Deep Carbon Observatory Thematic Institute:

Carbon from the Mantle to the Surface

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Presentation Highlights

Arellano, Santiago; Bo Galle and the NOVAC and DECADE collaborations: *On the time-dependent distribution of volcanic plume degassing intensity and its relation to the global emission of volcanogenic carbon.*

- Statistics of 5 years of ground-based remote sensing measurements of volcanic fluxes of SO2 on 16 volcanoes of the NOVAC network show that volcanic SO2 emission follows a heavy-tailed distribution.
- The distribution of changes in passive degassing intensity is modelled as alpha-stable, with a parameter alpha related to bulk properties of the magma, and indicates that passive degassing occurs close to a percolation threshold.
- This finding will help to improve the global time-averaged estimates of carbon emission, especially because volcanic CO_2 is being monitored in combination with SO2 within the DECADE-DCO initiative.

Arzilli, F. and Burton, M.: *Metamorphic devolatilization of subducting slabs: implications for CO_2 recycling.*

- We simulate the subduction of carbonate-bearing sediments.
- We investigate the metamorphic decarbonation through thermodynamic modelling.
- We study the CO_2 derived from the slab beneath the forearc and subarc regions.

Asimow, Paul and Mark Ghiorso: *New MELTS CO_2 -H_2O model, from carbonatites to degassing*

- Ghiorso and co-authors have developed a new version of rhyoliteMELTS with H_2O-CO_2 mixed volatile systematics that accurately reproduces vapor saturation and degassing behavior.
- Preliminary application of this model to high-pressure carbonated peridotite melting schematically gives the correct behavior of carbonatite and silicate melt production.
- Calibration efforts are underway to make a similar extension built on pMELTS for more accurate high-pressure behavior.

Avanzinelli, R., E. Ammannati, M. Casalini, T. Elliott, D.E. Jacob, S.F. Foley, S. Conticelli. *Recycling of carbon-rich sediments in the mantle source of silica-undersaturated ultrapotassic Western Mediterranean magmas.*

- Ultrapotassic magmas in Central Italy are either leucite-free or leucite-bearing
- Silica-undersaturated, leucite-bearing magmas require high XCO_2 during melting
- Geochemical and isotope data suggest the involvement of recycled carbonated sediments

Beaudry, Patrick; Marc-Antoine Longpré, Rita Economos, Boswell Wing, Thi Hao Bui and John Stix: *Sulfur isotope fractionation during degassing of Canary Island magmas*

• Magmas from the 2011-2012 eruption at El Hierro, Canary Islands, were exceptionally volatile-rich (in S, H_2O, CO_2).
• Open-system degassing of sulfur was accompanied by strong S-isotope fractionation.
• Triple S isotopes in phenocryst-hosted sulfide globules show only mass-dependent fractionation.

Bercovici, David. *Some open questions on the driving mechanisms and feedbacks of volatile sources and sinks.*
• Volatile cycles basically describe mass exchange between the Earth's interior and surface.
• Mantle dynamics and surface tectonics control the rates of these mass source and sinks, and many parts of this "engine" remain unresolved.
• We will examine a few open questions involving mantle melt transport of volatiles into the "source", and the influence of volatiles on the tectonic "sink"

Carter, Laura B. and Dasgupta, Rajdeep: *Basalt-Limestone and Andesite-Limestone Interaction in the Arc Crust—Implications for Volcanic Degassing of CO_2*
• Limestone assimilation increases with increasing T, decreasing P, increasing melt SiO2
• Ultracalcic, SiO2-poor melts, plagioclase, CaTs cpx, and scapolite are produced
• Limestone assimilation could release ≤1.2-1.4×10^12 g/y CO_2 in one Vesuvius-like system

Cartigny, Pierre. *Carbon in the Earth's mantle: Some obvious and weaker aspects of its cycle*.
• Carbon is massively exchanged between the Earth's surface and the deepest part of the mantle; is at steady state.
• Mantle-residence time is long (> 2 Gy).
• This leads to the possibility that some primordial heterogeneity still exists : d13C-values close to -4 per mille are likely

Castillo, Paterno R.: *The recycling of marine carbonates and sources of HIMU and FOZO ocean island basalts.*
• Recycled marine carbonate is a natural HIMU and has low 87Sr/86Sr and Rb/Sr ratios.
• Subducted slab has high U/Pb (1st Pb paradox) and low Th/U (2nd Pb paradox).
• Radiogenic Pb isotopes of oceanic basalts as potential tracer of recycled carbonates.

Chiodini, Giovanni: *Measurement of* CO_2 *fluxes at regional scale: the case of Apennines, Italy*
• We map and quantify the total C dissolved in large aquifers deriving CO_2 fluxes
• In Italy large degassing structures releases globally significant amount of CO_2
• A mutual relation links CO_2 degassing and seismicity

Ferguson, David; Yinqi Li and Charles Langmuir Harvard University: *Constructing a long-term record of mid-ocean ridge magma compositions.*
• Links between mid-ocean ridge magmatism and climate are difficult to evaluate as records of MOR magma compositions are short relative to glacial cycles.
• Volcaniclastic material hosted in seafloor sediments can be used to measure the composition of MOR lavas over 10s kyrs
• We present preliminary results from a new time-series of lava compositions from the Juan de Fuca ridge

Fischer, Tobias. Alessandro Aiuppa, Bo Galle, J. Maarten de Moor, Patrick Allard. *Global Deep Carbon Fluxes.*

- Globally about 14 volcanoes are monitored continuously for CO_2 flux and about half of those as a direct result of the DCO-DECADE efforts.
- Short-term (days) variations in C/S and gas fluxes provide new insights into phreatic eruption dynamics and allow precise forecasting of eruptions and their size.
- Correlations of C/S ratios in gases from arc volcanoes with petrological tracers show how different fluids from the slab affect gas compositions.
- This approach also allows for the identification of crustal carbon contribution to volcanic gas discharges.
- CO_2 degassing along faults in continental rifts, such as the East African Rift, contribute significantly to the global deep carbon emissions in addition to those from active volcanoes.

Foley, Stephen: *Carbon-bearing melts and fluids in mass transport and mantle evolution*

- Beginning of melting in the mantle is governed by volatile mixtures including carbon.
- Amount of melt and temperatures over which incipient melts operate varies with composition.
- Trace elements in olivine decipher source rocks and recognize carbonate-rich metasomatism

Gaillard, Fabrice. *The geodynamics of mantle melting and its geophysical expression*.

- Melting in the asthenosphere is related to CO_2 , H2O and redox.
- We convert this melting process into a geophysical signal.
- The low velocity zone, the asthenosphere, is due to CO_2 -rich melts.

Gaillard, Fabrice. *Carbon outgassing from a cooling planet and atmospheric chemical changes.*

- Cooling of the Earth's Mantle modified its melting regime.
- Hotter mantle must imply more reduced melts
- Less carbon was outgassed during the Archaean

Gazel, Esteban; Lowell Moore, Robert Bodnar. Geosciences, Virginia Tech: CO_2 *in melt inclusion bubbles.*

- To measure CO_2 in magmas we use melt inclusions (MI), droplets of melt trapped inside a crystal. MI can hold CO_2 dissolved in the melt, within vapor bubbles or as carbonate.
- Our recent study (Moore et al., 2015) shows that CO_2 contained in both the vapor and the glass phases needs to be measured to get the most accurate values.
- We found that 40-90% of the original CO_2 trapped in the MI is exsolved into the vapor bubble. • Additionally, many MI vapor bubbles also contain a carbonate mineral phase that needs to be considered if MI are to be used to determine global volcanic fluxes of CO_2 . Our goal is to continue producing this data for many locations and update estimates of CO_2 fluxes from volcanic environments.

Graham, D. W. - Oregon State University P. J. Michael -The University of Tulsa K. H. Rubin - University of Hawaii: *Variations in magmatic He,* CO_2 *and δ13C during the 2005-2006 seafloor eruption near 9°50'N on the East Pacific Rise.*

- The 2005-2006 lavas were volatile saturated in the crust at 1.4-2.2 km depth

- Vesicle CO_2 /He varies from kinetic fractionation during magma ascent and eruption
- Vesicle δ13C and CO_2 follow closed-system degassing behavior (no bubble loss)
- Total CO_2 /He varies from open-system degassing prior to or during crustal magma storage

Hauri, Erik; Alberto E. Saal, Marion Le Voyer, Elizabeth Cottrell, Katherine Kelley. *Measuring the C content of the mantle with melt inclusions.*

- Magmatic degassing expels CO_2 during eruption and prevents simple determination of C in magmas.
- Rare suites of C-undersaturated melt inclusions have been trapped prior to degassing.
- These melt inclusions can be used to directly determine the C content of their mantle source.

Hesse, Marc and Kiran Sathaye: *Large* CO_2 *accumulations in cratonic continental crust*

- Very large, 1.5 $GtCO_2$, accumulations of exist in stable cratonic crust over millennial timescales
- These volatiles have moved through crust without mobilizing much of the accumulated radiogenic noble gases, suggesting highly localized flow.
- Although 3He/4He rations suggest mantle input and a volcanic source, other volatiles commonly associated with volcanic emissions are absent

Horton, F., B.R. Hacker, R. Holder: CO_2 *flushing of the lower crust: Insights from the charnockite domain exposed in Madagascar and southern India*

- Crustal thinning likely destabilized carbonate minerals in the mantle lithosphere.
- The resulting CO_2 dehydrated >100,000 km2 of lower crust at the end of orogenesis.
- CO_2 -rich fluids removed heat producing elements, stabilizing of the lower crust.

Howell, D., F. Brenker, S. Kohn, G. Bulanova, C. Smith, A. Thomson, F. Nestola, P. Tack, J. Garrevoet, B. Vekemans, L. Vincze, M.J. Walter: *Carbonate inclusions in super-deep diamonds: Tracking the deep carbon cycle.*

- Identification of carbonate phases in sublithospheric diamonds has shown evidence of carbon being subducted into the transition zone
- Carbonates are rare inclusions that are very understudied due to them commonly being very small in size.
- We report non-destructive in situ analyses of these carbonate inclusions to elucidate more direct evidence of the deepest aspect of the carbon cycle

Huang, Fang and Dimitri A. Sverjensky. *Speciation and Sources of aqueous fluid inclusions in diamonds.*

- We identified sources of three end-members of fluid inclusions in diamonds;
- We modeled the speciations of major elements in these fluids;
- Organic carbons might be important under diamond formation conditions.

Jackson, M.G. and A.M. Jellinek: Connections between the bulk composition, geodynamics and habitability of the Earth.

- The bulk composition of the Earth is critical for its geodynamic evolution.
- A reduction in the U, Th and K content of the planet requires a modified plate tectonic regime over time.

• This plate tectonic regime drives volcanic degassing that yields a clement climate over time.

Keller, Tobias; Richard F Katz Institute: FOALAB, Dept. Earth Sciences, University of Oxford, UK. *Reactive melting and melt transport in carbonated peridotite beneath mid-ocean ridges.*

• A novel reactive disequilibrium multi-component melt model is introduced to model mantle melting with volatiles.
• Melt model recovers leading order characteristics of mantle melting with carbon dioxide (and water).
• Reactive melting leads to flow instabilities, which give rise to strongly heterogeneous carbon flux through the mantle.

Kelemen, Peter and Manning, Craig. *Revisiting the subduction zone carbon cycle: What goes down, mostly comes up.*

• Whereas previous reviews suggest that about half of subducted carbon is recycled into the convecting mantle, we found that subduction zone inputs and outputs may be balanced on a 5 to 10 Myr time scale.
• If so, the carbon content in the plates + oceans + atmosphere is increasing over geologic time.
• Subduction zone outputs may be larger than arc volcanic and diffuse output to the atmosphere and oceans, indicating substantial subsurface storage of carbon in the lithospheric mantle and crust.

Kellogg, Louise; University of California, Davis: *Modeling and Visualization for the Deep Carbon Observatory.*

• Mathematical and computational modeling provides a framework for interpreting observations related to carbon in Earth's interior through multiscales of space and time.
• Well-thought-out scientific visualization is not only a means to communicate but also a key component to the research itself.
• The talk will discuss the challenges and opportunities enabled by new technological developments.

Lambart, Sarah; Heather Savage, Peter B. Kelemen: *CRACK OR CLOG? Investigation of the reactive-cracking process and implications for the global carbon cycle.*

• The pressure of crystallization is higher than the tensile strength of rocks
• Reactive-cracking can happen under confining pressure
• Peridotite carbonation can be self-propagating.

La Spina, Giuseppe; Mike Burton; Mattia de' Michieli Vitturi: CO_2 *influence on magma ascent dynamics: a numerical investigation***.**

• The presence of CO_2 in the magmatic mixture induces the exsolution of H2O at depth.
• CO_2 has a strong influence on temperature and crystallization during the ascent.
• Extensive dehydration of magma was not observed even with very high CO_2 contents.

LeVoyer, Marion. *Heterogeneities in mantle carbon content assessed from Mid-Oceanic Ridge basalts*

• We found new C-undersaturated melt inclusions from the Equatorial Mid-Atlantic Ridge.

• CO_2 contents in the inclusions correlate with highly incompatible trace elements.
• We calculated an average mantle carbon content of 137±54 ppm CO_2
• We modeled a global mantle carbon ranging from 20 to 1200 ppm CO_2 .

Longpré, Marc-Antoine; John Stix, Andreas Klügel and Nobumichi Shimizu: *Carbon- and sulfur-rich oxidized magmas feed Canary Island volcanoes*

• Basanite magma erupted in 2011-2012 at El Hierro, Canary Islands, is extremely enriched in incompatible trace elements, such as Nb.
• Melt inclusions contain much higher concentrations of CO_2 , H2O and S than typical OIB or MORB.
• Sulfur speciation indicates that the initially oxidized magma became reduced upon degassing.

Lowenstern, J.B; Bergfeld, D.B., Evans, W.C., Hurwitz, S. (All at USGS Menlo Park) *Sorting out mantle versus crustal degassing at Yellowstone.*

• Yellowstone is one of earth's major CO_2 natural sources, fed by degassing of isotopically heavy carbon (-3.5 per mil) from the mantle.
• Studies of radiogenic He flux reveals radical changes in crustal permeability over geologic timescales.
• Rayleigh /boiling/degassing of geothermal waters has minimal impact on regional variations in gas chemistry.

Lucic, Gregor; John Stix, Boswell Wing: *Structural controls on the emission of magmatic carbon dioxide gas, Long Valley caldera, USA*

• Regional and resurgence faults control magmatic CO_2 emissions from Long Valley
• CO_2 in soil gases reflects a mixture of magmatic, biogenic and atmospheric C
• Cavity ring-down spectroscopy enables field based, same day measurements of CO_2 and δ13C

Lundstrom, Craig, O. Sigmarsson, T. Fisher, D. Zakharov: *Examining silicate-carbonatite cycles at Ol Doinyo Lengai through geochemical observation and laboratory experiments.*

• U-series disequilibria for silicates through carbonatite show large disequilibria in all parent daughter pairs.
• Fe isotope ratios show offsets between carbonatites and silicates
• Temperature gradient experiments involving nephelinite plus water-carbonate fluid show differentiation by thermal migration

Malowany, Kalina: *Spatial and temporal $^{13}C/^{12}C$ trends on Turrialba volcano, Costa Rica*

• Field-based isotopic study of CO_2 using a cavity ring-down spectrometer (CRDS).
• Heterogeneous isotopic composition of CO_2 from the high temperature vent, the plume gas and hydrothermal soil samples.
• High temperature vent samples show most magmatic values; hydrothermal system has modified CO_2 isotopic composition of fumarolic and soil gases.

Malinverno, Alberto and Ernesto A. Martinez: *The effect of temperature on organic carbon degradation in marine sediments*

- We examine the particulate organic carbon (POC) content of sediments sampled by deep ocean drilling.
- POC degradation during burial fuels subseafloor microbial life.
- POC degradation is more pronounced where sediments experienced higher temperatures.

Mazza, Sarah E., & Esteban Gazel: *Intraplate Volcanism and Deep Carbon Reservoirs in the Atlantic*

- Processes such as lithospheric delamination, edge driven convection, and mantle plumes can be related to the source of intraplate volcanism in the Atlantic.
- There is a clear relationship between silica under-saturated melts and a HIMU mantle-type endmember.
- Recycling of a carbonated reservoir into the mantle is thus required for the generation of silica under-saturated melts.

Menzel, Manuel D.; Garrido, Carlos J.; Sanchez-Vizcaino, Vicente Lopez; Claudio Marchesi; Padron-Navarta, Jose Alberto; Fumagalli, Patrizia: *The role of serpentinites in the deep carbon cycle – from sink to source*

- Listvenites can be used as a natural proxy of low P/T carbonation of abyssal serpentinites
- During subduction, blackwalls and metasomatic veins indicate coupled dehydration of serpentinite and decarbonation of marble at serpentinite-marble interfaces
- We will conduct high pressure experiments to investigate the role of COH fluids during dehydration of serpentinites

Michael, Peter J. - The University of Tulsa David W. Graham - Oregon State University. *The Behavior and Concentration of* CO_2 *in the Suboceanic Mantle: Inferences from Undegassed Ocean Ridge and Ocean Island Basalts*

- Depleted ocean basalts that erupt undersaturated in CO_2 have constant CO_2 /Nb or CO_2 /Ba.
- For ultradepleted through enriched ocean ridge basalts, CO_2 /Ba =105±9, averaged by ocean.
- CO_2 flux from mid-ocean ridges calculated with the CO_2 /Ba ratio is 1.25 x 1014g/yr.
- Calculated mantle CO_2 content depends more on melt models than on the CO_2 /Ba ratio.

Moore, Lowell R. ; Esteban Gazel, Rosario Esposito, Robert J. Bodnar: *Micro Raman* CO_2 *densimetry and applications for melt inclusions*

- Raman spectroscopy was used to determine the CO_2 content of bubble-bearing melt inclusions.
- We analyzed bubble-bearing melt inclusions from Kilauea (Hawaii), Fuego (Guatemala), and Seguam (Aleutians).
- Typically, if a bubble is present, 50-90% of the CO_2 in a MI is contained in the bubble, and CO_2 contents of MI that include the bubble are 1000s of ppm greater than those that do not.

Peuble, Steve: *The fate of Carbon during the experimental serpentinization of peridotites*.

- H2 and C-compounds synthesis during the alteration of peridotites.
- Pore scale transport/kinetics coupling favors fast CO_2 trapping in peridotites.
- Fluid flow and crystallographic orientation control the carbonation of peridotites.

Piccoli F., Vitale Brovarone A., Beyssac O., Martinez I., Chaduteau C.: *Rock carbonation by fluid-rock interactions during HP metamorphism: implications for Carbon cycling in subduction zones.*

- We performed a petrological and geochemical study of eclogite-facies metasomatic marbles.
- We performed stable isotope geochemistry analyses for carbonates and silicates.
- We propose a mechanism for carbonate precipitation at HP condition by fluid-rock interactions.

Russell, J.K.; C. Brett & T.J. Jones: *Kimberlite: Rapid Ascent of Lithospherically Modified Carbonatitic Melts*

- Kimberlites are carbonatitic melts modified by rapid ascent through mantle lithosphere
- Carbonatitic melts assimilate orthopyroxene causing a drop is CO_2 solubility and deep-seated vesiculation
- Assimilation-induced buoyancy leads to turbulent ascent and mechanical milling of mantle cargo.

Schmidt, Max W.: *Sediment melting at sub-arc conditions: a full parametrization of melt fractions and compositions and the mode of* CO_2 *transfer to the arc and deep mantle.*

- Sediment melts are highly siliceous granites only varying in K/Na ratio as a function of H2O-content and pressure
- Melting of carbonated sediments invariably produces also fluids which may contain more CO_2 than the melt
- CO_2 transfer to the arc only through leaching by fluids originating from underlying serpentine

Shirey, Steven B: *Mantle Carbon Pathways from Diamonds and Their Inclusions*

- Diamonds and their inclusions record the source of their carbon and its relationship to geologic processes.
- Craton-margin subduction, continental collision and plume magmatism are the major source of carbon and other volatiles to the continental lithospheric mantle.
- In the convecting oceanic mantle, slab subduction provides carbon and other volatiles to the mantle transition zone.

Sieber, M., G. Yaxley, J. Hermann: *Experimental demonstration of carbonation of serpentinite by slab-derived C-O-H fluids - a possible new fore-arc reservoir for carbon.*

- Carbonation of serpentinites by C-O-H fluids is controlled by the aCO_2 in the fluid
- With decreasing XCO_2 in the fluid Mg in carbonates increase and Ca, Fe, Mn decrease
- Carbonation of serpentinites occurs quickly and leaves a well-defined reaction front

Speelmanns, Iris M.; Carolin E. Höfer, Christian Liebske and Max W. Schmidt: *Experimental determination of nitrogen and carbon isotope fractionation between metal- and silicate melts*.

- We investigate N and C partitioning between metal and silicate melts
- N and C behaviour is studied by high pressure and temperature experiments
- N and C behaviour is investigated under the focus of early Earth conditions

Stagno, Vincenzo: *Carbonate melts, diamonds and carbides*.

- We investigated the mantle redox state during the Archean
- We determined the fo2 at which carbonate reduces to diamond during subduction
- We performed experiments in the C-Fe system with implications for the origin of carbide inclusions in diamonds

Tao, Renbiao: *Oxygen fugacity and deep carbon cycle in the S. W. Tianshan subduction zone*

- Various carbon-bearing phases have been identified in the S. W. Tianshan oceanic subduction zone
- We constrained the oxygen fugacity evolution of S. W. Tianshan subduction zone
- The abiotic hydrocarbons have been naturally observed and experimentally synthesized at high pressure conditions

Teagle, Damon A.H.; Jeff C. Alt, Rosalind M. Coggon, Michelle Harris, Chris Smith-Duque, Mathis P. Hain: *Carbon in the seafloor*.

- The upper ocean crust is a sink for C through the precipitation of calcium carbonate during low temperature ridge-flank hydrothermal alteration;
- There is substantially more carbonate in Mesozoic ocean crust than younger ocean crust;
- The precipitation of carbonate is episodic not continuous and may record past ocean chemistry.

Tiraboschi C., Tumiati S., Ulmer P., Pettke T., Poli S. *Solubility of forsterite + enstatite and magnesite + enstatite in high-pressure COH fluids.*

- We investigated COH fluids in equilibrium with forsterite+enstatite or magnesite+enstatite.
- We measured the amount of SiO2 and MgO in the aqueous fraction of buffered COH fluids
- We employed for the first time the cryogenic LA-ICP-MS technique on double capsule experiments

Tucker, Jonathan (Harvard University) Sujoy Mukhopadhyay (UC Davis) Helge Gonnermann (Rice University): *Reconstructing mantle carbon and helium contents from degassed MORBs.*

- Carbon and noble gases are kinetically fractionated during MORB degassing.
- A quantitative disequilibrium degassing model can predict undegassed compositions.
- Poorly constrained solubilities and diffusivities complicate robust predictions.

Vuilleumier, Rodolphe; Ari P. Seitsonen, Nicolas Sator and Bertrand Guillot: CO_2 *speciation and transport properties of* CO_2 *-bearing silicate melts from First-Principle simulations.*

- The equation of state of pure $CaCO_3$ and viscosity were determined
- The adiabat of $CaCO_3$ show that carbonate volcanism is possible only with a hot mantle such as the archean mantle
- CO_2 forms mainly free carbonates at rhyolitic compositions but is incorporared in the alumino-silicate structure at basaltic compositions

Wanless, V. Dorsey and Mark D. Behn: *Carbon Flux from Mid-Ocean Ridges Based on Volatile Contents from Olivine-Hosted Melt Inclusions*

- Maximum CO_2 contents in the melt inclusions are similar at all 5 ridges.
- Total mid-ocean ridge degassing flux estimates range from 3.36 ± 0.77 x10^14 to 1.57 ± 0.37 x10^14 g/yr .
- More than half of the total CO_2 released by melting beneath mid-ocean ridges may remain trapped in the lithospheric mantle.

Weiss, Yaakov, John McNeill, D. Graham Pearson, Geoff M. Nowell, Chris J. Ottley: *Highly saline fluids from a subducting slab as the source for fluid-rich diamonds.*
- Diamonds provide unique means to characterize fluids in the deep lithosphere.
- Highly-Saline fluids are parental to in-situ forming silicic and carbonatitic melts.
- Fluid chemistry indicate subducting slab as the source of the saline compositions.

Wirth, Richard: *Nanoinclusions and microstructure in diamond : indicators for diamond genesis*
- Nanoinclusions in diamond represent the source of diamond nucleation and growth
- Nanoinclusions in diamond are characteristic for their different origin
- Microstructural features characterize diamonds

Zhu, Jianjiang; Lifei Zhang, Yingwei Fei, Renbiao Tao: CO_2 *released from carbonated eclogites during their exhumation.*
- Aqueous fluids released by dehydration reactions of carbonated eclogites will dissolve carbonate minerals along their flow paths.
- Graphite can precipitate from C-H-O fluid at appropriate redox state
- The formation of graphite is inhibited during exhumation as a result of increasing oxygen fugacity and cause CO_2 release