



## ALTERNATIVE STORAGE TECHNOLOGIES

### Long-term storage of CO<sub>2</sub> as magnesium carbonate in Finland

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# CCS from Finland's perspective

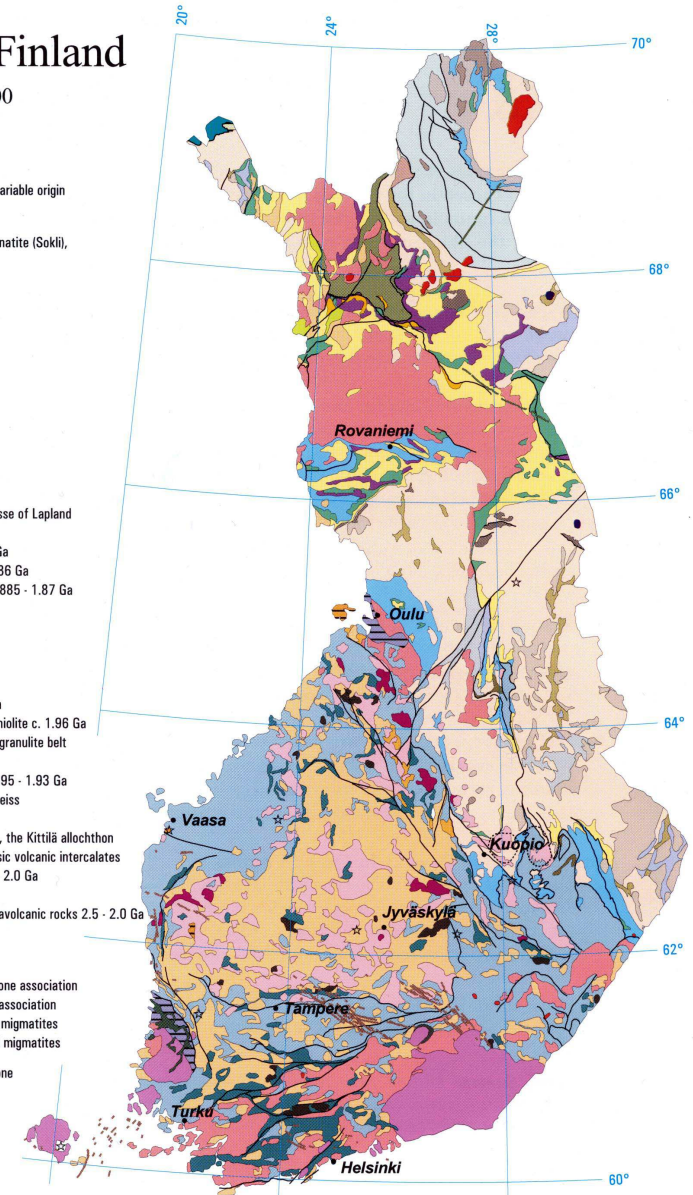
- The Kyoto protocol binds Finland to reduce its greenhouse emissions. The production and utilization of power and heat is already efficient and no suitable geological formations are known to exist for CO<sub>2</sub> sequestration.

- The only currently known long-term CO<sub>2</sub> storage alternative for Finland is mineral carbonation. Finland has widespread deposits of the minerals needed for carbonation (Aatos et al., 2006, Teir et al., 2006). The process still requires too much energy.

## Bedrock of Finland

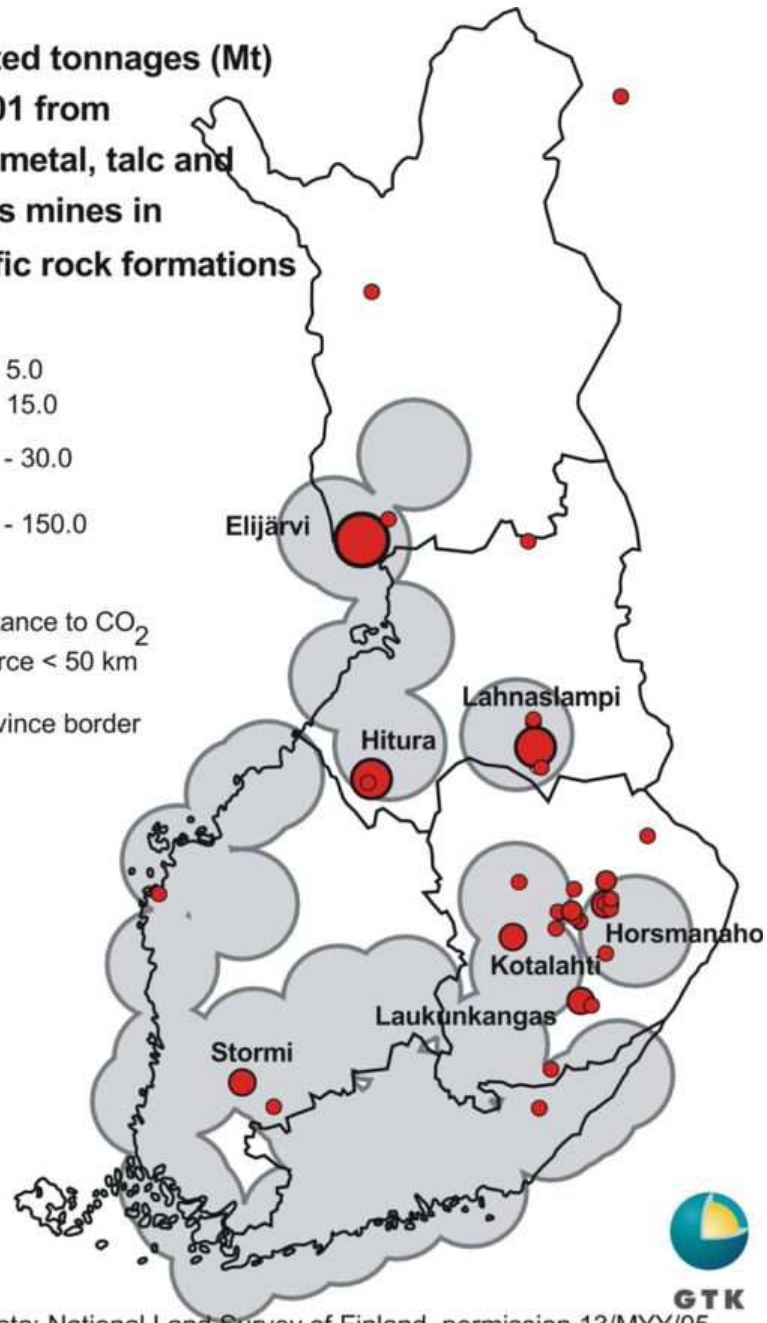
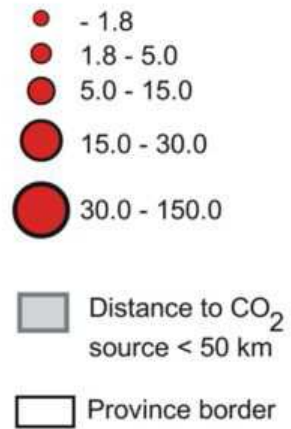
1 : 5 000 000

- Caledonian tectonic units**
- 1 Schists, gneisses or intrusions of variable origin
- Paleozoic**
- 2 Alkali rock pipe (livaara) and carbonatite (Sokli)
  - 3 Sandstone and shale, Cambrian
- Neoproterozoic**
- 4 Sandstone and shale, Vendian
- Mesoproterozoic**
- 5 Dolerite dykes, northern Finland
  - 6 Dolerite sills, Jotnian
  - 7 Sandstone and shale, Jotnian
  - 8 Rapakivi granite
  - 9 Gabbro-anorthosite
  - 10 Dolerite dyke swarms, Subjotnian
- Paleoproterozoic**
- 11 Quartzite and conglomerate, molasse of Lapland
  - 12 Postorogenic granitoids c. 1.8 Ga
  - 13 Late orogenic granites 1.85 - 1.8 Ga
  - 14 Granite and granodiorite 1.88 - 1.86 Ga
  - 15 Pyroxene granite and monzonite 1.885 - 1.87 Ga
  - 16 Granodiorite 1.89 Ga
  - 17 Gabbro-diorite 1.89 - 1.87 Ga
  - 18 Tonalite 1.92 - 1.91 Ga
  - 19 Mica schist and migmatite
  - 20 Mica schist
  - 21 Metavolcanic rocks 1.92 - 1.88 Ga
  - 22 Serpentinite and other rocks of ophiolite c. 1.96 Ga
  - 23 Garnet gneiss and diorite; Lapland granulite belt
  - 24 Anorthosite
  - 25 Foliated gabbro and granodiorite 1.95 - 1.93 Ga
  - 26 Gneissic granite and hornblende gneiss
  - 27 Quartzite and conglomerate
  - 28 Metavolcanic rock and mica schist, the Kittilä allochthon
  - 29 Calc-silicate rock, black schist, basic volcanic intercalates
  - 30 Quartzite with intercalates c. 2.3 - 2.0 Ga
  - 31 Layered intrusions 2.44 Ga
  - 32 Mafic, intermediate and felsic metavolcanic rocks 2.5 - 2.0 Ga
- Archean**
- 33 Latest Archean granitoids
  - 34 Metavolcanic rocks of the greenstone association
  - 35 Metasediments of the greenstone association
  - 36 Biotite ± hornblende gneisses and migmatites
  - 37 Tonalite-trondhjemite gneisses and migmatites
- Faults and major shear or thrust zone  
 ○ Kimberlite province  
 ☆ Impact site



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**All hoisted tonnages (Mt)  
until 2001 from  
Finnish metal, talc and  
asbestos mines in  
ultramafic rock formations**

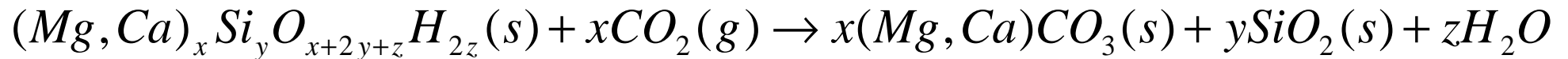


Base map data: National Land Survey of Finland, permission 13/MYY/05

# Research in Finland

- Aalto University, laboratory of energy engineering and environmental protection, since 2000
  - Åbo Akademi (ÅA), heat engineering laboratory, since 2005
  - Technical Research Centre of Finland (VTT)
  - Geological Survey of Finland (GTK)
  - And others
- 
- Climbus project (Ex situ mineral carbonation 2004-2010)
    - ECOSERP (Screening of resources 2004-2006)
    - CCS Finland (Application of CCS in Finland 2008-2011)

# Carbonation of silicate minerals



- Calcium- and magnesium-based silicates react with CO<sub>2</sub> to form environmentally harmless carbonates.
- Analogies are known in natural weathering processes of Ca- and Mg-silicates. The most promising Mg-mineral for mineral carbonation in Finland is serpentine.
- For carbonation of 1g CO<sub>2</sub> 2,1g serpentine is needed. There are huge serpentine resources, of several gigatonne, in Finland.
- The major hold-up for this technology is the large amounts of material involved and the carbonation reaction kinetics.

# Finnish research on long-term storage of CO<sub>2</sub> as magnesium carbonate

- The aqueous carbonation route seems promising due to fast reaction kinetics, but the energy economy of this approach is unattractive (Fagerlund et al., 2010). Recent development involve applying CO<sub>2</sub> mineral sequestration to flue gases directly.
- The direct carbonation is exothermic allowing for a process with a zero or negative overall energy input but suffers from too slow chemical kinetics and poor energy economy even at high temperatures and pressures (Zevenhoven et al., 2008).
- A staged process of CO<sub>2</sub> mineralisation via production of Mg(OH)<sub>2</sub> followed by gas/solid carbonation is under development at the Åbo Akademi University (Zevenhoven et al., 2010).

## Stepwise magnesium silicate carbonation via $\text{MgSO}_4$ & $\text{Mg}(\text{OH})_2$ (Zevenhoven et al., 2010)

- Preheated serpentine rock is thermally treated with ammonium sulphate at 400-500 °C at atmospheric pressure. A significant amount of the magnesium (Mg) in the serpentine is converted to sulphate which is further converted to  $\text{Mg}(\text{OH})_2$ .
- The  $\text{Mg}(\text{OH})_2$  produced is converted into  $\text{MgCO}_3$  in a pressurised fluidised bed reactor at pressures > 20 bar and temperatures 450-600 °C.
- The process has many benefits compared to the carbonation route of superheated aqueous suspensions but requires still too much energy.



# References

- **Aatos, S., Sorjonen-Ward, P., Kontinen, A. ja Kuivasaari, T. 2006.** Serpentiinin ja serpentiniitin hyötykäyttönäkymiä (Outlooks for utilisation of serpentine and serpentinite). Geological Survey of Finland (GTK), Report No. M10.1/2006/3, Kuopio, Finland. (In Finnish)
- **Fagerlund, J., Nduagu, E., Romão, I & Zevenhoven R. 2010.** CO<sub>2</sub> fixation using magnesium silicate minerals. Part 1: Process description and performance. *Energy-the Int. J. (special edition ECOS2010)*, submitted 2010
- **Teir, S., Aatos, S., Isomäki, O-P., Kontinen, A. and Zevenhoven, R. 2006.** Silicate mineral carbonation as a possible sequestration method of carbon dioxide in Finland. Finnish Association of Mining and Metallurgical Engineers. *Materia*, 1/2006, pp. 40–46. (In Finnish)
- **Zevenhoven, R., Teir, S. & Eloneva, S. 2008.** Heat optimisation of a staged gas-solid mineral carbonation process for long-term CO<sub>2</sub> storage. *Energy*, 33, 362-370.
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