Design of natural weathering process converting CO_2 streams directly into minerals and assessment of the environmental effects of productions of mineralization products

Prepared by: Patrick van Hemert
(TU Delft)

Reviewed by: Pacelli Zitha
(TU Delft)

Approved by: J.Brouwer
(CATO-2 Director)

1 Executive Summary (restricted)

A literature survey on weathering process was undertaken. It was concluded that the main physical-chemical aspects of weathering are covered in deliverable D04. More research is needed on the relation between weathering and climate but falls out of the scope of the Work-Package 3.2.

Distribution List

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Document Change Record

(this section shows the historical versions, with a short description of the updates)

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2 Applicable/Reference documents and Abbreviations

2.1 Applicable Documents

(Applicable Documents, including their version, are the “legal” basis to the work performed)

	Title	Doc nr	Version
AD-01d	Toezegging CATO-2b	FES10036GXDU	2010.08.05
AD-01f	Besluit wijziging project CATO2b	FES1003AQ1FU	2010.09.21
AD-02a	Consortium Agreement	CATO-2-CA	2009.09.07
AD-02b	CATO-2 Consortium Agreement	CATO-2-CA	2010.09.09
AD-03c	Program Plan 2011	CATO2-WP0.A-D.03	2010.12.07

2.2 Reference Documents

(Reference Documents are referred to in the document)

	Title	Doc nr	Version
RD-01			

2.3 Abbreviations

(this refers to abbreviations used in this document)

3 Design of natural weathering process converting CO_2 streams directly into minerals and assessment of the environmental effects of productions of mineralization products

Weathering refers to physical-chemical processes that contribute to the regulation of the amount of CO_2 in the atmosphere and in the lithosphere over geological times. This includes organic and inorganic chemical reactions occurring when CO_2 comes in contact hydrosphere and the earth's crust. These processes play a key role in the feedback loops of the carbon cycle and it is believed that they could be useful to control CO_2 emissions and their effects on the climate. Below a brief review of the status of the art is provided and future research directions highlighted.

3.1 Literature survey

The chemical weathering of rocks is one of the major global pathways for the exchange of carbon on earth. The weathering acts as sink for atmospheric CO_2 and as such it influences the long-term global climate through multiple feedback loops. The exact nature of these feedback loops have been important topics of research stimulated by growing concern that rapidly rising atmospheric concentration of CO_2 may adversely impact the global climate. Current knowledge of natural weathering processes is still limited and is unlikely to enable effective application of the feedback processes for CO_2 capture and storage.

The relation between chemical weathering, atmospheric concentration of $CO_{2,}$ and the climate was investigated by several authors in the last few decades (Kump, Brantley and Arthur, 2000; White and Brantley 1995). Experimental studies of mineral dissolution and geochemical reactions have been examined under controlled laboratory and field conditions (Liu, Dreybrodt and Liu, 2011; Foster and Vance, 2006). It was found that the rate of weathering, i.e. overall CO_2 consumption, is primarily controlled by the dissolution rate of soil minerals. This in turn depends on several factors including temperature, rainfall, soil solution pH, mineralogy, mineral surface area, physical denudation, age of the parent material and chelate concentration.

Reliable data concerning the kinetics of silicate mineral dissolution were gathered and compared with silicate weathering rates measured under realistic field conditions. Authors observed that the relative dissolution rates of silicate minerals obtained in the field are consistent with those determined under controlled laboratory conditions (Kump, Brantley and Arthur, 2000; White and Brantley 1995). However, overall mineral dissolution rates measured in the field maybe order of magnitudes lower than laboratory ones, especially when moisture content is low. Seepage of water in soils seemingly plays a significant role in the determination of mineral dissolution rates. When the seepage rate is slow, it allows chemical equilibrium conditions to be established within the solution, thus slowing down the dissolution of minerals. Existing data suggest that above a runoff of about 1 cm/year the chemistry of the stream is controlled by dilution rather than chemical equilibrium.

Others factors controlling the weathering processes include temperature, solution chemistry (especially the presence of organic and carbonic acids), reactive surface area and biological activities have also been investigated. The effects of temperatures have been studied in the laboratory leading to reasonable estimates of activation energies for the mineralization reactions (White and Blum, 1995). However, the other factors are much less understood. More broadly, the relation of the weathering processes and the climate has been surrounded by controversy due to difficulties encountered in analyzing geochemical and hydrological data. Numerical models (e.g. McCauley and DePaolo, 1997) have been developed to aid the interpretation of laboratory experiments and field studies and gain better understanding of the impact of chemical weathering on the climate and the environment. They have underlined the significance of the role played by various feedback loops in the carbon cycle in preventing excessive fluctuations of the concentration of the CO_2 in the atmosphere. Chemical weathering and erosion emerged as significant processes such carbon feedback loops and future research should devote more attention to these aspects.

The investigation of weathering reactions has also considered the use of crushed olivine rock along Earth's coastlines for capturing and storing atmospheric CO_2. Well controlled experimental studies (Hangx and Spiers, 2009) stressed that effectiveness of CO_2 storage by the above process depends strongly on the rate of dissolution of the olivine in agreement with others (Kump, Brantley and Arthur, 2000; White and Brantley 1995), the sequestration capacity of the dominant chemical reaction and the related CO_2 footprint. Its implementation at the desired scales requires the pulverization of olivine to grain sizes smaller than 10 microns. This is likely to meet with great technical and economic challenges in addition to posing risk of public health hazard. However, other authors (Schuiling and de Boer, 2009) have argued that natural olivine natural weathering rates could be faster than those estimated from laboratory experiments due to mechanical mixing that leads to collision and scrapping of olivine grains. This could well be the case for weathering in erosion dominated environment but evidence to start validating this hypothesis is scarce.

3.2 Summary

Existing studies on natural weathering underscore the significance of mineralization process due to CO_2-water-rock interactions in combination with fluid flow and transport processes. The geochemical reactions, thermodynamic aspects involved are largely covered in other parts of this work-package and other work-packages (e.g. cap rock integrity) of the CATO 2 projects. In order to fully explore the potential of the weathering as means of controlling CO_2 concentration in the atmosphere more and dedicated research is needed but it falls outside of the scope of the work-package.

3.3 References

Kump L.R., Brantley S.L. and Arthur M.A., Chemical Weathering, Atmospheric CO_2 and Climate, *Annu. Rev. Earth Planet. Sci.*, 28:611–67 (2000)

McCauley SE, DePaolo DJ. The marine 87Sr/86Sr and 18O records, Himalayan alkalinity fluxes and Cenozoic climate models. In *Tectonics, Uplift and Climate Change*, ed. W Ruddiman, New York: Plenum Publishing Co., 428–67. 1997.

Foster G.L. and Vance D., Negligible glacial–interglacial variation in continental chemical weathering rates, *Nature*, 444, 918-921 (2006)

Liu Z., Dreybrodt W. and Liu, H. Atmospheric CO_2 sink: Silicate weathering or carbonate weathering?, *Applied Geochemistry*, 26, S292–S294 (2011)

Hangx, S. J. T. and Spiers C. J, Coastal spreading of olivine to control atmospheric CO_2 concentrations: A critical analysis of viability, *International Journal of Greenhouse Gas Control*, 3(6), 757-767(2009)

Schuiling R.D., de Boer P.L., Coastal spreading of olivine to control atmospheric CO_2 concentrations: A critical analysis of viability. Comment: Nature and laboratory models are different, *International Journal of Greenhouse Gas Control*, *in press* (2010)

White, A. F. and Blum A. E., Effects of climate on chemical_ weathering in watersheds *Geochimica et Cosmochimica Acta*, 59(9), 1729-1747(1995)

White A.F. and Brantley S. L. (Editors), *Chemical Weathering of Silicate Minerals*, Reviews in Mineralogy, Vol. 31 (1995)