total surface area = 96 m²

Increase in surface area

(From Hess, 2013)
Important factors affecting chemical weathering rates

Climate (temperature and moisture)

(From Hess, 2013)
Quantifying weathering rates of base cations 1

Budget calculations

(Picture by Giuliana Zanchi)
Quantifying weathering rates of base cations 2

“Historical weathering rates”:
- Chemistry measurements at different depths.
- Assumption: Zirconium (Zr) resistant to weathering.
- Ratio between Zr and other elements on different depth gives weathering rates since last ice age.

(Photo: Cecilia Akselsson)
Quantifying weathering rates of base cations

Biogeochemical modelling

subroutine adjuststoich (AnFraction, mineralname, nminerals)
  use localweathering
  implicit none
  real(rk), intent(in) :: AnFraction
  integer, intent(in) :: nminerals
  character(*), intent(in) :: mineralname(nminerals)
  integer i, ii, jplagio, joligo
  character(*), parameter :: plagio='plagioclase'
  character(*), parameter :: oligo='oligoclase'
  real(rk) :: Anortite(elements), Albite(elements)

  if (mimicPROFILE4 then
    stoich(2,E_CA)=AnFraction*100
    stoich(2,E_KG)=0
    stoich(2,E_X)=0
    stoich(2,E_NA)=100-AnFraction*100
    stoich(2,E_AL)=(AnFraction*2*100+(100-AnFraction*100)*3)
    stoich(2,E_SI)=(AnFraction*2*100+(100-AnFraction*100)*3)
    stoich(2,E_P04)=0
    norm(PLAGIOCLASE)=plagio+2*(100-plagio)
    norm(2)=2*stoich(2,E_CA)+2*stoich(2,E_KG)+
    & stoich(2,E_X)+stoich(2,E_NA)
Quantifying weathering rates with biogeochemical modelling

Causal loop diagram showing important factors affecting weathering rates...

$BC = \text{base cations (Ca, Mg, Na, K)}$
Mini exercise: Climate change will change temperatures and moisture. It may also lead to increased harvesting (for biofuels). How will weathering be affected?

$BC = base\ cations\ (Ca,\ Mg,\ Na,\ K)$
Mini exercise: Climate change will change temperatures and moisture. It may also lead to increased harvesting (for biofuels). How will weathering be affected?
Soils – where the atmosphere, lithosphere, hydrosphere and biosphere meet.
Soils and soil processes – decisive for feeding the world

Some examples from the book “Jord” by Håkan Wallander
Soils and soil processes – decisive for feeding the world

Example 1: Natural fertilization of agricultural land around the Nile
Soils and soil processes – decisive for feeding the world

Example 2: *Pine plantations along the south coast of Skåne to prevent erosion and transport of sand to agricultural land*

*(Photo: Cecilia Akselsson)*
Soils and soil processes – decisive for feeding the world

Example 3: Terraces on the slopes in Nepal to prevent landslides

(Photo: Håkan Wallander)
Soils and soil processes – decisive for feeding the world

Example 4: Ecological agriculture or fertilizers to feed an increasing world population (9 000 000 000 in 2050)?

<table>
<thead>
<tr>
<th>Ecological agriculture:</th>
<th>Agriculture with fertilizers:</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Creates more fertile soils</td>
<td>+ More crops</td>
</tr>
<tr>
<td>+ More biodiversity...</td>
<td>- Less fertile soils</td>
</tr>
<tr>
<td>- Reduced crops (ca 1/5 lower)</td>
<td>- Less biodiversity</td>
</tr>
<tr>
<td></td>
<td>- Use of pesticides</td>
</tr>
</tbody>
</table>

What happens when we have emptied the P supplies (Peak phosphorous)?

(From ec.europa.eu)
Bedrock, regolith and soil

(From Hess, 2013)
Five factors for soil development

- The geologic factor
- The climatic factor
- The topographic factor
- The biological factor
- The time factor
The geologic factor

- Parent material often the dominating factor in early stages

- Parent material could be bedrock or transported sediments

- Chemical composition and physical properties depends on parent material

(From Hess, 2013)
The climatic factor

- Temperature and moisture accelerates chemical and biological processes

- Moving water carries dissolved chemicals and particles rearranging and providing nutrients

(From Hess, 2013)
The topographic factor
-Slope and drainage (erosion and runoff)

(From Hess, 2013)
The biological factor

- Organic matter: a source of nutrients
- Microorganisms, e.g. bacteria and fungi: Decomposition of organic matter, conversion of nutrients.
- Vegetation (including roots): Uptake of nutrients. Roots affects soil structure (drainage and aeration)
- Earth worms, ants etc: fertilizing, bioturbation
- Big animals: Grazing, compacting and dropping excreta.

The time factor

- The time required for soil formation depends on parent material and differs between different environments.
- Generally slow processes.
Soil components

- Inorganic materials
- Organic matter
- Soil air
- Soil water

*(The composition of an optimal soil for plant growth, From Hess, 2013)*
Inorganic materials

-Pieces of minerals, different sized e.g. sand and silt

-Clay important for plant nutrition (large surface area, important nutrient attach on the particles)

(From Hess, 2013)
Organic matter – litter, humus and living organisms

(Photo: Cecilia Akselsson)
Soil Air

(a) Wet soil

(b) Dry soil

(From Hess, 2013)
Soil water – different forms

- Gravitational water
- Capillary water (surface tension)
- Hygroscopic water (adhesion)
- Combined water (chemical bounds with soil minerals)

(From Hess, 2013)
Soil properties

- Color
- Texture
- Structure
Soil chemistry

*Colloids: important for water and nutrients*

- Soil particles smaller than 0.1 µm
- Inorganic colloids: clay
- Organic: humus (decomposed organic matter)
- Works like a sponge, soaks up water
- Attracts a large amount of ions
Soil chemistry

*Cation exchange on colloids*

- Negative colloids attract positive ions, e.g. Ca, Mg and K, which are important nutrients
- Ca, Mg and K easily exchanged by e.g. H (cation exchange)
- Cation exchange capacity (CEC): The ability of a soil to attract cations
- High CEC – fertile soils (high contents of clay and humus)
Soil horizons – a result of soil formation processes

O horizon
Loose and partly decayed organic matter

A horizon
Mineral matter mixed with some humus

E horizon
Zone of eluviation and leaching

B horizon
Accumulation of clay, iron and aluminum from above; zone of illuviation

C horizon
Partially altered parent material

R horizon
Unweathered parent material

(From Hess, 2013)
Processes in soil formation

-The 5 soil forming factors influence the rate of addition, loss, translocation and transformation.

-Soil profiles with soil horizons are created.

(From Hess, 2013)
Pedogenic (soil-forming) regimes

(From Hess, 2013)
Laterization (Lateritisering)

- Warm and moist regions (tropics and subtropics)
- Fast weathering, decomposition
- Most mineral leach, leaving Fe and Al oxides and quartz sand

*(From Hess, 2013)*
Podzolization (Podsoliserings)

- Positive moisture balance, cool regions (boreal forests in subarctic environments)

- Slow weathering, limited nutrient requirements, acid litter

- Leaching due to high precipitation and lots of acids: Fe and Al oxides and other elements leaches, creates a bleached layer and a layer enriched in the leached elements

Photo: Cecilia Akselsson
Soil types (jordmåner)

-“the parts of the earth crust's surface layer, that during different eras have been influenced by climate and organisms.” Source: Nationalencyklopedin (the Swedish National encyclopaedia).

-can give information about soil quality, sensitivity, applicability and management requirements
Soil classification: different systems

- US system (in the book)
- FAO system
- National system, Sweden
Soil classification: US system – The soil taxonomy

- 12 soil orders, many suborders, more levels...

- Some examples of orders: Spodosols, Inceptisols, Entisols and Histosols

- Applied in the US, but is very general and is often used worldwide
Soil classification: US system – The soil taxonomy

(From Hess, 2013)
Soil classification: FAO – Soil map of the world

-28 main groups, divided into subgroups

-Some examples of groups: Podsols, Cambisols, Histosols, Gleysols, Leptosols, Regosols och Arenosols.

-Applied in Sweden (Swedish Survey of Forest Soils), together with the national system
Soil classification: FAO – Soil map of the world

Degree of dominance
High   Low
Share (%)
Histosol  8
Leptosol  11
Arenosol  20
Podsol    45
Cambisol  10
Regosol   6

MarkInfo
Swedish Survey of Forest Soils (SK) 83-87
Map: Åke Nilsson

(http://www-markinfo.slu.se/)
National system, Sweden

- 13 soil types

- Covers e.g. different forms of podsols, brown forest soils, waterlogged soils and lithosoles

- Applied in Sweden (Swedish Survey of Forest Soils), together with the FAO system
National system, Sweden

Dominating soil type class

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humus podsol</td>
<td>13</td>
</tr>
<tr>
<td>Peat</td>
<td>10</td>
</tr>
<tr>
<td>Brown forest soil</td>
<td>20</td>
</tr>
<tr>
<td>Iron podsol</td>
<td>47</td>
</tr>
<tr>
<td>Lithosol</td>
<td>9</td>
</tr>
<tr>
<td>Disturbed soil</td>
<td>1</td>
</tr>
</tbody>
</table>

MarkInfo
Swedish Survey of Forest Soils (SK) 83-87
Map: Åke Nilsson

(http://www-markinfo.slu.se/)
National system, Sweden – Iron podsol

- Organic layer
- Light layer, weathered, mostly quartz left
- Reddish layer, enriched in substances from above, e.g. Fe compounds

Frequency map for soil type class:
Iron podsol

Frequency class (%) Share (%)
<17.0 6
17.1-34.0 20
34.1-51.0 25
51.1-68.0 35
>68.1 15

MarkInfo
Swedish Survey of Forest Soils (SK) 83-87
Map: Åke Nilsson
(http://www-markinfo.slu.se/)
National system, Sweden – Brown forest soil (Brunjord)

- No sharp boundaries between layers, mixed by earth worms

MarkInfo
Swedish Survey of Forest Soils (SK) 83-87
Map: Åke Nilsson
(http://www-markinfo.slu.se/)
National system, Sweden – Transition (övergång)type

-In between podzol and brown forest soil

(http://www-markinfo.slu.se/)
National system, Sweden – Lithosols

- Thin layer of organic soil horizon/mineral soil (max 10 cm)

Frequency map for soil type class: Lithosol

MarkInfo
Swedish Survey of Forest Soils (SK) 83-87
Map: Åke Nilsson

(http://www-markinfo.slu.se/)
Wrapping up minerals and soils – What have you learnt?

• three types of rock
• many soil types
• rock and soil consist of minerals
• weathering turns rock into soil and finally leads to release of nutrients
• parent material and climate are the most important factors for soil fertility
Weathering – the most important natural factor for counteracting acidification, and important for plant nutrition

Chemical weathering leads to release of base cations and counteracts acidity.

Ex: \(3 \text{KAlSi}_3\text{O}_8 + 2\text{H}^+ + 12 \text{H}_2\text{O} \rightarrow \text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2 + 6 \text{H}_4\text{SiO}_4 + 2 \text{K}^+\)
Acidification
The environmental objectives of Sweden

- Reduced climate impact
- A protective ozone layer
- A safe radiation environment
- A varied agricultural landscape
- A magnificent mountain landscape
- Clean air
- A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos
- Good quality groundwater

- Natural acidification only
- Zero eutrophication
- Thriving wetlands
- A good built environment
- A non-toxic environment
- Flourishing lakes and streams
- Sustainable forests
- A rich diversity of plant and animal life
- Reduced climate impact
- A protective ozone layer
- A safe radiation environment
- A varied agricultural landscape
- A magnificent mountain landscape
- Clean air
- A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos
- Good quality groundwater
History

-1967:
• Ulf Lundin, fishery expert in Uddevalla, contacted Svante Odén, SLU: fish death and low pH in lakes!
• Svante Odén had time series of precipitation chemistry. He found out that pH had decreased substantially in 20 years.

-1967: Article named “Nederbördens försurning” in DN. About increased acidification of precipitation due to S emissions, leading to acidified surface waters and fish death

-1979: UN/ECE Convention on Long-Range Transboundary Air Pollution!

-Critical loads (Kritisk belastningsgräns) defined 1988

-1999: Gothenburg protocol, target year: 2010

-2012: Revised Gothenburg protocol
Acid rain - Sources and acidification processes

**Sources**

Sulphur

![Sulphur Source](image1)

Nitrogen

![Nitrogen Source](image2)

Forestry

![Forestry Source](image3)

Road

![Road](image4)
Acid rain – sources and acidification processes

Sulphur

Main source of S: Combustion of coal and oil. Also industries, ships, etc.

\[ S + O_2 \leftrightarrow SO_2 \]

\[ SO_2 + O_2 \leftrightarrow 2 \text{ SO}_3 \]

\[ \text{SO}_3 + H_2O \leftrightarrow 2 \text{ H}^+ + \text{SO}_4^{2-} \]
Acid rain – sources and acidification processes

*Oxidized nitrogen (NO$_x$)*

Main source of NO$_x$: Traffic

\[
\begin{align*}
N_2 + O_2 & \leftrightarrow 2 \ \text{NO} \\
2 \ \text{NO} + O_2 & \leftrightarrow 2 \ \text{NO}_2 \\
2 \ \text{NO}_2 + H_2O & \leftrightarrow HNO_2 + H^+ + NO_3^- 
\end{align*}
\]
Acid rain – sources and acidification processes - *Reduced nitrogen (NH$_3$)*

Main source of NH$_3$: Fertilizers

\[ \text{NH}_3 + \text{H}_2\text{O} \leftrightarrow \text{NH}_4^+ + \text{OH}^- \]

\[ \text{NH}_4^+ + 2 \text{O}_2 \leftrightarrow 2 \text{H}^+ + \text{NO}_3^- + \text{H}_2\text{O} \]
Acid rain – sources and acidification processes

Surt vatten kommer från markytan.

(From www.capensis.se)
Acid rain – sources and acidification processes

Effects

- Low pH and high concentrations of toxic aluminium

- Negative effects on fish and other water living organisms

- Risk of negative effects on vegetation

- Increased leaching of nutrients important for trees (e.g. Mg and K) which can lead to nutrient imbalance

- Increased leaching of heavy metals (e.g. Cd and Pb)
Present situation and trends

Photo: Cecilia Akselsson
Acidification status today

- 10% of Swedish lakes and 20% of the forest soils are assessed as acidified.

- In SW Sweden 50% of the lakes and forest soils are assessed as acidified.

- 200 million SEK are spent on lake liming every year

- Measurements and modelling indicate slow recovery
Reductions of emissions in Europe

From EMEP, www.emep.int, april 2013

~80% reduction
Sulphur deposition trends

(Based on data from the SWETHRO network. Modified from Pihl Karlsson et al, 2011, Env. Poll.)
Antropogenically acidified lakes

Lakes (> 1 ha) in different effect classes in the year 2010, based on there modelled pH decrease since before insustrialization

(Filip Moldan, IVL, www.ivl.se/magiclibrary)
Acidification from forestry
Acidification from forestry

Tree growth: Uptake of base cations – BC: Ca, Mg, K. Release of H⁺.

Biomass harvesting: The BC losses and acidification becomes permanent.
Acification from forestry – increased biomass harvesting

- Notified harvest of residues
- Actual harvest of residues
- Harvest of residues in thinnings
- Stump harvesting
- Wood ash recycling

(Swedish forest agency)
Acidification from forestry

Acid rain removes base cations and acidifies...

...and biomass harvesting too.

Chemical weathering leads to release of base cations and counteracts acidity.

Ex: $3 \text{KAlSi}_3\text{O}_8 + 2\text{H}^+ + 12\text{H}_2\text{O} \rightarrow \text{KAl}_3\text{Si}_3\text{O}_{10} (\text{OH})_2 + 6\text{H}_4\text{SiO}_4 + 2\text{K}^+$
Acid deposition and forestry lead to losses of nutrients...

...and nutrients are necessary for all living organisms
Acidification in the perspective of Swedish rocks, soils and landforms
Acidification in the perspective of Swedish rocks, soils and landforms

(From Hess, 2013)

(From Hess, 2013)

(From Hess, 2013)

(Photo: Jonas Åkerman)
Acidification in the perspective of Swedish rocks, soils and landforms

(From Hess, 2013)

(Photo: Cecilia Akselsson)

(From Hess, 2013)

(Photo: Jonas Åkerman)
Acidification in the perspective of Swedish rocks, soils and landforms

(soil map from SGU)

(http://www-markinfo.slu.se/)