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Intrusion of basaltic sills into organic-rich mudstones, Isle of Skye, Scotland

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Injection of basalt sills into organic rich sedimentary rocks, including coal, has been proposed as a mechanism to augment the carbon release from flood basalts (e.g., Svensen, H. et al. 2009. Earth and Planetary Science Letters 277: 490-500). Release of isotopically light carbon (incorporated in CH_4 or CO_2) may also account for the negative carbon isotope excursions reported for contemporaneous ocean waters. Data to help constrain models for the production and eventual release of such gases into the atmosphere-ocean system are, however, scarce. High-resolution sampling of host mudstones adjacent to different sills of various thicknesses has the potential to provide information about the chemical and physical impact of heating, in particular the fate of carbon released from the heated contact zone (the 'near-field') into the far-field and surface environment.

Basaltic Palaeogene sills intrude near-horizontal Jurassic mudstones at several localities on the Trotternish Peninsula, in northern Skye, Scotland. The sills were emplaced at shallow depth; depending on the timing of emplacement relative to the overlying basalt lavas, the depth may have been as little as a few hundred metres, to as much as 2 kilometres. Several contact zones were sampled in 2009 from sites along the Trotternish coast, and in Elgol, southern Skye.

Preliminary studies of an organic-rich shale (original composition approximately 5 wt % C) adjacent to an 8 m thick dolerite sill near Bearreraig Bay reveal a zone of progressive carbon loss that extends approximately 40 cm from the contact. Within the sampled interval, approximately 50% of the original C is lost from this 40 cm wide near-field zone. Complete carbon loss is restricted to a few cm of hornfels at the sill-sediment contact. The loss of C is accompanied by an increase in δ^{13}C of about 1‰ indicating isotopic fractionation due to selective loss of isotopically light-carbon compounds (methane?), and/or local mixing with isotopically heavier magmatic C.

Assuming that the host rock had a uniform, pre-intrusion carbon content (5%) throughout the lower (and upper – not seen) near-field zones, and assuming that 50% of the carbon is released from the near-field zones during heating, the maximum amount of C released from both zones during the thermal event is estimated to be 50 kg C per m^2 of sill. For a sill of theoretical areal extent of 1000 km^2 (which for an 8 m thick sill would represent approximately 8 km^3 of magma, a much smaller volume than a typical flood basalt flow unit) this equates to approximately 50 Mt C . By comparison, the sill, with a volume of 8 km^3, a pre-emplacement C content of 9000 ppm, and assuming 50% C loss during emplacement, could release 27 Mt C, giving a theoretical combined release of approximately 77 Mt C. However, the amount of C eventually released to atmosphere will be significantly less, because the compounds expelled from the near-field must first migrate to the surface. Condensation of vapour phases in the cooler far-field zone, and reaction of solutions with country rocks, in addition to limited permeability of the host rocks, will restrict this expulsion.

Work is planned to extend the study to a range of sill thicknesses, and to evaluate the types of reaction and fractionation that occur within the near- and far-fields.