

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 CO₂ is being monitored in combination with SO₂ within the DECADE-DCO initiative.

Arzilli, F. and Burton, M.: *Metamorphic devolatilization of subducting slabs: implications for CO₂ recycling.*

- We simulate the subduction of carbonate-bearing sediments.
- We investigate the metamorphic decarbonation through thermodynamic modelling.
- We study the CO₂ derived from the slab beneath the forearc and subarc regions.

Asimow, Paul and Mark Ghiorso: *New MELTS CO₂-H₂O model, from carbonatites to degassing*

- Ghiorso and co-authors have developed a new version of rhyoliteMELTS with H₂O-CO₂ 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 XCO₂ 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, H₂O, CO₂).
- 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"

Carn, Simon A.: *Satellite measurements of volcanic degassing*

- Satellite measurements of CO₂ are challenging but SO₂ measurements are robust for eruptive degassing and for major sources of passive degassing
- Combining satellite measurements of SO₂ emissions with CO₂/SO₂ ratios is the best approach to estimate volcanic CO₂ fluxes
- Estimated eruptive CO₂ fluxes are ~39-116 Tg/yr with significant uncertainty (up to ~20% of estimated global subaerial volcanic CO₂ emissions)
- Satellite measurements combined with ground-based and in-situ data can improve constraints on passive (non-eruptive) plume CO₂ emissions

Carter, Laura B. and Dasgupta, Rajdeep: *Basalt-Limestone and Andesite-Limestone Interaction in the Arc Crust—Implications for Volcanic Degassing of CO₂*

- 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 $\leq 1.2-1.4 \times 10^{12}$ g/y CO₂ 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 : $\delta^{13}\text{C}$ -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.

Childress, Laurel and Neal Blair: *Sedimentary Organic Carbon: Active Margin Inputs and Fluxes*

- The nature of organic carbon input to subduction zones drives the subsequent reactivity of these materials
- Organic carbon may remain as near surface volatiles or include with deeper subduction packages
- Variability between margins characterized by subduction or accretion of sediment packages influences distribution of organic carbon in the subsurface

Chiodini, Giovanni: *Measurement of CO₂ fluxes at regional scale: the case of Apennines, Italy*

- We map and quantify the total C dissolved in large aquifers deriving CO₂ fluxes
- In Italy large degassing structures releases globally significant amount of CO₂
- A mutual relation links CO₂ 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 CO₂ 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.
- CO₂ 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

Frezzotti, M.L.: *Carbon in Upper Mantle Fluids: What Do We Still Need to Measure?*

- Deep subduction fluids are dominantly aqueous and contain relevant amounts of dissolved silica and alumina, ions, metal complexes, and polymerized species.
- The analyses of natural fluids show some evidence for carbon speciation in H₂O as ionic carbonate, and, possibly, organic species.

- In the lithosphere away from subduction zones, carbon mobility appears related to reacting and degassing of carbonate rich-melts.

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

- Melting in the asthenosphere is related to CO₂, H₂O and redox.
- We convert this melting process into a geophysical signal.
- The low velocity zone, the asthenosphere, is due to CO₂-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: *CO₂ in melt inclusion bubbles.*

- To measure CO₂ in magmas we use melt inclusions (MI), droplets of melt trapped inside a crystal. MI can hold CO₂ dissolved in the melt, within vapor bubbles or as carbonate.
- Our recent study (Moore et al., 2015) shows that CO₂ 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 CO₂ 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 CO₂. Our goal is to continue producing this data for many locations and update estimates of CO₂ 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, CO₂ 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 CO₂/He varies from kinetic fractionation during magma ascent and eruption
- Vesicle δ¹³C and CO₂ follow closed-system degassing behavior (no bubble loss)
- Total CO₂/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 CO₂ 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 CO₂ accumulations in cratonic continental crust*

- Very large, 1.5 GtCO₂, accumulations 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 $^3\text{He}/^4\text{He}$ ratios suggest mantle input and a volcanic source, other volatiles commonly associated with volcanic emissions are absent

Horton, F., B.R. Hacker, R. Holder: *CO₂ 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 CO₂ dehydrated >100,000 km² of lower crust at the end of orogenesis.
- CO₂-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.

Kagoshima, Takanori: *Geodynamic cycles of carbon and sulfur*

- Carbon flux from the mantle was estimated based on currently accepted mantle ^3He flux and CO₂/ ^3He ratios in the mantle and volcanic gases.
- Sulfur flux from the mantle was also estimated based on currently accepted mantle ^3He flux and S/ ^3He ratios observed in MORB, hydrothermal fluids, and volcanic gases.
- The constant C/S flux ratio during the Earth history may explain their present surface inventories.

Keller, Tobias and Richard F Katz *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.

Kueter, Nico; Max. W. Schmidt, Marvin. D. Lilley, Stefano M. Bernasconi: *High-T carbon isotope fractionation between COH-fluids and elemental carbon: first results*

- Experimentally observed COH-fluid speciation is in good agreement with thermodynamic speciation calculations computed for conditions at 2 kbar, 800 °C, and $fO_2 = IW+1$ to $WM+0.2$.
- Reduced, methane-dominated COH-fluids precipitate elemental carbon c. 5‰ lighter in $\delta^{13}C$. Theoretical calculations predict elemental carbon to be c. 1.5‰ heavier than the coexisting COH-fluid.
- At 800°C, 2kbar and $fO_2 = IW+1$ to $WM+0.2$, CH_4 is c. 4 to 10‰ and CO_2 c. 9 to 15‰ heavier in $\delta^{13}C$ compared to coexisting elemental carbon. Carbon isotope fractionation between CO_2 and CH_4 remains constant at $\Delta^{13}C(CO_2-CH_4)=5.2 \pm 0.68\text{‰}$ (2σ)

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: *CO₂ influence on magma ascent dynamics: a numerical investigation.*

- The presence of CO_2 in the magmatic mixture induces the exsolution of H_2O 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.
- CO₂ contents in the inclusions correlate with highly incompatible trace elements.
- We calculated an average mantle carbon content of 137±54 ppm CO₂
- We modeled a global mantle carbon ranging from 20 to 1200 ppm CO₂.

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

- Basaltic 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 CO₂, 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 CO₂ 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 CO₂ emissions from Long Valley
- CO₂ in soil gases reflects a mixture of magmatic, biogenic and atmospheric C
- Cavity ring-down spectroscopy enables field based, same day measurements of CO₂ 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

Luth, Robert; Rebecca Stone, and Isabelle Zelazny *Carbon Rising: Insights from "simple" system fluids and melts*

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

- Field-based isotopic study of CO₂ using a cavity ring-down spectrometer (CRDS).
- Heterogeneous isotopic composition of CO₂ from the high temperature vent, the plume gas and hydrothermal soil samples.

- High temperature vent samples show most magmatic values; hydrothermal system has modified CO₂ 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 subsurface 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*

- Serpentinites 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

Jennifer Middleton, Sujoy Mukhopadhyay, Jerry McManus, and Charles Langmuir: *Last Glacial Maximum and Hydrothermal Sediment Fluxes on the Mid-Atlantic Ridge*

- Changes in overlying water pressure associated with Pleistocene glacial cycles may affect hydrothermal output at mid-ocean ridges
- We measure major and trace elemental fluxes in sediment cores from the Mid-Atlantic Ridge to build a record of hydrothermal deposition for the last 50 kyr
- Data from the TAG vent field core indicate a dramatic increase in hydrothermal deposition coincident with Last Glacial Maximum and ending during the onset of glaciation

Michael, Peter J. - The University of Tulsa David W. Graham - Oregon State University. *The Behavior and Concentration of CO₂ in the Suboceanic Mantle: Inferences from Undegassed Ocean Ridge and Ocean Island Basalts*

- Depleted ocean basalts that erupt undersaturated in CO₂ have constant CO₂/Nb or CO₂/Ba.
- For ultradepleted through enriched ocean ridge basalts, CO₂/Ba = 105±9, averaged by ocean.
- CO₂ flux from mid-ocean ridges calculated with the CO₂/Ba ratio is 1.25 x 10¹⁴g/yr.
- Calculated mantle CO₂ content depends more on melt models than on the CO₂/Ba ratio.

Moore, Lowell R. ; Esteban Gazel, Rosario Esposito, Robert J. Bodnar: *Micro Raman CO₂ densimetry and applications for melt inclusions*

- Raman spectroscopy was used to determine the CO₂ 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 CO₂ in a MI is contained in the bubble, and CO₂ contents of MI that include the bubble are 1000s of ppm greater than those that do not.

E.M. Parmentier: *Exploring the role of melt physical property variations in melt migration: particularly viscosity and its dependence on volatiles.*

- Viscosity variations in buoyantly ascending melt in a compacting mantle can lead to viscous fingering instabilities.
- The scale of such instabilities can determine whether viscous fingering is a mechanism for the mixing of melts or the segregation of compositionally distinct melts.

Peuble, Steve, Andreani M., Daniel I., Cardon V., Grossi V.: *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 CO₂ trapping in peridotites.
- Fluid flow and crystallographic orientation control the carbonation of peridotites.

Piccoli F., Vitale Brovarone A., Beysac 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.

Pyle, Lacie. *Black carbon in soils: Landscape mobility and residence time*

- Black carbon (BC) is ubiquitous in soils and sediments.
- It is a recalcitrant form of carbon BC is produced from biomass and fossil fuel combustion and is transported to different reservoirs where it accumulates
- BC particle properties are variable, and this likely affects mobility

Ribeiro, J., R.J. Stern, K. A. Kelley, A. Shaw, F. Martinez, Y. Ohara: *Evidence for shallow dehydration of the subducting plate beneath the Mariana forearc: New insights into the deep water (and carbon) cycle at subduction zones.*

- The budget of H₂O and CO₂ are poorly constrained because we know very little about the shallow subduction processes occurring beneath forearcs.
- At cold subduction zones, water and carbon are thought to be mostly released beneath the arc front (>= 80 km depth to the slab).
- Olivine-hosted melt inclusions from Pliocene pillow lavas from the southernmost Mariana forearc show the highest H₂O/Ce (6000–19000) yet recorded in glasses from subduction zones (averaged arc lavas < 3000).

- Shallow slab fluids are more water-rich than deeper fluids released beneath arc front, and they peak at 70 - 80 km depth to the slab.

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 in CO₂ 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 CO₂ 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 CO₂ than the melt
- CO₂ 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 aCO₂ in the fluid
- With decreasing XCO₂ in the fluid Mg in carbonates increase and Ca, Fe, Mn decrease
- Carbonation of serpentinites occurs quickly and leaves a well-defined reaction front

Sisson, Tom and John Power, USGS Volcano Science Center: *Alaska-Aleutian long-period seismicity at mid-lower crustal depths - evidence for degassing through the entire arc crust*

- Active volcanic centers along the Alaska-Aleutian arc are associated with long-period seismicity at mid-crustal to uppermost mantle depths.
- Seismicity tends to be displaced 1-10 km to the side of the nearest active center, defining a seismogenic halo adjacent to an axial quiescent core.
- Fluid-enhanced embrittlement of wallrocks and marginal intrusions by egressing magmatic fluids is consistent with the style and distribution of seismicity, suggesting that magmas degas through the entire arc crustal thickness.

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 f_{O_2} 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: *CO₂ speciation and transport properties of CO₂-bearing silicate melts from First-Principle simulations.*

- The equation of state of pure CaCO₃ and viscosity were determined

- The adiabat of CaCO₃ show that carbonate volcanism is possible only with a hot mantle such as the archaic mantle
- CO₂ forms mainly free carbonates at rhyolitic compositions but is incorporated in the aluminosilicate structure at basaltic compositions

Walter, Michael, Andrew Thomson, Antony Burnham, Richard Brooker and Simon Kohn: *Superdeep diamonds and the source of deep mantle carbon*

- Mineral inclusions in superdeep diamonds record the presence of a low-degree melt, likely carbonatitic
- Superdeep diamonds, especially those from Juina, Brazil, have predominantly isotopically light carbon
- Mineral inclusions in diamonds with isotopically light and 'normal' carbon have isotopically heavy oxygen
- Superdeep diamonds and their inclusions record subduction and melting of carbonated oceanic crust, primarily in the transition zone

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

- Maximum CO₂ contents in the melt inclusions are similar at all 5 ridges.
- Total mid-ocean ridge degassing flux estimates range from $3.36 \pm 0.77 \times 10^{14}$ to $1.57 \pm 0.37 \times 10^{14}$ g/yr .
- More than half of the total CO₂ released by melting beneath mid-ocean ridges may remain trapped in the lithospheric mantle.

Werner, Cynthia. *CO₂ Degassing of Volcanoes - Active Venting and Plumes*

- Unique challenges exist for measurement of CO₂ emissions from active volcanoes
- Technological advances and new initiatives are leading to better global volcanic CO₂ estimates
- Significant CO₂ emissions can occur from volcanoes without significant SO₂ emission
- Future work should focus on deep degassing and the importance of active vs. passive degassing

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: *Nano-inclusions and microstructure in diamond : indicators for diamond genesis*

- Nano-inclusions in diamond represent the source of diamond nucleation and growth
- Nano-inclusions in diamond are characteristic for their different origin
- Microstructural features characterize diamonds

Zhu, Jianjiang; Lifei Zhang, Yingwei Fei, Renbiao Tao: *CO₂ 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 CO₂ release