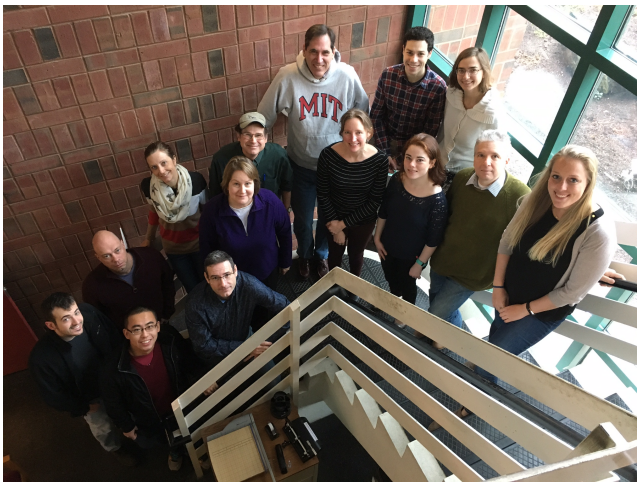
Workshop Report
EarthScope Synthesis Workshop:
Evolution of the Southern Appalachian Lithosphere
Brown University
March 27 – 29, 2017



Workshop participants

Susie Boote	University of South Carolina
Ruoshi Cao	University of South Carolina
Patrick Duff	University of South Carolina
Zachary Eilon	Brown University
Rob Evans	Woods Hole Oceanographic Institution
Karen Fischer	Brown University *(convener)*
Esteban Gazel	Virginia Tech
Robert Hawman	University of Georgia
Emily Hopper	LDEO/Columbia University
Stephen Hughes	University of Puerto Rico
James Knapp	University of South Carolina
Lijun Liu	University of Illinois at Urbana
Maureen Long	Yale University
Rachel Marzen	LDEO/Columbia University
Robert Moucha	Syracuse University
Paul Mueller	University of Florida
Benjamin Murphy	Oregon State University
Jeffrey Park	Yale University
Donna Shillington	LDEO/Columbia University *(convener)*
Lara Wagner	DTM/Carnegie Institution for Science *(convener)*
Elisabeth Nadin	EarthScope National Office

Workshop goals

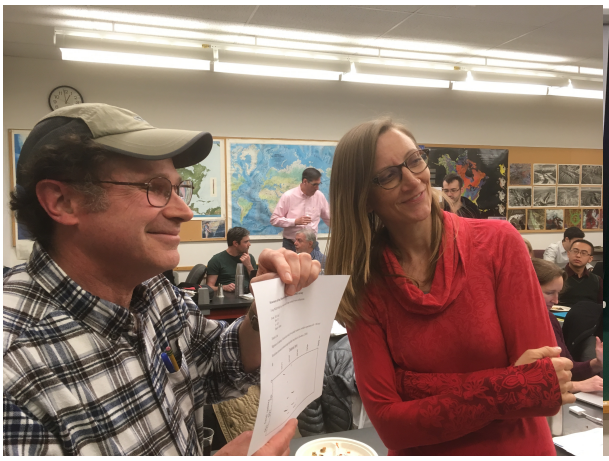
The primary goal of the workshop was to improve understanding of the evolution of the Appalachian lithosphere, with a focus on Phanerozoic processes spanning orogeny, rifting, and

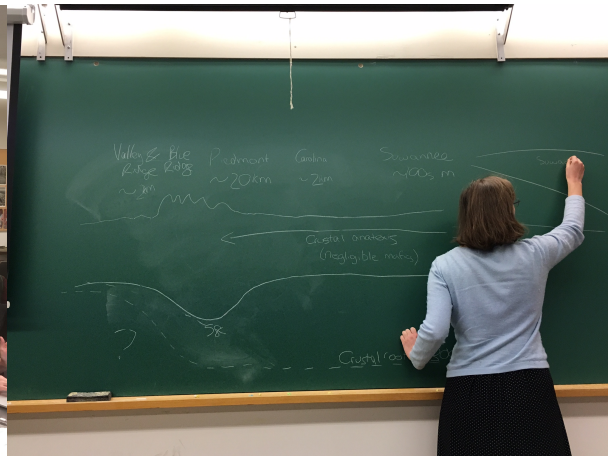
evolution up to the present-day. Critical to this understanding is how each stage of lithospheric evolution created structures and conditions that affected processes in the next. The workshop analyzed key constraints and models that relate to each stage of lithospheric evolution, developed an integrated view of the current state of knowledge, defined gaps in existing data and modeling, and identified targets for future research. Although the original proposal workshop focused on the southern Appalachians and adjacent Atlantic passive margin, workshop planning quickly expanded to encompass the central Appalachians.

The workshop was organized to enable the development of three types of outcomes:

- A common understanding of recent progress, gaps in knowledge, and targets for future work, including the identification of "grand challenges"
- A list of key synthesis papers to be written in the near future, including teams of authors for each
- Ideas for promising new research areas and projects

These outcomes are described later in the report.





Workshop program

Monday, March 27: Meeting participants shared highlights of recent research, key questions and priorities for future research through brief talks (12 minutes with 3 minutes of questions), followed by discussion, all in plenary mode. We ended the afternoon with a discussion that defined the topics of the breakout sessions for the next day.

Talks:

EarthScope Science, Education and Outeach

Elisabeth Nadin, *EarthScope National Office*

Greetings from the EarthScope National Office

Present-day lithospheric structure

Lara Wagner, *Carnegie Institution for Science*

Not so stable after all: Lithospheric structures beneath the southeastern United States

Benjamin Murphy, *Oregon State University*

Contemplating the highly anomalous Piedmont geoelectric resistor

Maureen Long, *Yale University*

New results from USArray on crustal structure and lithospheric anisotropy beneath the Appalachians

Rob Evans, *Woods Hole Oceanographic Institution*
Evidence for lithospheric loss beneath the Appalachians along the MAGIC line

Jeffrey Park, *Yale University*
What do we mean when we talk about lithosphere? Grain-boundary sliding and lithospheric seismic structure

Orogenic Processes

Paul Mueller, *University of Florida*
Rodinia vs. Pangea: Origin of Mesoproterozoic basement in eastern Laurentia

James Knapp, *University of South Carolina*
The Precambrian Brunswick Suture Zone: Preservation vs. reactivation of lithospheric structure

Susie Boote, *University of South Carolina*
Extent of preserved early- to mid-Paleozoic Gondwanan Suwannee Basin sequence and tectonic implications

Emily Hopper, *Lamont Doherty Earth Observatory*
Crustal and lithospheric structures in the southeastern US: Insights from SESAME

Patrick Duff, *University of South Carolina*
Southern Appalachian crustal structure from forward modeling of potential field data and retro-deformational structural modeling

Rifting Processes

Rachel Marzen, *Lamont Doherty Earth Observatory*
Relationships between crustal thinning, magmatism, and basin structure in the southeastern US from the SUGAR refraction seismic experiment

Ross Cao, *University of South Carolina*
The Jurassic(?) Hazlehurst Formation and its implications for the evolution of continental rifting in the southeastern U.S.

Donna Shillington, *Lamont Doherty Earth Observatory*
An overview of new constraints on syn- and post-rift processes on the Eastern Margin of North America from the GeoPRISMS ENAM Community Seismic Experiment

Post-rifting lithospheric evolution

Lijun Liu, *University of Illinois*
Look for the deep mantle origin of Appalachian rejuvenation

Robert Moucha, *Syracuse University*
A mid-Pliocene landscape evolution model of the US east coast: Role of dynamic topography, GIA, flexure and long-term sea level change

Esteban Gazel, *Virginia Tech University*
Post-rift magmatic evolution of the "passive-aggressive" eastern North American Margin

Stephen Hughes, *University of Puerto Rico*
Relict Paleozoic faults in the epicentral area of the 23 August 2011 central Virginia earthquake: Assessing the relationship between preexisting strain and modern seismicity

Karen Fischer, *Brown University*
Constraints on Appalachian lithospheric evolution from present-day crust and mantle structure

Tuesday, March 28: We conducted three breakout sessions in the morning that focused on detailed comparison and analysis of overlapping and sometimes conflicting research results

("staring and comparing"), followed by plenary reports and discussion.

Morning breakout sessions:

- Regional crust and mantle structures constrained by MT imaging and seismic tomography, including anisotropy
- Collisional structures, in particular the location/geometry/properties of Alleghanian suture(s)
- Observations and models for the location and timing of topographic evolution, magmatism and faulting

Two breakout sessions in the afternoon also involved detailed comparisons of results but segued into broader research questions, and were again followed by reports and plenary discussion.

Afternoon breakout sessions:

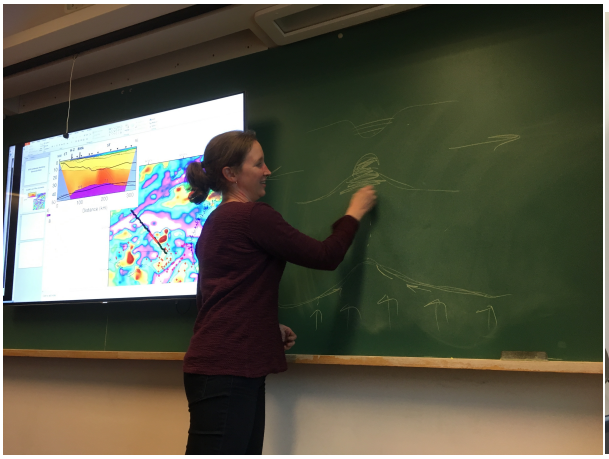
- Rifting and Central Atlantic Magmatic Province (CAMP)/rift magmatism
- Post-CAMP uplift and erosion and underlying processes

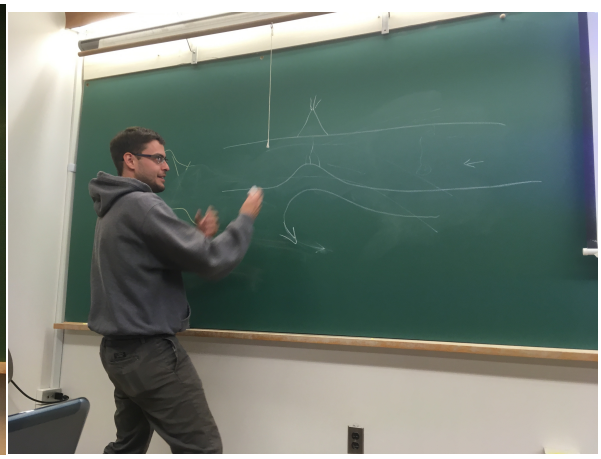
We concluded Tuesday afternoon with plenary discussion that outlined the specific workshop outcomes ("grand challenges," synthesis papers, new research areas/projects).

Wednesday, March 29: Teams met to work on synthesis papers and future projects and to discuss education and outreach possibilities

Workshop documents

Research talks and other results, discussion notes, and background papers were shared and archived on a Google drive.





Workshop outcomes

Grand Challenges

Workshop participants identified the following unresolved questions as broad and promising themes for future work.

1) What are the relative roles of inherited structures and properties from each stage of lithospheric evolution in subsequent stages?
2) What was the scale and geometry of the Appalachian orogen? What was its subsequent temporal evolution?
   - What are the clearest signatures of subduction in the crust and mantle? What was the subduction polarity?
   - What was the balance of strike-slip motion vs. head-on collision?
   - Was the deformation in the orogen thin-skinned or thick-skinned?
   - What were the orogen's paleotopography, paleo-crustal thickness and crustal root morphology, paleogeography, and paleo-mantle structure?
   - Where is the Alleghanian suture or sutures?
   - Was there any subduction during the Alleghanian in the southern Appalachians?
   - Do good analogies with modern orogens exist?
3) How do we reconcile the history of tectonic events recorded in the crust with present-day mantle structure?
   - How complete is the present-day expression of past processes in both?
   - Do the crust and mantle evolve independently or on different time-scales?
4) What was the style of Mesozoic rifting in the southern Appalachians and where does it fit in the spectrum of modern rifting behavior (i.e. narrow vs. diffuse rifting; the East African Rift system vs. the Basin and Range)?
   - What is the extent of the composite South Georgia Basin, and what is the extent and distribution of extension associated with it?
   - What is the relative timing of extension and magmatism in the South Georgia Rift and offshore at the successfully rifted margin?
   - How are magmatism and extension localized by preexisting sutures?
   - What were the roles of magmatic vs. mechanical processes?
   - What was the role of gravitational collapse post-orogenesis?
   - How are processes associated with rifting/opening of the Gulf of Mexico distinguished from processes associated with the rifting/opening of the Atlantic?
5) How does middle-aged (Phanerozoic) lithosphere evolve in the absence of obvious tectonic drivers?
   - What are the physical and chemical properties that create distinct shallow mantle anomalies (e.g. low velocity anomalies in Harrisonburg, Virginia, New England, and perhaps Florida; the Piedmont high resistivity band)? How do they relate to lithospheric instability? How do they relate to the post-CAMP magmatic history?
   - What is the role of large-scale mantle flow in determining lithospheric stability? What is the connection to mid-mantle and lower mantle high velocity anomalies?

- How does intraplate seismicity relate to the ongoing evolution of lithospheric structure? What past and present-day processes determine passive margin seismicity patterns? How does modern seismicity relate to Paleozoic terranes (e.g. why is the Suwannee terrane so seismically quiet)?
- How is ongoing lithospheric evolution linked to heat flow and hot springs? What mantle signatures are present in these observations?
- What are the implications of topographic evolution for lithospheric processes? How can mantle influences be separated from other factors (crustal isostasy, climate, stream capture, etc.)?

Synthesis Papers

A series of synthesis papers were outlined on the last day of the workshop. These papers were designed to address key questions through the integration and reconciliation of recent research results. Each team is considering the best venue for its synthesis paper, including the planned Geosphere volume initiated by the EarthScope Synthesis Workshop on the 4-D Evolution of North America.

1) Reconciling the Piedmont resistor (a highly resistive lithospheric root) with seismic models
   Park, Wagner, Murphy, Long, Evans, Liu
2) The southern Appalachian orogen at its peak: Scale and style of orogenesis
   Boote, Hopper, Duff, Marzen, Cao, Shillington, Knapp, Mueller, Hawman, Fischer
3) The Harrisonburg anomaly: Geophysical and geochemical constraints on its origin*
   Wagner, Gazel, Moucha, Long, Evans, Hughes, Hopper, Liu
4) Post-rift magmatic history and its links to present-day seismic/MT structure and geodynamical models of melting
   Moucha, Gazel, Wagner, Evans, Mueller, Fischer, Knapp, Liu
5) Reconciling different measures of seismic anisotropy and linking them to mantle flow
   Moucha, Wagner, Long, Fischer, Eilon, Liu
6) South Georgia Rift structure, relationship to sutures, lack of faulting in Paleozoic sediments offshore, relationship to magmatic distribution*
   Shillington, Marzen, Cao, Knapp, Duff

*Work on these synthesis papers will commence after primary research papers now in progress are published.

Synthesis Products

These potential maps and databases were identified as being particularly useful for synthesis papers and feasible based on published work.

1) Compilation of existing constraints from metamorphic paragenesis and thermochronometry on P-T conditions of rocks with Alleghanian imprint
2) Maps of estimated exhumation during and since orogeny
3) Map of estimated post-CAMP exhumation
4) Map of magmatic history

5) Compilation of crustal thickness constraints, including both onshore and offshore data
6) Compilation of basin geometries, depths and geographic extents, with distribution of normal faults

New Research Projects and Products

These projects and the resulting maps and databases were also identified as high priorities, but would require significant new work.

1) Re-migrate existing COCORP stacks with updated velocity models
2) Map/compilation of Alleghanian granites and their integration with other constraints on crustal geology; focus on depths of intrusions and their implications for unroofing
3) Compilation of clastic wedge sediment volumes as a constraint on how much material has been removed via erosion
4) Integration of onshore/offshore magmatism from recent crustal imaging studies and the structure of the J-reflector (e.g. waveform characteristics)
5) Integration of active/passive source constraints on mantle discontinuity structure throughout the region, with a focus on mid-lithospheric discontinuities and the lithosphere-asthenosphere transition
6) Campaign to measure helium isotopes and fluid chemistry in eastern U.S. hot springs
7) Continued analysis of the Eastern North America Community Seismic Experiment offshore dataset and its integration with the onshore datasets; a specific target of great interest is the offshore location of the Suwannee suture zone (the Alleghanian suture)
8) Incorporation of new constraints on mantle buoyancy structure and detailed/variable lithospheric structure (e.g. thick, viscous cratonic roots) into mantle flow models; assessment of implications for anisotropy and mantle melting
9) Analysis of mantle xenolith geochemistry and crystallographic preferred orientations, including xenoliths in New England and their relationship to the New England low velocity anomaly
10) Reconstruction of slip history on major faults (Towaliga, Bartletts Ferry, Goat Rock, Modoc, etc.); deciphering when strain was partitioned by existing faults, and when new stresses generated new faults

Education and Outreach Opportunities

Many workshop participants have engaged in creative education and outreach activities as part of their EarthScope-funded research projects. Discussion of new possibilities included:

1) Annotate select synthesis products to provide context for undergraduate, K-12 and public audiences, in collaboration with the EarthScope National Office
2) Work with the EarthScope National Office to develop feature stories:
   - Rob Hawman's extensive outreach work with rural school groups in northern Georgia
   - Old orogens and margins have a lot going on: seismicity, volcanism, dynamics processes at depth (e.g. the Virginia earthquake, Eocene volcanism, the Harrisonburg low velocity zone, the Piedmont resistor, etc.); passive margins are also an important

marker for sea-level rise; use the angle that EarthScope science has led to controversies and questions about geologic features that we thought were sorted out

3) Lessons to develop for educational applications:
   - The power of applying different methods, the importance of observing things in different ways, with the Piedmont resistor as an example
   - Old orogens and margins have a lot going on: seismicity, volcanism, dynamic processes at depth
4) Develop shared materials for use in outreach presentations by scientists
   - Donna Shillington is planning to talk at the Atlanta Geological Society
   - Share materials from Rob Hawman's outreach to Georgia schools