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Knowns and Unknowns in the Deep Earth Carbon Cycle

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There exist two carbon cycles on the Earth. The surface carbon cycle exhibits rapid movement of carbon through multiple biotic and abiotic reservoirs via the processes of biological respiration-photosynthesis, combustion of organic matter (by nature and man), weathering and burial of carbonaceous sediment, and exchange of CO_2between the oceans and atmosphere. Yet the surface carbon cycle contains less than half of the Earths budget of carbon. The deep-Earth carbon cycle contains most of the Earths carbon, yet its characteristics are poorly understood when compared with the surface cycle. The deep Earth contains multiple carbon-bearing reservoirs; sizes, ages, distributions and forms of the carbon in these deep-Earth reservoirs are poorly understood, and the abundance of carbon in each reservoir is unknown. It is apparent that carbon can form a variety of stable compounds at the high-pressure conditions of the Earths interior (diamonds, carbonates, graphite, C-O-H fluids and melts), but the presence of these carbon-bearing compounds is highly dependent on the abundance not only of carbon, but also hydrogen, oxygen, nitrogen and sulfur. Even more poorly-understood are the chemical exchange reactions between carbon and the silicate minerals of the Earths interior, the solubility of carbon in common deep-Earth minerals, and the chemical environment of carbon within these minerals.
The interface and interconnection of the surficial and deep-Earth carbon cycles are volcanoes and subduction zones. The deep-Earth cycles of carbon and water are closely linked, and the volatile systematics of magmas erupted at mid-ocean ridges, back-arc basins and convergent margins are key to observing the magmatic expression of the deep carbon cycle. We illustrate this by examining selected case studies from the Pacific Ocean. Mid-ocean ridge basalts from seamounts and intra-transform spreading centers provide small batches of melt that escape large-scale mixing at the ridge axis, and the data indicate the presence of depleted and enriched upper mantle components with different C and H_2O contents. Volatile-rich melt inclusions from Mariana arc-front volcanoes consistently range to higher CO_2/Nb than Pacific MORB, and these high CO_2/Nb ratios persist into the mantle behind the arc, as expressed in cross-chain volcanoes. Mariana Trough glasses and melt inclusions have CO_2/Nb ratios that do not exceed the values observed in Pacific MORB, suggesting minimal transport of subducted carbon into the back-arc.
Calcium carbonate is the most abundant alteration mineral in subducted MORB; altered MORB can approach 5% CO_2in the oldest oceanic crust subducting beneath the Mariana arc. Volcanic degassing studies indicate that only 5-10% of subducted $CO_2$is returned to the atmosphere in arc volcanoes. If average subducted MORB worldwide contains at little as 1% $CO_2$and 90% of this carbon is carried into the mantle, the rate of carbon subduction would deplete the exosphere of carbon in only ~300 million years. It is clear that we have not yet identified all the pathways of carbon delivery between the Earths mantle and its surface reservoirs, and the fluxes even along known pathways are very poorly estimated. Strategies to improve our understanding of the deep carbon cycle will be presented at the meeting.

Keywords: carbon cycle, magma, volcano degassing, mantle convection, subduction, water cycle