Observing deep carbon with an Icelandic volcano[1]

An important new chemical dataset from the basalt lavas of the Icelandic Borgarhraun volcano is helping Cambridge Earth Scientists John Maclennan and Dan McKenzie with colleagues from the US and Iceland estimate the carbon dioxide content of Earth's mantle. Borgarhraun is one of the few places in the world from where it is possible to probe the mantle CO2. This new data, published in the latest issue of Geology will improve understanding of the link between volcanism and long-term climate change.

Carbon present in upper mantle magmas plays an important role in the global carbon cycle, especially as these magmas deliver carbon into the oceans and atmosphere as carbon dioxide via volcanic eruptions. The release of carbon dioxide into the environment has a significant impact upon long-term global climate and other important earth processes such as volcanism, glaciation and possibly changes in sea-level. But estimating the carbon content of Earth's interior has proven to be highly problematic.

It has long been known that as magmas rise towards the surface and lose pressure their carbon becomes increasingly insoluble. The carbon is degassed as carbon dioxide with the result that most magmas arrive at the surface having lost most of their carbon. However, during the cooling and crystallisation of magma tiny pockets of quenched magma can become trapped within some mineral crystals.

Once enclosed, these miniscule samples (typically 200 -300 microns in diameter), known as melt inclusions, are so well sealed that they can survive the rigours of volcanic eruption without losing any of their volatile gas content and can be found in surface lavas. However, sampling and analysing the chemical contents of the inclusions requires highly sophisticated ion microprobe technology. Even so, most samples analysed in previous melt inclusion studies appear to have lost carbon by degassing prior to entrapment. Recovering measures of upper mantle carbon has proven to be very difficult.

But John Maclennan and his colleagues have successfully done so. The team sampled volcanic tephra erupted by the Icelandic volcano Borgarhraun around 8000 years ago. Within the Borgarhraun tephra there are mineral crystals, such as olivine and clinopyroxene, which contain melt inclusions. Furthermore, the composition of the chromium-rich clinopyroxene indicates that the melt began to crystallise at a depth of some 25km, which is close to the base of the crust under Borgarhraun.

Iceland straddles the North Atlantic mid-oceanic ridge and detailed studies of Borgarhraun show that the erupted magma provides a record of mantle composition under this segment of the mid-oceanic spreading ridge. The new analyses show large variations in CO2 and certain incompatible trace elements (ITEs) such as Nb, Th, Rb and Ba. Average

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[1] Published March 2018 © Department of Earth Sciences

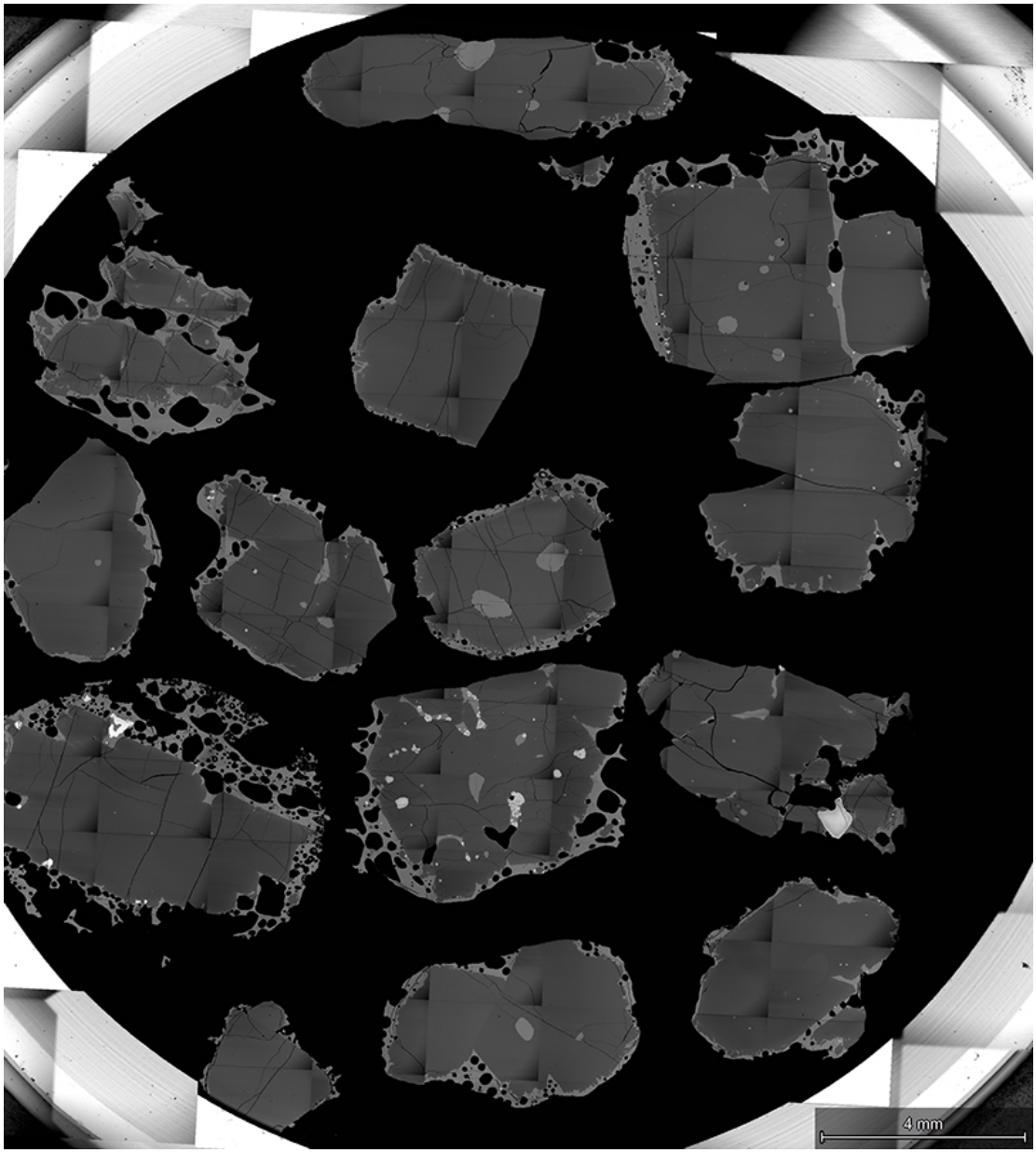
co2/ITE ratios from 161 melt inclusions have been precisely determined and compared with five other populations of undegassed samples sealed within melt inclusions from other mid-ocean ridge basalts.

Whilst upper mantle CO2/Ba and CO2/Rb are nearly homogenous, CO2/Nb and CO2/Th are broadly correlated with long-term indices of mantle heterogeneity and these are reflected in Nd isotopes from five of the six upper mantle regions which have been examined so far. However, there is a need for more samples and the team are actively seeking for them.

The new results suggest to the authors that heterogeneous carbon contents of the upper mantle are long-lived features. They speculate that average carbon abundances of the mantle sources of Atlantic mid-ocean ridge basalts might be higher by a factor of two than those of Pacific mid-ocean ridge basalts. Furthermore, this heterogeneity may indicate that the Atlantic Ocean basin has been polluted by small amounts of mantle wedge material during subduction episodes that impacted the convergent margins surrounding the ancient Iapetus Ocean. In contrast, there is evidence that the Pacific Ocean basin is nearly four times older and has a more extended history of upper mantle convection, which has flushed out continent-derived components.

Douglas Palmer, Sedgwick Museum

CO2 content beneath northern Iceland and the variability of mantle carbon, Hauri, Erik H. and Maclennan, J. and McKenzie, D. and Gronvold, K. and Oskarsson, N. and Shimizu, N. (2018) is published in *Geology*.



14 millimetre-sized tephra fragments from Borgarhaun in an epoxy mounting medium. The darker grey blocky pieces are olivine crystals within which there are pale grey melt inclusions, two of which are clearly seen in the central olivine. Image: Euan Mutch.