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The Larsen Ice Shelf System, Antarctica (LARISSA): Polar Systems Bound Together, Changing Fast



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SCIENCE

- 4 **The Larsen Ice Shelf System, Antarctica (LARISSA): Polar Systems Bound Together, Changing Fast**
Julia S. Wellner et al.

Cover: View of the RV *Araon* taken in Beascochea Bay, Antarctica. Taken by E. Pettit from a helicopter transporting LARISSA scientists en route to service seismic and GPS stations at Foyin Point, 17 April 2013. See related article, p. 4–10.



GSA 2019 Annual Meeting & Exposition

12	Registration	16	Pardee Keynote Symposia
12	Event Space Requests	17	Icebreaker
12	Transform Your Career by Attending a Short Course	17	GSA RISE
12	Childcare	18	AAPG Special Session
13	Schedule-at-a-Glance	20	Feed Your Brain— Lunchtime Enlightenment
14	Hotels	21	Be a Mentor: Make a Difference
14	Roommates & Rides	22	GeoCareers
15	Downtown Phoenix Hotel Map	23	Thank You Sponsors!
<hr/>			
24	Updated Position Statements		
24	36th International Geological Congress (IGC) Mentoring and Travel Grant Program		
26	Mentoring Tomorrow’s Geoscience Leaders at the 2019 Section Meetings		
28	Strategic Engagement in Science Policy Making: A Call to Action		
30	GSA Science Communication Fellowship Wrap-Up		
32	Geoscience Jobs & Opportunities		
35	GSA Foundation Update		
36	Groundwork: Teaching for Earth Resilience: A Strategy for Increased Diversity and Equity		
38	2020 Section Meetings Calendar		

The Larsen Ice Shelf System, Antarctica (LARISSA): Polar Systems Bound Together, Changing Fast

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ABSTRACT

Climatic, cryospheric, and biologic changes taking place in the northern Antarctic Peninsula provide examples for how ongoing systemic change may progress through the entire Antarctic system. A large, interdisciplinary research project focused on the Larsen Ice Shelf system, synthesized here, has documented dramatic ice cover, oceanographic, and ecosystem changes in the Antarctic Peninsula during the Holocene and the present period of rapid regional warming. The responsiveness of the region results from its position in the climate and ocean system, in which a narrow continental block extends across zonal atmospheric and ocean flow, creating high snow accumulation, strong gradients and gyres, dynamic oceanography, outlet glaciers feeding into many fjords and bays having steep topography, and a continental shelf that contains many glacially carved troughs separated by areas of glacial sediment accumulation. The microcosm of the northern Antarctic Peninsula has a tendency to change rapidly—rapid relative not just to Antarctica’s mainland but compared

to the rest of the planet as well—and it is generally warmer than the rest of Antarctica. Both its Holocene and modern glaciological retreats offer a picture of how larger areas of Antarctica farther south might change under future warming.

INTRODUCTION

Ice sheets cover most of the Antarctic continent and, in some places along the margin, connect to ice that has flowed from the land and now floats above liquid water. These areas of floating ice, called ice shelves, are dynamic in space and time and, while their loss does not directly contribute to sea-level change since the ice is already floating, they serve as a buttressing force to the glaciers behind them (Scambos et al., 2004). Among the most sensitive ice shelves are those in the northern Antarctic Peninsula. The major iceberg calving event on the Larsen C Ice Shelf in 2017 refocused attention on the ongoing ice loss from the Larsen Ice Shelf and the rapid changes in climate, ice, ocean, and life in this part of Antarctica. In January 1995 and again in March 2002, large areas of the more

northerly sections of the Larsen Ice Shelf disintegrated. Covered with melt ponds and riven with wide cracks, these 200-m-thick ice shelves lost thousands of square kilometers of area in just days to weeks (~1500 km² and 3250 km², respectively, for the Larsen A and B ice shelves; for comparison, Rhode Island is ~3150 km²). The lost areas of ice broke into myriad small ice blocks that toppled over, creating a rapidly expanding floating mass of ice rubble (MacAyeal et al., 2003). These breakup events stunned glaciologists and have become iconic examples of the effects of global climate change, rapid regional warming, and ice-shelf instability.

The Antarctic Peninsula has been among the fastest-warming areas on Earth. Data from weather stations and ice cores show a 2 to 3 °C increase in mean temperatures over the past 80 years (Zagorodnov et al., 2012; Barrand et al., 2013). The trend is attributed to the combined, and probably linked, effects of an increased northwesterly flow of warm, maritime air across the Antarctic Peninsula and a reduction in sea-ice extent in the northern Bellingshausen

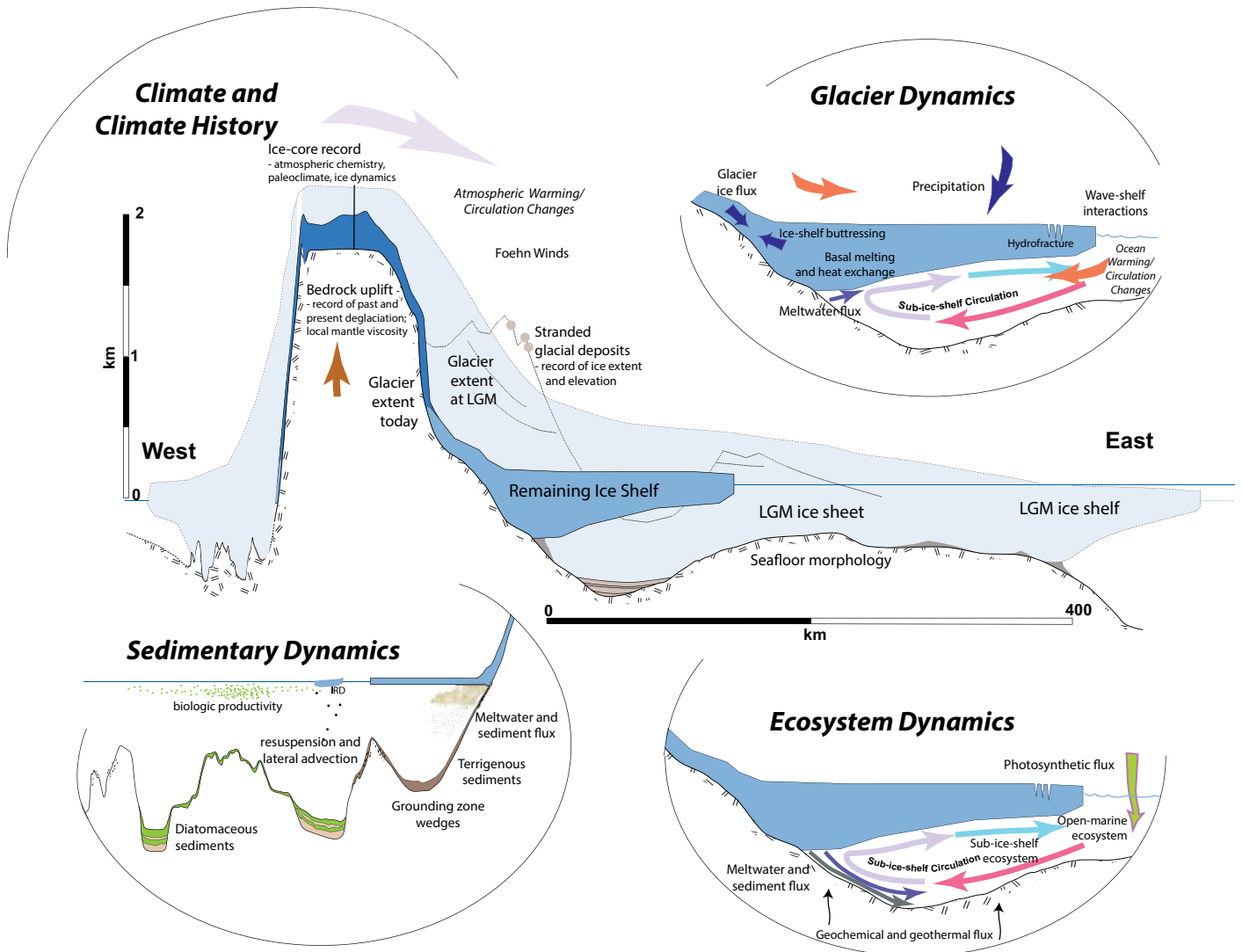


Figure 1. Schematic cross section through the Antarctic Peninsula showing the linked sedimentary, oceanographic, cryospheric, and biological systems from the western fjords to the Larsen embayment that were studied as part of the interdisciplinary LARISSA program. IRD—ice-rafted debris; LGM—Last Glacial Maximum.

and northwestern Weddell Seas. However, since ca. 2000, the warming trend has moderated (Turner et al., 2016), and a slight cooling has been observed since 2006 (Blunden and Arndt, 2012). During this period, sea-ice conditions in the northwestern Weddell Sea have been generally heavier, and landfast sea ice has persisted in the Larsen A and Larsen B embayments through several austral summers since 2012.

Disintegration of the ice shelves had large subsequent impacts on the region. Tributary glaciers of the ice shelves showed significant acceleration and drawdown following the event (Scambos et al., 2004). Regionally, increased ice flow from the Larsen A and Larsen B tributary glaciers now contributes a net ~10 Gt/yr of ice mass to the oceans (Berthier et al., 2012;

Scambos et al., 2014). The rapid changes in the Larsen Ice Shelf and northern Antarctic Peninsula region impacted an interconnected set of polar systems, presenting a natural laboratory for investigating an area of the Antarctic undergoing the kinds of effects anticipated in other areas under continued warming. The component systems have interrelated physical and ecological responses spanning annual to multi-millennial temporal scales (Fig. 1).

The LARsen Ice Shelf System Antarctica (LARISSA) project was designed to study the evolution of the northern Larsen from a holistic perspective. As part of the 4th International Polar Year (2007–2009), a set of multi-institution grants were awarded under the newly created U.S. National Science Foundation Antarctic Integrated

System Science (AISS) program. The collaboration of investigators spanned several universities across the United States, and included research partners in seven countries. Three major research cruises and six field visits were conducted over six years, beginning in 2009. Major cruises were conducted on the U.S. RV/IB *NB Palmer* and were supported by shorter cruises on the R/V *LM Gould*. International logistical and field support included a cruise on the RV/IB *Araon* with the Korea Polar Research Institute, Twin Otter air support out of Rothera Station from the British Antarctic Survey, logistical and collaborative support from Instituto Antártico Argentino, and, finally, remotely operated vehicle operations from the University of Ghent, Belgium. While the research has produced

numerous discipline-specific results and publications, we focus here on the cross-disciplinary results of the project. These studies focus on past climate variability from ice core records, current climate changes, seabed landforms (a window on past ice-flow patterns), and marine geologic core analysis (combining climatic, glacial, biological, and oceanographic histories preserved in sedimentary strata). Extensive sea ice and landfast-ice cover in the area of the Larsen Ice Shelf forced parts of each major cruise to include work on the western side of the Antarctic Peninsula. These western Antarctic Peninsula data have supported a comparison across the drainage divide between the warmer, wetter western Antarctic Peninsula and the colder, dryer Larsen side of the Antarctic Peninsula.

SEAFLOOR RECORDS OF CHANGES SINCE THE LAST GLACIAL MAXIMUM (LGM)

Multibeam sonar mapping was conducted on both sides of the Antarctic Peninsula and merged with existing multibeam mapping data of the area (Lavoie et al., 2015). This work shows that an extensive system of outlet glaciers and lateral ice domes extended from the present coastline during the LGM, reaching the shelf break in at least some areas on each side of the Antarctic Peninsula. Evidence for flowing grounded ice in the Larsen B embayment was found as deep as 1100 m below modern sea level. However, some areas that are inland of the maximum grounding line, and thus were overridden by glacial ice, show no evidence of having had grounded ice on the seafloor. Rather, these areas show flat-lying sedimentary layering interpreted as subglacial lake deposits formed when ice was grounded farther offshore but not in the deepest parts of the inland basin (Rebesco et al., 2014). A sudden drop in elevation in one area of Crane Glacier just inland of a set of exposed lake deposits within the fjord seabed was interpreted as a subglacial lake drainage event induced by recent (post-ice-shelf disintegration) surface slope changes (Scambos et al., 2011).

When expanded during the LGM, ice was grounded on the eastern continental shelf for several hundred kilometers beyond the current glacier grounding lines (Lavoie et al., 2015; Campo et al., 2017). Glacial geomorphic features on the seafloor record shifting ice-flow patterns as

deglaciation and flotation of the ice sheet progressed (Fig. 2). Flow reorientation during retreat, generally from flow that included a component of alongshore flow toward flow more directly offshore, reflected the changing ice sheet geometry as the grounding line of the ice sheet neared the modern coastline (Fig. 2). Strong elongation of the seabed features indicates rapid ice flow during the glacial maximum period. Several possible LGM-era ice-shelf collapses are noted near the continental shelf break in the form of iceberg furrows oriented sub-parallel to the seabed lineations. The arrangement of seabed features indicates a sudden discharge of many icebergs whose drift is still partially controlled by surrounding grounded ice. Ongoing ice retreat is governed in part by reorganization of flow patterns accompanying grounding line movement.

Marine sediment core data document a major difference in the long-term histories of the Larsen A and Larsen B embayments (Fig. 3). The former Larsen A experienced periods of shelf removal during the mid- to late Holocene (Brachfeld et al., 2003). Cosmogenic-nuclide exposure ages from coastal sites support a Larsen A ice-shelf

collapse during the mid-Holocene (Balco et al., 2013).

In contrast, the Larsen B embayment was continuously occupied by an ice shelf for at least 12,000 years prior to its 2002 disintegration (Domack et al., 2005a; Rebesco et al., 2014). Absolute diatom abundance in Larsen B sediment cores increased sharply upon ice-shelf breakout; however, pre-breakup Holocene sediments are almost completely depauperate (Domack et al., 2005a; Rebesco et al., 2014). This suggests either limited contribution from Weddell Sea waters to the sub-ice cavity or that these waters were diatom poor, which could be attributable to heavy sea-ice cover in the Weddell Sea limiting primary productivity.

Even during times of extended Holocene ice-shelf cover, styles of sediment accumulation differ between the two Larsen embayments. Though ice-shelf-free conditions are recorded only in mid-Holocene sediments from the Larsen A embayment, the consistent presence of diatom valves in sediment cores indicates their advection into the sub-ice cavity throughout the Holocene (Brachfeld et al., 2003). The Larsen A area is connected to the Bransfield

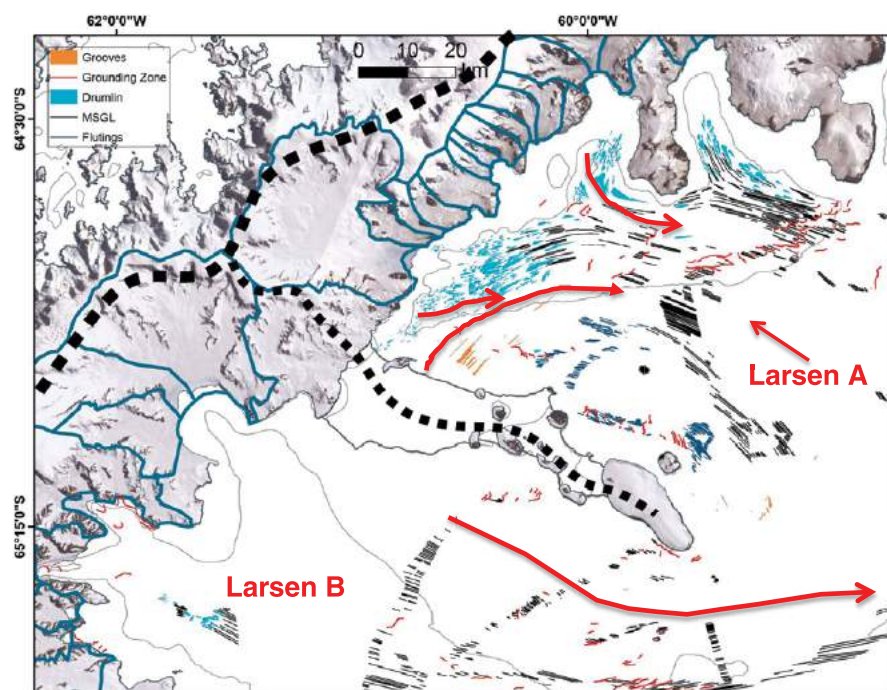


Figure 2. Geomorphic features mapped on the seafloor of the Larsen A and Larsen B embayments, which were used for reconstructing paleo-ice flow patterns on the shelf. Features are mapped across the area where multibeam data were collected. Gaps in the feature mapping largely represent areas where no geophysical data could be collected due to extensive ice cover. Thin solid lines are 500 m bathymetry contour. Blue lines represent modern ice divides. Dashed lines represent paleo-ice divides (Lavoie et al., 2015). Based on mapping from Campo et al. (2017). MSGL—mega-scale glacial lineations.

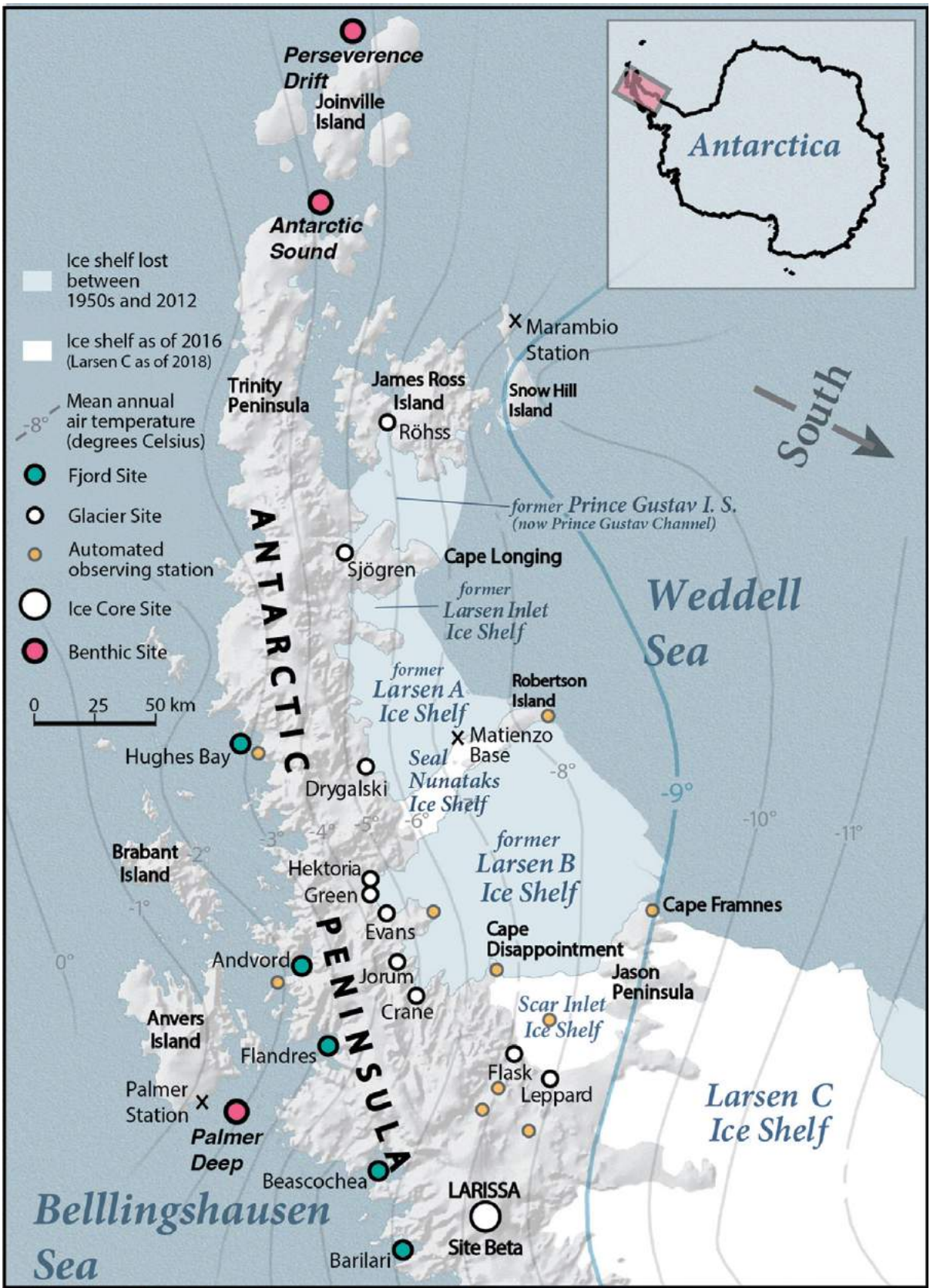


Figure 3. LARISSA study region and sites of research focus. Geographic features highlighted by circles were areas of detailed investigations or instrumentation in support of regional characteristics. Contours are isotherms of mean annual temperature at sea level; -9°C has been suggested as the limit of long-term ice-shelf stability in previous studies. Base map provided with permission from XNR/Terra Carta (www.terracarta.com).

Strait to the north and west, and source waters circulate between them, potentially allowing the influx of diatom valves. The Larsen B, on the other hand, is an embayment connected only to the continental shelf of the Weddell Sea, where gyre circulation brings water from the south, which has heavy perennial sea-ice cover and low productivity. The limited ocean circulation to the Larsen B cavity, now embayment, is also apparent from benthic foraminiferal faunal and stable isotope data (Domack et al., 2005a), indicating an absence of upper Circumpolar Deep Water or other warm, deep-water masses in the area.

Large increases in sediment flux occurred in all the ice-shelf-covered areas after shelf breakup. These included organic particulates and ice rafted and hemipelagic siliciclastic materials. Some sites received >3 m of sediment per year following ice-shelf breakup in the immediate vicinity of the glacier fronts (Rebesco et al., 2014), in contrast to <1 mm per year in the shelf-covered cavities during the Holocene (Domack et al., 2005a).

Similar to the Larsen A embayment, reduced glacier-ice extent and seasonally open water during the early to mid-Holocene is observed on the western Antarctic Peninsula in Barilari Bay, followed by late Holocene expansion of sea-ice cover that reached a maximum during the Little Ice Age (Christ et al., 2015). Outer bay glaciers in their advanced late Holocene positions were also sensitive to conditions akin to positive mean Southern Annular Mode (SAM) states (Reilly et al., 2016). Late Holocene cooling is also recorded in sediments from the tip of the Antarctic Peninsula, where the western and eastern Antarctic Peninsula systems meet (Kyrmanidou et al., 2018).

CLIMATE AND CRYOSPHERE EVOLUTION

At the ridge summit above the southernmost Larsen B, a 448.12 m ice core was collected to bedrock (LARISSA Site Beta ice core; Fig. 3). The time period from AD 1900 to 2009 is recorded in approximately the top 195 m of the ice core (Goodwin et al., 2016). The core records an increase in annual net accumulation over the twentieth century, with the greatest increase beginning in the 1970s contemporaneously with the increasing positive trend in the SAM. However, the relationship between SAM and accumulation greatly depends on the

phase of Pacific multi-decadal oscillation, underscoring the importance of tropical–polar teleconnections (Goodwin et al., 2016). The ice core–derived accumulation record also correlates with Bellingshausen Sea sea-ice extent, and both records exhibit a common response to short-term variations in the SAM and El Niño Southern Oscillation (Porter et al., 2016). Interestingly, mean air-temperature trends derived from an inversion of borehole temperature profiles (Zagorodnov et al., 2012) show differences from those estimated from the ice core–derived $\delta^{18}\text{O}$ record. Core sample $\delta^{18}\text{O}$ enrichment, which indicates warming, is modest during the twentieth century. This suggests that in addition to increased local near-surface temperatures, which are well documented from station data, other processes may have influenced the isotopic signature of the water vapor arriving over the Bruce Plateau (Goodwin et al., 2016). Moreover, in addition to conditions in the moisture source area such as reduced sea-ice extent in the Bellingshausen Sea, the increased annual net accumulation likely reflects other processes that affect the rate at which precipitation is delivered to the site.

Deployment of weather stations along the margins of the Larsen B, in conjunction with the analysis of a long-term weather time series recorded at the Argentine base Matienzo (situated between the Larsen A and Larsen B embayments; Fig. 3), provided further insight into the evolution of the regional climate since the 1960s. The observational record indicates a strong surface-warming trend over the Larsen embayments between 1962 and the early twenty-first century. This is linked to a higher frequency of foehn winds, warm, dry winds that flow down the lee side of a mountain range. In the Antarctic Peninsula, foehn winds result from the vertical deflection of the polar westerlies by the Antarctic Peninsula orography and dry adiabatic heating of the air mass as it descends the lee side (Cape et al., 2015). While their seasonal occurrence is tied to climatological storm tracks, their frequency is also tightly correlated to the SAM and the ongoing strengthening of the polar westerlies (Turner et al., 2014). Foehn events are responsible for almost all temperature excursions above the freezing point in the Larsen B region, linking melt intensity to seasonal foehn frequency. The combination of strong winds and low humidity during

the foehn conditions contributes to strong snow ablation, so that relatively little surface melting is needed to consume the winter snowpack and initiate surface-melt ponding. This relationship is perhaps best illustrated by the foehn-induced proliferation of melt ponds prior to the 2002 disintegration event. Similar melt seasons and melt ponding occurred in 1995 (the year of the Larsen A disintegration) and 2006, but surface-melt ponding was moderated during the period of the LARISSA project due to cooler climate conditions (Turner et al., 2016). Moreover, the downslope wind regime creates an extreme precipitation shadow effect on the eastern Peninsula glaciers and shelf areas. Measurements from automated multi-sensor stations (automated meteorology-ice-geophysics observing systems, or AMIGOS) show that during 2010–2012, accumulation ranged from ~3 m water equivalent per year at the LARISSA Site Beta site, to ~0.5 m per year on lower Flask Glacier, and near zero on the Scar Inlet Ice Shelf surface (Fig. 3).

A series of bedrock-sited continuous GPS (cGPS) recording stations were installed to determine current uplift rates, arranged to surround the inferred Bruce Plateau ice dome and augment the longer-term record from Palmer Station. The cGPS records show exceptionally high uplift rates, up to $14.9 \pm 2.7 \text{ mm yr}^{-1}$ (Nield et al., 2014). The present-day rates of rapid uplift represent acceleration from the longer-term rates of uplift in the Antarctic Peninsula, which is tied to the accelerated loss of ice from the region (Nield et al., 2014). Further, the cGPS data were used to estimate a local mantle viscosity of ($2 \times 10^{18} \text{ Pa s}$) and infer the local crustal thickness. The very low upper mantle viscosity results in a lithosphere system that responds very rapidly to changes in mass loading. Almost none of the current uplift can be attributed to residual rebound from the LGM ice retreat (Nield et al., 2014).

ONGOING ECOSYSTEM CHANGES

A profound transformation in ecosystem structure and function has occurred in the region as a result of the ice-shelf collapse. The previously dark, oligotrophic waters beneath the Larsen B ice shelf now support a thriving light-based phytoplankton community, with productivity rates and phytoplankton composition similar to other productive areas of the Weddell Sea and Antarctic continental shelf (Cape et al.,

2014). The Larsen B embayment is now intermittently a new coastal polynya, whose seasonal opening is triggered and maintained by the action of warm foehn winds. In this new state, the region has become an important component of the overall western Weddell Sea marine ecosystem. Its seasonal primary production will enable both pelagic and benthic habitat expansion.

Redistribution of chemical-based and light-based biological production following the ice-shelf breakup may have caused the demise of the extraordinary cold-seep ecosystem discovered in the newly exposed sub-ice-shelf area in 2005 (Domack et al., 2005b; Niemann et al., 2009). Extensive changes in the structure of benthic communities have occurred in the years following the shelf event, as previously absent phyto-detritus materials accumulate on the seafloor (Gutt et al., 2011). Lipid biomarkers in surface sediments suggest that seasonal sea-ice diatoms are important contributors to this flux of organic matter (Shimizu, 2016). The development of a new paleo-productivity index in marine sediments links ocean productivity measured as DMSP (dimethyl sulfonopropionate) and MSA (methanesulfonic acid) measured in ice cores, within time scales of thousands of years. The DMSP data are supported by complementary data on absolute diatom abundances, which document the very recent influx of a sea-ice-associated diatom community (Rebesco et al., 2014).

Studies conducted as part of LARISSA have also highlighted the dramatic differences between the rich benthic assemblages in fjords along the western Antarctic Peninsula and those on the open western Antarctic Peninsula shelf and in the Weddell Sea (Grange and Smith, 2013). Dropstone habitats add significantly to the diversity of benthic megafauna (Ziegler et al., 2017), indicating that ice-shelf collapse and massive dropstone production substantially alters formerly sub-ice-shelf ecosystems. Furthermore, LARISSA studies revealed that, in recent decades, a large population of king crabs crossed onto the western Antarctic Peninsula continental shelf. Warming trends along the western Antarctic Peninsula suggest that these relatively cold-intolerant crabs may extend their range farther onto the western Antarctic Peninsula shelf, with major invasive impacts in the next few decades (Smith et al., 2012).

RECENT EVOLUTION OF THE LARSEN CRYOSPHERE

Remote sensing, in conjunction with the automated multi-sensor stations, shows a dramatic evolution of the remaining section of the Larsen B Ice Shelf that suggests it is nearing an unstable state prone to disintegration (Khazendar et al., 2015). MODIS image series show increased bottom crevassing, and aerial photos as well as Landsat 8 images indicate both fine-scale surface fracturing and major new rifts in the Scar Inlet ice. Loss of the A-54 iceberg in February 2006 has led to instability in the Starbuck Glacier floating shelf front; however, cooling climate conditions have led to the formation of multi-year fast ice in the Larsen B embayment, which has been present continuously since early 2012. This fast ice appears to be inhibiting further calving of the Scar Inlet ice front. GPS systems installed on the ice as part of the AMIGOS stations indicate that while the ice shelf accelerated at a rate of $\sim 5\% \text{ yr}^{-1}$ between 2010 and 2012, since the formation of the persistent fast ice in 2012, the shelf has ceased to accelerate and instead exhibits an $\sim 3\%$ seasonal oscillation in flow speed, lagging the annual peak and trough in air temperature by ~ 30 days. Given that the Scar Inlet ice is already structurally weak, it is likely that this stabilization is temporary and that the next warm year will lead to the loss of the fast ice and rapid breakup of the Scar Inlet Ice Shelf.

INTEGRATED APPROACH TO UNDERSTANDING ONGOING CHANGES

The interdisciplinary and international field-based LARISSA program addressed the rapid, system-level changes taking place in the Larsen Embayment, Weddell Sea region of the Antarctic Peninsula, where the Larsen B ice shelf underwent a spectacular collapse in 2002. The research team, composed of ice core scientists, glaciologists, oceanographers, marine geologists, and biologists, including dozens of students and early career scholars, collaborated to characterize the effects of the collapse on the marine ecosystem as well as on glacier dynamics and interactions among the ocean, ice, geology, and biology, and to place these changes in the context of past changes in the region. Individual disciplinary projects each documented system change both during the Holocene and under modern conditions.

The startling outcome of synthesizing individual disciplinary studies is that the rapidity at which the area is changing now is not documented in data from the Holocene, yet is virtually universal in the recent changes observed in precipitation records, sediment accumulation rates, ecosystem changes, isostatic uplift, and, of course, ice cover. As dramatic change continues to characterize the Larsen region, potentially with additional breakup in the next warm year, additional study will provide insight into the complex evolution of one of the most interesting regions on Earth in a fundamentally integrated way. Knowledge of how changes unfolded in the Larsen B and adjacent areas will serve as a basis for understanding what may occur in larger drainage basins that will warm in the coming years and whose changes may have a greater effect far afield.

POSTSCRIPT

The LARISSA project was in many ways guided by the scientific vision of Eugene Domack, who dedicated much of his life to studying Antarctica and its connections to the rest of the world. Gene passed away suddenly during the preparation of this manuscript. The remaining authors, like colleagues around the world, mourn his passing.

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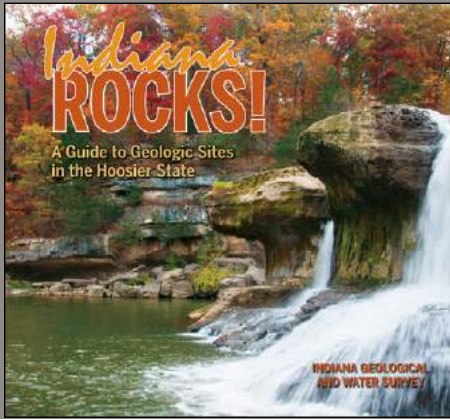
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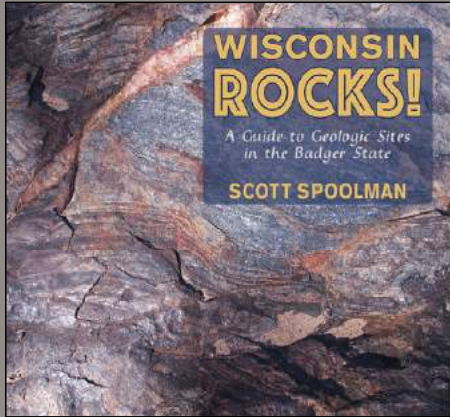
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Registration

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community.geosociety.org/gsa2019/attend/registration

Onsite Registration Hours

Sat., 21 Sept., 7 a.m.–7 p.m.

Sun., 22 Sept., 6:30 a.m.–6:30 p.m.

Mon.–Wed., 23–25 Sept., 7 a.m.–4:30 p.m.

Events Requiring Tickets/Advance Registration

Several GSA Divisions and Associated Societies will hold breakfasts, lunches, receptions, and awards presentations that require a ticket and/or advance registration (see the meeting website for a complete list). Ticketed events are open to everyone and can be purchased in advance **when you register**. If you are not attending the meeting but would like to purchase a ticket to one of these events, please contact the GSA Meetings Department at meetings@geosociety.org.

Accommodations & Services

GSA strives to create a pleasant and rewarding experience for every attendee. Let us know in advance of the meeting if you have needs that require further attention. Most dietary considerations can be met at no extra charge. Be sure to check the appropriate box **when you register** online, and a GSA staff member will contact you. GSA will also have a self-care room on-site for nursing mothers and other needs. Learn more at community.geosociety.org/gsa2019/attend/services.

Event Space Requests

29 August is the LAST day to submit a request for event space and event listing. GSA will not assign any additional meeting space after this date and cannot guarantee to list your event on the website or mobile app. Go to community.geosociety.org/gsa2019/connect/events to register your request today.

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Childcare

KiddieCorp will provide childcare services for GSA attendees on Sun.–Wed., 7 a.m.–6 p.m. The program is open to children six months to 12 years. Cost: US\$10 per hour per child for children two years or older and US\$12 per hour per child for children under two, with a one-hour minimum per child. The advance registration deadline is **23 August**.

Register now at community.geosociety.org/gsa2019/attend/family. Availability is limited and handled on a first-come, first-served basis.

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Schedule-at-a-Glance

Saturday, 21 Sept.

- ▶ Short Courses: 8 a.m.–5 p.m. (some begin on Friday)
- ▶ Pre-Meeting Field Trips (some begin earlier)
- ▶ Various business meetings of GSA, GSA Divisions, and Associated Societies
- ▶ PHOENIX ICEBREAKER: 5–7 p.m.

Sunday, 22 Sept.

- ▶ Oral Technical Sessions: 8 a.m.–noon
- ▶ GeoCareers Center: 9 a.m.–5 p.m.
- ▶ GeoCareers Events: 2–7 p.m.
- ▶ Poster Sessions: 9 a.m.–5:30 p.m.
- ▶ Lunch Break: noon–1:30 p.m.
- ▶ GSA Presidential Address & Awards Ceremony: noon–1:30 p.m.
- ▶ Oral Technical Sessions: 1:30–5:30 p.m.
- ▶ Exhibits Open: 2–7 p.m.
- ▶ Exhibits Opening Reception: 5:30–7 p.m.

Monday, 23 Sept.

- ▶ Oral Technical Sessions: 8 a.m.–noon
- ▶ GeoCareers Center: 9 a.m.–5 p.m.
- ▶ Company Connection: 10 a.m.–6:30 p.m.
- ▶ Poster Sessions: 9 a.m.–6:30 p.m.
- ▶ Exhibits: 10 a.m.–6:30 p.m.
- ▶ Lunch Break: noon–1:30 p.m.
- ▶ Feed Your Brain: 12:15–1:15 p.m.
(*Lunchtime Enlightenment*, buy your food and take it in)
- ▶ Oral Technical Sessions: 1:30–5:30 p.m.
- ▶ Collaborations & Conversations—Posters: 4:30–6:30 p.m.
- ▶ Alumni Receptions: evening hours

Tuesday, 24 Sept.

- ▶ Oral Technical Sessions: 8 a.m.–noon
- ▶ GeoCareers Center: 9 a.m.–5 p.m.
- ▶ Company Connection: 10 a.m.–6:30 p.m.
- ▶ Poster Sessions: 9 a.m.–6:30 p.m.
- ▶ Exhibits: 10 a.m.–6:30 p.m.
- ▶ Lunch Break: noon–1:30 p.m.
- ▶ Feed Your Brain: 12:15–1:15 p.m.
(*Lunchtime Enlightenment*, buy your food and take it in)
- ▶ Oral Technical Sessions: 1:30–5:30 p.m.
- ▶ Collaborations & Conversations—Posters: 4:30–6:30 p.m.

Wednesday, 25 Sept.

- ▶ Oral Technical Sessions: 8 a.m.–noon
- ▶ GeoCareers Center: 9 a.m.–noon
- ▶ Company Connection: 10 a.m.–2 p.m.
- ▶ Poster Sessions: 9 a.m.–6:30 p.m.
- ▶ Exhibits: 10 a.m.–2 p.m.
- ▶ Lunch Break: noon–1:30 p.m.
- ▶ Feed Your Brain: 12:15–1:15 p.m.
(*Lunchtime Enlightenment*, buy your food and take it in)
- ▶ Oral Technical Sessions: 1:30–5:30 p.m.
- ▶ Collaborations & Conversations—Posters: 4:30–6:30 p.m.

Thursday, 26 Sept.

- ▶ Post-Meeting Field Trips

Hotels

Reservation deadline: 28 August

community.geosociety.org/gsa2019/attend/travel/hotels

GSA has negotiated special hotel rates for GSA 2019 attendees. We appreciate your support by staying in the official GSA hotels; your patronage enables GSA to secure the meeting space at a greatly reduced cost, which in turn helps lower the cost of the meeting and your registration fees.

Orchid.Events (OE) is GSA's only official housing company for this meeting. To be included in the GSA room block and receive GSA rates, you must make your reservation through OE. Reservations are taken on a first-come, first-served, space-available basis. We recommend that you make your reservation early for the best opportunity to get the hotel of your choice.

Reservation Options

Online: Start at community.geosociety.org/gsa2019/attend/travel/hotels;

Phone: 7 a.m.–6 p.m. MST, Mon.–Fri.: +1-855-657-0547 (U.S. toll-free); +1-801-433-0661 (international);

Print: Download the form and fax (+1-801-355-0250; do not mail after faxing) or mail to Orchid.Events, 175 S. West Temple, Suite 30, Salt Lake City, UT 84101, USA.

Critical Dates

19 Aug.: The last day to cancel rooms without a penalty.

28 Aug.: Room rates are guaranteed as long as there are rooms available in the GSA room block.

29 Aug.: Hotel room rates and/or availability cannot be guaranteed.

12 Sept.: All changes, cancellations, and name substitutions must be finalized through Orchid Events (OE) by this date.

13 Sept.: Beginning on this date, you must contact the hotel directly for all changes, cancellations, and new reservations.

Before You Arrive

Once you receive your hotel acknowledgement and have booked your travel, please review your hotel arrival/departure dates for accuracy. If you do not show up on the date of your scheduled arrival, the hotel will release your room and you will be charged for one night's room and tax. If you have travel delays and cannot arrive on your scheduled date, please contact the hotel directly to make them aware of your new arrival date.

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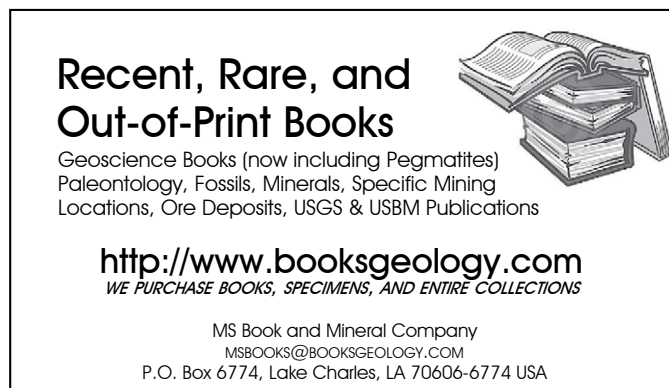
Use the GSA Roommates & Rides feature at community.geosociety.org/gsa2019/attend/travel/rooms-rides to share housing, airport shuttles, and/or carpool. You can also use this service to meet up with your colleagues at the meeting.



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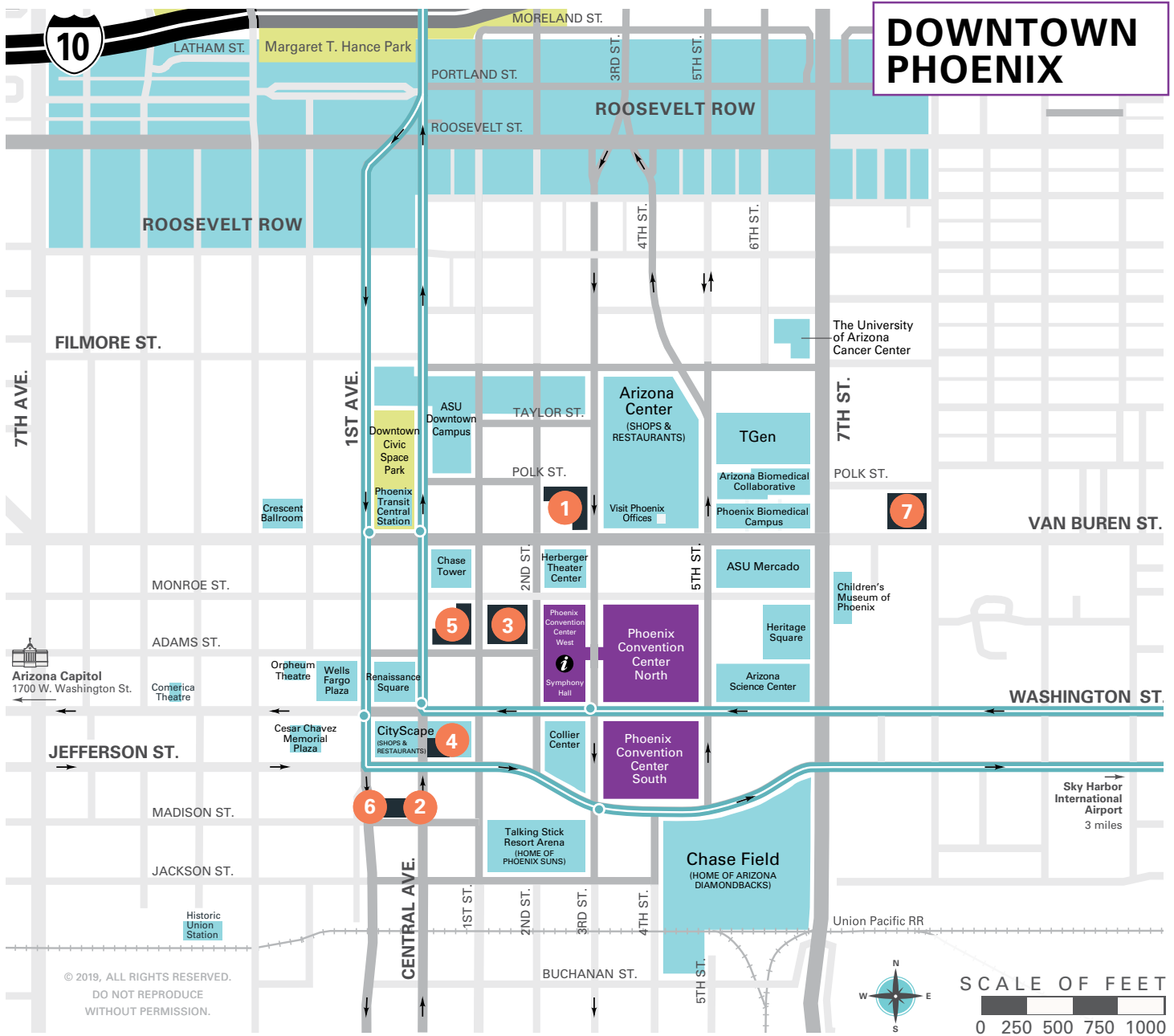
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Downtown Phoenix Hotel Map

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HOTELS

- 1 Sheraton Phoenix Downtown (HQ)
- 2 Courtyard by Marriott Phoenix Downtown
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- 4 Kimpton Hotel Palomar Phoenix
- 5 Renaissance Phoenix Downtown Hotel
- 6 Residence Inn by Marriott Phoenix Downtown
- 7 Springhill Suites by Marriott Phoenix Downtown

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Pardee Keynote Symposia



Joseph Thomas Pardee
(1871–1960)

All Pardee Keynote Sessions, listed here in chronological order, take place at the Phoenix Convention Center (PCC). These symposia are named after Joseph T. Pardee, an esteemed geoscience and GSA benefactor. Pardee sessions held in North Ballroom 120D, North Building, will be transcribed on-screen in real time.

Sunday

1:30–5:30 p.m., Hall A,
Special Presentation Area

P1. Digital Learning Innovation in the Geosciences

Cosponsors: *GSA Geoscience Education Division; American Geophysical Union; National Association of Geoscience Teachers; National Earth Science Teachers Association*

Monday

8 a.m.–noon, North Ballroom 120D, North Building

P2. Grand Ideas, Grand Events: Geoscience Research, Geoscience Education, and Human Connections to Grand Canyon at its Six Millionth, 150th, and 100th Anniversaries

Cosponsors: *GSA History and Philosophy of Geology Division; National Association of Geoscience Teachers; GSA Geoscience Education Division*

1:30–5:30 p.m., North Ballroom 120D, North Building

P3. Geoscience Communication in the Modern Age

Cosponsors: *GSA Geology and Society Division; GSA History of Geology Division; National Association of Geoscience Teachers; GSA Geoscience Education Division*

Tuesday

8 a.m.–noon, North Ballroom 120D, North Building

P4. Fostering an Inclusive Academic Culture for the 21st Century: Advancing Policies, Departments, and Supporting Faculty to Address the Needs and Challenges for Building a Healthy Geoscience Enterprise

Cosponsors: *GSA Geology and Society Division; American Geophysical Union; American Geosciences Institute*

1:30–5:30 p.m., North Ballroom 120D, North Building

P5. Extreme Impacts of Global Climate Change: Effective Communication for Geoscientists, Educators, Policy Makers, and the Press

Cosponsors: *GSA Quaternary Geology and Geomorphology Division; GSA Energy Geology Division; GSA Environmental and Engineering Geology Division; GSA Geology and Health Division; GSA Geology and Society Division; GSA History and Philosophy of Geology Division; GSA Hydrogeology Division; International Union for Quaternary Research (INQUA)*

Wednesday

8 a.m.–noon, North Ballroom 120D, North Building

P6. Understanding the Neoproterozoic Earth-Life System

Cosponsor: *GSA Sedimentary Geology Division*



ICEBREAKER

Get to Know Your Fellow Attendees

Saturday, 21 Sept., 5–7 p.m.

Join fellow industry professionals, students, academics, and GSA's Associated Societies to kick off the meeting with a beverage and great company.



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We support **Respectful Inclusive Scientific Events** and are committed to ensuring a safe and welcoming environment for all participants. We expect all meeting participants to abide by the GSA Events Code of Conduct in all venues at our meetings, including ancillary events, field trips, and official and unofficial social gatherings.

www.geosociety.org/rise

Notice of GSA Council Meetings

**GSA 2019 Annual Meeting & Exposition
Phoenix, Arizona, USA**

8 a.m.–noon, Saturday, 21 Sept.

8 a.m.–noon, Wednesday, 25 Sept.

GSA Headquarters Hotel—Sheraton Phoenix Downtown
340 N 3rd St, Phoenix, Arizona 85004, USA
Paradise Valley Room *

All GSA members are invited to attend
the open portions of these meetings.

**Meeting room is subject to change. Updates will be posted.*



AAPG Special Session

At the Forefront of Exploration and Critical Thinking: American Association of Petroleum Geologists (AAPG) 2019 Distinguished Lecturers (AAPG; GSA Energy Geology Division)

Session Co-Chairs: Robbie Gries; Russell Stands-Over-Bull
Tuesday, 1:30–5:30 p.m., Phoenix Convention Center

AAPG Distinguished Lecturers are selected over a two-year process, rewarding speakers for innovation in geoscience thinking or geoscience career development. Similar to GSA's James B. Thompson Jr. Distinguished International Lectureship, the lecturers are selected from a global list of stellar geoscience professionals. AAPG Distinguished Lecturers travel throughout the globe presenting to societies and universities over a two-year period.

Speakers



Irene Arango

Understanding Expulsion Capacity and Organic Porosity in Unconventional Petroleum Systems

Dr. Irene Arango is a senior geochemist with Chevron's Energy Technology Company, where she has worked for the past 12 years as an internal geochemical consultant on exploration and development projects worldwide. Arango has served as principal investigator in research projects on topics including pre-drill risk assessment of non-hydrocarbon gases in reservoirs (e.g., CO₂, H₂S) and geochemistry of unconventional plays. She has worked on identification of geochemical indicators of core areas and sweet spots in tight reservoirs, on the evaluation of processes controlling unconventional reservoir properties such as organic porosity and retention capacity, and on the assessment of oil fingerprints for improved unconventional field development. Arango has presented some of her work at AAPG, URTeC, and IMOG conferences and recently co-authored a review paper in *Organic Geochemistry* on organic porosity from a geochemical perspective. She was the recipient of AAPG's Gabriel Dengo Memorial Award in 2014 in recognition of the best AAPG paper presented during the 2013 AAPG International Conference ("Evaluating hydrocarbon expulsion efficiency from shale reservoirs").

Arango is the coordinator of Chevron's Hydrocarbon Charge Training Program and has presented classes for AAPG and at universities. Prior to her work at Chevron, she worked for Ecopetrol as a development geologist in the Llanos Basin (Colombia). Arango received her Ph.D. in geology with emphasis in geochemistry from Indiana University (2006), an M.S. (geology with minor in biology) from Indiana State University (2002), and an undergraduate degree in geology from the National University of Colombia (1998). She is an active member of AAPG, serving as session chair and judge of poster and oral sessions at various AAPG conferences, acting as co-chair of the Geochemistry, Basin Modeling, and Petroleum

Systems Theme of the 2017 Annual AAPG Conference, and being co-convenor for the AAPG-sponsored, 2019 Hedberg Conference on the evolution of petroleum systems analysis. Arango is technical reviewer for peer-review journals and serves as head of the Houston Organic Geochemistry Society, a group of petroleum system specialists that meets in Houston for technical talks and discussion. She enjoys spending time with her family and loves to travel.



Susan Cunningham

What it Takes to be Successful in Exploration

Susan M. Cunningham is an advisor for Darcy Partners, a research company connecting oil and gas companies with emerging technologies. She retired from Noble Energy in 2017, where she was most recently executive vice president of EHSR (Environment, Health, Safety and

Regulatory) global exploration and business innovation, after about 35 years of industry experience.

Before joining Noble Energy, Susan served as Texaco's vice president of core worldwide exploration from April 2000 to March 2001. Employed by Statoil from 1997 through 1999, she was responsible for West Africa exploration as well as vice president of deepwater Gulf of Mexico exploration. She began her career in 1980 in Calgary as a geologist at Amoco Canada. She moved to Houston in 1981 to join Amoco's International Region and held various exploration and development positions including managing director of Denmark, based in Copenhagen, and deepwater Gulf of Mexico exploration manager.

Active in the industry and the community, Susan served as chair of the Offshore Technology Conference (OTC) in 2010 and 2011, representing AAPG. She served on the board of Cliffs Natural Resources, an iron ore and metallurgical coal mining company from 2005 to 2014. She is currently serving on the board of Oil Search, an oil and gas company. She also served on the boards of the Houston Area Women's Center and the Houston Geological Society.

Susan holds a bachelor's degree in geology and physical geography from McMaster University in Ontario, Canada. She also completed a management program through Rice University's Office of Executive Development.



Michael Hudec

Evolution of the Salina del Bravo, Mexico: The Bravo Trough, Sigsbee Canopy, and Perdido Fold Belt

Dr. Michael Hudec is a senior research scientist at the Bureau of Economic Geology and directs the Applied Geodynamics Laboratory (AGL), an industry-sponsored research consortium studying salt tectonics.

He received his Ph.D. from the University of Wyoming in 1990, and

spent the next eight years at Exxon Production Research, where he specialized in salt tectonics, extensional tectonics, and seismic interpretation. His current research interests include palinspastic restoration of salt structures, deepwater structural styles, and evolution of the Gulf of Mexico Basin.



Lisa Stright

Template-Based Modeling: Bridging the Gap between Quantitative Outcrop Studies and Subsurface Reservoir Characterization

Dr. Lisa Stright is an assistant professor in the department of geosciences at Colorado State University. She has five years of industry experience as a reservoir engineer with

(RC)2/VeritasDG and Denver-based consulting company, MHA Petroleum Consultants. Her research and teaching interests are in bridging the gap between sedimentology, reservoir characterization and modeling, geophysics, and reservoir engineering.

Stright received a bachelor's degree in civil/environmental engineering from the University of Colorado Boulder, a master's degree in geological engineering from Michigan Technological University, and a master's degree in petroleum engineering and a doctorate in interdisciplinary geosciences, both from Stanford University.



Sophie Warny

From Biosteering Wells to Forensic Investigation or Past-Climature Reconstruction; What Palynology Can Do for Science and Society

Dr. Sophie Warny is an associate professor and the AASP Chair in Palynology in the department of geology and geophysics, and a curator at the Museum of Natural Science

(MNS), both at Louisiana State University (LSU) in Baton Rouge. She grew up in Belgium and France where she received two bachelor's degrees (one in geology and one in oceanography), and a Ph.D. from the Université Catholique de Louvain (in Belgium) in marine geology working under the direction of Dr. Jean-Pierre Suc. She is the director of the AASP - The Palynological Society Center for Excellence in Palynology (CENEX) and served in 2016 as the vice president of the GCSSEPM society. Her center, CENEX, focuses on various aspects of palynological research including the use of pollen, spores, and algae in biostratigraphic studies in collaboration with the industry to the use of pollen in forensic applications. The bulk of her research focuses on paleoceanography and paleoclimate reconstruction, including investigation of the palynological record to decipher past sudden warming events and climate variability in the Antarctic to help constrain their triggering mechanisms. She received a NSF CAREER award in 2011 and has published in journals such as *Science*, *Nature*, *Nature Geoscience*, *PNAS*, *Geology*, and *Gondwana Research*. Warny has supervised 19 theses and dissertations since starting in 2008 at LSU.





Lunchtime Enlightenment

Grab your lunch at a nearby convention center vendor and enjoy a little lunchtime enlightenment. Each presentation will take place in the North Ballroom 120D, North Building, Phoenix Convention Center.



Sunday, noon–1:30 p.m.
GSA Presidential Address: The Future of Geoscience in the Context of Climate Disruption
Donald I. Siegel

I speak to climate disruption, a sweeping self-inflicted tragedy of the commons for humanity. It is improbable, if not impossible, that sufficient numbers of developed

and undeveloped nations in the future will globally make the necessary economic and political decisions to avoid the worst of predicted climate disruption in the next 20 years. The ability to rapidly adapt to environmental disruptions as they evolve remains our best hope, coupled with successful transition to solar, wind, and modern nuclear energy as best we can. Junior and mid-career earth scientists in multiple GSA Divisions should have unprecedented opportunities in the future to participate in well-funded large-scale adaptation ventures that necessarily will include multidisciplinary intellectual challenges. You and I, as individuals—indeed ALL geoscientists—have a role to play in these efforts to ensure the future of humanity and what environments we choose to protect.



Monday, 12:15–1:15 p.m.
Switch is Back! Energy Poverty, the Energy Transition, and Modern Energy Education
Scott W. Tinker

Energy underpins all aspects of modern life, and the lack of energy inhibits over 2.5 billion people from entering into modern life. Although many of us have strong

opinions and beliefs, we really don't understand energy. Are there actually clean and dirty options? Are some forms good and others bad? What kinds of energy will actually address climate change globally and at scale? What are the options to lift one-third of the world from energy poverty and the impacts of doing so? What is the "energy transition," and can it happen quickly? What are the unintended consequences of well-intended energy policies? How do we become educated enough to participate in meaningful, non-partisan, fact-based, and civil dialogs about energy?

That is the vision of the Switch Energy Alliance (SEA), a non-profit whose mission is to *inspire an energy-educated future*. Building on the global energy film *Switch*—viewed in over 50 countries by 15 million people and on thousands of campuses—SEA develops world-class film and serves it via state-of-the-art web delivery. SEA has programs that reach K–12, higher education, professionals, and the public.

Join this Feed Your Brain session to see a clip from the new feature-length film, *Switch On*, which travels the globe immersing in energy poverty and examining workable solutions. Hear Dr. Scott Tinker give a short talk on energy, carbon, and poverty. And then engage in a meaningful conversation about how to frame the energy challenges and work together to move the dialog forward in a positive, outcome-based way.



Tuesday, 12:15–1:15 p.m.
2019 Michel T. Halbouty Distinguished Lecture: Climate Change: The Threat Multiplier
Katharine Hayhoe

For generations, human civilization has been building a climate debt, borrowing from the stability of the future to power the economic growth of the present. Through

fossil fuel combustion and land-use change we have disrupted the carbon cycle, overwhelming the influence of natural forcing on Earth's climate. As heat accumulates in the climate system, it drives long-term increases in temperature and sea level, and super-charges hurricanes, heat waves, and heavy precipitation events. These changes in turn exacerbate poverty, hunger, disease, refugee crises, and more. Today, the choice is stark: Can we do what it takes to avoid widespread dangerous change? Or will we remain mired in inaction until the full cost of this unprecedented experiment we're conducting with our planet falls due?



Wednesday, 12:15–1:15 p.m.
Your Park. Your Science. Our Future:
Inspiring Geoscience and Other STEM
Careers via Collaboration with the NPS
Meghan Kish

Beyond their draw as popular areas for recreation and the enjoyment of nature, the National Parks offer numerous opportunities to inspire and advance careers in the

STEM fields—especially those areas pertaining to the Earth sciences and the environment. The National Parks offer ideal settings to observe Earth processes, including geologic and environmental responses to anthropogenic influences. For example, matters of global concern currently being evaluated and managed by the National Park Service (NPS) include climate disruption impacts, water quantity and quality issues, stresses to the native ecosystems, and the management of resources exclusively set aside for the public. The NPS plays a crucial role in conveying these important issues to a larger audience and inspiring the next generation of scientific researchers who can address them. NPS collaborations with other organizations can enhance STEM interest and promote careers in STEM fields such as geology and environmental science. GSA has an excellent partnership with the NPS through its Geoscientists-in-the-Parks program, which offers a number of opportunities to garner practical experience while working on projects overseen by NPS staff.

Participants conduct scientific research, develop exhibits to enhance the visitor experience, and serve as interpreters to the public. In 2018, GSA awarded Behnaz Hosseini, a geoscience technician at Yellowstone National Park, an E-An Zen Outreach Grant to support her efforts to educate the public on hydrothermal systems through the hands-on use of thermal imaging technology.

The National Parks provide vast opportunities to learn science, enhance STEM literacy, and inspire science careers; however, there are challenges. Funding and staffing issues and park maintenance—particularly finding resources for future improvements and innovations—can limit the educational engagement that the NPS seeks to inspire. One solution is to increase partnerships with corporate entities, museums, colleges, and universities.

Meghan Kish, the current superintendent for the Southern Arizona Office of the NPS, is offering this session to focus on how the National Parks, in collaboration with industry, academia, and other scientific organizations, can serve to stimulate greater interest in STEM learning and careers in the National Parks. There will be a panel to include colleagues from across the service who have participated in or managed National Park STEM programs. The panel will engage the audience in discussions relating to the challenges the NPS has in terms of promoting STEM and the environment, and what it does, and will do, to improve and enhance positive outcomes.

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Be a Mentor: Make a Difference

“GSA has given me a platform to share my story and help students prepare for a career.” —**Brandy Barnes**, Draper Aden Associates

- Drop-in Mentor ■
- Networking Reception Mentor ■
- Résumé Mentor ■
- Women in Geology Mentor ■
- On To the Future Mentor ■

[community.geosociety.org/gsa2019/
connect/student-ecp/mentor](http://community.geosociety.org/gsa2019/connect/student-ecp/mentor)

If you are entering the job market or are supporting someone who is and want more information about career pathways in the geosciences, plan to attend one or more of the events below. PCC—Phoenix Convention Center.



GeoCareers Events

Visit the website for event details, dates, and times: community.geosociety.org/gsa2019/connect/student-ecp/geocareers

- **Résumé Library**—Upload your résumé for recruiters who will be at the meeting
- **Pre-Meeting Webinar:** Exploring a Career in Mining, Wed., 21 August, 11 a.m. MDT; register at <https://attendee.gotowebinar.com/register/8892842747569519875>
- **Pre-Meeting Webinar:** Geoscience Careers in the Petroleum Industry, Wed., 18 Sept., 11 a.m. MDT; register at <https://attendee.gotowebinar.com/register/3422063214384043523>
- **Geoscience Career Workshop:** Sun., 9–10:30 a.m., PCC, North Ballroom 120BC North Building
- **Company Lightning Talks:** Sun., 10:30–11:30 a.m., PCC, North Ballroom 120BC North Building
- **Panel Luncheon:** Sun., noon–1 p.m., PCC, North Ballroom 120BC North Building
- **Company Connection:** Sun., 2–7 p.m.; Mon.–Tues., 10 a.m.–6:30 p.m.; Wed., 10 a.m.–2 p.m.; PCC, Exhibits Hall E North Building

GeoCareers Center

PCC, 124AB North Building
Open Sun.–Tues., 9 a.m.–5 p.m., and Wed., 9 a.m.–noon

- Career Presentations
- Drop-In Mentoring
- Early Career Professional Coffee
- Geology Club Meet-Up
- Networking Reception
- Post or View Jobs
- Résumé Review Clinic
- Women in Geology Program

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Updated Position Statements

GSA Council recently approved minor revisions to two position statements: “Integrating Geoscience with Sustainable Land-Use Management” and “The Role of the Geoscientist in Assuring the Safety and Integrity of Infrastructure.” Summaries are below; full versions of all position statements are online at www.geosociety.org/positionstatements. GSA members are encouraged to use the statements as geoscience communication tools when interacting with policy makers, students, colleagues, and the general public.

Integrating Geoscience with Sustainable Land-Use Management

To ensure sustainable land-management practices that meet present and future needs of people and the natural systems on which they depend, the Geological Society of America (GSA) advocates use of comprehensive earth-science information in land-use planning and decision making. The geosciences address the origin, character, and interconnection of natural resources, as well as the natural and human-induced processes

that affect these resources. Geoscience information is critical to addressing natural and human-induced hazards, such as landslides, earthquakes, subsidence and sinkholes, floods, or droughts; natural resource availability, such as energy, water, soils and mineral resources; and environmental issues, such as soil erosion, changes to surface- and groundwater quantity and quality, and wetland destruction. Therefore, geoscience should be incorporated into all land and natural resources management decisions to enhance their integrity and sustainability.

The Role of the Geoscientist in Assuring the Safety and Integrity of Infrastructure

Geoscientists have a fundamental role in the engineering and architectural design, planning, construction, and maintenance of infrastructure systems in the built environment, and in understanding the functionality and sustainability of natural infrastructure, with respect to their relationship to local geology, hazards, and the environmental setting.

36th International Geological Congress (IGC) Mentoring and Travel Grant Program

Delhi, India | 2–8 March 2020

GSA is accepting applications for its mentoring and travel-grant program to the 36th International Geological Congress (IGC) in Delhi, India. Graduate students and early career professionals (within seven years of receiving their Ph.D.) are welcome to apply.

To be eligible, the applicant must be a resident or citizen of the United States and be enrolled in, or employed at, a U.S. institution. Each award is anticipated to be a maximum of US\$3,500.

Complete applications will consist of

- An online application form;
- A cover letter addressing your reasons for attending the meeting;
- A prioritized budget of expenses;
- A copy of your submitted abstract; and
- One letter of recommendation.

Applications must be received electronically no later than 30 Sept. 2019 at <https://rock.geosociety.org/eo/igc>.

This program is organized in collaboration with the GSA Foundation, the U.S. National Committee for Geological Sciences (of the National Academy of Sciences), and the Society of Economic Geologists.

Questions? Contact Jennifer Nocerino, jnocerino@geosociety.org, +1-303-357-1036.

Special Paper 541



Circum-Arctic Structural Events

Tectonic Evolution of the Arctic Margins and Trans-Arctic Links with Adjacent Orogens

Edited by Karsten Piepjohn, Justin V. Strauss, Lutz Reinhardt, and William C. McClelland

Circum-Arctic Structural Events: Tectonic Evolution of the Arctic Margins and Trans-Arctic Links with Adjacent Orogens

Edited by Karsten Piepjohn, Justin V. Strauss, Lutz Reinhardt, and William C. McClelland

The circum-Arctic region has received considerable attention over the past several decades with vigorous debate focused on topics such as mechanisms for opening the Eurasian and Amerasian basins, the importance of plume-related magmatism in the development of the Arctic Ocean, and mechanisms for ancient terrane translation along the Arctic margins. In recognition of the 25th anniversary of the Circum-Arctic Structural Events (CASE) program, an international polar research effort organized and led by the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) of Germany, this volume presents results from 18 major field expeditions involving over 100 international geoscientists from a broad spectrum of disciplines. The resulting publication focuses on the Proterozoic to Cenozoic tectonic evolution of the circum-Arctic region with correlations to adjacent orogens.

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Mentoring Tomorrow's Geoscience Leaders at the 2019 Section Meetings

The GSA GeoCareers Program provides mentoring and career pathway events at all meetings. At Section Meetings, students are invited to participate in the Roy J. Shlemon Mentor Program in Applied Geology and the John Mann Mentors in Applied Hydrogeology Program. These popular events, supported by the GSA Foundation through gifts from Roy J. Shlemon and John Mann (with additional financial assistance from Poland Springs and GSA's Northeastern and Southeastern Sections), are designed to extend the mentoring reach of individual professionals. Together, mentor volunteers and students meet in a relaxing, informal setting to discuss careers in geology over lunch.

This past spring, 276 students and 33 mentors participated in the Shlemon Program, and 224 students and 28 mentors attended the Mann Program. Both mentors and students left the events expressing feelings of personal and professional

growth. As a result of these programs, new friendships were made and professional contacts were established that will last well into the future.

In addition to mentoring, GSA also provided three career workshops for students designed to help them plan and prepare for their job search. The workshops covered career planning and informational interviewing, career exploration, and cover letters, résumés, and CVs. Working professionals from academia, government, and industry were invited to answer questions and help attendees maneuver the career exploration process.

GSA gratefully acknowledges the following mentors for their individual gifts of time and for sharing their insight with students. To learn more about these programs, or to be a mentor at a future Section Meeting, please contact Jennifer Nocerino, jnocerino@geosociety.org.

The Roy J. Shlemon Mentor Program in Applied Geology *Helping Mentor Students Since 1996*

NORTHEASTERN SECTION MEETING

Erika Amir-Lin, AECOM

Matthew Baird, Larson Design Group

Rose-Anna Behr, Pennsylvania Dept. of Conservation and Natural Resources

Allison Drouin, Credere Associates LLC

Will Ernst, The Boeing Company

Frank Getchell, WSP USA

Craig Heindel, Waite-Heindel Environmental Management

Clifford Lippitt, S.W. Cole Engineering Inc.

Gregory Lull, Katahdin Analytical Services

Laura Szymanski, The Geological Society of America

Gregory Walsh, U.S. Geological Survey

Amber Whittaker, Maine Geological Survey

Scott Wieman, NASA Goddard Space Flight Center

SOUTH-CENTRAL/NORTH-CENTRAL/ ROCKY MOUNTAIN JOINT SECTION MEETING

Tony Layzell, Kansas Geological Survey

Jason Patton, National Association of State Boards of Geology (ASBOG®)

Shannon Rentz, U.S. Department of the Interior

C.A. Ruleman, U.S. Geological Survey

David Saja, The Cleveland Museum of Natural History

Jessica Vahling, Anadarko Petroleum Corporation

SOUTHEASTERN SECTION MEETING

Bill Aley, Taylor Engineering Inc.

Brandy Barnes, Draper Aden Associates

W. R. Doar III, South Carolina Geological Survey

Jim Heller, Alabama Dept. of Environmental Management

Randy Kath, National Association of State Boards of Geology (ASBOG®)

Marci Robinson, U.S. Geological Survey

Ronald Wallace, Georgia Environmental Protection Division

Kerry Wright, Froehling and Robertson Inc.

CORDILLERAN SECTION MEETING

Alexandros Konstantinou, ExxonMobil Upstream Business Development

Jim O'Connor, U.S. Geological Survey

Brian Olson, Quanta Subsurface

Jeff Rubin, Tualatin Valley Fire & Rescue

Matthew von der Ahe, Aspect Consulting LLC

Kasey White, The Geological Society of America

The John Mann Mentors in Applied Hydrogeology Program

Helping Mentor Students Since 2004

NORTHEASTERN SECTION MEETING

Mary Alldred, State University of New York, Plattsburgh
Erika Amir-Lin, AECOM
Matthew Baird, Larson Design Group
Aaron Bierly, Pennsylvania Dept. of Conservation and Natural Resource
Ian Desjarlais, Wood Environment and Infrastructure Solutions
Will Ernst, The Boeing Company
Frank Getchell, WSP USA
Craig Heindel, Waite-Heindel Environmental Management
Kent Koptiuch, Nestle Waters North America Inc.
Clifford Lippitt, S.W. Cole Engineering Inc.
Martha Nielsen, U.S. Geological Survey
Laura Szymanski, The Geological Society of America
Scott Wieman, NASA Goddard Space Flight Center

SOUTH-CENTRAL/NORTH-CENTRAL/ROCKY MOUNTAIN JOINT SECTION MEETING

Levi Crooke, Kansas Dept. of Health and Environment
Andrea Croskrey, Texas Water Development Board
Cara Peterman, U.S. Geological Survey
Charlotte Philip, Kansas Dept. of Agriculture
Jessica Vahling, Anadarko Petroleum Corporation

SOUTHEASTERN SECTION MEETING

James Connors, James J. Connors & Associates, LLC
Brooke Czwartacki, South Carolina Dept. of Natural Resources
J. Wright Horton Jr., U.S. Geological Survey
Donald Jones, Quality Environmental Solutions Inc.
John Paul Lingush, HydroGeo Environmental
Ronald Wallace, Georgia Environmental Protection Division

CORDILLERAN SECTION MEETING

Aurora Bouchier, Oregon Water Resources Dept.
Lee Florea, Indiana Geological and Water Survey
Sarah Lewis, Oregon Dept. of Geology and Mineral Industries
Donald Sweetkind, U.S. Geological Survey

Geoscience Career Exploration Workshops

Helping Mentor Students Since 2014

NORTHEASTERN SECTION MEETING

Mary Alldred, State University of New York, Plattsburgh
Erika Amir-Lin, AECOM
Will Ernst, The Boeing Company
Arthur Merschhat, U.S. Geological Survey

SOUTH-CENTRAL/NORTH-CENTRAL/ROCKY MOUNTAIN JOINT SECTION MEETING

Rex Buchanan, Kansas Geological Survey
Chuck Brewer, GSI Engineering
Jeffrey Ryan, University of South Florida

SOUTHEASTERN SECTION MEETING

Brandy Barnes, Draper Aden Associates
Amy Brock-Hon, University of Tennessee at Chattanooga
Ronald Wallace, Georgia Environmental Protection Division

CORDILLERAN SECTION MEETING

Nancy Calhoun, Oregon Dept. of Geology
Trevor Contreras, Washington Geological Survey
Alexandros Konstantinou, ExxonMobil Upstream Business Development
Isabel Montañez, University of California Davis

Strategic Engagement in Science Policy Making: A Call to Action



Monica E. Gowan

In April 2019, while serving as GSA's Geology and Public Policy Committee Chair, I spent two weeks on Capitol Hill immersed in the daily business of the 116th U.S. Congress. Working out of GSA's Geoscience Policy Office in Washington, D.C., with Kasey White, Director of Geoscience Policy, and Laura Szymanski, GSA Science Policy Fellow, my visit had a three-fold purpose: (1) to support GSA's work on policy issues impacting the geoscience community, especially through congressional staff meetings; (2) seek out collaborative prospects with other science-based organizations to positively shape the direction of science policy and amplify our common messages; and (3) identify pathways for GSA members to engage in science policymaking at the "next level," beyond GSA's Congressional Visit Days.

In ten days, I participated in 26 events, hustling between the House and Senate sides of Capitol Hill and to other venues such as the National Press Club and collaborative partner offices. I attended:

- Nine congressional hearings, a Senate committee executive session, a House of Representatives special session on the first 100 days of the 116th Congress, and a full Senate vote;
- Four congressional committee and two congressional office staff meetings;
- Two science advisory briefings, two science coalition meetings, and a planning meeting for a congressional caucus briefing; and
- Three meetings with scientific trade associations and professional societies.

All of this I found immensely informative and instructive on how our representative democracy works and the compelling need for scientists to participate in it. These are not new concepts for many of you. However, as someone who has been a bit of a policy wonk for longer than her years as an earth and health scientist combined, I find parts of the song remain the same and bear repeating. In this article I offer a mini-refresher on the foundations of U.S. federal government and the role of Congress, and strongly advocate that you engage in science policy not only because of your expertise but in your role as a citizen. This can be one of the most important and impactful things you do in your career.

Accompanying this article are posts on GSA's *Speaking of Geoscience™* blog, where I offer tips on how to quickly develop an action plan for delivering messages that maximize your influence with Congress. I dive into a few science policy issues in the 116th Congress and discuss collaborative opportunities on cross-over issues with other stakeholders. I also share observations on expectation management and staying positive at a time in history when Congress can appear intractably divided.

Refresher: Foundations of American Government

For more than 230 years, the Declaration of Independence and U.S. Constitution have formed the basis of America's representative democracy. The Declaration of Independence avowed that we consent to be governed. The Constitution laid out a blueprint for a federal government with three branches, executive, judicial, and legislative. Within this blueprint, the constitutional framers instilled a system of checks and balances to prevent a concentration of power within any branch, and to spread power across the government. Article I of the Constitution provides the legislative branch (Congress) with explicit powers, including the power to make all federal laws, regulate commerce, tax and borrow money, and provide oversight of the other two branches.

Congressional Powers: What Lies Beneath?

Laws, commerce, money, oversight. Regardless of your preferences for the role of government on these politically sensitive subjects, it is important to remember that the framers—many of them devotees of scientific enlightenment—believed that a stable, functioning society relies on agreed-upon social norms and values underpinning each of these enumerated powers. This is culture, and it defines us as a society.

Problematically, as scientists we are vulnerable to the scientific enlightenment trap: "information is the answer." Yet intellectual achievements, while a significant part of culture, do not occur in a social vacuum. Further, culture wars diminish when people focus on shared social values.

In fact, "we the people" are part of the fourth branch, the unofficial term for groups with the opportunity to exert *positive social influence* on the federal government. Along with elections, this is how we exercise our consent to be governed. Congress' role is to do the people's business, so, arguably, the greatest opportunity for defining American culture is with Congress.

How do we exert social influence in Congress? We need to set aside our expert hats and strategically engage with Congress in a social context, as citizens in our district or state and on Capitol Hill. We must accept that policy decisions cannot be based solely on facts. We must identify and appeal to shared social norms and values. Fortunately, this is not as big a leap from science as it might seem.

Upping Your Game—Be a Civic Scientist

As geoscientists, we observe, categorize, and analyze earth and planetary systems, materials, phenomena, and their inter-relationships. Then we present facts and interpretations. This is our familiar role as subject matter experts. As citizens, the next step is presenting evidence-based statements of facts and interpretations with the opinion that policy action is needed. We can present our statements with policy options. We can present our statements with the opinion that a specific policy action is needed. Now we are bringing in values.

Speaking of values, it is worth recalling that when we engage in our highly trained way of developing and presenting evidence, another construct is also at work, often subconsciously. This is our level of scientific integrity and professional ethics. Our principles act as internal oversight—our own system of checks and balances—on how we do science, where we apply our expertise, and how we relate to each other and to society.

One of the burdens of expertise is earning and keeping the public trust. If we ignore our ethical relationship with society, people will not consent to listen to us. And with growing anti-intellectualism in our culture, shared values are more important than ever. Therefore, our responsibility and role in civil society is not entirely dissimilar from that of lawmakers. Neither law nor science can be value free. We must be civic scientists.

“A ‘civic scientist’ to me is a true scientist who uses his or her knowledge, accomplishments, and analytical skills to help bridge the gap between science and society.” —Dr. Neal Lane, 1998–2001 Assistant to the President for Science and Technology

One way to strategically bridge this gap is by demonstrating that our knowledge is consequential, timely, and a means for meeting societal needs and values. For example, let’s reframe a few geoscience themes into messages reflecting the expressed powers of Congress and a non-partisan values perspective:

- We value Congress’ work on *laws* to strengthen and protect infrastructure during mass evacuations, and are reaching out to offer insight on how geological factors affect the foundational integrity of infrastructure and might be addressed in your bill;
- We are developing forecasting models for climate, atmospheric, and space weather events and would like to meet to discuss our concerns about potential impacts on the nation’s health and ability to conduct *commerce*;
- Because we understand significant *money* is required for assuring long-term nuclear waste storage, we would like to talk with you about safety risks and offer ideas on appropriations for innovative R&D toward mitigating these risks; and
- We are aware of plans to develop a federal onshore energy production strategy in order to promote national security, and given your congressional *oversight* role with oil and gas production, we are seeking inclusion of best practices for siting new pipelines.

We can also bridge this gap through relationship-building. In Congress, the words of cultural anthropologist Margaret Mead still ring true:

“Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it’s the only thing that ever has.”

Yes, Someone is Listening—and Responding

Wait. You’re a trained skeptic. Why should you engage with Congress when politics is just a power game, right? Wrong!

If you take away one thing from this article, I hope it will be this: Members of Congress and their staff are incredibly committed to their work and their values, and by and large, they listen closely as they try to balance many competing interests. Granted, your values might not always align with your member of Congress but regardless you will find *they still want to know what you think*. Why? Because you are their constituent.

Members of Congress are also positively influenced by constituent advocacy. The highest-rated strategies for having a lot of positive influence on congressional decisions are not visits from lobbyists or blast emails; they are in-person member and staff meetings with constituents, communications from individuals and constituent groups in the member’s district or state, constituent comments at in-person or telephone town halls, and personalized constituent messages. That means your direct participation as a constituent counts—a lot—and has more influence on lawmakers’ decisions than other advocacy strategies. Learn more at www.congressfoundation.org/projects/communicating-with-congress/citizen-centric-advocacy-2017.

Lastly, if you harbor reservations about requesting a meeting with your member’s office, know it is perfectly okay to ask for and take their time. I can occasionally fall into the trap of thinking, “they are busy people doing the nation’s work; I don’t want to be a bother.” Yes, they are busy people, but they are doing the people’s work. They are professionals. This is their job. Their responsibility is to listen and ours is to speak up. So remember, constituent visits are expected and welcomed! Relationship-building with congressional staff also offers the potential to be a valued and trusted informal adviser on an ongoing basis, with opportunities to make an even greater impact with Congress—and on the future of the geoscience profession.

Next Steps: Practicalities and Other Lessons Learned

GSA can connect you with tools for doing your homework on the issues, honing your science policy communication skills, and putting the “positive social influence” in your advocacy. GSA’s Kasey White is the lead author of “Working with Congress: A Scientist’s Guide to Policy,” a 78-page manual published by AAAS. I also invite you to visit GSA’s *Speaking of Geoscience*[™] at <https://speakingofgeoscience.org> to read my accompanying blogs on the most useful lessons I learned during my spring 2019 stint on Capitol Hill. It was an honor to participate on behalf of GSA.

Through the Lens of a Scientist *and* Science Translator



Sarah Derouin

GSA has always been my “go-to” scientific organization. The mixture of approachability and scientific rigor has always felt in balance. And to me, the Annual Meetings are the perfect size—big enough to stretch my scientific inclinations, yet small enough to comfortably network and socialize with colleagues.

For years, I attended and presented at meetings as a scientist. Now, with my career change to science communication,

my interactions with GSA have broadened: I look at geoscience research through the lens of a scientist *and* a science translator.

Considering my appreciation for the Society, I was thrilled to be the 2018–2019 Science Communication Fellow for GSA. The position allowed me to interview key leaders in the field and write about their research, mentor science communication interns, and even speak with congressional representatives during Climate Science Day—quite a list of activities over a 10-month span!

One of my tasks as a fellow was writing press releases on studies published in GSA’s premier journals. Once written, these press releases were posted to listservs, social media, and science news organizations like EurekAlert, where geoscientists, journalists, and the geology-curious could read them. (If you’d like to see press releases on new research, go here: www.geosociety.org/news.) The main goal of a press release is to break down new research into easy-to-understand language while underscoring why the scientist’s findings matter. I always made sure to highlight the take-home message for policy makers, the public, and the research community.

The sheer range of topics, geographic locales, and findings published in GSA’s journals is astounding; it was often hard to choose which study I would cover for a press release. Once I picked a few favorites, GSA journal editors, GSA communication staff, and I would narrow down the list to one. Over the past year, I covered topics ranging from New Madrid faulting to meteorites in the Atacama Desert. Each study was fascinating, and the scientists were a joy to talk with.

Talking with scientists about cool new geology is always a highlight in my science communication work. At the GSA 2018 Annual Meeting in Indianapolis, I was able to share my enthusiasm for a great interview with six science communication interns. This diverse group included undergraduates to Ph.D. students, all of whom were interested in bolstering their science communication chops. Their interests ranged from science policy to profiles to podcasts, and I appreciated their enthusiasm. It was fun to talk shop—both about geology and science communication—in the meeting press room. (If you’re interested in being a science communication intern at this year’s meeting, you can apply here: <http://bit.ly/2wP7HzR>.)

I wasn’t just writing and mentoring during my stint as a fellow; I also got an opportunity to learn about science and public policy. This past spring, I attended Climate Science Day in Washington, D.C. Over the two-day event, I learned how to best approach congressional representatives to share climate science information.

I spent the first day with other scientists and policy wonks, learning what approach was most effective during a congressional visit. Clear, approachable, non-jargon language was key, and I learned the importance of summarizing the main points—there’s not a lot of time to pontificate in a 20-minute meeting. The second day was filled with small group meetings with congressional staff, where we presented requests, called “asks,” that could range from offering yourself as an on-call expert to asking for a town hall in their district to address a climate-related issue.

I learned a lot during my D.C. visit and came back with a new appreciation for science communication and public policy. I hope to continue to build on my experience and participate in more policy work.

I may be biased, but I believe that science communication is more important than ever. Clearly describing new science to a wide audience is essential in advancing science and is crucial to creating strong policy and protections.

Working with Justin Samuel, Christa Stratton, and the staff at GSA has been wonderful, and I am grateful to have been the Science Communication Fellow this past year. The experience has connected me with a great group of scientists, communicators, and policy experts, and has taught me new skills that I will take with me into my career.

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Q:

Can students submit papers to GSA publications?

A: YES!

If you're a student or early career author with research you're looking to share, GSA publications are happy to receive your article submission. GSA publishes scientific papers on all aspects of geology. We invite you to explore our six peer-reviewed journals at <https://pubs.geoscienceworld.org/gsa> and find the best fit for your paper.

You can also learn more about our journals, how to prepare and submit your paper online, and what to expect from the review and publication process on our author information page at www.geosociety.org/AuthorInfo.

And if you're planning to attend the GSA Annual Meeting in Phoenix, Arizona, USA, you'll want to apply for our highly successful workshop for early career geoscientists, “**What's Your Problem; What's Your Point?**,” to be held on Sunday, 22 Sept., 11:30 a.m.–2 p.m. This workshop, led by experienced GSA science editors, focuses on the process of preparing your research for submission and navigating the editorial process. You'll get advice on what to include, what to leave out, and how best to structure your manuscript, as well as how to avoid frustrating your paper's reviewers. Apply online by 9 August at www.geosociety.org/GSA/Publications/GSA/Pubs/WritersResource.aspx.

GEOSCIENCE JOBS & OPPORTUNITIES

Ads (or cancellations) must reach the GSA advertising office no later than the first of the month, one month prior to the issue in which they are to be published. (Note: Combined March/April issue releases on March schedule.) Print ads will also appear on the Geoscience Job Board to coincide with the month of print issue. **Contact: advertising@geosociety.org, +1-800-472-1988 ext. 1053, or +1-303-357-1053.** Email correspondence should include complete contact information (including phone and mailing address). Rates are in U.S. dollars.

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POSITIONS OPEN

Faculty Position, Paleontology, University of Michigan

The Museum of Paleontology and the Dept. of Earth and Environmental Sciences at the University of Michigan are searching for a full-time tenure-track faculty candidate in the field of Paleontology at the assistant professor/assistant curator level. This is a university year appointment with an expected start date of September 1, 2020. The Museum of Paleontology has recently relocated its internationally significant collections of plant, invertebrate, and vertebrate fossils to the new Research Museums Center. Paleontology faculty labs and offices are in the newly completed Biological Sciences Building, which houses other academic units and the Museum of Natural History which attracts over 165,000 visitors a year.

We seek applicants who have broad research and teaching interests within developing areas of evolutionary or environmental paleontology. We are especially interested in applicants investigating the invertebrate fossil record, although exceptional candidates with other areas of taxonomic expertise will be considered. The Museum and Department invite applicants in fields including, but not restricted to: macroevolution, interactions of developmental biology and evolution, extinction dynamics, paleoecology, organismal paleobiology, and biotic responses to global change.

The successful candidate is expected to establish an externally funded research program and contribute to excellence in undergraduate and graduate teaching. Applicants must have a Ph.D. at the time of appointment and should submit the following: (1) cover letter; (2) CV; (3) statement of current and future research plans; (4) statement of teaching philosophy and experience; (5) evidence of teaching excellence, if available; (6) statement of activities contributing to diversity, equity, and inclusion in academia; (7) up to four publications; and (8) the names and contact information for at least four references.

Information about the Museum and Department can be found at www.lsa.umich.edu/paleontology and www.lsa.umich.edu/earth. To apply please go to <https://ummp-earth.lsa.umich.edu/search19/>, complete the online form, and upload the required application documents as a single PDF file. If you have

any questions or comments, please send an email message to ummp-earth-search@umich.edu.

The application deadline is August 31, 2019, for full consideration, but applications will continue to be reviewed until the position is filled. We expect to begin on-campus interviews in late Fall 2019.

The University of Michigan is supportive of the needs of dual career couples and is an Affirmative Action/Equal Opportunity Employer. Women and members of minority groups are encouraged to apply.

Geochemistry Lab Manager, Miami University

The Dept. of Geology and Environmental Earth Science at Miami University invites applications for a Geochemistry Lab Manager position. The Lab Manager will be expected to manage trace metal geochemistry, ICP-OES/MS and powder XRD labs. Duties will include training and supervision of lab users, laboratory maintenance, data quality assurance, assistance in teaching laboratory-based courses, oversight of radiation and environmental health and safety compliance, and laboratory financial management. Laboratory technique development and adaptation for analysis of diverse geologic and environmental materials expected, with opportunities to pursue research and external funding. Required: M.S. or Ph.D. in geology or related field, at least 4 years of experience in major and trace element analysis of geologic materials by plasma techniques at the time of the appointment, and proven experience in successful training and supervision of geochemistry lab users. Desired: experience in LA-ICP-MS, powder XRD and HPLC analysis; expertise in laboratory technique development, and electrical and mechanical abilities. Submit letter of application, curriculum vitae and unofficial copy of transcripts to <http://jobs.miamioh.edu/cw/en-us/job/495595>. Letters of reference will be requested upon receipt of application. Inquiries can be directed to Cathy Edwards at edwardca@miamioh.edu. Position not eligible for H-1B sponsorship. Review of applications will begin on September 2, 2019, and continue until position is filled.

Miami University, an EO/AA employer, encourages applications from minorities, women, protected veterans and individuals with disabilities. Miami does not permit, and takes action to prevent harassment, discrimination and retaliation. Requests for reasonable accommodations for disabilities should be directed to ADAFacultyStaff@miamioh.edu or 513-529-3560. Annual Security and Fire Safety Report may be found at <http://www.MiamiOH.edu/campus-safety/annual-report/index.html>. Criminal background check required. All campuses are smoke- and tobacco-free.

Assistant Lecturer/Assistant Teaching Professor Position, Geoscience, Miami University

The Dept. of Geology and Environmental Earth Science at Miami University invites applications for a full-time Assistant Lecturer or Assistant Teaching Professor position on the Oxford campus, beginning August 2020. The Assistant Lecturer/Assistant Teaching Professor will teach undergraduate

courses, including foundation courses in physical and environmental geology, as well as intermediate level courses; advise undergraduate students; and provide professional service to the department and university. Required: M.S. in geoscience (for appointment as Assistant Lecturer) or Ph.D. in geoscience (for appointment as Assistant Teaching Professor) by time of appointment, and documented teaching experience; applicant must be a U.S. citizen, a lawful permanent resident, admitted for residence as an applicant under the 1986 immigration amnesty law, refugee, or asylee. Desired: interest in contributing to supervision of undergraduate student research and field-based experiences. Submit letter of application, curriculum vitae, and evidence of teaching effectiveness to <http://jobs.miamioh.edu/cw/en-us/job/495551>. Letters of reference will be requested upon receipt of application. Inquiries can be directed to Cathy Edwards at edwardca@miamioh.edu. Review of applications will begin on October 2, 2019, and continue until position is filled.

Miami University, an EO/AA employer, encourages applications from minorities, women, protected veterans and individuals with disabilities. Miami does not permit, and takes action to prevent harassment, discrimination and retaliation. Requests for reasonable accommodations for disabilities should be directed to ADAFacultyStaff@miamioh.edu or 513-529-3560. Annual Security and Fire Safety Report may be found at <http://www.MiamiOH.edu/campus-safety/annual-report/index.html>. Criminal background check required. All campuses are smoke- and tobacco-free.

Collection Manager, University of Kansas Biodiversity Institute

The University of Kansas Biodiversity Institute seeks a collection manager to oversee its world-class research collections in invertebrate paleontology. The collections consist of extensive invertebrate fossil and micro-fossil specimens, along with archives and library holdings. The collections have strengths in Cambrian, Carboniferous and Cretaceous fossils, microfossils, echinoderms, brachiopods, and arthropods, and fossils from Antarctica. University curators and students, and national and international scholars, use the collections extensively for research and education. The collection manager is responsible for day-to-day activities in the collection and reports to the curator-in-charge. This is a full-time (12-month appointment), non-tenure track position. To learn more and apply go to <http://employment.ku.edu/staff/14823BR>.

Application review begins 3 September 2019. EO/AA. We celebrate diversity in all forms.

Assistant Professor (Tenure Track), Paleoclimate Sedimentology, University of Lausanne

The Faculty of Geosciences and the Environment (FGSE) of the University of Lausanne invites applications for a professorship in Paleoclimate Sedimentology, to be based in the Institute of Earth Sciences (ISTE).

We are looking for an excellent sedimentologist who focuses on the reconstruction of past climate changes (including sedimentary, paleocli-

mate, biological and paleoceanography changes) at geological timescales using the stratigraphic and sedimentary record. We seek a candidate who can provide an innovative interpretation of sedimentary archives, using laboratory, and field techniques and reconstructing Earth system history. The ideal candidate should have a strong background in geology, a strong commitment to field-based research and a willingness to contribute to field-based teaching.

The successful candidate will actively participate in the research activities of the Institute of Earth Sciences, will teach in the Bachelor of Geosciences and Environment and in relevant Masters taught by the FGSE, and will supervise masters and doctoral students.

Appointment will be at the Assistant Professor level (tenure track). However, exceptionally, we will consider outstanding candidates for direct appointment to the Associate or Ordinary Professor level, notably if this corresponds with our equal opportunity objectives.

The application should include a cover letter (max 0.5 page), a full Curriculum Vitae, a research statement (max. 4 pages), a teaching statement (max. 2 pages), PDFs of the three most significant publications, and the names and contact information of five referees. For further information, contact Prof. Frédéric Herman, Dean of the FGSE (frederic.herman@unil.ch).

Application deadline: August 24th, 2019 (23:59 Swiss time GMT+2).

The application in PDF must be shared in several document not bigger than 9.9 MB and will be considered only if sent through this website where you find a full description of the position: <https://bit.ly/2PPF6Da>. Or www.unil.ch/central/en/home.html -> Jobs -> search sedimentology.

Assistant (Tenure-Track), Associate (Tenured), or Full (Tenured) Professor in Sedimentary Geology, Jackson School of Geosciences, Department of Geological Sciences, The University of Texas at Austin

The Dept. of Geological Sciences in the Jackson School of Geosciences at The University of Texas at Austin is seeking to hire a faculty member in Sedimentary Geology at the Assistant, Associate or Full professor level. We seek a creative individual who has an innovative research program in sedimentary geology and addresses questions related to clastic sedimentation, dynamic stratigraphy, depositional systems, and basin architecture over geological time scales, with broad applicability to the energy industry. A demonstrated ability to integrate a range of approaches and data types is required, potentially including field-based inquiry, linked surface and subsurface investigations, incorporation of seismic data, and analytical or modeling approaches. The successful candidate will be expected to establish an internationally recognized research program and excel at teaching, mentoring, and service roles within the department, and should have a strong record of securing external research funds. We seek an individual who facilitates collaborations among faculty, researchers, and students in the department and university, and is capable of teaching courses over a wide range of geoscience topics, particularly courses in stratigraphy, sedimentology, and basin analysis.

As part of the Jackson School of Geosciences (www.jsg.utexas.edu), the Dept. of Geological Sciences (www.jsg.utexas.edu/dgs) has over 50 faculty and a community of research scientists with a broad

range of specialties, as well as access to outstanding research facilities and support. The department has one of the largest combined graduate and undergraduate enrollments of any Earth Science program in North America and is located in a thriving metropolitan area with a dynamic, multicultural community of over 1 million people. The department is interested in building a culturally diverse intellectual community; we strongly encourage applications from all under-represented groups.

Required application documents include a cover letter, curriculum vitae, a statement of research, statement of teaching, statement addressing past and/or potential contributions to diversity through research, teaching, and/or service, and contact information for at least 5 references. Review of applications will commence September 1, 2019, and will continue until the position is filled. Further information about the department is available at <http://jsg.utexas.edu/dgs>. Apply here: <https://apply.interfolio.com/65059>.


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On To the Future Mentors— Creating a Community of Support

Community lies at the heart of GSA’s identity. This spirit of collegiality and inclusion gave rise to GSA’s On To the Future (OTF) program, which has emerged as a crucial community supporting emerging geoscientists from a diversity of backgrounds to attend their first GSA Annual Meeting. At the forefront of the program’s success are our volunteer mentors. In the following, four OTF mentors describe why they dedicate their time and talents to the program, and how this community of support has profoundly enriched their careers.

When **Joseph Nolan**, a 2013 OTF participant and mentor since 2017, applied to OTF, he expected a “one and done” grant. Instead, “I was blown away that I was committing to an entire community of extraordinary individuals. I feel like OTF is a second family.” This experience of community proved so invigorating that he quickly volunteered to serve as a mentor. “OTF has provided a place and source of knowledge I can use to hone my mentoring and guidance skills, and has prepared me to be a better support system. It teaches students and mentors how to be successful, which in turn helps us teach others to be successful. This amazing group of people is touching lives and creating lasting effects in our communities.”

In 1981, **Claudia Mora**, former GSA president, attended her first GSA Annual Meeting—an experience that impacted her desire to become a geoscientist. Growing up in a home where women were not expected to pursue professional careers, and without role models to guide her, the annual meeting helped Claudia to see herself, “as part of (the geoscience) community, which was tremendously empowering and influential.” This community support was important to Claudia as an aspiring geoscientist and inspires her to give back to the community as a mentor, so that, through sharing her experiences, she can continue the tradition of generous support.

For **Jenny Nakai**, participating in OTF in 2013 was an opportunity to explore the interaction between the geology and geophysics communities within GSA and engage with cutting-edge scientific research. Her positive experience of our community not only led to becoming an OTF mentor, but also to serving on GSA’s Diversity in the Geosciences Committee. For Jenny, the mentoring relationship is central to OTF’s success. “The OTF program is a great way to develop mentor/mentee relationships. I put a lot of effort into being a mentor, and I think it will help my mentee

decide if she would like to pursue the geosciences. I am grateful for my mentors that put the same work into helping me.”

Larry Davis, Professor Emeritus at the University of New Haven, can attest to the importance of mentor investment. His mentor—Dorothy Echols of Washington University in St. Louis—not only encouraged him to attend his first GSA Annual Meeting, but actively included him in that community by introducing him to her colleagues. This left an indelible impression upon Larry and inspires his service to our community through mentoring, even in retirement. “Working with OTF helped me realize what mentoring really was. It provided me with a perfect opportunity to meet new/future geologists and to share my experience with them. Their enthusiasm was contagious and I really felt that I was honoring the memory of Dorothy Echols and all of my other mentors by giving back and mentoring the next generation.”

You can help the next generation of geoscientists write their story of success. By supporting OTF, you will be giving students access to role models and community leaders whose insights and experiences will profoundly shape the course of their geoscience careers. If you would like to donate to OTF, please contact Clifton Cullen at +1-303-357-1007 or ccullen@geosociety.org. To begin your journey as an OTF mentor, go to <http://bit.ly/2X1KJ7w>.



Larry Davis leading a group of aspiring geoscientists at Nelson Rocks in West Virginia.

Teaching for Earth Resilience: A Strategy for Increased Diversity and Equity

Sarah K. Fortner, *Geology Dept. and Environmental Science Program, Wittenberg University, Springfield, Ohio 45501, USA;* **Cathryn A. Manduca**, *Science Education Resource Center, Carleton College, Northfield, Minnesota 55057, USA;* **Laura A. Guertin**, *Dept. of Earth Science, Penn State Brandywine, Media, Pennsylvania 19063, USA;* **David W. Szymanski**, *Dept. of Natural and Applied Sciences, Bentley University, Waltham, Massachusetts 02452, USA;* and **Joshua Villalobos**, *El Paso Community College, El Paso, Texas 79998, USA*

INTRODUCTION

The geosciences fall behind all other reporting science, technology, engineering, and math (STEM) fields in graduation rates of underrepresented minorities (URM) (Wilson, 2017). Improving diversity and inclusion in our profession is important not only to meet the demand of our workforce, it is critical for improving community and policy outcomes. For this reason, we suggest that geoscience educators adopt a focus on earth resilience and the approaches it requires. Earth resilience is the ability to equitably, justly, and sustainably manage, plan, and adapt to resource challenges at local to global scales. The work of earth resilience professionals (e.g., disaster planning, environmental justice) calls for more than disciplinary skills and habits; it relies on empowering the talents of underrepresented and marginalized communities and networking to improve outcomes. Drawing from these strategies, earth educators might support more diverse and inclusive geosciences by (1) connecting with URM students through culturally and societally relevant curriculum that builds the disciplinary and civic skills and habits needed for social change, and (2) creating networks that expand entry points, mentoring, representation, and career preparation (Fig. 1). We describe examples of strategies that begin to empower URM students and call for greater investment on their behalf.

CURRICULUM FOR SOCIAL CHANGE

Equitably and justly addressing challenges like climate change, natural disasters, air quality, water quality, challenges

that disproportionately impact underrepresented and marginalized populations, calls for a curriculum that goes beyond our traditional view of core competencies (e.g., Mosher et al., 2014). Outcomes in communities will be determined by how well our graduates can navigate codes, laws, and power structures, as well as their ability to work across disciplines, cultures, and identities. Those working on earth-resilience challenges (e.g., disaster response) navigate these challenges by working in and with the communities and engaging them in all aspects of project development (e.g., NRC, 2012). Outcomes improve when barriers to participation are reduced and efforts incorporate the interests and strategies that resonant with communities (NRC, 2012). Education that engages students in communities to address resilience priorities provides a mechanism for developing these skills.

Within our courses, active, societally and culturally relevant engagement provides students with the skills and habits needed for both geoscience and social change. Active learning (e.g., low stakes practice of skills and habits) reduces disproportionately high URM student failure rates in STEM disciplines (Freeman et al., 2014). The historically black colleges and universities geosciences working group has also identified a need to incorporate culturally (e.g., Pan-African) and societally relevant content that appeals to diverse students (Archer et al., 2019). More than 50% of URM STEM students surveyed rated *working for social change* as an “essential” or “very important” professional goal, significantly more than

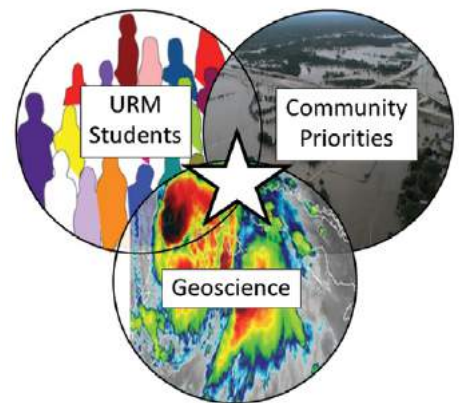


Figure 1. An earth-resilience approach to geoscience education features an intentional focus on improving underrepresented minority (URM) student and community outcomes. Within our courses, active and culturally situated learning co-delivers disciplinary and civic skills and habits needed to improve community outcomes. Networks expand entryways, mentors, representation, resources, and opportunities for URM students.

non-URM students (Garibay, 2015). The InTeGrate Project (<https://serc.carleton.edu/integrate/>) offers insight into how to join the skills and habits identified by professionals with the skills and habits needed for social change (Gosselin et al., 2019). Openly available course modules engage students in evaluating the reliability of information (e.g., *Carbon, Climate and Energy Resources*), analyzing justice issues (e.g., *Environmental Justice and Freshwater Resources*), mirroring the community participatory process (e.g., *Food as the Foundation for Healthy Communities*), and connecting earth challenges to governance and ethics (e.g., *Lead in the Environment*).

NETWORKS TO BUILD CAPACITY

Networks with broader communities are sorely needed to improve geoscience student outcomes. Undergraduates especially need relevant work experience. Yet most geoscience graduates have only completed one research experience, and fewer than 60% have had an internship (Wilson et al., 2017). Access to opportunities is especially important at two-year colleges, which serve the greatest percentage of URM students but often face greater barriers (e.g., time, resources). Building and capitalizing on networks can improve pathways into the geosciences; expand perspectives, representation, or mentoring opportunities; and link learning about Earth to community concerns and employment opportunities. Programs that engage K–12 schools, employers, community groups, alumni, or other programs expand interest, mentoring, representation, and access to research, internship, and geotechnical opportunities.

One example that expands URM student opportunities using networks is NSF-funded *Service Learning Activities Targeting the Earth Science*, which engages students in service-learning opportunities around local water issues. The program unites El Paso Community College, The University of Texas at El Paso, and El Paso Water Utilities in developing activities that attract new geoscience majors and actively work with communities on priority issues (Doser, 2018). Another example is the EarthConnections project. Developed through pilots in three communities, EarthConnections

emphasizes co-creation with the community, coupling of classroom learning and community application, connecting learning opportunities for students of different ages, and mentoring and signposting that help students define an educational path aligned with their interests (Manduca et al., 2018).

The next step toward earth resilience is to move from a few examples to a widespread effort to connect geoscience learning and resilience both locally and globally. This approach will help make our discipline relevant and reciprocal with diverse communities, diversify our science, and strengthen the capacity for living successfully and equitably on Earth.

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2020 GSA Section Meetings



South-Central

9–10 March
Fort Worth, Texas, USA
Chairs: Omar Harvey, omar.harvey@tcu.edu; Arne Winguth, awinguth@uta.edu
www.geosociety.org/sc-mtg

Fort Worth Stockyards. Photo by Visit Fort Worth.



Joint Southeastern–Northeastern

20–22 March
Reston, Virginia, USA
Chairs: Arthur Merschat, amerschat@usgs.gov; Patrick Burkhart, patrick.burkhart@sru.edu
www.geosociety.org/se-mtg

Great Falls Park. Photo by Visit Fairfax.



Rocky Mountain

4–5 May
Provo, Utah, USA
Chair: Daniel Horn, hornsd@uvu.edu
www.geosociety.org/rm-mtg

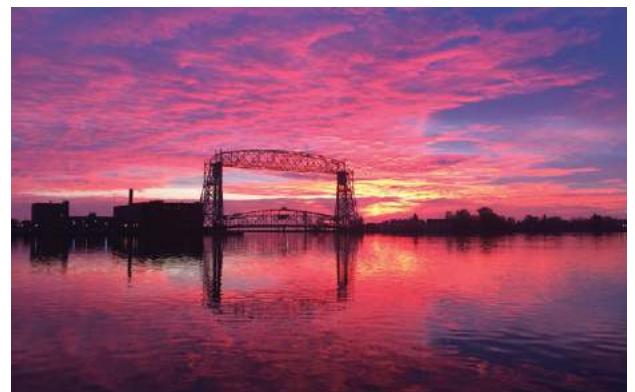
Mount Timpanogos. Photo by Hike395 via Wikimedia Commons.



Cordilleran

12–14 May
Pasadena, California, USA
Chair: Doug Yule, doug.yule@csun.edu
www.geosociety.org/cd-mtg

City Hall. Photo by Pasadena Convention & Visitors Bureau.



North-Central

18–19 May
Duluth, Minnesota, USA
Chair: Amy Myrbo, amyrbo@umn.edu
www.geosociety.org/nc-mtg

Aerial Lift Bridge at sunrise. Photo by Visit Duluth.

Special Paper 533

Tectonosedimentary Relations of Pennsylvanian to Jurassic Strata on the Colorado Plateau

Tectonosedimentary Relations of Pennsylvanian to Jurassic Strata on the Colorado Plateau

by William R. Dickinson

William R. Dickinson (1931–2015) formally retired in 1991, but he didn't stop working, researching, and writing. His work with University of Arizona professor George Gehrels on identifying sandstone provenance using detrital-zircon U-Pb geochronology led to the determination that much of the Pennsylvanian to Jurassic sandstone of the Colorado Plateau was derived from the orogenic belt now associated with the Appalachian Mountains. Further detrital-zircon studies led to Dickinson preparing this publication in order to identify key aspects of the sedimentary and tectonic history of Mesozoic strata of the Colorado Plateau and directly adjacent areas. Dickinson divided the strata into seven depositional systems, but completed writing on only the lower five (Moenkopi, Chinle, Glen Canyon, San Rafael, Morrison) before his death in July 2015. The manuscript, however, was comprehensive in its treatment of upper Paleozoic strata and the lower five Mesozoic "deposystems," and an abstract and concluding text by Jon Spencer helped to complete the work.

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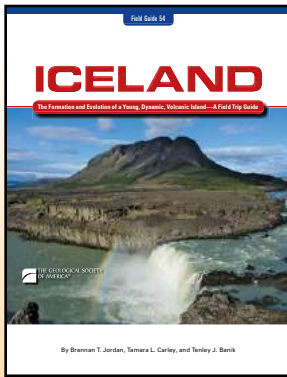
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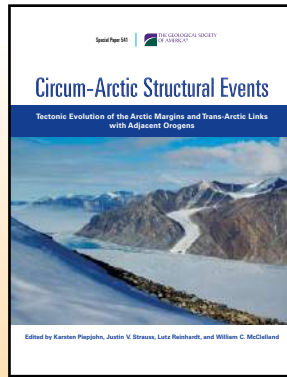


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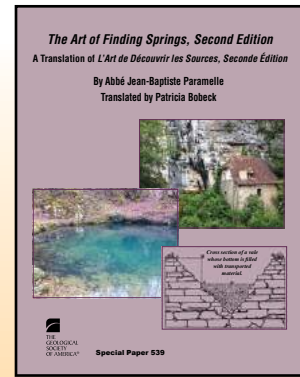
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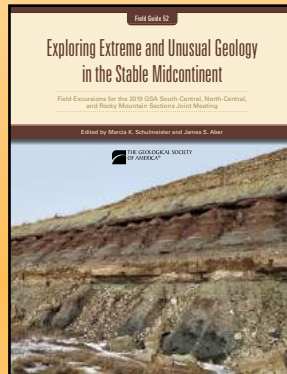
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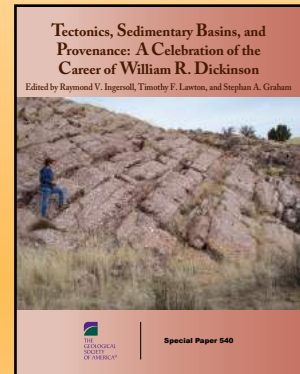
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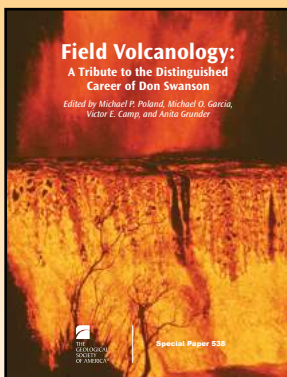
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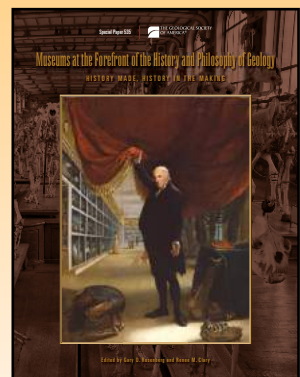
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