Magmatic Drivers of Eruption

Pete Barry – WHOI
MDE Co-Chair

Houston Meeting | November 14, 2022

Eruption plume of Great Sitkin volcano, Alaska captured by Lauren Flynn (USFWS) May 25, 2021.

Motivation: Why study Magmatic Drivers of Eruption?

- Make scientific discoveries using integrative and collaborative approach.
- Connect the most hazardous volcanoes on Earth to underlying subduction drivers.
- Address societal needs (i.e., volcanic hazards, forecasting).
- 800 million people live in regions that are directly exposed to volcanic hazards. Vast majority in subduction zones.
- Critical mineral and energy resources also occur in subduction zones.

Big picture questions:

Q1: How do trans-crustal processes initiate eruptions at arc volcanoes?

Requires investigating eruption cycles at restless volcanoes.

Q2: What controls magma supply rate?

Requires understanding both eruption cycles and arc scale, trans-crustal processes.

Q3: What is the depth and distribution of magma?

Requires understanding arc scale, trans-crustal processes.

Spatial and Temporal Scales of the Trans-crustal Magmatic System

MDE Hypothesis Grid

Magmatic System Controls	Magmatic System Responses: Eruption precursors and run-up time	Magmatic System Responses: Plutonism, intrusion, and repose	Magmatic System Responses: Eruption style, vigor, and duration
Supply Rates: Magma and Volatiles ▪ What controls production rate in the mantle? ▪ What controls recharge rate? ▪ What controls recharge composition? ▪ What controls volatile accumulation?	High CO_2 / S gases weeks to month prior to eruption signal deep recharge. *Werner et al. (2020)* Mafic eruptions have shorter intiation times. *Kent et al. (2019)*	Intrusive flux is related to extrusive flux. *Till et al. (2019)* Mafic eruptions have shorter repose times. *Passarelli & Brodsky (2012)*	Slow subduction is correlated with lava domes. *Zellmer (2009)* Fast magma ascent results in higher intensity eruptions. *Gonnermann & Manga (2012)*
Depth and Distribution of Magma ▪ How does magma travel through the entire crust? ▪ How deep does the volcanic system extend? ▪ Why and where do magmas stall? ▪ What controls storage depths prior to eruption?	Mantle can recharge during an eruption. *Ruprecht & Plank (2013)* Slow vanguard ascent and staging of eruptions. *Roman & Cashman (2018)* Magma systems shallow due to thermal priming. *Gualda et al. (2018)*	Optimal depth of magma chamber growth. *Huber et al. (2019)* Plutons focus due to thermal weakening. *Ardill (2018)* Magma supply influences reservoir location. *Lerner et al. (2020)*	Basaltic Plinian eruptions are sourced from shallow magma systems. *Bamber et al. (2020)* Rhyolitic Plinian eruptions sourced from depth and magma ascends quickly *Castro & Dingwell (2009)*
Rheology and Stress State ▪ What controls magma density, viscosity, and volatiles? ▪ What controls crustal rheology? ▪ What controls the stress state of the crust? ▪ What are the roles of slope failure and earthquakes in eruption triggering?	Rheology, tectonic stress, buoyancy control magma stalling depths. *Watanabe et al. (1999)* Static stress from M≥7.5 earthquakes < 200 km away can trigger eruptions. *Nishimura (2017)*	Silic magma systems have longer repose. *Passarelli & Brodsky (2012)* Longer repose -> weakened crust and reduced failure *DeGruyter & Huber (2014)* Large viscous systems require an external trigger. *Gregg et al. (2012)*	Extesion favors calderas. *Wilson et al. (1995)* Microlites growing rapidly and heterogeneously during ascent from shallow storage can cause basaltic Plinian eruptions. *Sable et al. (2006)* *Bamber et al. (2020)*

Big picture questions:

Q1: How do trans-crustal processes initiate eruptions at arc volcanoes?
Requires investigating eruption cycles at restless volcanoes.

Q2: What controls magma supply rate?
Requires understanding both eruption cycles and arc scale, trans-crustal processes.

Q3: What is the depth and distribution of magma?
Requires understanding arc scale, trans-crustal processes.

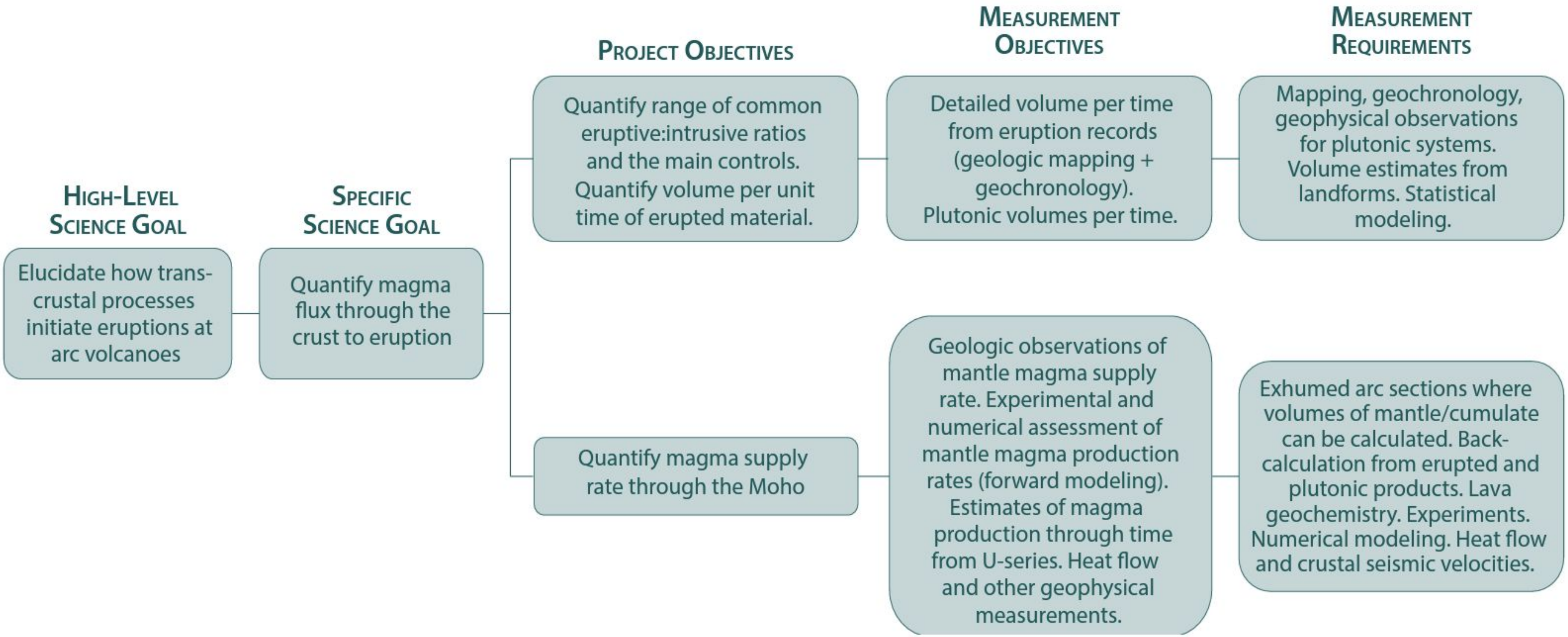
Hypotheses:

Hypothesis-A: Gas and magma composition are linked to eruption precursors, run-up times, and intensities

Hypothesis-B: Mantle magma production and supply rates govern the intrusive/extrusive mass budget, repose time, magmatic architecture

Hypothesis-C: Periods and drivers of different external eruption triggers exist over timescales of minutes to > 100,000 years

Example of Traceability Matrix approach:



Notional Experiments: INSTRUMENTAL, REMOTE SENSING, AND GEOLOGICAL EFFORTS

Q1: Eruption initiation

Sparse Sensor Arrays

Scope:
- 30 Restless Volcanoes
- probability of ≧0.8 for capturing 10 eruptions in a 10-year period

Ideal Locations:
- Full range of magma type, degassing and deformation modes, unrest and eruptive style, and subduction and upper plate parameters
- Restless

Rapid Response Arrays

Deployment Scope:
- Strategic caches of instruments
- Widespread remote sensing to identify candidate targets.
- Rapid Human Deployment
- CONVERSE-type Advisory Group

Ideal Locations:
- Ideally housed in target regions

Q2: Magma supply
Q3: Depth & distribution

Dense Imaging Arrays

Scope:
- 3 different arcs:
  slow, medium, fast convergence
- 10 volcanoes, pair in each arc

Ideal Locations:
- Range of Convergence Rates
- Simple crustal tectonics/structure (representative)
- Excellent Exposures/Access

Exhumed Arc Systems

Targets / Scope:
- Different Depths
- Different Magma Fluxes
- Different Compositions
- Not starting from Scratch
- Co-location

Big picture questions:

Q1: How do trans-crustal processes initiate eruptions at arc volcanoes?

Requires investigating eruption cycles at restless volcanoes.

Q2: What controls magma supply rate?

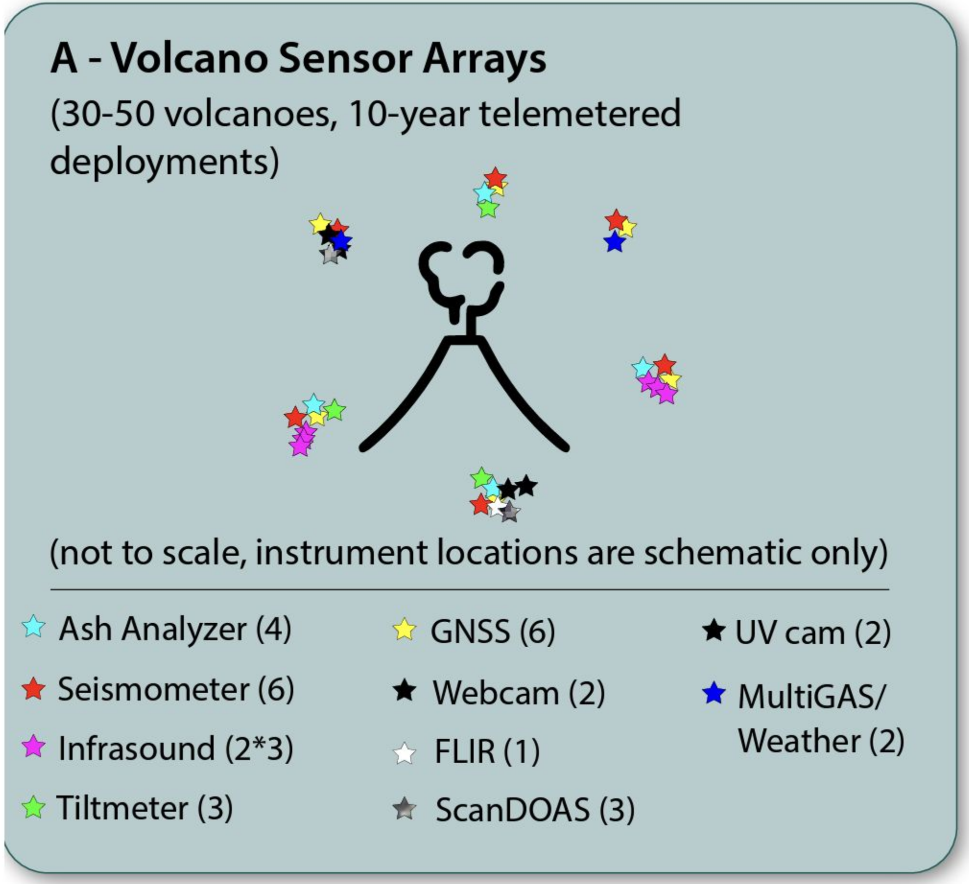
Requires understanding both eruption cycles and arc scale, trans-crustal processes.

Q3: What is the depth and distribution of magma?

Requires understanding arc scale, trans-crustal processes.

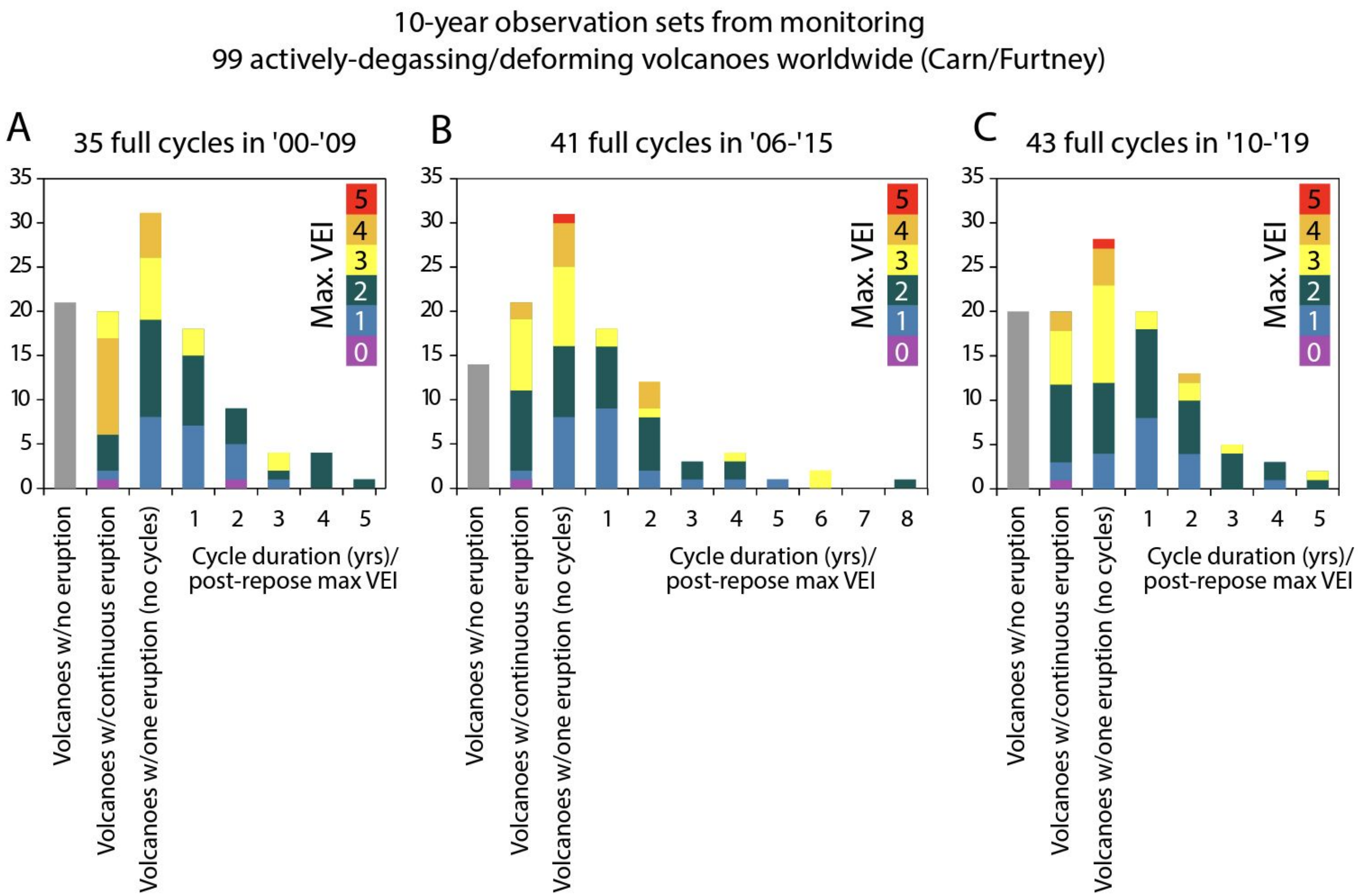
Sensor Arrays (30-50 volcanoes):

- Sparse instrument deployments of seismometers, acoustic sensors, MultiGas sensors, DOAS, GNSS receivers.
- Coupled with geochemical and geological studies.
- Volcano Remote Sensing, at a large number of systems that are likely to erupt within the coming decade.



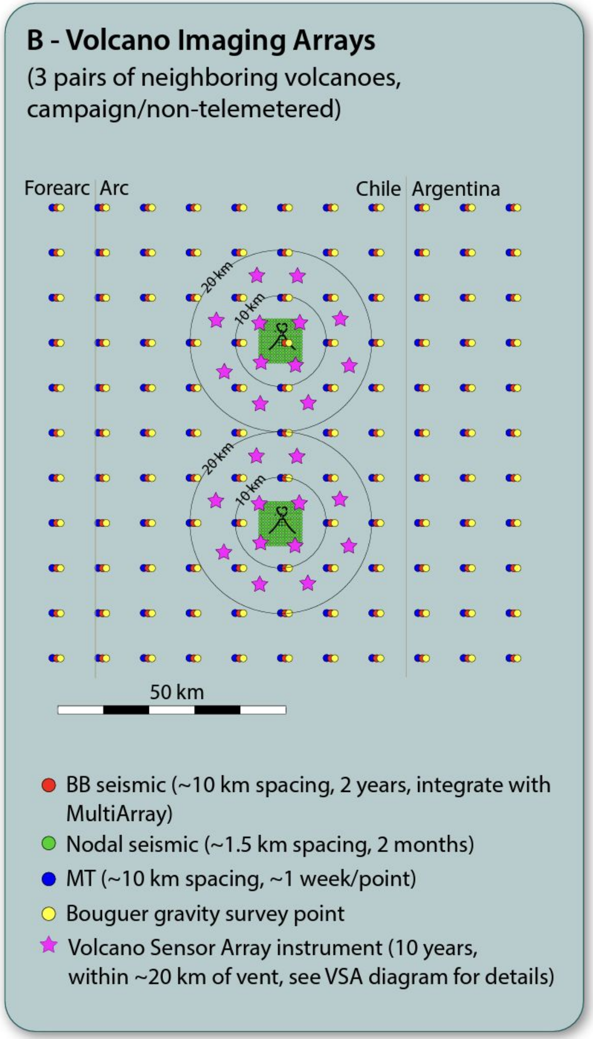
Likelihood of capturing an eruption:

- If we had deployed Volcano Sensor Arrays at all 99 volcanoes worldwide that were degassing over a 10-year period between 2000 and 2020, we would have observed ~30 full eruption cycles.



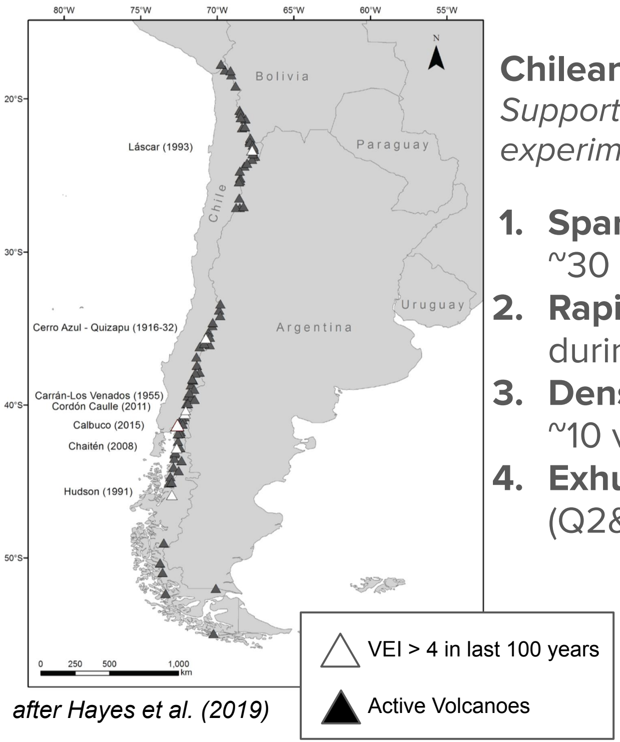
Imaging Array (10 volcanoes):

- Dense instrumentation arrays on a ~3 carefully chosen systems.
- Investigate volcano pairs in each system.
- Quantify magma supply rates from the mantle, the geometry of the trans-crustal magmatic system, and eruptive histories Therefore, these systems do not need to erupt during the duration of the Volcano Imaging Array deployment



Geographic Targets

Big Picture Questions:
Q1: How do trans-crustal processes initiate eruptions at arc volcanoes?
Q2: What controls magma supply rate?
Q3: What is the depth and distribution of magma?



after Hayes et al. (2019)

Chilean Arc

Supports all 4 notional experiments:

1. **Sparse Sensor Array**
   ~30 volcanoes (Q1)
2. **Rapid Response**
   during eruptions (Q1)
3. **Dense Imaging Array**
   ~10 volcanoes (Q2&3)
4. **Exhumed Arc Systems**
   (Q2&3)

Alaska-Aleutian Arc

Supports an analogous Sparse Sensor Array and Rapid Response Arrays (Q1):

- High probability of catching an eruption
- Range of volcano types, unrest and eruptive styles, and subduction and upper plate parameters
- Links to and enhances current monitoring efforts

Cascades Arc

Supports analogous Dense Imaging Arrays (Q2&3):

- Range of stress states, basement types, slab age
- Large variations in volcano and eruption types (strato, shield, caldera, and distributed / flank volcanism)
- Excellent exposure and accessibility for deployments

Phasing

Phase 0: What we can do Right Away

- Community Building (i.e., this workshop)
- Analyses of Existing Samples & Laboratory Experiments – Develop Common Protocols
- Modeling – Guide Array Placement

Phase 1: Initial Field Programs

- Develop Pilot Sensor Arrays on End-Member Volcanoes
- Form CONVERSE-type Volcano Advisory Group and Rapid Response Pool
- Human Deployment for Exhumed Arc and Sensor Volcano Mapping, Sampling
- Targeted Analytical, Experimental Modeling Lab studies

Phase 2: Focused Field Program and Sensor Arrays

- Develop Imaging Arrays in Focus Area
- Human Deployment for Mapping, Sampling at Focus Area
- Roll out Sensor Arrays to 10-20 volcanoes
- Widely-Distributed Analytical, Experimental Modeling Lab studies within Focus Area

Phase 3: Full Roll-Out

- Imaging Arrays & Mapping Campaigns in 2 Complementary Regions, Multiple Exhumed Sites
- Full Sensor Deployment at 30 Volcanoes
- Fully-Distributed Analytical, Experimental Modeling Lab studies

Modeling to address MDE objectives:

Guided by the outcomes and report from the Modeling Collaboratory for Subduction (MCS) Volcanic Systems Workshop (Gonnermann and Anderson, 2021)

Physical/numerical model development

- Involves both development of new physics and model implementation/validation
- Accomplished through thematic Community Working Groups (CWGs)
- MCS facility to support new code and updating of existing codes

Inversion and data assimilation

- Organizing researchers to develop frameworks for joint inversions and uncertainty
- Bridge between volcano researchers, applied mathematicians, and data scientists

Training and human capacity building

- Programmatic conduit for development of a growing pool of modelers
- Training for researchers interested in specific codes

Thanks to the 2021-2022 MDE Working Group:

Geoff Abers	Cornell University
Pete Barry	WHOI
Ben Black	CCNY
Claire Bucholz	Caltech
Simon Carn	Michigan Tech
Esteban Gazel	Cornell
Trish Gregg	University of Illinois
*Matt Haney	US Geological Survey
*Chris Huber	Brown University
Shaul Hurwitz	US Geological Survey
*Adam Kent	Oregon State University
Eric Kiser	University of Arizona
Pete LaFemina	Penn State
Yves Moussallam	LDEO
Carolina Muñoz-Saez	University of Nevada Reno
*Diana Roman	Carnegie
*Christy Till	Arizona State University
Rick Wessels	US Geological Survey
Heather Wright	US Geological Survey
Wenlu Zhu	University of Maryland

** Steering Committee Member*

<u>Welcome</u> to the new MDE Working Group:

Geoff	Abers
Álvaro	Amigo Ramos
Peter	Barry
Ben	Black
Laura	Bono Troncoso
John	Browning
Daniel	Díaz
Esteban	Gazel
Matt	Haney
Kayla	Iacovino
Jeffrey	Johnson
Adam	Kent
Vali	Memeti
Carolina	Munoz Saez
Daniel	O'Hara
Mike	Poland
Lizzette	Rodriguez
Diana	Roman
Francisco	Vera
Kevin	Ward