

Carbonate Precipitation in Engineered Environments; Carbon Sequestration by Design

David A. C. Manning*, Phil Renforth and Carla-Leanne Washbourne
School of Civil Engineering and Geosciences and Institute for Research on Environment and Sustainability, Newcastle University, Newcastle upon Tyne, UK, NE1 7RU.

*david.manning@ncl.ac.uk

Summary

Calcite precipitation in urban and other disturbed soils takes place as a natural consequence of the weathering of artificial calcium silicate minerals and glasses. In studies of such soils in the UK, twice as much carbonate C has been observed in urban soils as is held within rural soils as organic C. This process takes place by carbonation of soil minerals derived from demolition or waste disposal. Estimates of the overall capacity of soils to accommodate C in this way are of the order of 100-1000 MT annually, which is comparable to other carbon capture technologies. This passive sequestration of C requires very low energy inputs, and can be designed into land remediation and other engineering works.

Introduction

The precipitation of carbonate minerals in soils is a very well known phenomenon, especially for soils from arid climates. Recently, we have discovered that carbonate precipitation takes place in soils (and related environments, such as landfills) that have been artificially enriched in Ca as a consequence of engineering activity. This process takes place in areas where natural pedogenic carbonate precipitation may be unrecognized or insignificant.

The creation of engineered environments where carbon capture is part of the designed function provides us with an opportunity to remove CO₂ from the atmosphere. Key questions concern:

- a) can a significant amount of CO₂ be removed?
- b) How quickly can this be achieved?
- c) What is the process of CO₂ removal?

Method

We have investigated the distribution of calcite precipitates in soils from a number of urban or industrial sites in northern England and California. Urban soils at sites where demolition has taken place commonly contain dust and fine particulates derived from recovery of secondary aggregates, often with on-site crushing. These fines tend to be Ca-rich; they typically contain calcium hydroxide (portlandite) and calcium silicate minerals derived from the cement component of construction materials. Calcium silicate glasses occur in locations where slag derived from iron and steel making occurs within the soil. Estimates suggest the global production of Ca-rich materials to be on the order of 10⁴ MT/year, which could capture approximately 10² -10³ MT C/year. This is equivalent to other carbon capture and storage technologies (IPCC, 2005), yet requiring a comparatively negligible energy input. By demonstrating the carbon capture potential of Ca-rich materials, this paper provides justification for monitoring their production on a global scale.

Results

For soils that contain industrially-created calcium minerals, measurement of the CaCO_3 content has shown that this typically reaches 20-30 wt%. Depth profiles vary from location to location, but it is quite usual to observe an increase in calcium carbonate with depth, to a maximum value directly related to site geochemical conditions, with a reduction in CaCO_3 concentration as the climatically limited depth of soil-calcite precipitation is approached.

The key factors that enable calcium carbonate precipitation to take place in soils concern the availability of both Ca and bicarbonate/carbonate ions in solution. Investigation of the C and O stable isotope ratios for carbonates from urban soils and from soils developed on iron and steel slags has shown very clearly that there are two dominant sources for C: derived from photosynthesis, or from hydroxylation of CO_2 under high pH conditions (Figure 1). In both cases, an atmospheric source for C is required, and remobilization of geological carbonate plays a very minor role. The introduction of C into soils as a consequence of photosynthesis by plants growing at a particular site annually equals the amount fixed as above-ground biomass (Kuzyakov and Domanski, 2000; Manning, 2008), and so C availability is unlikely to be a limiting factor. Instead, it is likely that the amount of calcium in the soil, in an appropriate form (i.e. not a carbonate), is likely to be critical.

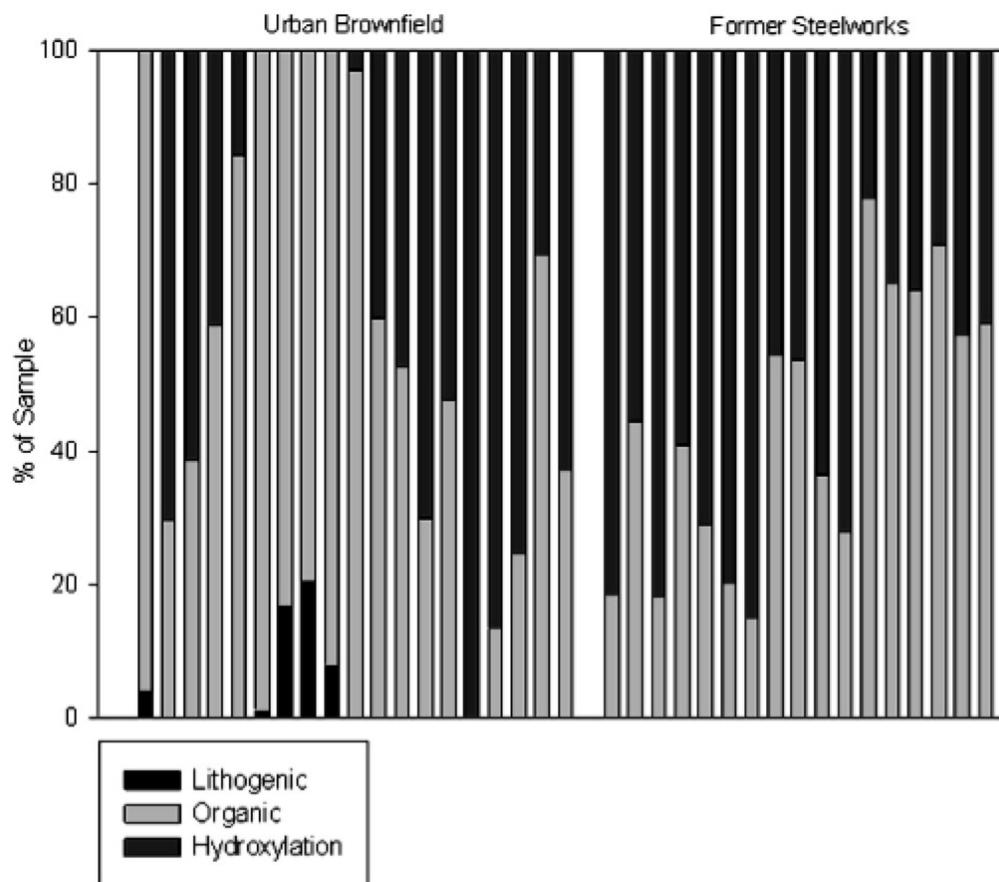


Figure 1. Relative proportions of C derived from different sources in soil carbonates from Byker (urban brownfield) and Consett (former steelworks). From Renforth et al., 2009.

Conclusions

Based on observations made in this study, we have shown that urban soils typically accumulate up to 30 kg/m² (300 T/ha) of carbon as calcium carbonate. This is almost twice the typical organic C content of rural soils (17.5 kg/m² in the UK). Scaling up, the carbon sequestration potential of such soils can be assessed. Based on the annual amounts of crushed concrete and slag that are produced each year in the UK, the sequestration potential is 8 MT C/year, corresponding approximately to the amount associated with emissions (less those associated with energy use) arising from the manufacture of cement. Thus carbonation of artificial calcium silicates in soils provides one way to close the loop in carbon emissions associated with cement manufacture.

Acknowledgements

We acknowledge support from the Natural Environment Research Council and from the Engineering and Physical Sciences Research Council.

References

- IPCC (2005) Bert Metz, Ogunlade Davidson, Heleen de Coninck, Manuela Loos and Leo Meyer (Eds.) Carbon Dioxide Capture and Storage, Cambridge University Press, UK. pp 431.
- Kuzyakov Y and Domanski G (2000) Carbon input by plants into the soil – review. *Journal of Plant Nutrition and Soil Science* 163, 421-431.
- Manning DAC (2008) Biological enhancement of soil carbonate precipitation: passive removal of atmospheric CO₂. *Mineralogical Magazine* 72, 639-649.
- Renforth P, Manning DAC, Lopez-Capel E (2009) Carbonate precipitation in artificial soils as a sink for atmospheric carbon dioxide. *Applied Geochemistry* 24, 1757-1764.