TALKS

Monday 23rd September

Structure and Basin Evolution of the Caribbean-northeastern South America Arc-Continent Collision Zone From the BOLIVAR Project

Gail Christeson and BOLIVAR Science Team

The BOLIVAR Project acquired seismic reflection and wide-angle refraction data in the southeastern Caribbean. We map three seismic megasequences within the Grenada and Tobago basins using the BOLIVAR and other available seismic reflection profiles to investigate changes in sediment supply and basin evolution. The striking similarity of the half-graben structure of the Grenada and Tobago basins that flank the Lesser Antilles arc, and their similar smooth basement character, deep-marine seismic facies, and Paleogene sediment thickness suggest that the two basins formed as a single Paleogene forearc basin adjacent to the now dormant Aves Ridge. Uplift and growth of the Lesser Antilles arc divided the Grenada and Tobago basins by early to middle Miocene time. Inversion of normal faults and uplift effects along both edges of the Lesser Antilles arc are most pronounced in its southern zone of arc collision with the South American continent. The late Miocene to Recent depositional histories of the Grenada and Tobago basins are distinct because of isolation of the Grenada basin by growth and uplift of the Neogene Lesser Antilles volcanic ridge.

The velocity structures of the late Cretaceous Aves Ridge remnant arc and Miocene and younger Lesser Antilles arc are remarkably similar, which implies that magmatic processes have remained moderately steady over time. Crustal thickness is ~26 km at the Aves Ridge and ~24 km at the Lesser Antilles arc. In comparison to the Izu-Bonin and Aleutian arcs, the Lesser Antilles arc is thinner and has no evidence for a lower crustal cumulate layer which is consistent with the estimated low magma production rates of the Lesser Antilles arc. Crustal thickness beneath the Grenada and Tobago basins is 4-10 km, and the velocity structure suggests that these basins could be floored by oceanic crust. A decrease of ~1 km/s in average seismic velocity of the upper crust is observed from NW to SE across the North Coast fault zone; we argue that this marks the suture between the far-travelled Caribbean arc and the passive margin of the South American continent. Current strike slip motion between the Caribbean and South American plates is located ~30 km to the south, and thus material originally deposited on the South American passive margin has now been transferred to the Caribbean plate.

Imaging Seismic Discontinuities Beneath the North American-Caribbean Plate Boundary Using S-to-P Receiver Functions

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The evolution of the North American-Caribbean plate boundary has resulted in the formation of numerous micro-plates and a transition from oblique subduction to oblique collision moving from west to east. However, there is still much uncertainty as to how these tectonic features are expressed in the upper mantle. Here we use S-to-P receiver functions to map seismic discontinuities across the plate boundary, placing constraints on crustal and lithospheric thicknesses, as well as the structures associated with subduction and collision.

We used data from earthquakes >Mw 5.5 located at 55-80° away and recorded at 72 seismic stations located along the plate boundary from Puerto Rico through to Jamaica, and hand selected the best 1323 out of 8323 waveforms. S-to-P receiver functions were then calculated using an extended time multi-taper deconvolution followed by a depth migration to determine a 3-D image of seismic discontinuities along the plate boundary.

Velocity increases with depth are consistently seen at depths of 30-35 ± 3 km along the plate boundary, which corresponds to the Moho depth. The exception is across the Cayman trough, where we observe crustal thinning of 5 km likely related to the locally rifted crust. A second strong velocity increase with depth is observed at depths of 60-70 ± 4 km, which is observed north of Puerto Rico and in southern Hispaniola. North of Puerto Rico this feature maps well to the Moho of the subducting North American plate. Similarly, in southern Hispaniola this feature can be explained by the under thrusting of the Caribbean Large Igneous Province (CLIP) under central Hispaniola. Deeper discontinuities are not always well-resolved but a strong velocity decrease with depth is observed at a depth of 135 ± 8 km, which maps to the spatial extent of the CLIP south of the plate boundary. This feature is likely the deep Lithosphere-Asthenosphere boundary (LAB) of the CLIP. The LAB is also observed to shallow above the Beata Ridge by 25 km, which has implications for the initiation mechanism of magmatic episodes by either mantle plumes or lithospheric thinning that occurred during the evolution of the Caribbean Plate. It will also help to constrain kinematic plate reconstruction models for the region.

Active-source seismic imaging of the incoming plate: quantifying hydration patterns within the Lesser Antilles subduction system

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To-date, most of the global subduction systems studied with modern geophysical techniques are in the Pacific, where oceanic lithosphere formed at fast-spreading rates is consumed. However, crust generated by slow-spreading axes such as the Mid-Atlantic Ridge is much more heterogeneous, being formed by a combination of magmatic and tectonic extension. Here, large faults may allow water penetration and hydrothermal alteration deep into the lithosphere. Faulting is expected to increase towards seafloor-spreading segment ends where melt supply is lower. In extreme cases, low-angle detachment faults can form Oceanic core complexes (OCCs) that expose mantle rocks at the seabed. It is suggested that this along-strike variation of faulting exerts a significant control on the delivery of water to subduction zones. A key objective VoiLA was to test this hypothesis at the Lesser Antilles Arc.

We present results of an active source-OBS experiment collected during leg 3 of JC149. The line is located parallel to and about 600 km west of the islands of St Lucia to Dominica and extends ~225 km. The line spans five seafloor-spreading segments separated by three non-transform offsets (NTO) and the Marathon FZ. We have completed a tomographic inversion of 20,400 p-wave and 5,950 s-wave picks to determine the Vp/Vs ratio of the crust and upper mantle.

Throughout much of the profile we observe Vp/Vs ratios typical of dry and unaltered oceanic crust (~1.8). Areas with higher Vp/Vs ratios are found in two settings. First, values up to 1.96 but limited to the upper crust are seen at the inside corner of the Marathon FZ. More laterally localised, but deeper and higher Vp/Vs values (up to 2.09) are present in areas identified as OCCs close to the NTOs. The two modes of faulting at the ridge axis have therefore left distinct hydration signatures in the oceanic crust, which we suggest are equivalent to 6.5 - 14.0 wt% of water. Overall, these values are higher than those reported in the Pacific Ocean, confirming that the Atlantic is delivering wetter oceanic lithosphere to its subduction zones.

Hydration linked to FZs, whilst likely to vary over time, will be spatially consistent. In contrast the hydration bought by OCCs will be irregular, as the process of crustal-scale faulting is less-common and the NTOs themselves are spatially transient. Overall therefore our work shows that there should be a correlation between increased hydration and FZs on the incoming plate, but all regions of the down-going slab may be hydrated due to the presence of OCCs.

High resolution seismic imaging of the Lesser Antilles incoming plate, outer rise and accretionary prism: Implications for the hydration of slow-spreading Atlantic lithosphere

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Subduction of chemically bound water in oceanic crust has long been known to be the primary method by which volatiles are reintroduced to the mantle. It has been proposed that the amount of water stored in the slab should vary globally, depending on factors including the age, spreading rate and degree of alteration. This variable hydration can in turn exert a strong control on subduction zone processes including intraslab seismicity and arc volcanism.

Here we present the results of a new, high-resolution, 2D seismic profile, shot by the R.R.S. James Cook in 2017, across the outer-rise and accretionary prism of the Lesser Antilles arc in the region of the Tiburon Basin. The Atlantic Ocean setting presents the opportunity to test our understanding of incoming plate hydration through comparison with better studied Pacific Ocean examples. Wide-angle P-wave arrivals along the 174km profile, modelled in tomo2d, resolve clear velocity perturbations in the incoming Atlantic lithosphere. Comparison with a coincident multi-channel streamer reflection profile allow us to tie these velocity variations to tectonic features, such as the outer-rise, which is identifiable by recent extensional faulting in the overlying sediments.

As well as being the first such experiment across slow-spreading Atlantic oceanic crust our profile samples significantly older crust (>90Ma) than the majority of existing studies. We identify clear hydration of the lower crust and mantle marked by a significant reduction in lower crustal and mantle velocities from ~30km outboard of the accretionary prism. This result has implications not just for the amount of water being delivered into the Lesser Antilles subduction zone, but for the global subduction water budget as a whole.

Wednesday 25th September

La Désirade and the plate tectonic origin of the Lesser Antilles basement

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The Lesser Antilles Arc (LAA) basement comprises pre-Cenozoic arc and back-arc crust **(1, 2)**. Studies of the Greater Antilles Arc (GAA), Aves Ridge, Tobago and Venezuela have evidenced SW-dipping subduction processes since ~135 Ma, via arc magmatism including boninites and high-pressure metamorphism. However, two complications exist. Firstly, scattered subduction-related crustal and mantle units in the Caribbean demonstrably pre-date the initiation of SW-dipping subduction (e.g. La Désirade in the eastern LAA). Secondly, an explanation is required for an additional 'Malpelo' slab seen in mantle tomography beneath the Caribbean **(3)**. A plate tectonic framework for these observations can constrain the origin of the LAA basement.

La Désirade contains three thrust-bounded Late Jurassic mafic sequences (~155-145 Ma; radiolarian biostratigraphy) cut by a trondhjemite pluton (~143 Ma; U-Pb zircon CA-TIMS). Mid-Cretaceous thrusting affected the mafic units (106-107 Ma; $^{40}Ar/^{39}Ar$ on adularia) **(see 4 for references)**. La Désirade formed in an oceanic back-arc basin, based on geochemistry and likely eruption depths **(5)**. Radiolarian biozonation argues for an origin ~20° from the palaeoequator, which no current tectonic model can account for. A new palaeomagnetic study supports an origin ~8° N, firmly in the inter-American realm, initially proposed by **(5)** and now backed up by the latest reconstruction of **(6)**.

Included in **(6)** is provision that W-dipping subduction outboard of the Americas accounted for arc magmatism which formed the GAA and probably the basement to the Aves Ridge. This subduction may relate to the Malpelo slab of **(3)**. In the Early Cretaceous (~110 Ma) the southern end of the arc system collided with a pre-existing, W-facing inter-American subduction system which stretched from the Andes to the Cordillera and included La Désirade. The collision forced a subduction polarity reversal, obduction of La Désirade as evidenced by the $^{40}Ar/^{39}Ar$ dates of **(4)**, and establishment of a new arc.

Consequentially, the LAA basement will contain ubiquitous Jurassic - Early Cretaceous inter-American oceanic and arc crust as seen on La Désirade and N Tobago. Additionally, Cretaceous arc material, as exposed on S Tobago, Venezuela and the Aves Ridge, will be related to the post-reversal arc. These poorly exposed rocks show no continental isotopic signatures, but we cannot rule out periodic deposition of continent-derived sediment onto the arc, or into the trench, to explain aspects of modern LAA geochemistry. The LAA basement contains no Caribbean Oceanic Plateau material.

Refs: ***(1)*** *Allen et al. 2019 doi:10.1130/G46708/1.* ***(2)*** *Gomez et al. 2018. doi:10.1190/INT-2016-0176.1.* ***(3)*** *van der Meer et al. 2018. doi:10.1016/j.tecto.2017.10.004.* ***(4)*** *Corsini et al. 2011. doi:10.1029/2011TC002875.* ***(5)*** *Neill et al. 2010. doi:10.1016/j.lithos.2010.08.026.* ***(6)*** *Boschman et al. 2019. doi:10.1029/2018JB016369.*

Tomographic Imaging of the Puerto Rico-Virgin Islands Microplate and Subduction Zone

E.A. Vanacore

The Puerto Rico-Virgin Island (PRVI) microplate, situated along the Northeastern Caribbean margin, is a component of the highly complex oblique subduction of the North American plate beneath the Caribbean Plate. The PRVI microplate is bound to North by the Puerto Rico Trench, to the West the Mona Passage, to the South the Muertos Trough (which may also be a subduction structure), and the East by the Anegada Passage. Imaging of this subduction zone is limited by the seismic array geometry available from the local regional networks. Moreover, the use of ocean bottom seismometers is limited by the depth of the Puerto Rico Trench which reaches depths of over 8,000m. The region, however, is quite seismically active as the Puerto Rico Seismic Network locates ~3,500-4,000 earthquakes a year in the PRVI region. This seismicity makes some limited imaging of the region possible. Here the preliminary P wave tomographic results are presented using local and teleseismic sources from the implementation of the local LOTOS codes as well as the finite marching method code TOMODD. As part of the tomography calculation an updated 1D model is generated using the VELEST code to act as a stable staring model. This new 1D model is verified via comparisons with receiver functions calculated at Puerto Rico Seismic Network stations. The preliminary results not only highlight features of the local subduction zone structure, but also highlight the need for future amphibious arrays in the region to increase imaging resolution. The need for amphibious arrays is of particular interest to image the Muertos Trough and the extensional crustal structures in the Mona Passage which are not well resolvable given the current data availability. In this presentation the preliminary tomographic results and tectonic implications will be discussed as well as the pitfalls and challenges of tomographic imaging in the region such as local 1D model selection and balancing of local seismic sources due to earthquake swarm activity.

The role of arc migration in the development of the Lesser Antilles: A new tectonic model for the evolution of the eastern Caribbean from active source seismic and magnetic anomaly data

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We present a new compilation of marine magnetic anomaly and active-source seismic reflection/refraction data collected in 2017 during cruise JC149. We combine these geophysical data with geochronology and geochemistry of rock samples from the region to propose a new tectonic model for the eastern Caribbean region that includes arc migration in both directions. We conclude that since the start of the Paleogene (~60Ma) there were two phases of back-arc spreading and eastward arc migration towards the incoming Atlantic. A third and final phase of arc migration to the west subdivided the earlier back-arc basin on either side of the present-day Lesser Antilles Arc. According to our model both the Tobago and southern Grenada basins originated by back-arc extension.

Continental arc systems often show evidence of large-scale migration both towards and away from the incoming plate. In oceanic arc systems however, whilst slab roll-back and the associated processes of back-arc spreading and arc migration towards the incoming plate are commonplace, arc migration away from the incoming plate is rarely observed. To our knowledge, this is the first example of regional multi-directional arc migration in an intra-oceanic setting and has implications for along-arc structural and geochemical variations. The back and forth arc migrations are probably due to the constraints the neighbouring American plates impose on this isolated subduction system rather than variations in subducting slab buoyancy.

Can seismology image mantle water in subduction zones?

Geoff Abers

Most water in the earth's mantle is stored in two ways. At very low temperatures substantial water may be bound in hydrous minerals. These minerals (serpentines, etc.) have substantially lower elastic moduli than equivalent anhydrous silicates, so in principle should be easily detected. In cold forearcs, thermal models indicate that global H2O storage could exceed 10 wt% H2O and add to few percent of the world ocean. However, in all but the hottest subduction zones the rate at water is delivered from subducting plates via dehydration is low compared with the lifetime of most subduction zones. Seismic velocities in forearcs generally indicate little hydration consistent, with the strongest evidence for slow wavespeeds being in Cascadia where the hot slab releases most water before reaching subarc depths. Even there, new evidence suggests that a lack of forearc Moho may be more due to unusually fast upper-plate crust than hydrated mantle. In hotter parts of subduction zones water is stored as hydrogen defects in nominally anhydrous minerals such as olivine. Unfortunately, no good direct measurements exist to show how this hydration changes seismic behavior. The main effect is on seismic attenuation, which perhaps varies with viscous relaxation, and reduces wavespeed via physical dispersion. In the hot part of the mantle wedge, the case for a substantial effect of water on seismic attenuation is equivocal – the competing effect of water-enhanced grain growth means that the net effect should be minor. However, we observe very high attenuation beneath arcs and back-arcs. Laboratory-calibrated models are unable to reproduce this very high attenuation for any reasonable temperature and H2O content. Similar measurements beneath the Juan de Fuca ridge, where mantle H2O is low, show similar extreme attenuation indicating that water is unlikely to be responsible. Rather, partial melt seems to dominate these signals, even at very low melt fraction, and mask any contribution from H2O. While such effects are not well calibrated, it seems likely that seismic images are excellent tools for mapping out variations in mineralogy and melt content in the mantle.

Seismic attenuation imaging of volatile cycling in the Lesser Antilles subduction zone

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Subduction zones are key regions where water is exchanged between the solid Earth, oceans, and atmosphere. Yet, water transport within subduction zones is only partially understood. Most studies have focussed on the subduction of fast-spread lithosphere in circum-Pacific margins; however, the subduction of plates formed at slow-spreading ridges may result in a greater fluid fraction entering the deep Earth (e.g. via serpentinised fracture zones). A natural laboratory to test this is the Lesser Antilles subduction zone, under investigation by the VoiLA project (Volatile Cycling in the Lesser Antilles). To track pathways of volatiles through the subduction zone, we image 3-D variations in seismic attenuation beneath the Lesser Antilles from local earthquakes. The earthquakes were recorded by 34 broadband ocean bottom seismometers deployed for 14 months.

We inverted the amplitude spectra of P- and S-waves from 378 local earthquakes for the path-averaged attenuation operator (t*). We obtained ~2,600 and ~1,500 t* measurements for P- and S-waves, respectively. We inverted these data for a 3-D tomographic Qp and Qs model.

Our images highlight the main domains of the subduction zone. The subducting plate is imaged as a weakly attenuating structure (Qp > 250; Qs > 200), consistent with hypocentres of intermediate-depth earthquakes. We also find a low attenuation anomaly (Qp~500; Qs ~300) extending to ~80 km depth above the subducting slab beneath the forearc and arc. We interpret this low attenuation anomaly as the cold-corner of the mantle wedge. Finally, a very high attenuation anomaly (Qp ~80; Qs ~25) lying above the slab in the back-arc at 80-130 km depth is consistent with the mantle wedge asthenosphere, the core of which is laterally offset west of the arc by 50-70 km. This mantle wedge anomaly is most prominent in the back-arc behind Martinique and Dominica.

The location of the attenuating mantle wedge beneath the back-arc is consistent with local velocity tomography images from local earthquakes and teleseismic surface waves. Based on kinematic thermal-mechanical modelling of the Lesser Antilles margin, which verifies a relatively cold subduction zone, significant fluids and/or melt are needed to explain the observed high attenuation values in the mantle wedge. The location of the strongly attenuating mantle wedge is consistent with high observed B/Nb ratio, indicating high water content in magmas. Finally, the large depth extent of the cold mantle wedge corner requires a greater than normally assumed decoupling depth, possibly a common feature of slow subduction zones.

Seismic imaging of the Lesser Antilles subduction zone using S-to-P receiver functions and P-to-S delay times: Insights from VoiLA

Ben Chichester

Constraining the depths and pathways of volatiles and melt within the mantle wedge is important for a better understanding of subduction zone processes. The Lesser Antilles arc, where oceanic lithosphere generated at the slow spreading Mid-Atlantic Ridge is being subducted beneath the Caribbean plate, represents an important end-member that is helpful for global understanding. The downgoing plate is hypothesised to carry significant hydration, in particular in fracture zones and core complexes. Here, we calculate S-to-P (Sp) receiver functions using land and ocean-bottom data recorded by the VoiLA project to image 3-D structure of the overriding plate, mantle wedge, and the subducted slab.

Firstly, using *P*-to-*S* (*Ps*) scattered waves from the conversion of teleseismic earthquake *P*-waves at the crust-sediment boundary and preexisting relationships, we estimate sediment thickness beneath each OBS in order to properly rotate and migrate the Sp waveforms. We find that sediment thickness varies greatly from 0.03 km (95% confidence region: 0.01-0.05 km) on the arc-platform to 7.93 km (95% confidence region: 4.59-7.95 km) in the back-arc Grenada Basin.

Sp receiver functions illuminate a seismic velocity increase with depth that varies in depth in an undulant fashion along-arc at depths that range from 34-43 ± 4 km, shallowest beneath Dominica and Martinique and deepest beneath St. Lucia. We infer that the shallower discontinuities are mid-crustal and related to magma intrusion, whereas deeper discontinuities represent the Moho. A velocity decrease with depth is imaged beneath the northern arc and back-arc at depths of 76-79 ± 5 km, which is likely the base of the overriding Caribbean plate. Its visibility beneath the northern portion of the arc could be related to relatively greater amounts of melt ponding beneath the plate here, and possibly also more melt generation. Hints of a negative-positive phase are imaged beneath the arc in the south at depths of 105 ± 5 km and 119 ± 5 km, respectively, which may demarcate the crust of the down-going slab, possibly only visible owing to shallower slab dip in this region. Overall, our results suggest that melt ponds beneath the overriding plate relatively homogenously over a wide-spread area in the north, the visibility of which may pertain to greater volatile input in the north. Discrete serpentine sources in the slab may further preferentially provide additional melt supply, causing punctuated regions of greater magmatism and variations in crustal structure along-arc.

Widespread hydration of the back arc and the link to variable hydration of the incoming plate in the Lesser Antilles

Nick Harmon

The amount of water and volatiles stored in the downgoing plate and the depth at which they are released into the mantle wedge are key variables in the mass balance of earth's mantle, but are difficult to constrain. The Lesser Antilles subduction zone is a global end member for slow subduction of slow spread, highly tectonized, hydrated oceanic lithosphere, which could result in variable rehydration and volatilization of the mantle. Here we present a 3D shear velocity model from Rayleigh wave tomography and a series of numerical experiments of mantle flow to constrain the degree of hydration and partial melting of the back arc mantle wedge. We find the average shear velocity of the upper 20 km of the mantle of the incoming plate varies from 4.74 ± 0.08 km/s in the south to 4.54 ± 0.08 km/s in the north suggesting an addition of 2-3 weight % water to the upper mantle in the north due to serpentinization and a relatively dry mantle in the south. Beneath the arc/back arc behind the largest northern islands in the arc, Guadeloupe/Martinique, we image low shear velocities (4.20±0.05 km/s) at 70-90 km depth. Based on comparisons with geodynamic models of the thermal structure of the Lesser Antilles we infer an equivalent of 3000 $H/10^6Si$ in the mantle as either a free fluid phase or melt/fluid-the equivalent of ~ 1% melt fraction, with 0.02 weight % water at 2 GPa and 1200 °C. The seismic observations and thermal modelling suggest a cold slab that releases a significant amount of water 140-160 km depth to create the anomalies in the back arc. The melt may pond beneath the fast lid and move further into the back arc in the north. The north-south variation in the incoming plate structure is likely related to a change from mid-Atlantic slow spread lithosphere in the north and lithosphere related to continental break up in the south. Stark variations the hydration incoming plate result in stark variations in mantle wedge hydration and volcanic arc production.

Soliciting hydrothermal systems: the case of La Soufrière of Guadeloupe (FWI) unrest

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We have re-assessed the main physicochemical features of the hydrothermal system of La Soufrière of Guadeloupe (FWI) andesitic volcano. A careful analysis of different techniques adopted historically for gas sampling and analysis by OVSG has allowed us to extend the use of our modeling and of gas thermobarometers as back as possible to the last 20 years, also including data from the 1976-77 phreatic eruption. We then tracked the evolution of P-T conditions of the gas equilibrium zone within the hydrothermal system, often reaching or exceeding critical point conditions. Our results show that long-term P-T fluctuations characterize the behavior of the hydrothermal system in relation to injections of more magmatic deeper-sourced fluid into the hydrothermal system. This is also corroborated by concomitant fluctuations of halogen species recently determined in alkaline samples as well as condensates. Whether such long-term P-T increases reflect an oscillating behavior of the deep source injecting fluids upward, or are due to the modulation determined by the volcano structure via the many structures dissecting the edifice and relaxing the accumulated tensions, is matter of the ongoing investigations. Nevertheless, available data show that the recent unrest phase recorded between February and the end of April 2018 (Moretti et al., submitted; see also OVSG-IPGP reports) was due to the temperature increase and pressure build-up of the hydrothermal system, which originated a rapidly occurring (in the order of days) but sharp peak in monitored geochemical quantities. Therefore, scenarios that could lead to the sudden decompression of critical fluids must be considered in monitoring strategies and risk analysis.

Thursday 26th September

Fluid migration pathways in the mantle wedge: the role of the wedge thermal structure, fluid properties, and fluid influx

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Arc volcanism is mainly generated by the addition of hydrous fluids that trigger flux melting in the hot region of the mantle wedge. While thermo-petrological models predict the release of aqueous fluids from the subducting slab over a wide depth range, arc volcanoes are observed only in a relatively narrow region which lies 100±30 km above the top of the slab, suggesting the existence of some mechanism that focuses fluids and/or melts beneath the arcs. To assess the physical factors that exert a first-order control on fluid migration (FM) pathways through the mantle wedge, we use numerical 2D Darcy's-Stokes flow models.

Recent FM models have suggested that spatial variations in mantle shear viscosity and permeability are critical factors that control FM pathways in the mantle wedge [Wilson et al., 2014; Cerpa et al., 2017]. On one hand, we have shown that the relatively small grain size predicted by the models near the tip of the corner flow leads to the trap of fluids released beneath the forearc and their down-dip drag towards the sub-arc region by mantle solid flow. Once they reach this region, the fluids start to migrate upwards. Moreover, we have explored the effects the fluid viscosity on FM pathways. We find that this factor may play a key role in defining fluid paths. In particular, when a temperature-dependent fluid viscosity is applied, models predict greater entrapment of shallow and relatively cool fluids by the downgoing mantle, promoting their arc-ward transport [Cerpa et al., 2019].

On the other hand, our numerical models suggest that some of the fluids that can be released at post-arc depths are also focused towards the sub-arc region by mantle compaction and mantle incoming flow. Yet, most of those fluids tend to focus beneath the back-arc. Thus, the fate of such deep-released fluids in old-slab subduction zones remains an outstanding issue. To improve our understanding of the FM pathways, we are currently developing models for the Lesser Antilles subduction zone where fluids are predicted to be released at around 150-km depth, and/or deeper if dense hydrous magnesium silicate phases are stable in the subducting lithospheric mantle.

Kinematic Modelling of the Lesser Antilles Subduction Zone

Ben Maunder, Saskia Goes, Isabel Papanagnou, Jeroen van Hunen and the VoiLA Team

By using kinematic thermo-mechanical models, we are able to predict the thermal structure of the Lesser Antilles subduction zone for a given set of model inputs: some of which are constrained (e.g. slab geometry, slab velocity) and some of which are less so (e.g. decoupling depth, hydration state of the incoming plate, slab age). From the thermal structure we are able to compute seismic properties and by comparing these to the results coming out of the VoiLA project we are able to begin linking the different types of data, as well putting constraints on the dynamics of the system. Some first examples are as follows:

- The only way to match certain features in the seismic attenuation data (i.e. the large “cold nose”) in the kinematic model is by increasing the decoupling depth from the global average of ~80 km to ~120 km. Interestingly, a separate study suggests that extremely slow subduction of extremely old lithosphere (as is the case in the Antilles) may indeed naturally result in exceptionally deep plate decoupling.
- The deeper maximum depth of seismicity in the northern slab compared to the south can be explained as result of a systematic variation in temperature along strike due to variations in slab dip and subduction obliquity.
- The central slab must be comprised of lithosphere which is ~120 Myrs old in order for the slab dehydration horizon to underlay the low velocity anomaly in the mantle wedge, presumed to be the result of percolating fluids/melts. This matches well with new plate reconstructions.
- Our calculation of the 3D mantle wedge flow field should help us better understand seismic anisotropy results.

Variations in crust and upper mantle structure along and across the Lesser Antilles Arc combing seismic land stations and OBS

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Continental crustal is predominantly formed along subduction zones. Therefore, a study of the crustal and upper mantle structure around those regions provides insights into crust formation processes. However, previous works show that there are significant variations between different arc systems as well as variations in a single subduction zone; this includes crust and upper mantle structure and mineral composition, as well as varying amounts of subducted sediments and water. A detailed investigation is therefore needed. Compared to most subduction environments the Lesser Antilles Arc (LAA) is a zone of slow subduction of the North and South American plates at the eastern boundary of the Caribbean plate.

Here, we investigate variations in the crustal and upper mantle structure of the LAA using shear wave splitting and ambient noise tomography. We map anisotropic patterns along and across the arc observing occurrences of two independently propagating shear waves (splitting). Results from teleseismic events can be attributed to sub-slab mantle flow and the existence of pre-existing anisotropy in the subducting slab and results from local events can add information about contributions from the crust and the mantle wedge. Using a combination of seismic broadband land stations and a temporary network of ocean bottom seismometers (OBS), we are able to extend the area of interest into the fore- and back-arc to study the contribution of the mantle wedge. We can confirm previously recorded patterns of mostly trench-parallel alignment along the arc. However, the pattern changes in many parts of the fore- and back-arc regions, showing that observations along the island-arc stations cannot be representative of the entire region.

Due to the relatively slow subduction the amount of seismicity is low compared to most other arc settings, which hinders more detailed seismic investigations in some areas. However, it is possible to use the abundant noise information recorded by the station network for further investigation. We use cross-correlated seismic noise recorded by the same stations for an ambient noise tomography of the LAA. The temporary instalment of the OBS network provides enough information to generate seismic velocity maps and cross-sections that show significant variation in depth and lateral extend. With both methods we confirm previous findings of a complex subduction environment with significant variations on short length scales of tens of kilometres.

Olivine trace element chemistry in the Lesser Antilles: evidence for crustal reworking

Authors: Matthew Thirlwall, Hannah Johnson and Christina Manning (all Royal Holloway)

Several islands in the southern Lesser Antilles have unusually magnesian lavas relative to the products of most island arcs. These have usually been interpreted as primitive melts, despite isotopic evidence that many have undergone crustal contamination. Olivine crystals in them are typically small and often skeletal, which has suggested that their magnesian character is not the result of accumulation.

We report results of an extensive laser ablation study of olivine major and trace element chemistry in Antilles lavas. Olivines in primitive lavas range from Fo80-91, with lavas from Grenada, Carriacou and St Vincent all showing similar ranges. Most olivines in each sample have Fo substantially less than equilibrium values. The olivines show marked bimodality in CaO contents, with about half having relatively normal magmatic CaO of 0.13-0.20%, and half having very low CaO of 0.025-0.08%, similar to mantle xenolith olivines. Low-Ca olivine cores are commonly surrounded by a normal-Ca rim, but they both show the full Fo range suggesting the cores are not disaggregated mantle olivines. The low Ca cores also have low Al, Sc, Cr and Y, but similar Ni and Mn. These characteristics are not consistent with them being mantle olivines, but they show great similarities to olivines from cumulate xenoliths from several locations. Olivine cores are interpreted to be derived from disaggregated cumulates. Their ubiquity in high-Mg lavas in the Antilles suggests that all of these have interacted with crustal cumulates and supports arguments that their isotopic composition are strongly affected by crustal processes.

Variations in the supply of fluids to the Lesser Antilles subduction zone

George F. Cooper, Colin G. Macpherson[2], Jon D. Blundy[1], Saskia Goes[3] & the VoiLA Group

Oceanic lithosphere carries volatiles, notably water, into the mantle at convergent plate boundaries. This water has long been proposed to exercise key controls upon the production of magma, earthquakes, the formation of continental crust and, potentially, mineral resources. However, determining the relationship between fluid release, fluid pathways and observed surface expressions has proved challenging. Only a few subduction zones currently subduct plates formed by slow spreading, which forms lithosphere with highly non-uniform hydration. Such subduction zones provide a unique end member for studying the deep water cycle, which motivated a recent project, targeting the Lesser Antilles Arc. By studying boron trace element and isotopic fingerprints of melt inclusions, which are most likely to retain the signatures of the original fluids, we find that the supply of water to the central arc is much higher than in the north or south. This region of high water supply correlates with regions of higher rates of earthquakes, the location of historic interplate earthquakes, higher magma productivity and thicker arc crust, as well as prominent low shear velocities in the mantle below and behind the arc. Furthermore, the boron isotopes show that the main source of the high water supply is serpentinite, i.e. hydrated mantle rather than crust or sediments. The source of the highest supply of water is most likely a boundary between two seafloor-spreading domains that has gone down beneath the central arc over the past 10-20 Myr. These combined geochemical and geophysical data provide the clearest indication to date of a direct connection between structure and hydration of the downgoing plate and the evolution of the arc and its associated hazards.

Formation of continental crust at arc settings

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It is widely accepted that continental crust is formed mainly in volcanic arcs, at least since the Archean, and on average has intermediate or "andesitic" bulk composition. One way to derive the bulk composition of deep crust is to link geophysical data (seismic velocities, density) to plausible crustal lithologies, such as those from exhumed crustal sections of xenoliths in volcanic rocks. We use this approach to reconstruct crustal composition along the Lesser Antilles island arc combining constraints from petrology of magmatic crustal xenoliths, whole rock data, melt inclusion chemistry, experimental petrology data, modeling of magma chemistry from amphiboles and seismic receiver functions.

As a first step, we derived the crustal structure of the Lesser Antilles using an inverse approach that combines constraints from petrology of magmatic crustal xenoliths and seismic receiver functions (Melekhova et al. 2019). Xenoliths show considerable island-to-island variation in petrology from plagioclase-free ultramafic lithologies to gabbros and granodiorites. Xenoliths represent predominantly cumulate compositions with equilibration depths in the range 5 to 40 km. We use xenolith mineral modes and compositions to calculate seismic velocities (v_P, v_S) and density at the estimated equilibration depths. We create a five-layer model of crustal structure for testing against receiver functions (RF) from island seismic stations along the arc. Along the arc we see variations in the depth and strength of both Moho and mid-crustal discontinuity (MCD) on length-scales of tens of km. The Moho is the dominant discontinuity beneath some islands (St. Kitts, Guadeloupe, Martinique, Grenada), whereas the MCD dominates beneath others (Saba, St. Eustatius).

In the second step, we used the obtained crustal modal as a base for calculating average crustal composition of Lesser Antilles arc. We found that bulk crustal composition of Lesser Antilles arc is low magnesium basalt. There is some variation in bulk crustal composition from island to island, but none of it is close to andesite. Additional mechanisms are required for genesis and growth of continental crusts at arc settings to explain andesitic nature of bulk continental crust.

Syn- and post-magmatic processes beneath Petit St. Vincent, Lesser Antilles

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Petit St. Vincent lies roughly in the middle of the Grenadines archipelago, southern Lesser Antilles. Constituent volcanoes define a subduction-related intra-oceanic island arc distinguished by abundant and diverse plutonic xenoliths and lavas. We have determined the mineral and melt inclusion compositions of a suite of xenoliths and one lava to explore magma differentiation processes beneath Petit St. Vincent. The sole lava analysed is basaltic. Xenoliths are dominated by calcic plagioclase, clinopyroxene and hornblende, but also contain plagioclase- and hornblende-free assemblages. Olivine is notably rare in xenoliths but substantial in the lava. Hornblende is conspicuously absent from the lava. Xenoliths provide textural and geochemical evidence for a hydrous crystal mush with open system processes operating within the crust. Extensive hornblende proportions, low melt inclusion totals (≥91 wt.%) and high Al_2O_3 contents (23.5 wt.%) suggest that melt water contents are high. Uralitization and widespread zoning (normal and reverse) advocate for the percolation of reactive melts through the mush triggering the breakdown of clinopyroxene and crystallisation of hornblende and the crystallisation of compositionally distinct rims.

A subset of xenoliths displays microtextural evidence for post-magmatic deformation in the form of microcracks, grain contacts, mortar textures, foliations and asymmetric boudins. Mineral chemistry and petrography show that they are cognates with undeformed xenoliths. Thermometry calculations distinguish these xenoliths at lower temperatures than undeformed xenoliths. Deformation microstructures make a case for shear localization in an active brittle-ductile transition zone beneath this volcano. Deformed xenoliths sample mid-crustal sections at various distances from this zone defining changing strain intensities. A shear zone would facilitate the infiltration of 'exotic' fluids/melts that could explain the high K_2O (<5.4 wt.%) and Cl (0.9 wt.%) concentrations measured in xenolith melt inclusions and high Ca contents of plagioclase. This study demonstrates the first appearance of deformation microstructures from plutonic xenoliths on such a sizeable scale, further highlighting the spatial variability along the Lesser Antilles arc.

Spatio-Temporal evolution of Martinique island: A record of Lesser Antilles arc activity since the Oligocene

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Martinique is the island where the most complete history of the Lesser Antilles arc can be studied as it recorded continuous eruptive activity for the past 25 Ma. We have obtained ~60 unspiked K-Ar ages on lava flows and domes. The Old arc has been active from 24.8 to 20.8 Ma across the Oligocene-Miocene boundary. Then, the submarine to subaerial Intermediate arc was active in Martinique between 16.1 and 7.1 Ma. Next, during the Pliocene, Morne Jacob shield volcano was built from 5.5 to 1.5 Ma and experienced a creeping of its northern flank at about 2.2 Ma. It induced geochemical changes in shallow reservoirs, as evidence by the eruption of more basic lavas. Then, monogenetic volcanoes with various dynamisms and chemistries erupted in the southwestern Trois Ilets peninsula (2.4 to 0.345 Ma). Simultaneously, the Carbet Complex (1 Ma – 322 ka), Mt Conil (550 – 125 ka), and finally the Mt Pelée (< 125 ka) were erupted along the western sector of the island. Flank collapses have been recurrent processes on northern Martinique, typically at 337, 120, 25 and 9 ka.

We have modelled paleotopographies of the Mt Conil – Mt Pelée complex and computed edifice volumes as well as the volumes removed by erosion or previously recognized mass wasting events. The rather good preservation of volcanic landforms and the high temporal resolution available allow us to discriminate 10 successive stages and model these surfaces evolution though time by construction – erosion processes. Volumes of each constructional stage were estimated at about 35.2 km^3, 26.2 km^3, 8.3 km^3, and 2.5 km^3 for a total cumulative erupted volume of 72.2 km^3. Volumes displaced by each flank collapse were estimated at 14.7 km^3, 8.8 km^3, and 3.5 km^3, thus about 37% of the total constructed volume. The volcano has been built at an average rate of 0.13 km^3/kyr during the last 550 kyr. During that time, construction rates varied by a factor of 15, from 0.04 km^3/kyr in early stages up to 0.52 km^3/kyr after the second flank collapse.

We estimate that the Mt Conil – Mt Pelée complex accounts for about 10% of the Lesser Antilles arc production in the last 100 kyr. Our data support the regional scale observations that the whole recent Lesser Antilles arc experiences a high volcanic activity since 600 ka, probably linked to a permanent establishment of rising magma plumes in regularly spaced and tectonically controlled batches.

Hydrous magmas trigger igneous garnet fractionation in magmas associated with porphyry systems

Matthew Loader

Porphyry sulphide ore deposits account for most of the world's copper production, as well as containing significant quantities of gold and molybdenum. They form due to magmatic volatile phase exsolution and country rock interaction in shallow (2-5 km), sub-volcanic environments, and represent a rare but highly valuable by-product of arc magmatism. An abundance of magmatic volatiles, of which H_2O is the main component, is considered essential for the generation of large porphyry deposits. Like other critical ore-forming components (e.g. metals, ligands), this water is ultimately derived from the underlying magmatic system, which characteristically have elevated Sr/Y, Sm/Yb, and Eu/Eu* ratios suggesting a strong amphibole and garnet control on magma trace element budgets. However, it is not well understood how the high magmatic water content and the atypical magma chemistry relate to one another, or why switches from amphibole- to garnet-dominant fractionation tend to be coincident with episodes of porphyry mineralization.

One explanation is that progressive crustal thickening, perhaps induced by flat slab or ridge subduction, causes the metamorphism of amphibolitic lower crust to eclogite or granulite facies. This would impart cryptic garnet signatures on magmas in equilibrium with the lower crust, and water liberated during metamorphism could make these magmas especially hydrous and enhance their ore-forming potential. Although this process may account for gradual changes in geochemical ratios over orogenic length and timescales (20- 30 Myr), changes from amphibole- to garnet-dominated fractionation can be rapid and very localized, precluding regional scale crustal thickening as an explanation.

Here, we present an alternative mechanism whereby heterogeneous volatile flux from the downgoing slab due to ridge or fracture zone subduction can lead to highly localised batches of water-rich andesitic magmas in the lower crust. In such magmas at moderate pressures (0.8 GPa), garnet may be stabilised as an igneous phase, the fractionation of which would generate the observed geochemical features. Thus, we propose that garnet signatures in magmas associated with porphyry systems are a consequence of hydrous magmatism.

Friday 27th September

Recent seismic studies in the central Lesser Antilles : early fruit from the WI permanent virtual seismic network

Valerie Clouard, O'Leary Gonzalez Matos, Steve Tait, Jean-Bernard de Chabalier and Jordane Corbeau

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Motivated by the great Indonesian tsunami of 2004 and in order to contribute to the Caribe Early Warning System, the Caribbean seismic operators have greatly improved their seismic network during the last decade. In the Lesser Antilles, the IPGP volcano observatories in collaboration with the SRC have deployed a virtual network of 20 stations (including broadband seismometers, GNSS and strong motion sensors, and satellite transmission), co-funded by the European Interreg Caraïbe program. Our recent studies use these high quality seismic stations. We calculate new moment tensors for earthquakes with M>3. While most of these earthquakes reflect intraplate deformation of the Caribbean plate from the subduction to the volcanic arc, we also identify two patches of thrust earthquakes matching the rupture areas of the two Lesser Antilles large historical earthquakes of 1839 and 1843. We also obtained vertical profiles of S-wave velocities below these seismic stations, ie, below the volcanic arc. We interpret these velocities in terms of lithospheric structures, and partial melt in the crust or in the mantle wedge. We also show that the depth of the subducting plate gradually increases from south to north, and interpret an abrupt change between Dominica and Guadeloupe as the transition between the North and South America plates.

Provenance of detrital zircons from Dominica, Lesser Antilles

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Dominica is located in the center of Lesser Antilles volcanic arc and is considered to be one of the most volcanically productive and hazardous islands within the arc. It has nine potentially active volcanic centers (Pleistocene or younger in age) and had a period of explosive activity within the last 170 kyrs which produced nearly 60 km^3 of volcanic deposits. Four periods of volcanism were previously classified by K-Ar dating: Younger Pliocene – Recent, Older Pleistocene, Pliocene, and Miocene (~7 Ma). Older lavas are primarily effusive basalt-basaltic andesite whereas more recent volcanism consists of crystal-rich andesite and dacite pyroclastic deposits and lava domes. Recent studies refined the ages of the youngest eruptions with ^{14}C dating (Boudon et al., 2017) and U-Th dating of zircons (Frey et al., 2018 and Howe et al., 2015). Through U-Pb dating, Howe et al. (2015) identified a few older inherited zircons (~54 and ~48 Ma), likely derived from South America. We conducted a more intensive LA ICP-MS U-Pb zircon study and 36 zircons were found to be detrital (<1% of all zircons analyzed). There were four concordant age populations. The youngest is 52-123 Ma with 200-1600 ppm U. The older populations were 160-230 Ma, 342-600 Ma, and 1200-1726 Ma and all zircons contained <200 ppm U. For a subset of these zircons, Hf isotope analyses were also done, which correlates time of crystallization with the mantle extraction age. Epsilon Hf values ranged from -26 to +15, with older U-Pb ages generally correlating with more negative epsilon Hf values. This data confirms a Proterozoic mantle extraction age and likely Guyana Shield provenance for the oldest zircon population. Other potential sources of the various detrital zircon populations include the Eocene Caribbean arc (<100 Ma), a western Andean source from the Venezuelan Coastal Range, or an older western Andean source, in addition to the Guyana Shield (>1 Ga). There are two possible models for the incorporation of zircon xenocrysts in the young lavas and pyroclastic deposits. The zircons could be derived from the sediment in the accretionary wedge, which was then transported down with the slab and subsequently incorporated into the magma (e.g. Rojas et al., 2013). However, in order to preserve the zircons at such high temperatures, crystal residence times must have been very short (thousands of years). Alternatively, the zircons could be from a sliver of older crust that underlies the Antilles and were assimilated upon eruption.

Geochemical and temporal evolution of the St Kitts magmatic system, Lesser Antilles

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Detailed petrological and geochemical study of plutonic and cumulate rocks can provide insights into the inner workings of transcrustal magmatic systems (e.g. Melekhova et al., 2017; Otamendi et al., 2016). This crustal architecture in turn influences the eruptive style, chemical diversity, thermal evolution and erupted volume at the associated volcanic system. Here we focus on the volcanic island of St. Kitts in the Lesser Antilles, an island that is largely uninterrupted by sediment contamination and pre-existing crustal structure.

Whole rock major and trace element analysis of volcanic rocks show two distinct magmatic lineages that can be ascribed to differentiation at various crustal depths. We use major element modelling to show the cumulate assemblages needed to generate these trends. In-situ mineral trace element data for the cumulate and plutonic xenoliths are used to constrain the differentiation process as well as mineral reactions, particularly between clinopyroxene and amphibole. Thermodynamic modelling provides estimates of the equilibrium P-T (Pressure-Temperature) conditions for the cumulate xenoliths; this technique acts as a complement to multiple reaction thermobarometers or as an alternative when suitable phase assemblages are unaivalable.

Collectively, these techniques allow us to develop a clearer picture of the magmatic system below St Kitts.

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Operational Volcanic and Earthquake Forecasting in the Eastern Caribbean

Joan Latchman

Prediction is the primary goal of all scientific investigations and, in this regard, earthquake and volcanic forecasting are important aspects of seismological research in the English-speaking Eastern Caribbean, in the hazard preparedness effort. While we cannot predict the exact date, time, magnitude and location of the next damaging episode, scientists at the Seismic Research Centre seek patterns that appear precursory to the occurrence of major events for operational forecasting and alerts. Insights from Operational Volcanic Forecasting, implemented successfully several times with volcanic unrest and eruption episodes in the Eastern Caribbean, since the 1970's, continue to be applied to periods of locally anomalous geophysical activity. In the Eastern Caribbean, with one exception, elevated seismicity has been precursory to the volcanic eruptions in the 20th Century. Large earthquakes in the magnitude range 7.0-7.9 occur, on average, every 20-30 years, and those of magnitude 8 and larger, about100 or so years. These observations have been, and are being, used to promote the need for, and benefits, of having preparedness measures in place. Earthquake and volcanic hazard analyses have produced maps that may be used, in this regard, for planning and development. On shorter time scales, the piecewise gradient-tracking technique, a variant of the Gutenberg-Richter *b*-value, often provides signals of the possible imminence of moderate to major earthquakes, in the region, that have the potential to cause damage or casualties. Seismo-volcanic unrest episodes are used in a similar way. Disaster coordinators are apprised of such regional and extra-regional patterns, the status of activity and our prognoses, which allow them an opportunity to tailor timely and appropriate response measures. Even secondary effects of earthquake occurrence have been found useful in forecasting: the groundwater impact of a strong earthquake was used to identify more likely productive areas for groundwater exploitation.

Physical modelling of explosive eruption columns and umbrella clouds and ash dispersal with application to the recent Plinian eruptions of Montagne Pelée, Martinique.

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The presentation will give an overview of a long-term research program to investigate the physics of explosive eruption columns and in particular how they transport and inject ash into the atmosphere. Study of the basic fluid dynamics involved, based on theoretical work and laboratory experiments, enables us to give an account of both the vertical column and the umbrella cloud that spreads horizontally at the neutral buoyancy level in the stratified atmosphere. We will emphasize the physics of mixing between the eruption column and the surrounding air and also the importance of the total grain-size distribution in the eruption jet which depends on the efficiency of magma fragmentation. Among the most important phenomena that determine both qualitatively and quantitatively the risk that arises from these eruptions are those of partial and total column collapse, causing the eruption to switch from generating a convective to a collapsing column which generates pyroclastic density currents on the ground. We will discuss data collected on four plinian eruptions of Montagne Pelée whose deposits can be studied at numerous locations in the field. All of these eruptions have been affected by partial and total column collapse, and provide an excellent field laboratory to test the performance of the physical models we have developed. The four eruptions also show a range of dispersal directions, showing that they were affected by different wind fields. We show how these data can be understood given the different eruption fluxes involved and the range of wind direction data that are available for the region and discuss some of the implications for the risk posed by explosive eruptions
in the Antilles.

Compositional Trends and Volatile Fluxes through Volcanic Arcs: Perspectives from southern Chile

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A general feature of continental margin magmas is that volcanic rocks from arcs or arc segments with thick continental crust are compositionally distinct from volcanic rocks erupted through thinner crust; or from island arc settings. The Southern Volcanic Zone of the Andes (SVZ; 33-46° S) is a classic setting for examining the mechanisms leading to enriched magma compositions in continental arcs, because both crustal thickness and magma chemistry vary consistently along strike. The SVZ inspired Hildreth and Moorbath's 'Melting-Assimilation-Storage-Homogenisation' (MASH) hypothesis, which associated chemically and isotopically 'enriched' signatures with crustal processing of magmas. However, the scarcity of primitive samples from the northern SVZ, where the continental crust is thickest (50km), compared to the relative abundance of such magmas in the southern SVZ may have led to an overemphasis of the role of crustal processing in along-arc trends. New work on mafic samples from Don Casimiro and Maipo volcanoes in the northernmost SVZ; on mafic samples from the southern SVZ and from rear-arc samples in Argentina place new constraints on the problem, and offer some new perspectives.

We argue that the relative enrichment of the mafic magmas of the northern SVZ may have an origin in the mantle, and not the crust. Along-arc trends in composition can be explained by the presence of an enriched ambient mantle component superimposed on a northward decline in melt extent. Rather than crustal recycling, enriched signatures in mafic arc volcanics may arise from recycling of metasomatized subcontinental lithospheric mantle (MSCLM). This hypothesis is consistent with the isotopic composition of MSCLM melts across South America, as well as the isotopic compositions of samples from the Argentinian rear arc. These rear-arc centres not only corroborate the findings at the arc front, they also reveal variability in the supply of slab fluids to regions well behind the arc. If ambient mantle enrichment is not taken into account, petrogenetic models of evolved lavas may exaggerate the role of crustal assimilation, and models for the growth of continental crust may overestimate the amount of continental material that must be recycled back into the mantle to satisfy mass balance.

POSTERS

Understanding the petrophysical properties of Montserrat's geothermal reservoir

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Despite the destructive nature of volcanoes, there has been recent developments within the Eastern Caribbean to utilize this energy to help lower the dependence of expensive imported fossil fuels. Geothermal energy, the thermal energy derived from the crust, can be harnessed to produce electricity by effectively targeting high temperature and permeability regions within a geothermal system. In Montserrat, previous exploration data (geological, geochemical and geophysical) were used to identify the Montserrat geothermal system in the south-western part of the island and delineate potential drilling targets. To further understand the Montserrat Geothermal system and constrain previous models, direct petrophysical measurements are made from cores retrieved from the third geothermal well drilled (~ 2.7 km depth) in Montserrat. Forty-one plugs (26 vertical and 15 horizontal), were prepared from the core samples (core 1, core 2 and core 3 retrieved at 1478 m, 1700 m and 2100 m, respectively). We measured the density, porosity, and permeability of the plugs. Permeability measurements were made at 10, 30, 50 and 70 MPa effective pressures. The density and porosity range between 2.35 – 2.70 g/cm^3 and 1 – 16 %, respectively. Results shows that low porosity is correlated to high density and high porosity is correlated to low density. These measurements along with a preliminary geological assessment help to distinguish between dense igneous rocks of low porosity and the low density volcaniclastic sediments of high porosity. Results also shows that carbonate rock samples has high density and low porosity. There is also the possibility the measured density and porosity can be reflective of the various degrees of hydrothermal alteration within the Montserrat Geothermal system. Permeability of the samples ranged from 10^{-17} to 10^{-21} m^2. We observed that samples with low porosity has high permeability, while samples with high porosity has low permeability. This study reveals that the various degrees of alteration should be assessed to fully understand the primary and secondary controls on porosity and permeability.

Chlorine isotopic composition of thermal springs along the Lesser Antilles arc and fumaroles from La Soufrière de Guadeloupe

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Chlorine is moderately soluble in magmas, highly soluble in waters and, unlike most other volatiles, is considered chemically non-reactive. Such unique combination of geochemical features can be used to inimitably characterize the origin of magmas, their differentiation, degassing and interaction with liquids. Chlorine stable isotope compositions ($\delta^{37}Cl$) of Earth's reservoirs have been used for 10 years to constrain the origin of Cl in arc magmas [*e.g.,* 1-4], and only recently used in volcanology, as tracers of magmatic degassing and/or subsurface gas/liquid interactions [5-6].

In order to constrain the sources and fate of Cl associated with arc volcanism, this study reports $\delta^{37}Cl$ signatures of thermal springs from several locations along the Lesser Antilles arc (West Indies): la Soufrière de Guadeloupe (French West Indies); Boiling Lake, Valley of Desolation and other locations (Dominica); and LiaMuiga (St-Kitts). The studied samples show wide ranges of temperature (22-92°C), pH (3-8), Cl content (10-2000 ppm), Cl/Br ratio (100-1000) and $\delta^{37}Cl$ value (-1‰ to 0‰). These results unravel that magmatic Cl displays negative $\delta^{37}Cl$ values, close to -0.7‰, all along the arc, that is consistent with a slab-derived origin. The consistency with the melt inclusion data from Saint Vincent, located at the South of the arc ($\delta^{37}Cl$ averaging -0.64‰ [4]), further confirms our starting hypotheses, made in [3], that Cl isotopes do not fractionate (ie. no loss of magmatic Cl) over their high-temperature path from magma to thermal springs.

For further constraining local magmatic and hydrothermal processes at la Soufrière de Guadeloupe, we report: *i/* $\delta^{37}Cl$ data on recently collected gases (mean temperature of 97°C, $\delta^{37}Cl$ up to +8‰); *ii/* a 40 years record of $\delta^{37}Cl$ values and Cl and Br concentrations of one thermal spring (Galion, with discrete peaks of Cl contents that are anti-correlated with $\delta^{37}Cl$ values down to -1.3‰), and *iii/* a 15 years record of the summit acid pond (Tarissan, pH = -0.8 to +0.8; [Cl] = 1-15 wt.%, $\delta^{37}Cl$ decreasing from +0.3 to -0.9‰). We quantify that more than 90% of the HCl escaping the large hydrothermal system of La Soufrière is likely lost (ie. not sampled) via scrubbing over subsurface water condensation on its way up to the surface, at least at site CSC. More broadly, we suggest that for locations where the magma $\delta^{37}Cl$ is known, the $\delta^{37}Cl$ value of the emitted gas is a quantitative tracer for scrubbing of chlorine and other water-soluble gas species.

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Unradiogenic $^{87}Sr/^{86}Sr$ cumulate plagioclase crystals in xenoliths from Martinque and St. Vincent, Lesser Antilles.

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Arc lavas from the central and southern Lesser Antilles show diverse radiogenic isotopic compositions and considerable variation at individual volcanic centres [1]. Debate centers on whether this variation represents addition of subducted sediment to the mantle source, or assimilation of arc crust by magma *en route* to the surface.

$^{87}Sr/^{86}Sr$ ratios of individual plagioclase crystals from cumulate xenoliths, entrained in erupting lavas, record the melt isotopic compositions during crystallization in crustal reservoirs so should track potential contamination of host magma. It may also be possible to determine $^{87}Sr/^{86}Sr$ records of magmas at different crustal levels since thermobarometric and petrological data suggest cumulate formation over a range of depths (≤15 km, pressures of ≤4 GPa) [2]. Cores of zoned plagioclase or deep formed cumulates enriched in radiogenic strontium would support a significant sedimentary input to mantle sources. However, increasing $^{87}Sr/^{86}Sr$ ratios from core to rim, and/or in progressively shallower cumulates, would indicate the presence of crustal contamination.

We have analysed unzoned plagioclase crystals from cumulates xenoliths found on Martinique and St Vincent. Martinique whole-rock (WR) $^{87}Sr/^{86}Sr$ data from erupted lavas span the whole LA arc range, however, the isotopic composition of cumulate plagioclase is unradiogenic and resticted. Cumulate plagioclase St Vincent also completely overalap with the unradiogenic Martinique cumulates, despite the differences in the isotopic compositions of the erupted lavas at both islands. Therefore, we provide strong evidence that the radiogenic Sr isotopic signature recorded in Martinique lavas is due to shallow level assimilation rather than imparted by sediment recycling into the mantle source.

Plume chemistry for eight Lesser Antilles volcanoes obtained during the 2018-2019 Multi-Gas campaign

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There are 19 volcanic centers in the Lesser Antilles volcanic Arc, of which only two centers, Kick em Jenny and Soufriere Hills have erupted in the past decade. The presence of fumarolic activity coupled with the episodic occurrence of volcano seismic crisis in some islands, suggets that there are several potentially active centers in the Lesser Antilles Arc which will erupt in the future. The measurements of volcanic plume chemistry and volatile fluxes has long known to be useful tools for characterizing the degassing dynamics of volcanic plumbing systems, constraining and understanding deep seated processes, and last and most importantly, generating baselines of ratios and fluxes for volcano monitoring purposes at the different centers. The advent of the multigas instrument pack has revolusionized the measurment of the major volatile species at volcanoes thus making it easier to obtain insights into plumbing system processes ongoing at these volcanic centers. Here we present plume chemistry and concentration ratios of the species obtained (H_2O, CO_2, H_2S, SO_2) using a Multi GAS instrument pack from eight volcanic centers in the Lesser Antilles from 2018-2019.

The ratios obtained varied somewhat with H_2O/CO_2 values in the range of 1-50, while H_2S/SO_2 values also show some variation Soufriere St Vincent at the low end ~ 18 and Wotten Waven Dominica leading the way with at ~ 192. We highlight the importance of the CO_2/S_{tot} ratio as a useful monitoring tool in forecasting eruptions at volcanoes , most of the systems are low temperature systems < 100 ^oC with a strong hydrothermal signature, the CO_2/S_{tot} ratios range from 3 in the case of Boiling Lake up to 35 in the case of Sulfur Springs St Lucia however the man value is around 25. Our data shows that the systems of the Lesser Antilles display degassing signatures which are typical of Arc volcanoes, we also demonstrate that processes such as H2O addition and scrubbing are commonplace in the Lesser Antilles Arc and lastly we also acknowledge the crustal contribution to the CO_2 output in some systems.

Slab Tear and Fold of the Caribbean Plate beneath Northwestern South America

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The southernmost edge of the Caribbean (CAR) plate, a buoyant large igneous province, subducts shallowly beneath northwestern South America (SA) at a trench that lies northwest of Colombia. The CAR-SA subduction is marked by an absence of volcanism and three Laramide-style uplifts – the Santa Marta Massif (SM), the Sierra de Perija (PE) and the Merida Andes (MA)–the latter being ~500 km from the trench. Plate coupling between the flat subducting CAR and the Maracaibo block is proposed to have driven the uplift of the MA. We combine observations from finite-frequency teleseismic P-wave tomography, Ps receiver functions (RF), and seismicity to illuminate intermediate-depth structures and relate those observations to surface deformation.

Although the CAR is known to subduct at a shallow angle from the west and underthrust from the north, its geometry and influence are unclear. There is ongoing discussion if the CAR seafloor and the subducting CAR slab are continuous and deforming or separated by a tear; our observations favor a slab tear in the CAR near where the SM and PE ranges meet the Oca fault.

We interpret a small seismic cluster as the hinge of the tear. It is further identified in a northern trench-parallel RF profile where two vertically offset interfaces overlap and in the corresponding finite frequency tomography profile. The tear separates the northern, presumed-to-be underthrust CAR from the southern, flat subducting slab. Atop the flat-subducting CAR we observe a large, high velocity anomaly with similar thickness to the slab. A shallower trenchward-dipping interface is observed in the RF. We examine two sources for the anomaly: 1) Ablated lithosphere removed from either the North Andean Block (NAB) or the SA continent; and 2) underthrusted CAR overlying the flat slab. We compare synthetic tomography results for the two hypotheses and conclude the tomographic anomaly is likely the underthrust CAR atop the subducting CAR. However, we cannot rule out the possibility that some lithosphere was removed from SA. The trenchward-dipping interface observed in the RF may indicate type A subduction of South America beneath the NAB as suggested by Audemard and Audemard (2002), in which case the SA slab penetrates deeper into the mantle than expected.

P-wave seismic structure of mature Atlantic Ocean crust

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Our current knowledge of the structure of mature Atlantic Ocean crust relies on studies older than 25 years which suffer from limited lateral resolution. We present results from an active seismic experiment, with 54 ocean-bottom seismometers spaced every 4 km, conducted over ~65 Ma central Atlantic crust in 2017. The profile crosses four ridge segments separated by a transform (Marathon) and two non-transform offsets. The data have been analysed using forward and inverse modelling to produce a 2D p-wave velocity model.

We identify two types of crustal segment. The first displays a classic two-layer structure with a high velocity gradient layer 2 (~1.0 s^{-1}) above a lower gradient layer 3 (0.2 s^{-1}). Here the PmP reflector coincides with the 7.5 kms^{-1} contour and an increase to >7.8 kms^{-1} less than 1 km below. We interpret these segments as having been dominated by magmatic processes, with PmP representing a petrological boundary between crust and mantle. The second has a much reduced velocity gradient contrast between upper and lower crust and a PmP reflector shallower than the 7.5 kms^{-1} contour. We interpret these segments as tectonically controlled, with PmP representing a serpentinised (alteration) front. Within the second segment type we made what we believe to be the first identifications of Oceanic Core Complexes in mature oceanic crust. These features have a ~20 km wide "domal" morphology, with shallow basement and increased upper-crustal velocities. Internally they show seismic velocity inversions, which we interpret as due to alteration and rock-type assemblage contrasts across a crustal-scale detachment fault.

All three discontinuities share the same primary characteristics, with no apparent correlation with size of the ridge-offset. Within them the PmP reflector shallows by up to 3.1 km over distances of about 15 km and the velocity gradient becomes linear (0.5-0.7 s^{-1}). Both orders of discontinuity present major boundaries to magmatic and tectonic processes at the MAR, and both probably have undergone equivalent amounts of serpentinisation.

These results have important implications for serpentinisation: Both first and second order discontinuities apparently have similar degrees of serpentinisation. Magmatic-dominated segments have limited serpentinisation, whereas the tectonically-dominated segments may carry significant bound water. However the nature of a given segment probably changes with time, so that supply of water within the subduction zone varies temporally as well as spatially.

Reconciling mantle wedge thermal structure with arc lava thermobarometric determinations in oceanic subduction zones

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Subduction zone mantle wedge temperatures impact plate interaction, melt generation, and chemical recycling. However, it has been challenging to reconcile geophysical and geochemical constraints on wedge thermal structure. Here we chemically determine the equilibration pressures and temperatures of primitive arc lavas from worldwide intraoceanic subduction zones and compare them to kinematically driven thermal wedge models. We find that equilibration pressures are typically located in the lithosphere, starting just below the Moho, and spanning a wide depth range of 25 km. Equilibration temperatures are high for these depths, averaging 13008C. We test for correlations with subduction parameters and find that equilibration pressures correlate with upper plate age, indicating overriding lithosphere thickness plays a role in magma equilibration. We suggest that most, if not all, thermobarometric pressure and temperature conditions reflect magmatic reequilibration at a mechanical boundary, rather than reflecting the conditions of major melt generation. The magma reequilibration conditions are difficult to reconcile, to a first order, with any of the conditions predicted by our dynamic models, with the exception of subduction zones with very young, thin upper plates. For most zones, a mechanism for substantially thinning the overriding plate is required. Most likely thinning is localized below the arc, as kinematic thinning above the wedge corner would lead to a hot fore arc, incompatible with fore-arc surface heat flow and seismic properties. Localized subarc thermal erosion is consistent with seismic imaging and exhumed arc structures. Furthermore, such thermal erosion can serve as a weakness zone and affect subsequent plate evolution. For this contribution, we will compare results from our global study with PT conditions of primitive arc magmas and thermal models for the Antilles subduction zone.

Volcano ready communities project, St. Vincent and the Grenadines

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St. Vincent and the Grenadines is among the most disaster-prone territories in the world, and is affected on a regular basis by the negative impacts of natural hazards such as volcanoes, earthquakes, hurricanes, landslide, rainfall events, storm surge and drought. The Volcano Ready Communities Project seeks to reduce vulnerability to the multi-hazard environment of the Soufriere Volcano through a combination of activities designed to enhance community early warning procedures, increase adaptive capacities, strengthen awareness, and enhance response capacities. The Project comprises four components which seek to increase the resilience of the 12 communities in St. Vincent and the Grenadines to volcanic and other natural hazard events. The communities have been divided into two groups and they are (a) Windward communities comprising Fancy, Owia, Sandy Bay, Overland and Big Level, South Rivers, Park Hill, Colonaire, and (b) Leeward communities comprising Fitz Hughes, Chateaubelair, Rose Hall, and Spring Village. Protocols to alert men, women, children, the elderly, disabled and other vulnerable populations, about volcano and other related natural hazards and their potential impacts are being developed with the target communities. A number of gender-sensitive multi-hazard, public awareness and education materials are also being developed and programmes implemented. The materials are being shared with schools, businesses, community groups, and the residents of the target communities. Information on best practices are also being captured through audio visual media. The public awareness programme developed under the Project ensure that socially constructed roles of men, women, youth, disabled and other vulnerable groups in the 12 target communities are addressed through specific messages about how to deal with the volcano and other natural hazards. Volcano level contingency plans for the 12 communities in the high-risk zones of the Soufriere Volcano are also being prepared. The stakeholders (government, civil society, and the private sector) are being engaged to assist the at-risk communities with the development and identification of resources required for the continued implementation of the volcano plans.

Recent temporal changes in the geochemistry of hydrothermal fluids of Dominica, Lesser Antilles

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A revised fluid characterizations is presented for the active volcanic-hydrothermal systems on Dominica, Lesser Antilles obtained over the period 2009 to 2017. Hydrothermal waters of Dominica cover a wide spectrum of pH, temperatures and chemical composition. The pH of the thermal waters range from acidic to neutral (pH values of 1-7.8) and are predominantly Na-SO_4 in character (Na= 14 – 2127 mg/L; SO_4= 1– 1725 mg/L). Acid-sulphate waters are likely derived from the CO_2-H_2S rich steam up-flow, generated by boiling of meteoric waters, which partially condenses and is dissolved in shallow groundwater. No significant temporal changes have been observed in the geochemical composition of the waters for most of the hydrothermal systems studied since last reported in 2011. The Boiling Lake, however, has shown a progressive change from a dominantly Na-SO_4 composition in 2010, to a Na-Cl composition from 2013 to 2017. The lake also experienced a ~6 week episode of instability (draining and refilling with cessation in hydrothermal activity) in November 2016, which was possibly related to a moderate-sized landslide into the lake. This contrasts with the previous instability episode in 2004/2005 that lasted ~6 months and was attributed to a regional earthquake-trigger. The changes in composition between Na-SO_4 and Na-Cl may be a result of hydrothermal fluid contributions from two different aquifers underlying the lake: a shallower acid-sulphate hydrothermal aquifer and a more deeply-sourced brine aquifer.

Reservoir temperatures determined by quartz geothermometers have shown no significant changes over the monitoring period for most hydrothermal systems, suggesting steady-state degassing of the magma chambers. In two areas, however, temperatures have shown some increase: Watten Waven (from 83 ˚C – 90 ˚C to 89 ˚C -139 ˚C) and Sulphur Springs (from 145 ˚C - 152 ˚C to 93 ˚C – 243 ˚C). The elevated reservoir temperatures have affected the isotopic composition of the waters ($\delta^{18}O$ = -5.7 to 9.1‰ and δD = -8 to 20.5‰), which reflect a dominantly meteoric source, with boiling/degassing and evaporation also playing a contributing role.

Pre-eruptive crystallization conditions in the past 25 Ma at Martinique Island as revealed by textural and chemical variation in phenocryst

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This study aims to constrain the magma storage conditions beneath Martinique Island to improve our understanding of the migration from the old to recent Lesser Antilles volcanic arcs. The island sits at a bifurcation point that shows 3 temporal groups: one old volcanic arc (25 – 20 Ma), one young volcanic arc (< 6 Ma), and an intermediate (16 – 6 Ma) arc that outcrops best in Martinique, making it ideal to study the continuous evolution of the Lesser Antilles volcanism.

Currently, volcanic centers from the recent and intermediate arc have been selected for this study. These complexes range from basalt to dacite. Gros Ilet (7 Ma) has a plagioclase composition An_{93} – An_{45}, with cores more Ca-rich than the rims. Morne Jacob (5.5 – 1.5 Ma) has a plagioclase composition An_{89} – An_{44}, with cores more Ca-rich than the rims. Trois Ilet (1332 – 346 ka) have plagioclase compositions An_{100} – An_{44}, with both cores more Ca-rich than the rims and rims more Ca-rich than the cores. Plagioclase textures also show evidences of magma mixing and reservoir remobilization. Piton du Carbet (998 – 322 ka) have plagioclase compositions ranging from An_{94} to An_{46}, with rims more Ca-rich than the cores. Mont Conil (543 - 125 ka) have plagioclase compositions ranging from An_{97} to $An_{49,}$ with cores more Ca-rich than the rims. Lastly, Mount Pelée (<125 ka) has a plagioclase composition ranging from An_{86} to An_{49}, with oscillatory Ca-rich cores and rims.

Preliminary results of thermobarometry calculations have been done on plagioclase and pyroxene crystals for Gros Ilet, Trois Ilet and Piton du Carbet samples. Magmas from Gros Ilets and trois Ilets, in the SW of the island, crystallized between 37 and 3 kbar. In the center of the island, Pitons du Carbet magmas crystallized between 19 and 10 kbar. Overall, Mg-rich orthopyroxene and clinopyroxene can be linked to recharge of melt near mid-crustal levels and could have grown at the same time as plagioclases. Ca-rich clinopyroxene could have already formed within the melt at depth before being remobilized by recharge then recrystallized along with orthopyroxene and plagioclase. Overall, the data from Gros Îlet, Trois Ilet, and Piton du Carbet Complex lavas shows that pyroxene crystallize at both deep and shallow depths, and plagioclase crystallize at very shallow depths. Pyroxene in dacitic magma could potentially show that a silicic reservoir has been intruded by a more mafic-rich melt that rejuvenated that reservoir.
Similar work will be done on older volcanic complexes to give a better insight of pre-eruptive storage conditions on Martinique Island. Thermodynamic calculations and chemical data provided will lead to a better understanding of magma remobilization, magma mixing, a magmatic evolution at shallow depths beneath Martinique Island.

MultiGAS survey from low-T° fumaroles in a tropical environment. Effects from internal and external forcing: example from La Soufriere de Guadeloupe (FWI)

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Fumarolic gas survey of dormant volcanoes is fundamental because the compositional and flux changes in gas emissions have actually been recognised as signals of unrest or even precursors of eruptions on several dormant volcanoes in hydrothermal unrest [1-5].

Here we report on the chemical compositions (CO_2, H_2S, SO_2, H_2) and mass fluxes of fumarolic gas emissions from the low-temperature (from 97° to 104°C) volcanic-hydrothermal system of La Soufrière de Guadeloupe (Lesser Antilles). These data, since 2017, are acquired from portable MultiGAS (measurements performed monthly) and two permanent MultiGAS stations (4 automated 20' measurements per day). These MultiGAS data are discussed along with other geochemical and geophysical parameters monitored at OVSG, such as the complete chemical gas composition sampled by Giggenbach bottles, fumarole temperature and volcanic seismicity in order to track the deep-sourced magmatic signal and detect potential signs of unrest [6].

However, dealing with the MultiGAS data in a low-T fumarolic system in a tropical environment is not straightforward due to external forcing. Hence, interpretation of the observed chemical changes must consider the dynamics of (i) scrubbing processes by the hydrothermal system and the perched volcanic pond [7], (ii) rainfall and the groundwater circulation (i.e. rainy vs non-rainy seasons, extreme events), (iii) water-gas-rock interactions [7], (iv) plume condensation, (v) sulphur deposition and remobilization, and (vi) gas-atmosphere chemical interaction.

[1] Giggenbach and Sheppard, 1989; [2] Symonds et al., 1994; [3] Hammouya et al., 1998; [4] De Moor et al., 2016; [5] Allard et al., 2014; [6] Moretti et al., submitted; [7] Symonds et al., 2001

The 1902-3 eruptions of the Soufrière, St Vincent: impacts, relief and response

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Retrospective analysis of the contemporary colonial and scientific records of a major explosive eruption of the Soufrière of St Vincent from 1902-1903 reveals how this significant and prolonged event presented challenges to the authorities charged with managing the crisis and its aftermath. In a small-island setting vulnerable to multiple hazards, the spatial footprint of the volcanic hazard and the nature and intensity of the hazard effects were rather different to those of other recurrent hazards such as hurricanes. The eruption affected the same parts of the island that had been impacted by prior explosive eruptions in 1718 and 1812, and hurricanes in 1831 and 1898, with consequences that disproportionately affected those working in and around the large sugar estates. The official response to the eruption, both in terms of short-term relief and remediation, was significantly accelerated by the existence of mature plans for land-reform following the collapse of the sugar market, and ongoing plans for rebuilding in the aftermath of the destructive hurricane of 1898. The picture that this analysis helps to illuminate provides insights both into the nature of the particular eruptive episode, and the human and social response to that episode. This not only informs discussion and planning for future explosive eruptions on St Vincent, but provides important empirical evidence for building effective responses in similar multihazard contexts.

Dynamics of back-arc ridge jumps with application to the Caribbean

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Back-arc rifting is observed in extensional subductions settings, where extensional stresses have caused rupture of the overriding lithosphere. In several narrow subduction zones with a long subduction history, such as the Scotia arc, central Mediterranean or Marianas, several ridges have been active in the course of history. Nearly instantaneously, the ridges have been jumping closer to the trench in a regular pattern. The dynamics behind this process remain unknown.

To understand this process we run simple 3D-models to simulate a long narrow slab subducting between two continental plates which retreats and creates necessary STEP-faults self-consistently. After the creation of a back-arc basin, transform faults between trench and back-arc basin form. Our results suggest that ridge jumps are a consequence of these transform faults, linking the ridge with the trench (and decoupling the overriding plate from neighboring plates), failing to remain active once the trench is too distant from the ridge. Without active transform faults, the overriding plate is coupled strongly to neighboring plates, the link between ridge and trench disappears and a new ridge opens due to stress localization closer to the trench. In a parameter study, we show that the timing between ridge jumps are reduced for narrow slabs, and, subducting fails completely for slabs narrower than 400km where the energy to create STEP-faults is insufficient. Also, the new ridge tend to form closer to the trench for narrower slabs, consistent with the location of maximum strain induced by the toroidal flow around the slab.

The Caribbean underwent a complex tectonic history (Allen et al., 2019). Subduction at its eastern edge is evidenced from the Cretaceous 'Great Arc of the Caribbean', of which the Aves Ridge Backarc forms the remains of the backarc spreading ridge. Around ~60-40 Ma, this spreading stopped, and the arc jumped eastwards, with back-arc extension starting in the Grenada and Tobago basins. The timing and distance of the back-arc ridge jump in the numerical models are discussed in the context of the data for the Caribbean.

Kinematics of the Lesser Antilles Subduction Zone

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The Lesser Antilles subduction zone has been subject of debate regarding the degree of coupling along the plate interface and the possibility of large megathrust earthquakes. Over the last century, the region has been seismically quiet, with no large thrust events recorded, leading to the question whether this subduction zone is able to produce large interplate earthquakes or not. The slow subduction velocity of ~20 mm/yr makes this question even more challenging, as mega-earthquake recurrence times would be up to many hundreds of years in the case of a fully locked subduction interface, and up to several thousands of years for a partially locked interface. The record of two large historical earthquakes, a M ~7.5 in 1839 and M ~8 in 1843, is often referred to as evidence supporting the seismic character of the Lesser Antilles subduction zone. It remains, however, questionable whether these events actually occurred along the subduction interface. Although there are a few moderate magnitude ($4 < M < 6.5$) thrust events on, or close to, the plate interface in the instrumental record, all magnitude greater than 6.5 events in the region have a normal faulting mechanism. This holds in particular for the four largest earthquakes in the historical record (M_S 7.5 1953; M_S 7.5 1969; M_S 7.4 1974; and M_W 7.4 2007), which are all normal faulting events within the subducting slab. Classic block models based on GPS data from the various islands suggest a low coupling along the Lesser Antilles arc, making the occurrence of large megathrust earthquakes less likely. Uncertainties related to the distance of the GPS-stations from the trench, the non-uniqueness of the inversion and the time window of roughly 20 years, which is only a fraction of the estimated earthquake recurrence time, cast doubts on how well such interseismic coupling estimates represent the actual degree of locking along the subduction interface. Here we attempt to derive a meaningful set of uncertainties on the distribution of interseismic coupling using a Bayesian approach. By exploring the entire range of model parameters and including *a priori* information, we aim to provide a probabilistic estimate of the interseismic coupling along the Lesser Antilles subduction zone, allowing us to have a more robust idea about possible occurrence of future megathrust earthquakes.

Origins of porphyry-type ore deposits in magmatic arcs: the importance of magma redox state, volatile flux and geodynamic setting

Jamie J. Wilkinson, Matthew A. Loader

Porphyry-type ore deposits are the source of much of the copper, molybdenum, gold and silver used by humans. They typically form in magmatic arcs above subduction zones. However, generation of economically significant deposits is restricted to specific arc segments and limited periods of time. In this presentation, we introduce the geology of porphyry ore deposits and highlight the key processes and parameters that control their formation, starting with volatile flux and melting of the mantle wedge, through long-term enrichment of magmas with metals and water in the deep crust under lithospheric compression, and ultimately to emplacement of magma in the mid- to shallow crust where volatile exsolution and mineralization may take place.