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Executive Director and Publisher: Vicki S. McConnell

Science Editors: Mihai N. Ducea, University of Arizona, Dept. of Geosciences, Gould-Simpson Building, 1040 E 4th Street, Tucson, Arizona 85721, USA, ducea@email.arizona.edu; **Peter Copeland,** University of Houston, Department of Earth and Atmospheric Sciences, Science & Research Building 1, 3507 Cullen Blvd., Room 314, Houston, Texas 77204-5008, USA, copeland@uh.edu.

Managing Editor: Kristen "Kea" Giles, kgiles@geosociety.org, gsatoday@geosociety.org

Graphics Production: Emily Levine, elevine@geosociety.org

Advertising Manager: Ann Crawford, +1-800-472-1988 ext. 1053; +1-303-357-1053; Fax: +1-303-357-1070; advertising@geosociety.org

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SCIENCE

Cover: Southwest facing view of Dobzebo (elevation 6436 m), near Zazê Township (查孜乡), Ngamring County, Shigatse, Tibet. Dobzebo owes its relief to Neogene extensional deformation following the attainment of extreme crustal thickness and high elevation. Photo by Aislin Reynolds, 2019. See related article, p. 4–10.

GSA CONNECTS 2021

GSA NEWS

Jurassic to Neogene Quantitative Crustal Thickness Estimates in Southern Tibet

Kurt E. Sundell*, *Dept. of Geosciences, University of Arizona, Tucson, Arizona 85721, USA, sundell@arizona.edu;* ***Andrew K. Laskowski,*** *Dept. of Earth Sciences, Montana State University, Bozeman, Montana 59717, USA;* ***Paul A. Kapp,*** *Dept. of Geosciences, University of Arizona, Tucson, Arizona 85721, USA;* ***Mihai N. Ducea,*** *Dept. of Geosciences, University of Arizona, Tucson, Arizona 85721, USA,* and *Faculty of Geology and Geophysics, University of Bucharest, 010041, Bucharest, Romania;* ***James B. Chapman,*** *Dept. of Geology and Geophysics, University of Wyoming, Laramie, Wyoming 82071, USA*

ABSTRACT

Recent empirical calibrations of Sr/Y and La/Yb from intermediate igneous rocks as proxies of crustal thickness yield discrepancies when applied to high ratios from thick crust. We recalibrated Sr/Y and La/Yb as proxies of crustal thickness and applied them to the Gangdese Mountains in southern Tibet. Crustal thickness at 180–170 Ma decreased from 36 to 30 km, consistent with Jurassic backarc extension and ophiolite formation along the southern Asian margin during Neo-Tethys slab rollback. Available data preclude detailed estimates between 170 and 100 Ma and tentatively suggest ~55 km thick crust at ca. 135 Ma. Crustal thinning between 90 and 65 Ma is consistent with a phase of Neo-Tethys slab rollback that rifted a portion of the southern Gangdese arc (the Xigaze arc) from the southern Asian margin. Following the continental collision between India and Asia, crustal thickness increased by ~40 km at ~1.3 mm/a between 60 and 30 Ma to near modern crustal thickness, before the onset of Miocene east-west extension. Sustained thick crust in the Neogene suggests the onset and later acceleration of extension in southern Tibet together with ductile lower crustal flow works to balance the ongoing mass addition of under-thrusting Indian crust and maintain isostatic equilibrium.

INTRODUCTION

The Tibetan Plateau is the largest (~1,500 × 3,500 km), high-elevation (mean of ~5,000 m) topographic feature on Earth and hosts the thickest crust of any modern orogen, with estimates in southern Tibet of ~70 km (Owens and Zandt, 1997; Nábělek et al., 2009), and up to ~85 km (Wittlinger et al., 2004; Xu et al., 2015). The Tibetan Plateau formed from the sequential accretion of continental fragments and island arc terranes beginning during the Paleozoic and culminated with the Cenozoic collision between India and Asia (Argand, 1922; Yin and Harrison, 2000; Kapp and DeCelles, 2019). The India-Asia collision is largely thought to have commenced between 60 and 50 Ma (e.g., Rowley, 1996; Hu et al., 2016); however, some raise the possibility for later collisional onset (e.g., Aitchison et al., 2007; van Hinsbergen et al., 2012). Despite ongoing ~north-south convergence, the northern Himalaya and Tibetan Plateau interior are undergoing east-west extension, expressed as an array of approximately north-trending rifts that extend from the axis of the high Himalayas to the Bangong Suture Zone (Molnar and Tapponnier, 1978; Taylor and Yin, 2009) (Fig. 1).

The Mesozoic tectonic evolution of the southern Asian margin placed critical initial conditions for the Cenozoic evolution of the Tibetan Plateau. However, much of the Mesozoic geologic history remains poorly understood, in part due to structural, magmatic, and erosional modification during the Cenozoic. There is disagreement even on first-order aspects of the Mesozoic geology in the region. For example, temporal changes in Mesozoic crustal thickness are largely unknown, and the paleoelevation of the region is debated. Most tectonic models invoke major shortening and crustal thickening due to shallow subduction during the Late Cretaceous (e.g., Wen et al., 2008; Guo et al., 2013), possibly pre-conditioning the southern Asian margin as an Andean-style proto-plateau (Kapp et al., 2007; Lai et al., 2019). Alternatively, Late Cretaceous to Paleogene shortening may have been punctuated by a 90–70 Ma phase of extension that led to the rifting of a southern portion of the Gangdese arc and opening of a backarc ocean basin (Kapp and DeCelles, 2019). These represent two competing end-member hypotheses for the Mesozoic tectonic evolution of southern Tibet that are testable by answering the question: Was the crust in southern Tibet thickening or thinning between 90 and 70 Ma?

Contrasting hypotheses about the Cenozoic tectonic evolution of southern Tibet are testable by quantifying changes in crustal thickness through time. In particular, the Paleocene tectonic evolution before, during, and after the collision between India and Asia was dependent on initial crustal thickness, and in part controlled the development of the modern Himalayan-Tibetan Plateau. Building on the hypothesis tests for the Late Cretaceous, if the crust of the southern Asian margin was thickened before or during the Paleocene, then this explains why the southern Lhasa Terrane was able to attain high elevations only a few million years after the onset of continental collisional orogenesis (Ding et al., 2014; Ingalls et al., 2018). However, if the Paleocene crust was thin, then we can ask the question: When did the crust attain modern or near modern thickness? Answering this question is a critical test of alternative tectonic models that suggest rapid surface uplift from relatively low elevation (and presumably thin crust) during the Miocene (e.g., Harrison et al., 1992; Molnar et al., 1993) or Pliocene (Dewey et al., 1988) as the product of mantle lithosphere removal (England and

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*Now at Dept. of Geosciences, Idaho State University, Pocatello, Idaho 83209, USA

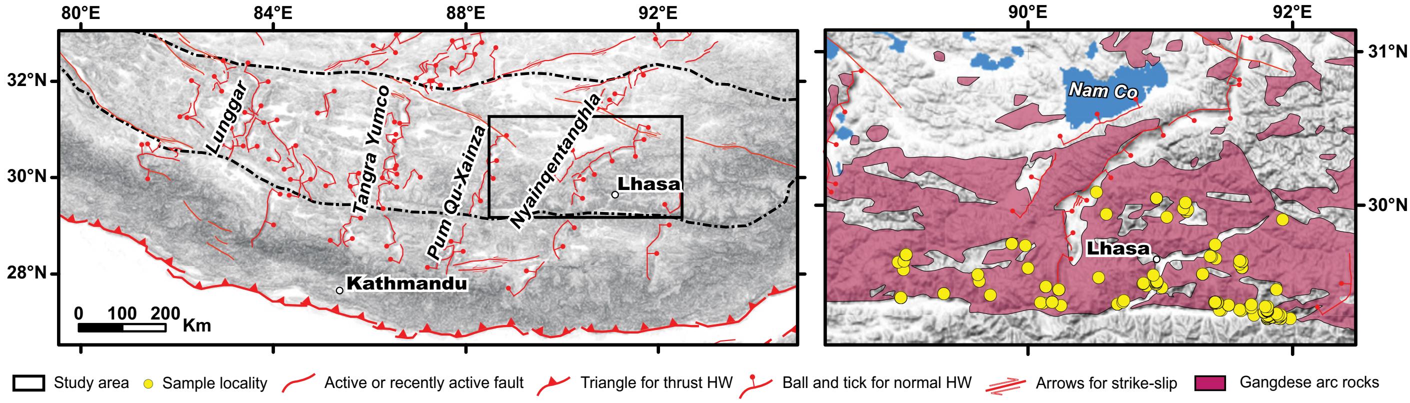

Figure 1. Digital elevation model of southern Tibet with major tectonic features. Active structures from *HimaTibetMap* (Styron et al., 2010). The basemap is from MapBox Terrain Hillshade. Lake locations are from Yan et al. (2019). Data points include only the filtered data (supplemental material [see text footnote 1]). HW—hanging wall.

Houseman, 1988). Finally, what happened after the crust was thickened to extreme levels, as we have in the modern? Did the plateau begin to undergo orogenic collapse (Dewey, 1988) resulting in a net reduction in crustal thickness and surface elevation that continues to present day (e.g., Ge et al., 2015), as evidenced by the Miocene onset of east-west extension (e.g., Harrison et al., 1995; Kapp et al., 2005; Sanchez et al., 2013; Styron et al., 2013, 2015; Sundell et al., 2013; Wolff et al., 2019)? Or did Tibet remain at steady-state elevation during Miocene-to-modern extension (Currie et al., 2005) with upper crustal thinning and ductile lower crustal flow (e.g., Royden et al., 1997) working to balance continued crustal thickening at depth driven by the northward underthrusting of India (DeCelles et al., 2002; Kapp and Guynn, 2004; Styron et al., 2015)?

Igneous rock geochemistry has long been used to estimate qualitative changes in past crustal (e.g., Heaman et al., 1990) and lithospheric (e.g., Ellam, 1992) thickness. Trace-element abundances of igneous rocks have proven particularly useful for tracking changes in crustal thickness (Kay and Mpodozis, 2002; Paterson and Ducea, 2015). Trace-element ratios provide information on the presence or absence of minerals such as garnet, plagioclase, and amphibole because their formation is pressure dependent, and each has an affinity for specific trace elements (e.g., Hildreth and Moorbath, 1988). For example, Y and Yb are preferentially incorporated into amphibole and garnet in magmatic melt residues, whereas Sr and La have a higher affinity for plagioclase (Fig. 2A). Thus, high Sr/Y and La/Yb can be used to infer a higher abundance of garnet and amphibole and a lower abundance of plagioclase, and may be used as a proxy for assessing the depth of parent melt bodies during crustal differentiation in the lower crust (Heaman et al., 1990). These ratios have been calibrated to modern crustal thickness and paired with geochronological data to provide quantitative estimates of crustal thickness and paleoelevation through time (e.g., Chapman et al., 2015; Profeta et al., 2015; Hu et al., 2017, 2020; Farner and Lee, 2017).

We build on recent efforts to empirically calibrate trace-element ratios of igneous rocks to crustal thickness and apply these revised calibrations to the eastern Gangdese mountains in southern Tibet (Fig. 1). This region has been the focus of several studies attempting to reconstruct the crustal thickness using trace-element proxies (e.g., Zhu et al., 2017) as well as radiogenic isotopic systems such as Nd and Hf (Zhu et al., 2017; Alexander et al., 2019; DePaolo et al., 2019), and highlight discrepancies in different geochemical proxies of crustal thickness. As such, we first focus on developing a new approach to estimate crustal thickness from Sr/Y and La/Yb, both for individual ratios, and in paired Sr/Y–La/Yb calibration. We then apply these recalibrated proxies to data from the Gangdese mountains to test hypotheses explaining the Mesozoic and Cenozoic tectonic evolution of southern Tibet.

METHODS

Sr/Y and La/Yb (the latter normalized to the chondritic reservoir) were empirically calibrated using a modified approach reported in Profeta et al. (2015). Calibrations are based on simple linear regression of ln(Sr/Y)–km and ln(La/Yb)–km; and multiple linear regression of ln(Sr/Y)–ln(La/Yb)–km (Figs. 2B–2D). We also tested simple linear regression of ln(Sr/Y) × ln(La/Yb)–km (see GSA Supplemental Material[1]). Regression coefficients and residuals (known minus modeled thickness) are reported at 95% confidence (±2s).

The revised proxies were applied to geochemical data compiled in the Tibetan Magmatism Database (Chapman and Kapp, 2017). Geochemical data used here comes from rocks collected in an area between 29 and 31°N and 89 and 92°E. Data were filtered following methods reported in Profeta et al. (2015) where samples outside compositions of 55%–68% SiO_2, 0%–4% MgO, and 0.05–0.2% Rb/Sr are excluded to avoid mantle-generated mafic rocks, high-silica felsic rocks, and rocks formed from melting of metasedimentary rocks. Filtering reduced the number of samples considered from 815 to 190 (supplemental material; see footnote 1).

We calculated temporal changes in crustal thickness based on multiple linear regression of ln(Sr/Y)–ln(La/Yb)–km (Fig. 2B). Each estimate of crustal thickness is assigned uncertainty of ±5 m.y. and ±10 km; the former is set arbitrarily because many samples in the database do not have reported uncertainty, and the latter is based on

[1]Supplemental Material. Filtered and unfiltered geochronology-geochemistry results are from the Tibetan Magmatism Database (Chapman and Kapp, 2017); the full data set between 89–92 °W and 29–31 °N was downloaded 20 July 2020. All data are available online at jaychapman.org/tibet-magmatism-database.html. MATLAB code is available at github.com/kurtsundell/CrustalThickness and incorporates the filtered data to reproduce all results presented in this work. Go to https://doi.org/10.1130/GSAT.S.14271662 to access the supplemental material; contact editing@geosociety.org with any questions.

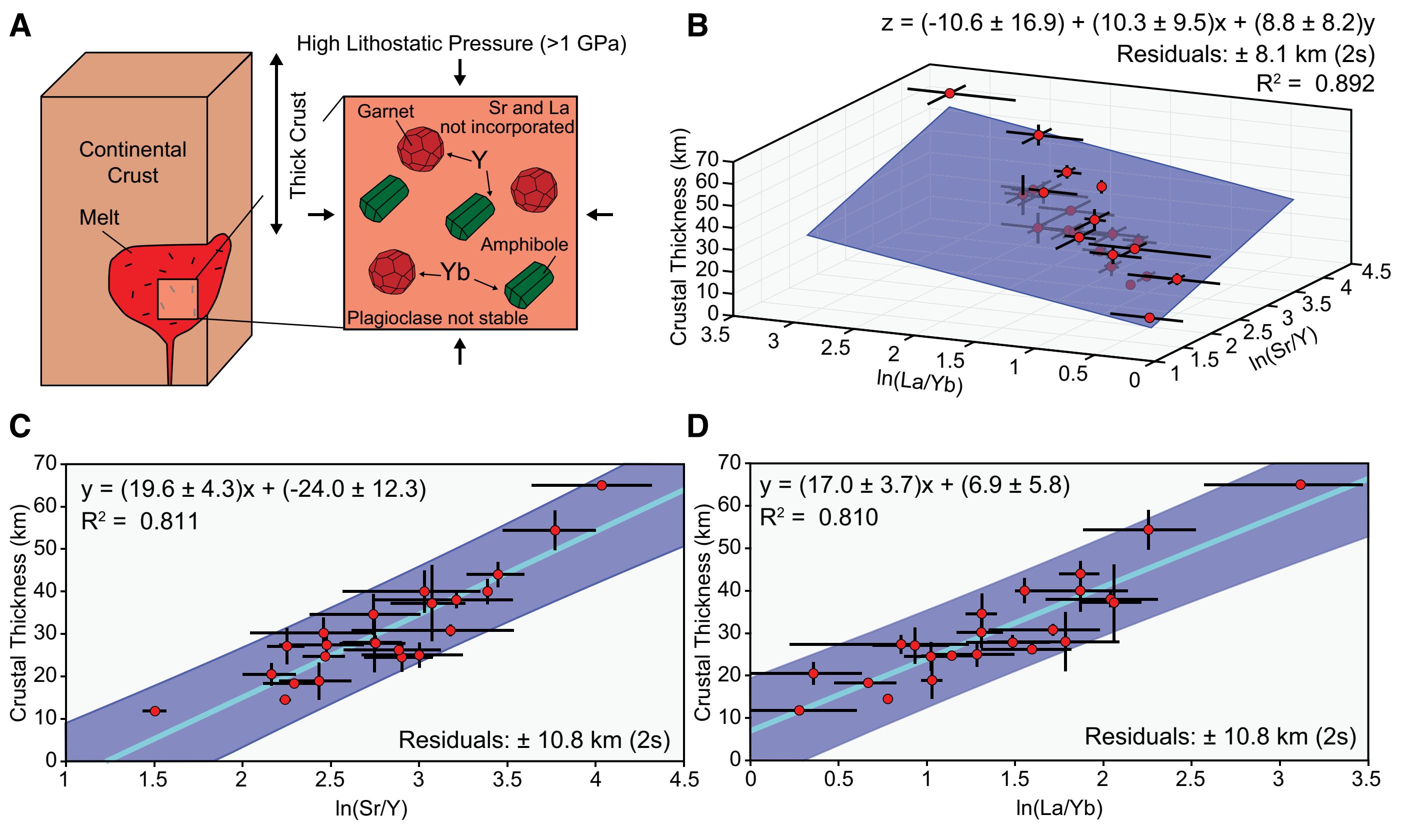

Figure 2. (A) Schematic partitioning diagram for Y and Yb into minerals stable at high lithostatic pressures >1 GPa such as garnet and amphibole. (B–D) Empirical calibrations using known crustal thicknesses from data compiled in Profeta et al. (2015) based on (B) multiple linear regression of ln(Sr/Y) (*x*-axis), ln(La/Yb) (*y*-axis), and crustal thickness (*z*-axis); (C) simple linear regression of ln(Sr/Y) and crustal thickness; and (D) simple linear regression of ln(La/Yb) and crustal thickness. Equations in parts B–D include 95% confidence intervals for each coefficient. Coefficient uncertainties should not be propagated when applying these equations to calculate crustal thickness; rather, the 2s (95% confidence interval) residuals (modeled fits subtracted from known crustal thicknesses) are more representative of the calibration uncertainty.

residuals calculated during proxy calibration (Fig. 2). Temporal trends were calculated using two different methods. The first method employs Gaussian kernel regression (Horová et al., 2012), a non-parametric technique commonly used to find nonlinear trends in noisy bivariate data; we used a 5 m.y. kernel width, an arbitrary parameter selected based on sensitivity testing for over- and under-smoothing. The second method involves calculating linear rates between temporal segments bracketed by clusters of data that show significant changes in crustal thickness: 200–150 Ma, 100–65 Ma, and 65–30 Ma. Trends are reported as the mean ±2s calculated from bootstrap resampling 190 selections from the data with replacement 10,000 times.

RESULTS

Proxy calibration using simple linear regression of ln(Sr/Y)–km and ln(La/Yb)–km yields

$$\textit{Crustal Thickness} = (19.6 \pm 4.3) \times \ln(Sr/Y) + (-24.0 \pm 12.3), \quad (1)$$

and

$$\textit{Crustal Thickness} = (17.0 \pm 3.7) \times \ln(La/Yb) + (6.9 \pm 5.8), \quad (2)$$

whereas multiple linear regression of ln(Sr/Y)–ln(La/Yb)–km calibration yields

$$\textit{Crustal Thickness} = (-10.6 \pm 16.9) + (10.3 \pm 9.5) \times \ln(Sr/Y) + (8.8 \pm 8.2) \times \ln(La/Yb). \quad (3)$$

Crustal thickness corresponds to the depth of the Moho in km, and coefficients are ±2s (Figs. 2B–2D and supplemental material [see footnote 1]). Although we report uncertainties for the individual coefficients, propagating these uncertainties results in wildly variable (and often unrealistic) crustal thickness estimates, largely due to the highly variable slope. Hence, we ascribe uncertainties based on the 2s range of residuals (Figs. 2B–2D). Residuals are ~11 km based on simple linear regression of Sr/Y–km and La/Yb–km, and ~8 km based on multiple linear regression of Sr/Y–La/Yb–km.

Application of these equations yields mean absolute differences between crustal thicknesses calculated with individual Sr/Y and La/Yb of ~6 km. Paired Sr/Y–La/Yb calibration yields absolute differences of ~3 km compared to Sr/Y and La/Yb. Discrepancies in crustal thickness estimates between Sr/Y and La/Yb using the original calibrations in Profeta et al. (2015) are highly variable, with an average of ~21 km, and are largely the result of extreme crustal thickness estimates (>100 km) resulting from linear transformation of high (>70) Sr/Y ratios (supplemental material [see footnote 1]); such discrepancies are likely due to a lack of crustal thickness estimates from orogens with rocks that are young enough (i.e., Pleistocene or younger) to include in the empirical calibration.

For geologic interpretation, we use results from multiple linear regression of Sr/Y–La/Yb–km to calculate temporal changes in crustal thickness (Figs. 3B–3D). Results show a decrease in crustal thickness from 36 to 30 km between 180 and 170 Ma. Available data between 170 and 100 Ma include a single estimate of ~55 km at ca. 135 Ma. Crustal

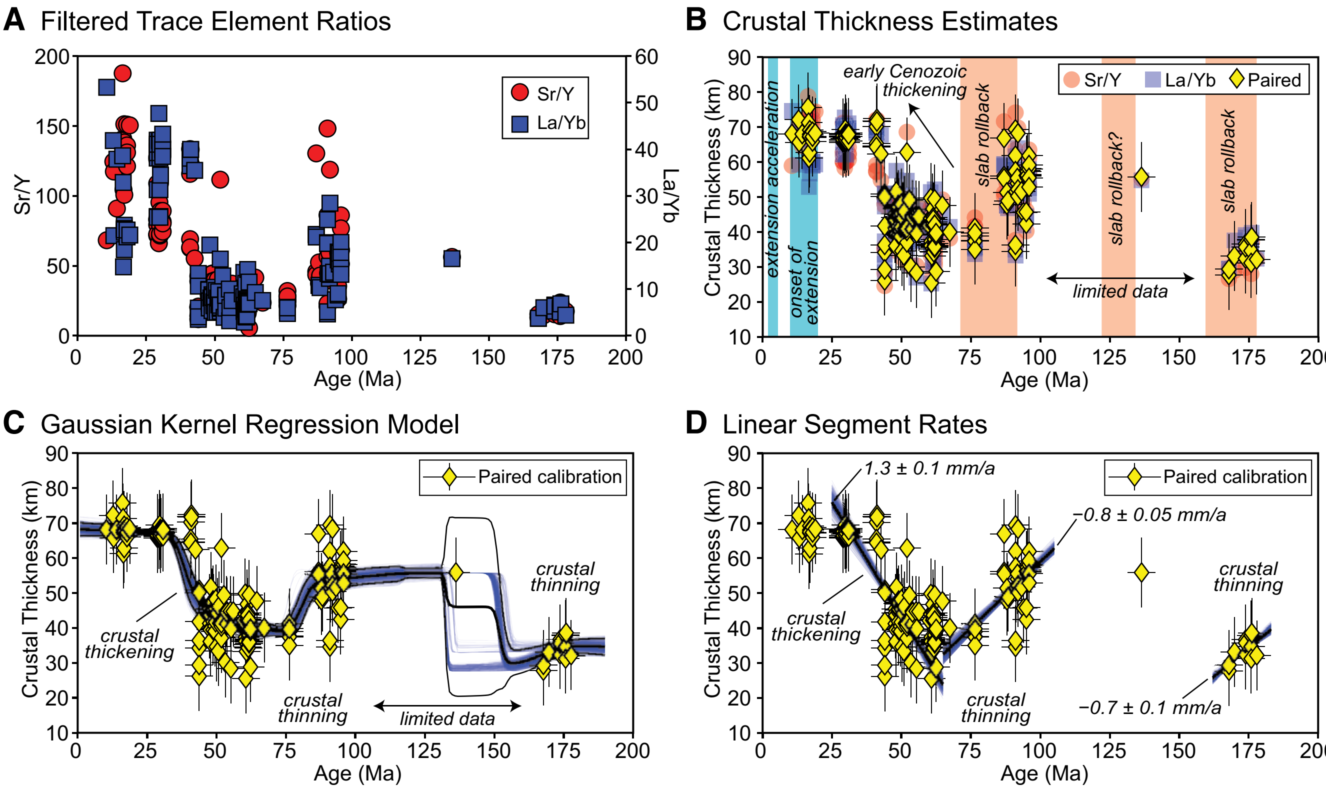

Figure 3. Results of new Sr/Y and La/Yb proxy calibration applied to data from the Tibetan Magmatism Database (Chapman and Kapp, 2017) located in the eastern Gangdese Mountains in southern Tibet. (A) Filtered Sr/Y and La/Yb data extracted from 29 to 31°N and 89 to 92°W. (B) Values from part A converted to crustal thickness using Equations 1, 2, and 3 (see text). (C–D) Temporal trends based on multiple linear regression of Sr/Y–La/Yb–km; trends are calculated from 10,000 bootstrap resamples, with replacement. (C) Gaussian kernel regression model to determine a continuous thickening history. (D) Linear regression to determine linear rates for critical time intervals.

thickness decreased to 30–50 km by ca. 60 Ma, then increased to 60–70 km by ca. 40 Ma (Fig. 3). The two different methods for calculating temporal trends in crustal thickness (Gaussian kernel regression and linear regression) produced similar results (Figs. 3C–3D). The Gaussian kernel regression model produces a smooth record of crustal thickness change that decreases from ~35 to ~30 km between 180 and 165 Ma, decreases from ~54 to ~40 km between 90 and 75 Ma, increases from ~40 to ~70 km between 60 and 40 Ma, and remains steady-state from 40 Ma to present; the large uncertainty window between 160 and 130 Ma is due to the bootstrap resampling occasionally missing the single data point at ca. 135 Ma (Fig. 3C). Linear rates of crustal thickness change indicate thinning at ~0.7 mm/a between 180 and 170 Ma, thinning at ~0.8 mm/a between 90 and 65 Ma, and thickening at ~1.3 mm/a between 60 and 30 Ma (Fig. 3D).

DISCUSSION

Early to Middle Jurassic crustal thickness in southern Tibet was controlled by the northward subduction of Neo-Tethys oceanic lithosphere (Guo et al., 2013) in an Andean-type orogen that existed until the Early Cretaceous (Zhang et al., 2012), punctuated by backarc extension between 183 and 174 Ma (Wei et al., 2017). The latter is consistent with our results of minor crustal thinning from ~36 to ~30 km between 180 and 170 Ma (Figs. 3B–3D) and supports models invoking a period of Neo-Tethys slab rollback (i.e., trench retreat), southward rifting of the Zedong arc from the Gangdese arc, and a phase of supra-subduction zone ophiolite generation along the southern margin of Asia (Fig. 4A) (Kapp and DeCelles, 2019). Rocks with ages between 170 and 100 Ma are limited to a single data point at ca. 135 Ma and yield estimates of ~55 km thick crust (Fig. 3B–3D). This is consistent with geologic mapping and geochronological data that suggest that major north-south crustal shortening took place in the Early Cretaceous along east-west–striking thrust faults in southern Tibet (Murphy et al., 1997).

The strongest crustal thinning trend in our results occurs between 90 and 70 Ma at a rate of ~0.8 mm/a (Fig. 3D). Crustal thinning takes place after major crustal shortening (and thickening) documented in the southern Lhasa terrane prior to and up until ca. 90 Ma (Kapp et al., 2007; Volkmer et al., 2007; Lai et al., 2019), following shallow marine carbonate deposition during the Aptian–Albian (126–100 Ma) across much of the Lhasa terrane (Leeder et al., 1988; Leier et al., 2007). Late Cretaceous crustal thinning to ~40 km (closer to the average thickness of continental crust) supports models that invoke Late Cretaceous extension and Neo-Tethys slab rollback that led to the development of an intracontinental backarc basin in southern Tibet and southward rifting of a southern portion of the Gangdese arc (referred to as the Xigaze arc) from the southern Asian continental margin (Kapp and DeCelles, 2019) (Fig. 4B). If a backarc ocean basin indeed opened between Asia and the rifted Xigaze arc during this time, it would have profound implications for Neo-Tethyan paleogeographic reconstructions and the history of suturing between India and Asia; this remains to be tested by future field-based studies.

Paleogene crustal thickness estimates indicate monotonic crustal thickening at rates of ~1.3 mm/a to >60 km following the collision between India and Asia. This is in contrast to models explaining the development of modern high elevation resulting from the removal

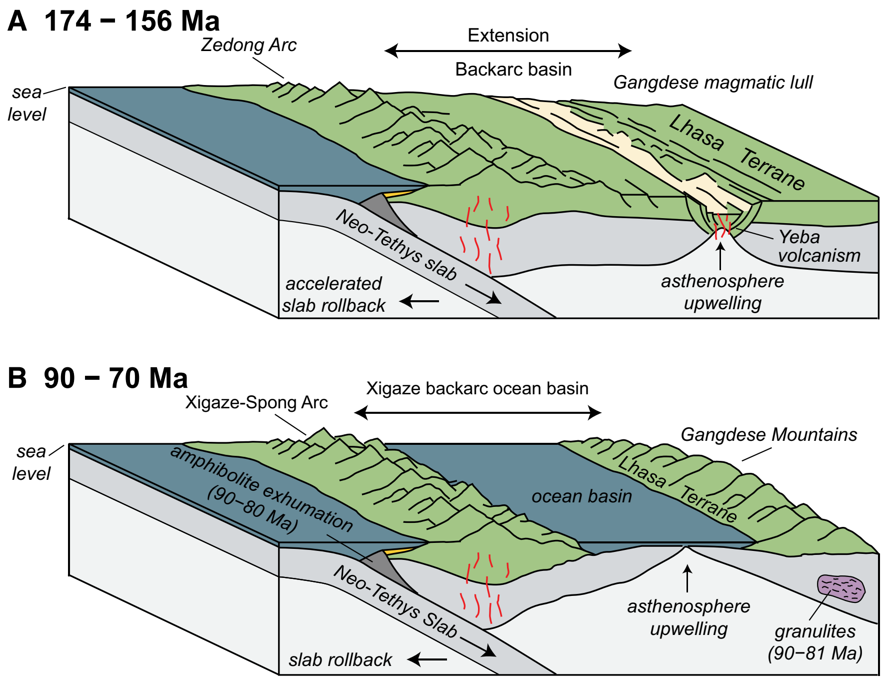

Figure 4. Tectonic interpretation after Kapp and DeCelles (2019). (A) Middle–Late Jurassic accelerated slab rollback during formation of the Zedong Arc drives the opening of an extensional backarc basin. This is consistent with the generation of the late-stage, juvenile (asthenosphere derived) Yeba volcanics (Liu et al., 2018). (B) Late Cretaceous slab rollback results in the opening of a backarc ocean basin.

of mantle lithosphere during the Miocene or Pliocene (Dewey et al., 1988; England and Houseman, 1988; Harrison et al., 1992; Molnar et al., 1993). The timing of crustal thickening in the late Paleogene temporally corresponds to the termination of arc magmatism in southern Tibet at 40–38 Ma and may indicate that the melt-fertile upper-mantle wedge was displaced to the north by shallowing subduction of Indian continental lithosphere (Laskowski et al., 2017). Crustal thickening during the Paleogene may be attributed to progressive shortening and southward propagation (with respect to India) of the Tibetan-Himalayan orogenic wedge as Indian crust was accreted in response to continuing convergence. We interpret that thickening depended mainly on the flux of crust into the orogenic wedge, as convergence between India and Asia slowed by more than 40% between 20 and 10 Ma (Molnar and Stock, 2009), subsequent to peak crustal thickening rates between 60 and 30 Ma.

Estimates of crustal thickness based on Sr/Y and La/Yb differ both in time and space compared to estimates using radiogenic isotopes. Determining crustal thickness from Nd or Hf relies on an extension of the flux-temperature model of DePaolo et al. (1992), which calculates the ambient crustal temperature and assimilation required to produce measured isotopic compositions (e.g., Hammersley and DePaolo, 2006) assuming a depleted asthenospheric melt source with no contribution from the mantle lithosphere; crustal thickness is then calculated based on an assumed geothermal gradient on the premise that a deeper, hotter Moho would result in more crustal assimilation than a shallower, cooler Moho. In addition to using La/Yb to estimate Cenozoic crustal thickness, DePaolo et al. (2019) use the flux-temperature model to suggest that crustal thickening in southern Tibet was nonuniform based on Nd isotopes. Specifically, they estimate crustal thickness of 25–35 km south of 29.8° N until 45 Ma, followed by major crustal thickening to 55–60 km by the early to middle Miocene. Critically, they suggest that north of 29.9° N the crust was at near modern thickness before 45 Ma and that there was a crustal discontinuity between these two domains, which Alexander et al. (2019) later interpret along orogenic strike to the east based on Hf isotopic data. In contrast, our results show that crustal thickening was already well under way by 45 Ma, potentially near modern crustal thickness, and with no dependence on latitude (Figs. 3B–3D and supplemental material [see footnote 1]). Radiogenic isotopes such as Nd and Hf are not directly controlled by crustal thickness and concomitant pressure changes. Rather, variability in Hf and Nd is likely due to complex crustal assimilation, to which pressure-based (not temperature-based) proxies such as Sr/Y and La/Yb from rocks filtered following Profeta et al. (2015) are less sensitive.

Crustal thickness of 65–70 km between 44 and 10 Ma based on trace-element geochemistry is similar to modern crustal thickness of ~70 km estimated from geophysical methods (Owens and Zandt, 1997; Nábělek et al., 2009) and are 10–20 km less than upper estimates of 80–85 km (Wittlinger et al., 2004; Xu et al., 2015). Upper-crustal shortening persisted in southern Tibet until mid-Miocene time, but coeval rapid erosion (Copeland et al., 1995) may have maintained a uniform crustal thickness. Our results are inconsistent with models that invoke net crustal thinning via orogenic collapse (Dewey, 1988) beginning in the Miocene and continuing to present day (Ge et al., 2015). Rather, our results are consistent with interpretations of thick crust in southern Tibet by middle Eocene time (Aikman et al., 2008; Pullen et al., 2011), which continued to thicken at depth due to the ongoing mass addition of underthrusting India (DeCelles et al., 2002) before, during, and after the Miocene onset of extension in southern Tibet (e.g., Harrison et al., 1995; Kapp et al., 2005; Sanchez et al., 2013). We favor a model in which continued crustal thickening at depth is balanced by upper crustal thinning (Kapp and Guynn, 2004; DeCelles et al., 2007; Styron et al., 2015), with excess mass potentially evacuated by ductile lower crustal flow (Royden et al. 1997). In this view, late Miocene–Pliocene acceleration of rifting in southern Tibet (Styron et al., 2013; Sundell et al., 2013; Wolff et al., 2019) is a consequence of the position of the leading northern tip of India (Styron et al., 2015), because this region experiences localized thickening at depth, which in turn increases the rate of upper crustal extension in order to maintain isostatic equilibrium.

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THE GEOLOGICAL SOCIETY OF AMERICA®

CONNECTS 2021

10–13 October
Portland, Oregon, USA

IMPORTANT DATES

Now open: Registration and travel grant applications

Mid-June: Housing opens

28 June: Meeting room request deadline—fees increase after this date

20 July: Abstracts deadline

August: Student volunteer program opens

7 September: Early registration deadline

7 September: GSA Sections travel grants deadline

13 September: Registration and student volunteer cancellation deadline

14 September: Online Short Courses begin

15 September: Housing deadline for discounted hotel rates

Keep Our Meeting Respectful and Inclusive

GSA is committed to fostering a professional, respectful, inclusive environment at all GSA meetings and events, where all participants can participate fully in an atmosphere that is free of harassment and discrimination based on any identity-based factors.

GSA's EVENTS CODE OF CONDUCT (the "Events Code") includes a list of dos and don'ts to guide participants in promoting a professional, respectful, inclusive environment. It also explains how to report concerns and the steps GSA takes to investigate complaints and enforce violations. All participants must read and agree to comply with the Events Code as part of the meeting registration process.

RISE stands for **Respectful Inclusive Scientific Events.** GSA displays RISE signs at meetings and events to reinforce the Events Code and promote a positive, professional climate. Although GSA strives to prevent misconduct, GSA takes all conduct concerns seriously and provides resources at meetings to address any issues. Typically, such resources include maintaining an on-site RISE office and dozens of trained GSA staff and volunteers known as RISE Liaisons who are available to discuss any concerns that might arise at GSA meetings.

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Commitment to Care

The Geological Society of America considers the safety and well-being of all those on site at Connects 2021 in Portland, Oregon, USA, as our top priority. Our Commitment to Care is a living document that will continue to evolve as updates become available from the Oregon Convention Center (OCC), the Centers for Disease Control (CDC), and local government. We are incorporating innovative features that will further enhance the on-site experience and safety for everyone in attendance.

NAME BADGE AND LANYARDS will be printed using on-demand print kiosks throughout the pre-function area at the convention center. Seamlessly scan your QR code, and your badge will be printed in a touchless system, grab a lanyard off the rack, and be on your way.

ON-SITE MEDICAL

- Hiring local EMTs
- Dedicated space for EMTs to meet with attendees who feel ill

HAND SANITIZER

- Touchless hand sanitizer dispensers will be placed at key guest and employee entrances, as well as high-use areas such as public lobby spaces, restroom entrances, stairs, elevators, escalators, employee work areas, and offices.

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- Responsible food & beverage/seating/barriers for meeting space.
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- Enhanced cleaning including using electrostatic disinfectant sprayers in each meeting room between morning and afternoon technical sessions, in addition to the OCC's standard overnight cleaning services.
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By attending GSA Connects 2021, you agree to abide by and engage in certain health-and-safety precautions while attending the event. This includes, but is not limited to, wearing a mask at all times within the convention center and/or hotels when not consuming food or beverages, minimizing face touching, frequently washing your hands, sneezing and/or coughing into your elbow, engaging in appropriate physical distancing, respecting others' request for space, and avoiding risky environments such as overcrowded bars or restaurants. You agree to not attend any GSA event if you feel ill or had recent exposure to a COVID-19 case.

Call for Papers

Abstracts deadline: 20 July

SUBMITTING AN ABSTRACT

Abstracts form opens 1 June
Submission deadline: Tues., 20 July

- **Abstract non-refundable submission fee:**
  GSA MEMBERS: professionals: US$60; students: US$25;
  NON-MEMBERS: professionals: US$80; students: US$50;
- To begin your submission, go to **https://community.geosociety.org/gsa2021/program/technical;**
- For detailed guidelines on preparing your submission, please go to **https://gsa.confex.com/gsa/2021AM/categorypreparation.cgi.**

TWO-ABSTRACT RULE

- You may submit two volunteered abstracts, *as long as one of the abstracts is for a poster presentation*;
- Each submitted abstract must be different in content; and
- If you are invited to submit an abstract in a Pardee Keynote Symposium or a topical session, the invited abstracts do not count against the two-abstract rule.

POSTER PRESENTERS

- You will be provided with one horizontal, free-standing 8-ft-wide by 4-ft-high display board and Velcro for hanging your display at no charge.
- Each poster booth will share a 6-ft-long by 30-inch-wide table.
- Electricity is available for a fee.
- Morning Session: Posters will be displayed 9 a.m.–1 p.m., with presenters present 11 a.m.–1 p.m.
- Afternoon Session: Posters will be displayed 2:30–6:30 p.m., with presenters present 4–6 p.m.

ORAL PRESENTERS

The normal length of an oral presentation is 12 minutes plus three minutes for questions and answers. You *must* visit the Speaker Ready Room at least 24 hours before your scheduled presentation. All technical session rooms will be equipped with a PC Windows 10/MS Office 2016. Presentations should be prepared using a 16:9 screen ratio.

HYBRID EVENTS

This year, GSA is planning an in-person meeting in Portland, Oregon, USA. We will also be offering an online component where we will be streaming live from 10 session rooms, in addition to the GSA Presidential Address, Pardee Keynote Symposia, and the GSA Noontime Lectures.

ABSTRACT SUBMISSIONS: EXPECTED BEHAVIOR

The submission of an abstract implies a sincere intent to present the submitted research in person during the meeting. Authors and presenters are expected to display integrity in disseminating their research; adhere to the content and conclusions of abstracts, as submitted and reviewed; remain gracious by offering collaborators the opportunity for recognition as co-authors; make sure that listed co-authors have made a bona fide contribution to the project, are aware of their inclusion, and have accepted that recognition; and be diligent in preparing a polished product that conveys high quality scholarship. GSA strives to promote diversity among conveners and presenters when organizing panels, keynotes, and other invitational sessions.

Special Lectures

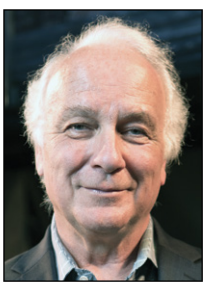
Barbara (Barb) L. Dutrow

Asmeret Asefaw Berhe

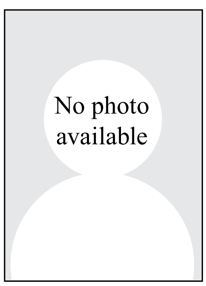
Sun., 10 Oct., noon–1:30 p.m.
Barbara Dutrow,
GSA Presidential Address:
"Minerals Matter: Science, Technology, and Society."

Mon., 11 Oct., 12:15–1:15 p.m.
Asmeret Asefaw Berhe,
2021 Michel T. Halbouty Distinguished Lecture:
"On Soil Erosion and Biogeochemical Cycling of Essential Elements."

Noontime Lectures



Ken Lambla



June Lambla

Marek Ranis

Missy Eppes

Tues., 12 Oct., 12:15–1:15 p.m.
Ken Lambla, June Lambla, Marek Ranis, and Missy Eppes,
"Bringing Art to Your Science and Thus Your Science to the People: Joining Visual Culture and Scientific Evidence." *Cosponsored by GSA Geology and Society Division; GSA Geoscience Education Division; GSA History and Philosophy of Geology Division; GSA Quaternary Geology and Geomorphology Division.*

Katie Stack Morgan

Wed., 13 Oct., 12:15–1:15 p.m.
Katie Stack Morgan,
"The Mars 2020 Perseverance Rover in Jezero Crater."

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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 tickets 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.

NON-TECHNICAL EVENT SPACE REQUESTS

Deadline for first consideration: 28 June

Please let us know about your non-technical events via our online request system—connect via **https://community.geosociety.org/gsa2021/connect/events.** Meeting space at the official GSA event locations is reserved on a first-come, first-served basis, and the form will include options for in-person, hybrid, and online events. We look forward to including your business meetings, town halls, luncheons, workshops, and receptions.

TRAVEL GRANTS

You still have time to apply for grants. Various groups are offering grants to help defray your costs for registration, field trips, travel, etc., for GSA Connects 2021. Check the website at **https://community.geosociety.org/gsa2021/connect/student-ecp/travel-grants** for application and deadline information. Note: Eligibility criteria and deadline dates may vary by grant. The deadline to apply for the GSA Student Travel Grant is 7 Sept.

MEDIA REGISTRATION

GSA welcomes working members of the press to attend for the purpose of gathering news and information to produce media coverage of GSA Connects 2021. Complementary media registration allows access to technical sessions, the Resource and Innovation Center, and the newsroom. Public Information officers from geoscience-related institutions and agencies may also apply. Check the meeting website or contact communications@geosociety.org for further information on eligibility and how to apply.

CONTINUING EDUCATION UNITS

GSA offers continuing education units (CEUs) toward continuing education requirements for employer, K–12 school, or professional organizations. Please check the meeting website after the meeting to download your CEU certificate.

STUDENT VOLUNTEERS

The Student Volunteer Program will open in early July. Earn complimentary registration when you volunteer to work for at least ten hours, plus get an insider's view of the meeting. Please wait to register for the meeting until you sign up as a volunteer, unless you want to reserve a space in a Field Trip or Short Course. Details: **https://community.geosociety.org/gsa2021/registration/volunteers.**

2021 Organizing Committee

General Co-Chair: **Ian Madin,**
ian.madin@oregon.gov

General Co-Chair: **Jeff Rubin,**
jnrubin@aya.yale.edu

Field Trip Chair: **Anita Grunder,**
grundera@geo.oregonstate.edu

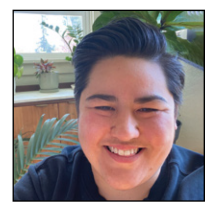
Field Trip Co-Chair:
Adam Booth, boothad@pdx.edu

Technical Program Chair:
Amy Brock-Hon,
amy-brock-hon@utc.edu

Technical Program Vice-Chair:
Robinson Cecil,
robinson.cecil@csun.edu

Sponsorship Chair:
Scott Burns, burnss@pdx.edu

Student/Early Career Professionals Chair: **Kevin Gardner,**
kgardne2@uoregon.edu



K–12 Outreach Chair:
Robyn Dahl, dahlr4@wwu.edu

Community Education Chair:
Gina Roberti,
gina.m.roberti@gmail.com

Hotels

GSA has selected a range of hotels in terms of proximity to the Oregon Convention Center (OCC), rate, and style to meet your needs and preferences. Below is the list of hotels and group rates for our block. Rates are in U.S. dollars and do not include the current applicable tax of 15.57% per room per, per night. Complimentary basic Internet will be provided in all guest rooms booked through GSA/Connections Housing.

Hotel	Rate (tax not included) (single/double)	Each Additional Adult (3rd & 4th person)	Distance to OCC	Parking Daily/24-hr
Hyatt Regency Portland at OCC (HQ) (GBAC STAR™ Accredited)	US$209	US$25	Adjacent	US$36 Valet
DoubleTree by Hilton Portland	US$189	US$20	5 Blocks	US$37 Valet / US$27 Self
Crowne Plaza Portland-Downtown Convention Center	US$224	US$20	4 Blocks	US$15 Self
Hilton Portland Downtown	US$214	US$10	1.7 mi—adjacent to light rail	US$52 Valet
Hotel Rose Downtown Portland	US$223	US$20	1.7 mi—one block to light rail	US$20 Self
Portland Marriott Downtown Waterfront	US$170	US$5	2.2 mi—10 blocks to light rail	US$46 Valet

HEALTH AND SAFETY INFORMATION

Over the past year, hotels have been implementing cleaning and safety protocols in response to the COVID-19 pandemic. Some hotels and venues, including the Oregon Convention Center and Portland International Airport, have completed the GBAC STAR™ cleanliness and training accreditation process through the Global Biorisk Advisory Council (GBAC). Please check the health and safety information for each hotel. You can expect to see changes throughout each hotel, including contactless hotel check-in, enhanced housekeeping services, and pre-packaged dining options. Due to changing COVID-19 guidelines, the availability and pricing of hotel amenities such as valet parking, fitness facilities, and dining options are subject to change without notice. Check the hotel website for the most up-to-date information regarding amenities and services.

Hyatt Regency Portland at OCC: https://www.hyatt.com/info/global-care-and-cleanliness-commitment
DoubleTree by Hilton Portland: https://www.hilton.com/en/corporate/cleanstay/
Crowne Plaza Portland–Downtown Convention Center: https://bit.ly/3v4ehyI
Hilton Portland Downtown: https://www.hilton.com/en/corporate/cleanstay/
Hotel Rose Downtown Portland: https://www.staypineapple.com/health-safety-and-updated-travel-policies/sanitation-protocols
Portland Marriott Downtown Waterfront: https://whattoexpect.marriott.com/pdxor

ALERT: The official GSA housing bureau is Connections Housing. To receive the GSA group rate at each hotel, reservations must be made through Connections Housing and not directly with the hotels. GSA and Connections Housing will NOT contact attendees directly to solicit new reservations. If you are contacted by a vendor who claims to represent GSA, please notify the GSA meetings department at meetings@geosociety.org. Please do not make hotel arrangements or share any personal information through any means other than a trusted, reliable source.

HOTELS

- Oregon Convention Center
- 1 Hyatt Regency Portland at OCC (HQ)
- 2 Doubleree by Hilton Portland (Co-HQ)
- 3 Crowne Plaza Portland-Downtown Convention Center
- 4 Hilton Portland Downtown
- 5 Hotel Rose Downtown Portland
- 6 Portland Marriott Downtown Waterfront

Travel & Transportation

There are many options to navigate your way to Portland, Oregon, USA. Learn more at **https://www.travelportland.com/plan/transportation/.**

Portland International Airport (PDX; **https://www.flypdx.com/**) is 11 miles from the Oregon Convention Center and has more than 400 flights daily. PDX is a Global Biorisk Advisory Council STAR accredited facility (**https://gbac.issa.com/issa-gbac-star-facility-accreditation/**).

Ground Transportation is easy from the airport. Go to **https://flypdx.com/GroundTransportation/Rideshare** to learn more about app-based rideshare options and pickup/drop off locations within the airport terminals.

Amtrak is another way to arrive at the city. Learn more about schedules and fees at **https://www.amtrak.com/stations/pdx.**

Credit: Travel Portland.

ARRIVING AT THE CONVENTION CENTER

The Oregon Convention Center (OCC) encourages guests to use TriMet MAX light rail (**https://trimet.org/#/planner**), the Portland Streetcar (**https://portlandstreetcar.org/**), and TriMet buses for the easiest arrival and departure experience. All have stops right outside the OCC. If you plan to drive, **please allow for ample time to park** before your event. For more information on parking garages, electric car charging stations, driving directions, and bike parking, go to **https://www.oregoncc.org/attend/parking-directions.**

HEALTH & SAFETY

GSA is staying up to date on all travel guidelines, considerations, and restrictions from global and local authorities. Stay informed with what PDX, TriMet Safety, and major U.S. airlines are doing by checking their websites.

Childcare by KiddieCorp

Location: Oregon Convention Center

Hours: Sun.–Wed., 7 a.m.–6 p.m. daily

Ages: Six months to 12 years

Cost: US$10 per hour per child for children two years and older and US$12 per hour per child for children 23 months and under. There is a one-hour minimum per child, and at least one parent must be registered for the meeting. This is a discounted rate; GSA subsidizes 85% of the total cost for this service to attendees.

Late pick-up fee: US$5 per child for every five minutes the parent is late.

Reserve childcare in advance: To ensure that the center is properly staffed and to facilitate planning of games and other activities for the children, advance registration is required. On-site registration may be possible, at a slightly higher cost, if space is available. The deadline for advance childcare registration is **13 Sept.**

Cancellations: For a full refund, cancellations must be made to KiddieCorp prior to 13 Sept. Cancellations made after 13 Sept. will incur a 50% fee. No refunds after 22 Sept.

About: KiddieCorp is a nationally recognized company that provides on-site children's activities for a comfortable, safe, and happy experience for both kids and parents. Childcare services are a contractual agreement between each individual and the childcare company. GSA assumes no responsibility for the services rendered.

More info: www.kiddiecorp.com/parents.html

Register securely at https://form.jotform.com/KiddieCorp/gsakids

Contact: KiddieCorp, +1-858-455-1718, info@kiddiecorp.com.

KiDDiE CORP

Scientific Field Trips

Descriptions and leader bios are online.

401. **Warren Hamilton Field Trip: Dikes, Vents, and Magma Transport in the Columbia River Flood Basalt Province.** Tues.–Sat., 5–9 Oct. US$1,115. Leaders: Joseph Biasi, California Institute of Technology; Rachel Lynn Hampton; Leif Karlstrom; Kendra Murray; John A. Wolff.

402. **Deep-Water Deposits of the Eocene Tyee Formation.** Thurs.–Sat., 7–9 Oct. US$1,400. Leaders: Michael Sweet, University of Texas at Austin Institute for Geophysics; Gwladys Gaillot; Manasij Santra.

403. **From the Ocean to the Mountains: How Pacific Coast Geology Shapes Marine and Terrestrial Ecosystems.** Thurs.–Sat., 7–9 Oct. US$1,475. Endorsers: *NOAA Teacher at Sea; Climate Literacy and Energy Awareness Network (CLEAN); Edmunds Central School District.* Leaders: Spencer Cody, Edmunds Central School District; John McAlpin; Tom Savage.

404. **River versus Arc: The Geology of the Columbia River Gorge.** Thurs.–Sat., 7–9 Oct. US$590. Endorsers: *GSA Quaternary Geology and Geomorphology Division; GSA Structural Geology and Tectonics Division.* Leaders: Jim E. O'Connor, U.S. Geological Survey; Ray E. Wells; Scott Bennett; Charles M. Cannon; Lydia Staisch; Gabriel Gordon; Anthony Pivarunas.

405. **A Volcanic Tour of Central Oregon: Newberry Volcano Geothermal Scientific Drilling and Fort Rock Geoarchaeological Sites.** Thurs.–Sat., 7–9 Oct. US$645. Endorsers: *GSA Continental Scientific Drilling Division; GSA Geoarchaeology Division; GSA Limnogeology Division; Oregon State University College of Earth, Ocean, and Atmospheric Sciences.* Leaders: Adam Schulz, Oregon State University; Alain Bonneville; Johan C. Varekamp; Andrew Meigs; Tom Connolly; Jayde Hirniak; Marie Jackson.

406. **Silicic Lava Domes of the Cascades of Oregon and Northern California.** Thurs.–Sun., 7–10 Oct. US$875. Leaders: Jonathan Fink; Steven W. Anderson.

407. **A Slice into Time: Stories Written in the Walls of the Columbia River Gorge.** Fri., 8 Oct. US$180. Leader: Gina Roberti, Mount St. Helens Institute.

408. **Paleofloods and Earthquakes: Hydrologic and Seismic Loadings for USACE Dams in Central Oregon.** Fri.–Sat., 8–9 Oct. US$400. Endorser: *U.S. Army Corps of Engineers.* Leaders: Keith Kelson, U.S. Army Corps of Engineers Dam Safety Production Center; Erica Medley.

409. **Pleistocene Landscapes and Geoarchaeology of the Oregon Coast.** Fri.–Sat., 8–9 Oct. US$410. Endorsers: *Oregon State University, Department of Anthropology; Pacific Slope Archaeological Laboratory.* Leaders: Loren Davis, Oregon State University; Steve Jenevein; Michele Punke.

410. **Tectonics and Paleogeography of a Post-Accretionary Forearc Basin, Coos Bay Basin, SW Oregon.** Thurs.–Sat., 7–9 Oct. US$955. Endorser: *GSA Sedimentary Geology Division.* Leaders: John Armentrout, Cascade Stratigraphics; David L.S. Blackwell; Laird B. Thompson.

411. **Terroir of Wine of the Willamette Valley, Oregon.** Fri., 8 Oct. US$270. Leader: Scott Burns, Portland State University.

412. **Geology of the Columbia Gorge and the Effects of Wildfire There.** Sat., 9 Oct. US$173. Leader: Scott Burns, Portland State University.

413. **Developing Landslide Chronologies Using Landslide-Dammed Lakes of the Oregon Coast Range.** Sat., 9 Oct. US$235. Endorsers: *GSA Quaternary Geology and Geomorphology Division; GSA Environmental and Engineering Geology Division.* Leaders: Logan Wetherell; William Struble; Sean LaHusen.

414. **Living with Volcanoes in the Pacific Northwest.** Sat., 9 Oct. US$180. Leader: Gina Roberti, Mount St. Helens Institute.

415. **John Day Basin of Oregon and the Evolution of Landscapes and Ecosystems through the Cenozoic.** Thurs.–Fri., 14–15 Oct. US$475. Endorser: *John Day Fossil Beds National Monument.* Leaders: Nicholas A. Famoso, John Day Fossil Beds National Monument; Samantha S.B. Hopkins; Joshua X. Samuels.

INDUSTRY TRACKS

GSA's field trips offer sessions relevant to applied geoscientists.
Look for these icons, which identify sessions in the following areas:

Economic Geology **Energy** **Engineering** **Hydrogeology and Environmental Geology**

416. **Exploring an Eccentric Era of Explosivity and Extension in the Central Oregon Cascades Arc: The Deschutes Formation Ignimbrite Flare-up.** Thurs.–Sat., 14–16 Oct. US$640. Leaders: Bradley W. Pitcher, Vanderbilt University; Anita L. Grunder; Adam J.R. Kent.

417. **Flood Basalts, Rhyolites, and Subsequent Volcanism of the Columbia River Magmatic Province in Eastern Oregon.** Thurs.–Sun., 14–17 Oct. US$615. Leaders: Emily Cahoon, Washington State University; Martin J. Streck; Mark L. Ferns.

418. **Mount St. Helens—Four Decades of Geologic, Geomorphic, Ecologic, and Engineering Insights and Challenges Since its 1980 Eruption.** Thurs., 14 Oct. US$335. Endorser: *GSA Quaternary Geology and Geomorphology Division (Kirk Bryan Field Trip).* Leaders: Jon Major, U.S. Geological Survey Cascades Volcano Observatory; Scott Burns; Patrick Pringle.

419. **Stream Corridor Enhancement: Techniques for Bringing Greater Stream Function into the City.** Thurs., 14 Oct. US$245. Endorser: *Clean Water Services.* Leaders: Anne MacDonald; Matthew Brennan; Dennis O'Connor.

420. **The Mount Hood Fault Zone—Active Faulting at the Crest of the Dynamic Cascade Range.** Thurs.–Fri., 14–15 Oct. US$515. Leaders: Ian Madin; Scott Bennett; Ashley R. Streig.

421. **Upper Grand Coulee—New Views of a Channeled Scabland Megafloods Enigma.** Thurs.–Sun., 14–17 Oct. US$728. Endorser: *GSA Quaternary Geology and Geomorphology Division.* Leaders: Richard Waitt, Cascades Volcano Observatory; Brian F. Atwater; Jim O'Connor; Isaac J. Larsen; Michelle A. Hanson; Bruce N. Bjornstad; Karin E. Lehnigk.

422. **Accessible Field Geology of the Columbia River and Mount Hood.** Thurs., 14 Oct. Apply at **https://forms.gle/sFWB3nxzLWw1CFrz5.** Endorsers: *International Association for Geoscience Diversity; GSA Geoscience Education Division; National Association of Geoscience Teachers (NAGT); GSA Committee on Diversity.* Leaders: Anita Marshall, University of Florida; Nancy Riggs; Leah Miller; Kreeya Olson; Christopher L. Atchison.

423. **Middle Jurassic to Early Cretaceous Tectonic Evolution of the Western Klamath Mountains and Outboard Franciscan Complex, Northern California–Southern Oregon.** Fri.–Mon., 15–18 Oct. US$625. Endorser: *GSA Structural Geology and Tectonics Division.* Leaders: Alan Chapman, Macalester College; Todd A. LaMaskin; J. Douglas Yule; William L. Schmidt.

424. **Terroir of Wine of the Columbia Gorge—Relationship of Wine Flavor to Geology/Soils.** Fri., 15 Oct. US$300. Leader: Scott Burns, Portland State University.

Portland EarthCache Sites

While you're in Portland, take advantage of the chance to visit EarthCache sites in the area.

EarthCaching, a 17-year collaboration between GSA and Geocaching Headquarters, is a GPS-based outdoor activity that brings people to sites of geological interest. The program is designed primarily for the general public, and GSA encourages geoscience professionals and students to get involved as well by visiting EarthCache sites and by developing additional sites.

To find relevant sites in Portland, create a free account at geocaching.com and consider this list of EarthCaches (**bit.ly/earthcaches_portland**). You can also search via the GC-code associated with a specific EarthCache. Below you'll find some information on the EarthCache sites closest to the Oregon Convention Center, including their GC-codes and comments from people who have visited and "logged" these sites at Geocaching.com. More details are online at **https://www.earthcache.org.**

"ANCIENT WALLS" (GC38GYB)

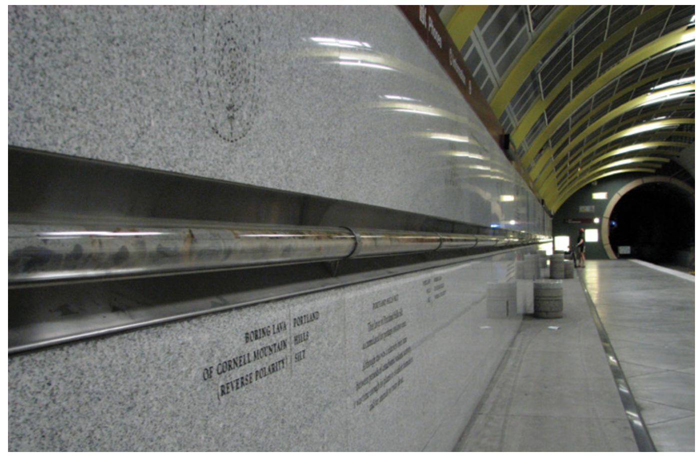
Enjoy the first part of a walking tour that explores the building stones in downtown Portland. It starts at Pioneer Place and ends at First Congregational Church.

From the logs: "The fossils at Pioneer Place are the reason this gets a favorite. We had several shoppers ask us what we were doing; there were four of us on the floor with magnifying glasses and taking measurements, so we had the opportunity to explain geocaching. Thanks again for a fun EarthCache." —middleagespread

"ANCIENT WALLS II" (GC3E2HB)

Continue a walking tour that explores downtown Portland's building stones. This segment begins at the PacWest Center and ends near Nordstrom.

From the logs: "This may have been the best time I have had geocaching! I have always loved old brick buildings and carved stone, but now I have a huge appreciation and newfound love for stones!!! Thank you so much for putting this together—truly awesome, informative and FUN!!" —WindyMatters



Core sample and geologic timeline permanently displayed along the wall of the eastbound platform of the Washington Park station of the MAX light rail system, in Portland, Oregon. Credit: Ulmanor at en.wikipedia, https://creativecommons.org/licenses/by-sa/3.0/deed.en.

"TUALATIN MOUNTAINS GEOLOGIC HISTORY" (GC3W7G0)

Travel west from downtown Portland to Washington Park, home to the deepest underground transit station in North America, to see an interpretive exhibit with a core sample that illustrates the geologic history of the Tualatin Mountains, including the ca. 16 Ma Grande Ronde Basalt formation.

From the logs: "As someone who thought that they were going to become a geologist one day, this is super cool!! I love that there's a core here, and that there's interpretation around it!" —ohkpond

"WILLAMETTE RIVER SEDIMENTATION EARTHCACHE" (GC23BW6)

Take in a view of the Willamette River from the Eastbank Esplanade and learn about the river's geological history and relationship with humans.

From the logs: "Thanks for the information and the time to ponder our surroundings in a way that we don't normally. Looking into the past, and at what the area would be like without human interventions." —mudder91

Short Courses

Learn and explore a new topic!

Early registration deadline: 7 Sept.
Registration after 7 Sept. will cost an additional US$30.
Cancellation deadline: 13 Sept.

Can I take a short course if I am not registered for the meeting? YES! You're welcome to—just add the meeting non-registrant fee (US$55) by 7 Sept. to your course enrollment cost. Should you then decide to attend the meeting, your payment will be applied toward meeting registration.

GSA K–12 teacher members: You are welcome to take short courses without registering for the meeting or paying the non-registrant fee.

Continuing education units (CEUs): Most professional development courses and workshops offer CEUs. One CEU equals 10 hours of participation in an organized continuing education experience under responsible sponsorship, capable direction, and qualified instruction.

See **community.geosociety.org/gsa2021/science-careers/courses** or contact Jennifer Nocerino, jnocerino@geosociety.org, for course abstracts and additional information.

The following short courses are open to everyone. Early registration is highly recommended to ensure that courses will run.

ONLINE SHORT COURSES

501. **Geophysics for Bedrock and Formation Mapping.** Tues., 14 Sept., 7–11 a.m. PDT. US$35. Limit: 50. CEU: 0.4. **Instructors:** Jimmy Adcock, Guideline Geo AB; Morgan Sander-Olhoeft, Guideline Geo Americas Inc. **Endorser:** *Guideline Geo.*

502. **Climate Adaptation Planning for Emergency Management.** Tues., 14 Sept., 11 a.m.–3 p.m. PDT *and* Wed., 15 Sept., 11 a.m.–3 p.m. PDT. FREE. Limit: 45. CEU: 0.8. **Instructors:** Jeff Rubin, semi-retired emergency manager; Douglas Stolz, Cross Product Atmospheric. **Endorsers:** *GSA Geology and Society Division; GSA Marine and Coastal Geology Division; GSA Geology and Health Division; National Disaster Preparedness Training Center (NDPTC); Federal Emergency Management Agency (FEMA).*

503. **Age-Depth Modeling of Sedimentary Deposits.** Wed., 15 Sept., 9–11 a.m. PDT. *and* Wed., 22 Sept., 9–11 a.m. PDT. *and* Wed., 29 Sept., 9–11 a.m. PDT. US$30. Limit: 50. CEU: 0.6. **Instructors:** Lisa Park Boush, University of Connecticut; Maarten Blauw, Queen's University; Amy Myrbo, University of Wisconsin. **Endorsers:** *GSA Limnogeology Division; GSA Geochronology Division; GSA Continental Drilling Division; GSA Quaternary Geology and Geomorphology Division; GSA Sedimentary Geology Division; EarthRates RCN.*

504. **Introduction to Field Safety Leadership.** Thurs., 16 Sept., 8 a.m.–noon. PDT. US$45 professionals; US$25 students. Limit: 50. CEU: 0.6. **Instructors:** Kevin Bohacs, ExxonMobil (retired); Kurt Burmeister, California State University, Sacramento; Greer Barriault, ExxonMobil Upstream Integrated Solutions. **Endorser:** *ExxonMobil Upstream Integrated Solutions.*

505. **NASA Data Made Easy: Getting Started with Synthetic Aperture Radar.** Thurs., 16 Sept., 10 a.m.–2 p.m. PDT. US$20 (those who complete the course can get three free GSA e-books of their choice). Limit: 50. CEU: 0.4. **Instructors:** Cynthia Hall, NASA Headquarters; Andrea Nicolau, Spatial Informatics Group; Africa Flores-Anderson, NASA SERVIR; Heidi Kristenson, Alaska Satellite Facility.

506. **Your Thesis is Software: Tools for the Geoscientist to Help Write Better Code, from Version Control to Test-Driven Development.** Fri., 17 Sept., 9 a.m.–3 p.m. PDT. US$10. Limit: 50. CEU: 0.6. **Instructors:** Simon Goring, University of Wisconsin; Socorro Dominguez, University of Wisconsin–Madison. **Endorser:** *Throughput Database.*

507. **Ground-Penetrating Radar—Principles, Practice, and Processing.** Fri., 17 Sept., 7 a.m.–2 p.m. PDT. US$45. Limit: 50. CEU: 0.7. **Instructors:** Greg Johnston, Sensors & Software; Troy De Souza, Sensors & Software. **Endorser:** *Sensors & Software.*

508. **From Airborne Electromagnetic Method Data to 3D Hydrogeological Conceptual Model.** Mon., 20 Sept., 9 a.m.–1 p.m. PDT *and* Tues., 21 Sept., 9 a.m.–1 p.m. PDT. US$35. Limit: 50. CEU: 0.8. **Instructors:** Tom Martlev Pallesen, I•GIS; Thomas Bager Rasmussen, I•GIS; Simon Boetker Rasmussen, I•GIS. **Endorser:** *I•GIS.*

INDUSTRY TRACKS

GSA's short courses offer sessions relevant to applied geoscientists.
Look for these icons, which identify sessions in the following areas:

Economic Geology | **Energy** | **Engineering** | **Hydrogeology and Environmental Geology**

509. **3D Hydrogeological Modeling: How to Build Them and Why?** Wed., 22 Sept., 9 a.m.–1 p.m. PDT. *and* Thurs. 23 Sept., 9 a.m.–1 p.m. PDT. US$35. Limit: 50. CEU: 0.8. **Instructors:** Tom Martlev Pallesen, I•GIS; Simon Boetker Rasmussen, I•GIS. **Endorser:** *I•GIS.*

510. **Introduction to Seismic Structural Interpretation.** Fri., 24 Sept., 8 a.m.–3 p.m. PDT. US$35. Limit: 50. CEU: 0.7. **Instructors:** Kellen Gunderson, Chevron Energy Technology Company; Timothy Shin, Total E&P Americas LLC. **Endorsers:** *GSA Structural Geology and Tectonics Division; GSA Energy Geology Division.*

511. **Foundations in the Design and Teaching of Geoscience Courses Using Active Learning Strategies.** Mon., 27 Sept., 8 a.m.–3 p.m. PDT. US$45. Limit: 50. CEU: 0.7. **Instructors:** Leilani Arthurs, University of Colorado Boulder; Chu-Lin Cheng, University of Texas Rio Grande Valley; Ming-Tsan Lu, The University of Texas Rio Grande Valley; Patrick Shabram, Front Range Community College.

512. **Find Your Voice: Hazards and Science Communication in Crisis and Calm.** Tues., 28 Sept., 9 a.m.–1 p.m. PDT. US$20 professionals; US$10 students and early career professionals. Limit: 50. CEU: 0.4. **Instructors:** Elizabeth Westby, USGS Cascades Volcano Observatory; Beth Bartel, Michigan Technological University; Wendy Stovall, USGS Yellowstone Volcano Observatory; Wendy Bohon, Incorporated Research Institutions for Seismology.

513. **Head, Shoulders, Knees, and Toes: Medical Geology Fundamentals.** Tues., 28 Sept., 8 a.m.–2 p.m. PDT. US$45 professionals; US$25 students. Limit: 50. CEU: 0.6. **Instructors:** Laura Ruhl, University of Arkansas at Little Rock; Robert Finkelman, University of Texas at Dallas; Reto Gieré, University of Pennsylvania; Malcolm Siegel, University of New Mexico. **Endorsers:** *GSA Geology and Health Division; International Medical Geology Association.*

514. **An Introduction to Stratigraphic Data Analysis in R (SDAR), a Quantitative Toolkit to Analyze Stratigraphic Data.** Wed., 29 Sept., 11–3 p.m. PDT, *and* Thurs., 30 Sept., 11–3 p.m. PDT. US$35. Limit: 50. CEU: 0.4. **Instructor:** John Ortiz, Colombian Geological Survey and Corporación Geológica ARES.

515. **Geosciences and Society: A Teaching Workshop.** Thurs., 30 Sept., 8–11 a.m. PDT. US$30. Limit: 50. CEU: 0.3. **Instructors:** Anne Marie Ryan, Dalhousie University; Carl-Georg Bank, University of Toronto.

516. **3D Printing for Geoscience and Engineering: Emerging Technology in Education, Research, and Communication.** Fri., 1 Oct., 9 a.m.–3 p.m. PDT. US$35. Limit: 50. CEU: 0.6. **Instructors:** Rick Chalaturnyk, University of Alberta; Sergey Ishutov, University of Alberta; Kevin Hodder, University of Alberta; Gonzalo Zambrabo, University of Alberta. **Endorsers:** *GeoPrint; Petroleum Institute of Mexico.*

517. **Machine Learning in Geosciences: Existing and Novel Tools to Mine Geologic Data.** Fri., 1 Oct., 9 a.m.–3 p.m. PDT. US$35. Limit: 50. CEU: 0.6. **Instructors:** Velimir Vesselinov, Los Alamos National Laboratory; Bulbul Ahmmed, Los Alamos National Laboratory. **Endorser:** *Computational Earth Science Group, Los Alamos National Laboratory.*

518. **Forensic Geochemistry: Contaminant Sources/Release Ages and Aquifer Continuity in Soil/ Groundwater Systems Using Stable Radiogenic Isotopes of Strontium (Sr) and Lead (Pb).** Mon., 4 Oct., 9 a.m.–3 p.m. PDT. US$35. Limit: 50. CEU: 0.6. **Instructor:** Richard W. Hurst, Hurst Forensics. **Endorsers:** *GSA Hydrogeology Division; GSA Geoarchaeology Division; GSA Quaternary Geology and Geomorphology Division.*

519. **Introduction to Structure from Motion (SfM) Photogrammetry.** Mon., 4 Oct., 9 a.m.–3 p.m. PDT. US$35. Limit: 50. CEU: 0.6. **Instructors:** Christopher Crosby, UNAVCO; J Ramon Arrowsmith, Arizona State University; Chelsea Scott, Arizona State University. **Endorsers:** *OpenTopography; UNAVCO.*

520. **Resistivity Surveying: Getting the Best and Making the Most from Electrical Resistivity Tomography and Induced Polarization Data.** Tues., 5 Oct., 7 a.m.–1 p.m. PDT. US$35. Limit: 50. CEU: 0.6. **Instructors:** Jimmy Adcock, Guideline Geo AB; Morgan Sander-Olhoeft, Guideline Geo Americas Inc. **Endorser:** *Guideline Geo.*

521. **New Approaches to Date Brittle and Ductile Deformation.** Tues., 5 Oct., 6–9 p.m. PDT. US$20. Limit: 50. CEU: 0.3. **Instructor:** Yu Wang, China University of Geosciences (Beijing).

522. **Introduction to Planetary Image Analysis with ArcGIS.** Wed., 6 Oct., 9 a.m.–3 p.m. PDT. US$25. Limit: 50. CEU: 0.6. **Instructor:** Zoe Learner Ponterio, Cornell University. **Endorsers:** *Spacecraft Planetary Image Facility; Cornell University.*

523. **Teaching Quantitative Structural Geology.** Wed., 6 Oct., 9 a.m.–3 p.m. PDT. US$20. Limit: 50. CEU: 0.6. **Instructors:** David Pollard, Stanford University; Stephen Martel, University of Hawaii.

PORTLAND IN-PERSON SHORT COURSES

524. **Sequence Stratigraphy for Graduate Students.** Fri.–Sat., 8–9 Oct., 8 a.m.–5 p.m. PDT. US$25 (those who complete the course can get three free GSA e-books of their choice). Limit: 55. CEU: 1.6. **Instructors:** Morgan Sullivan, Chevron Energy Technology Company; Bret Dixon, Tall City Exploration. **Endorser:** *Chevron Energy Technology Company.*

525. **Methods and Geological Applications in Geo-Thermo-Petro-Chronology I.** Fri., 8 Oct., 8 a.m.–5 p.m. PDT. US$40. Limit: 40. CEU: 0.8. **Instructors:** George Gehrels, University of Arizona; Kurt Sundell, University of Arizona; Sarah George, University of Arizona; Mauricio Ibanez, University of Arizona; Peter Reiners, University of Arizona; Allen Schaen, University of Arizona.

526. **Methods and Geological Applications in Geo-Thermo-Petro-Chronology II.** Sat., 9 Oct., 8 a.m.–5 p.m. PDT. US$40. Limit: 40. CEU: 0.8. **Instructors:** George Gehrels, University of Arizona; Kurt Sundell, University of Arizona; Sarah George, University of Arizona; Mauricio Ibanez, University of Arizona; Peter Reiners, University of Arizona; Allen Schaen, University of Arizona.

527. **Introduction to Drones (sUAS) in the Geosciences.** Sat., 9 Oct., 8 a.m.–5 p.m. PDT. US$112. Limit: 24. CEU: 0.8. **Instructor:** Gregory Baker, Colorado Mesa University. **Endorsers:** *GSA Hydrogeology Division; GSA Geoarchaeology Division; GSA Quaternary Geology and Geomorphology Division.*

528. **Talking Science: A Communicating Science Workshop.** Sat., 9 Oct., 8 a.m.–5 p.m. PDT. US$150. Limit: 30. CEU: 0.8. **Instructor:** Steven Jaret, American Museum of Natural History. **Endorser:** *GSA Planetary Geology Division.*

529. **Quantitative Analysis, Visualization, and Modelling of Detrital Geochronology Data.** Sat., 9 Oct., 8 a.m.–5 p.m. PDT. US$75 professionals; US$50 students. Limit: 50. CEU: 0.8. **Instructors:** Joel Saylor, University of British Columbia; Kurt Sundell, University of Arizona; Glenn Sharman, University of Arkansas.

530. **Geodynamic History of the Middle Part of the Alpine-Himalayan Orogenic Belt.** Sat., 9 Oct., 9 a.m.–5 p.m. PDT. US$112. Limit: 20. CEU: 0.7. **Instructors:** Abdollah Saidi, Deputy for the Middle East Sub-Commission; Akram Shahhosseini, Geological Survey of Iran.

531. **Applying Virtual Microscopy to Geoscience.** Sat. 9 Oct., 9 a.m.–5 p.m. PDT. US$100 professionals; US$50 students. Limit: 25. CEU: 0.7. **Instructors:** Christopher Prince, PetroArc International; Suzanne Kairo, Indiana University. **Endorser:** *PetroArc International.*

532. **How to Create your Own 3D Videogame–Style Geologic Field Trip and Host it Online: Accessible, Immersive Data Visualization for Education and Research.** Sat., 9 Oct., 9 a.m.–5 p.m. PDT. US$70. Limit: 20. CEU: 0.7. **Instructors:** Mattathias (Max) Needle, University of Washington; John F. Akers, University of Washington; Juliet G. Crider, University of Washington. **Endorsers:** *GSA Structural Geology and Tectonics Division; GSA Geoinformatics Division; GSA Geoscience Education Division.*

533. **Improv to Improve the Geoscience Community.** Sat., 9 Oct., 1–5 p.m. PDT. US$20. Limit: 20. CEU: 0.4. **Instructor:** Erik Haroldson, Austin Peay State University (APSU). **Endorsers:** *APSU Department of Geosciences; APSU College of STEM; APSU Diversity Committee.*

534. **Stormwater Infiltration in Washington State Using Deep Underground Injection Control Wells.** Sat., 9 Oct., 1–5 p.m. PDT. US$100. Limit: 20. CEU: 0.4. **Instructors:** Jay Chennault, Associated Earth Sciences Inc.; Curtis Koger, Associated Earth Sciences Inc.; Jennifer Saltonstall, Associated Earth Sciences Inc. **Endorser:** *Associated Earth Sciences Inc.*

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Drop-in Mentor. This one-on-one mentoring activity takes place in the GeoCareers Center. Students have 30 minutes to ask questions and seek advice. About 28 mentors are needed.

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647

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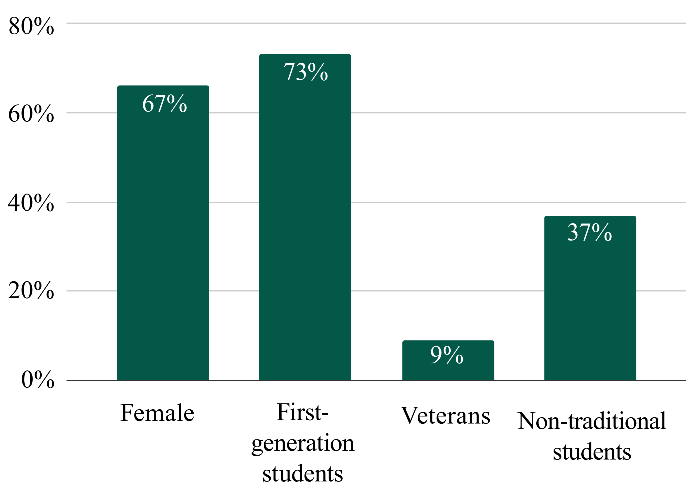

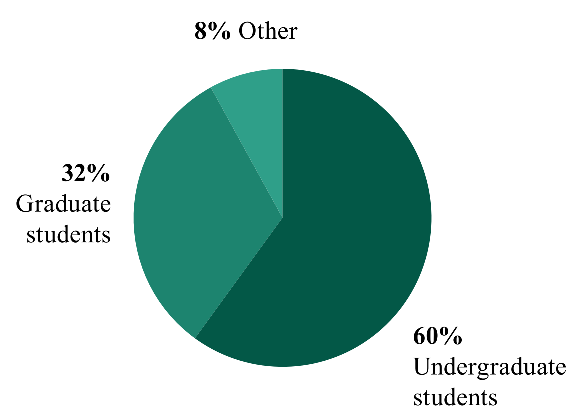

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Collaborations and Conversations Reception: 4:30–6:30 p.m.

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Seeing What You Know: How Researchers' Backgrounds Have Shaped the Mima Mound Controversy

Isaac E. Pope, *Science Dept., Centralia College, Centralia, Washington 98531, USA*

As the boundaries of science are pushed toward infinity, so has the ever-widening divide among ever-deepening disciplines. Though early scholars often shared a common language and context through which to filter controversies, the establishment of niche specialties has developed distinct and sometimes competing jargons and philosophies that continually morph through time. Even so, Earth remains steadfastly interdisciplinary in nature, leading to clashes between disciplines. Few controversies remain so entrenched in this divide as the origin of the Mima mounds.

Found in the Puget Lowland of Washington State, USA, Mima mounds have baffled geologic thought for over a century (Fig. 1). Clustering in the thousands along proglacial terraces, the Mima mounds are domelike ellipsoids composed of a sandy loam overlying relatively impermeable coarse-bedded gravels (Pope et al., 2020; Pringle and Goldstein, 2002; Goldstein and Pringle, 2020). Up to 2 m high and 12 m in diameter, the mounds are elongated parallel to the downslope gradient of the host terraces (Tabbutt, 2016). Similar mounds, referred to by Washburn (1988) as "Mimalike mounds," have been found extending across the Northwest United States into Midwest North America and to Africa and beyond (Johnson and Horwath Burnham, 2012). The discovery of Mimalike mounds in a plentitude of geologic environments, conditions, and compositions has led to a range of conjecture nearly as diverse as the mounds they describe (Johnson and Horwath Burnham, 2012), yet each model appears to be largely advocated by researchers based on their specialty.

Concentrating on the Puget Lowland glaciation, J Harlen Bretz proposed that the Mima mounds had been produced after differential melting formed depressions or "sun cups" in thin sheets of ice along proglacial terraces, which were later filled with sediment and left as mounds after the ice melted (Bretz, 1913). Though dissatisfactory to Bretz as a comprehensive explanation for the Mima mounds, the sun cups hypothesis has been revived several times, such as by pedology graduate student R.C. Paeth (Paeth, 1967) and most recently by Quaternary geologists Robert Logan and Timothy Walsh (Logan and Walsh, 2009).

Figure 1. At their type locality in Washington State, Mima mounds are a locally thickened sandy loam up to 2 m high, clustering along proglacial terraces. Similar mounds have been found across the world in a plentitude of geologic environments, which has led to a range of hypotheses nearly as diverse as the mounds they describe.

Rather than resulting from glacial conditions, some suggest mounds were produced from vegetation-anchoring of wind-blown deposits, in some cases following extended droughts (Seifert et al., 2009). Though proposed to explain mound topography in California (Barnes, 1879), Quaternary geologists in the American Midwest have become major advocates of the aeolian model of mound formation (e.g., Slusher, 1967; Seifert et al., 2009).

On the other hand, biologists Walter Dalquest and Victor Scheffer hypothesized that the mounds resulted not from geologic activity but by bioturbation. Dalquest and Scheffer (1942) proposed that a sandy loam overlying the proglacial terraces became a locally thickened biomantle around activity centers of burrowing rodents. This idea has become a favorite among biology and geography researchers in the Mima mound controversy and has been applied to a number of sites in North America and elsewhere (see Johnson and Horwath Burnham, 2012).

The most recent model to have been developed was forwarded by Andrew Berg, a geologist in Washington State. Berg (1990) proposed that earthquakes mobilized loose sediment into concentrated heaps, forming mounds. Though the hypothesis has not been further developed in the literature, it has amassed a following of Pacific Northwest geologists, particularly those interested in earthquakes and volcanism resulting from the Cascadia Subduction Zone.

While most advocates adhere to models relying on data within their discipline, some models have been overturned by experts within the same field. A popular model in the mid-twentieth century propounded that mound topography resulted from polygonal permafrost cracking and subsequent melting of ice wedges, as seen in current periglacial environments. Eminent periglacial geologist A.L. Washburn organized a conference in the

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1980s focusing on the origin of the Mima mounds within periglacial settings, concluding that such a model was insufficient for explaining the Puget Lowland mounds and other sites (Washburn, 1988). With the abundance of competing models, some have proposed a polygenetic approach, yet even these models can be based on a dominant theme augmented by lesser models (such as the Dalquest-Sheffer–based polygenetic model of Johnson and Horwath Burnham, 2012). Even so, it remains uncertain if the disparate mound fields share a common origin at all, rather than causes specific to the site.

Representing a host of specialties, these models continue to fuel a vibrant controversy, exemplifying the Method of Competing Hypotheses (Chamberlin, 1890; Elliott and Brook, 2007). Based on the proposition that rival models enhance research within a scientific discipline, this method has resulted in such a fruitful debate for two primary reasons. First, the multidisciplinary research results in a variety of ideas and enhances creativity, expanding the range of research. Conversely, the competing models create a check-and-balance system—the expansion of research in one field provides data to be accounted for in models held in another discipline, thereby constraining the range of conjecture on the mounds' origins.

This equilibrium of enhancing geologic thought and constraining speculation generates a dynamic mode of inquiry. The ready exchange of information can lead to a revolutionary development of a debate. Such a position is commendable to any controversy because it prevents stagnation (Chamberlin, 1890). On the other hand, the Mima mound controversy cautions that sometimes researchers may be biased by their specialty. To advance, we must be prepared to consider data beyond our field of expertise and integrate it into our own.

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Recruiting to Geosciences through Campus Partnerships

***Cinzia Cervato**, Dept. of Geological & Atmospheric Sciences, Iowa State University, Ames, Iowa 50011, USA*

INTRODUCTION

Increasing reliance of U.S. colleges and universities on student tuition makes recruitment a high priority for geoscience departments. In 2017, ~70% of geoscience graduates did not enter university declaring geology as a major, up by 10% since 2013 (Wilson, 2019). They discovered geology by taking an introductory geoscience course to fulfill general education or a previous major's requirement (Stokes et al., 2015). Thus, inspiring students to pursue a geoscience career through general education courses is a critical recruitment tool. However, what happens when these courses are taught online because of a pandemic, budget cuts, or to accommodate students' need for flexibility? It is not easy to be inspired through a computer screen.

This paper aims to describe two innovative pathways to recruit new undergraduate and graduate students at a large public research institution where, rather than focusing recruitment efforts on incoming students, a program recruits students who are already on campus and majoring in high-enrollment programs by offering them a path to earn a geology degree as a secondary major.

GRADUATION RATES AND FUTURE EMPLOYMENT TRENDS

The American Geosciences Institute (AGI; Gonzales and Keane, 2020) projects growth of >20,000 geoscience jobs by 2029, a 4.9% increase from 2019, higher than the projected growth in the U.S. workforce of 3.7%. By comparing the number of projected retirements and geoscience graduates, the expected shortfall is ~130,000 full-time geoscientists. While some of these positions will be covered by increased efficiency and use of technology, the expectation is that the demand will exceed the number of graduates and that programs will need an intentional focus on attracting and training new students.

AGI data (Wilson, 2019) show steady growth in geoscience undergraduates at four-year institutions since 2009 and a slight rise in degrees awarded since 2013 that do not match recent concerns expressed by departments about decreasing undergraduate enrollments. Data from the Integrated Postsecondary Education Data System (IPEDS, 2021) show that, of 288 geology programs at U.S. doctoral-granting institutions, 128 (44%) saw a decline in graduates from 2013 to 2019. Almost 40% of these programs (112) had fewer than 10 graduates in 2019, and 20 had none. Only 56 had ≥25 graduates. In the same period, the number of graduates in half of the 123 geology/earth-science programs at B.S.- and M.S.-granting institutions increased or stayed the same.

GEOLOGY AS SECONDARY UNDERGRADUATE MAJOR

Most science, technology, engineering, and math (STEM) majors must complete one year of calculus and physics and one or two semesters (one to three quarters) of chemistry. Some degrees require additional math and physics courses, often enough to earn a minor. On the other hand, a double major adds several more courses and typically at least one year to the undergraduate degree, delaying students' entrance into the workforce and adding to their financial burden.

The situation at Iowa State University (ISU) is typical of many geoscience departments: More than half of the geology graduates enrolled between 2004 and 2013 had entered the university either as undeclared (13%), engineering (11%), meteorology (4%), physics (4%), or one of 19 other majors. They had discovered geology through an introductory course or the learning community (Cervato and Flory, 2015). Most enroll in the B.S. geology, with smaller numbers pursuing B.S./B.A. earth-science degrees. This paper focuses on the B.S. geology program, the most popular undergraduate geoscience degree in the U.S. (66.6% of 2013–2017 graduates; Wilson, 2019).

The author has actively pursued STEM recruitment for more than a decade in collaboration with colleagues in other departments. These efforts include the physics+ program, an alternative path to a double major inspired by the Engineering Physics program at the University of Illinois at Urbana–Champaign. It consists of core physics courses to which additional physics courses can be added to create a traditional physics degree or courses in other majors that could replace equivalent physics courses. These degrees, e.g., B.S. physics with aerospace engineering emphasis, are considered double majors and intended for students who do not plan to pursue graduate studies in physics.

Unlike physics, only a few programs require a geology course. Thus, the author adopted a different approach to creating "geology+" programs and focused instead on identifying majors with an affinity for geology to provide pathways to geology for students in select majors. Similar paths were created for meteorology and aerospace and electrical engineering.

The first step of the year-long process was producing a geology "core" program. By comparing our B.S. geology curriculum with Drummond and Markin's (2008) analysis of nearly 300 B.S. geology degrees offered in the U.S., as well as the degree requirements at ten peer land-grant institutions, we identified 31 credits of core courses and labs (introductory physical and historical geology, mineralogy and optical mineralogy, petrology, sedimentology and stratigraphy, structural geology, and field camp) that include courses required by more than 60% of the programs analyzed by Drummond and Markin (2008), with the addition of optical mineralogy. Although the department agreed that these courses represent the foundation of geology, we also agreed that this reduced

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curriculum is only acceptable for students also majoring in another program.

Next, we identified programs with similar math, physics, and chemistry requirements and professional similarities with the broad field of geology (materials science and engineering, civil engineering, and environmental science) or that complement it (biology and meteorology). Collectively, there are close to 2,000 undergraduates majoring in these programs at ISU. Just 1%–2% of these students pursuing a geology+ degree would add a significant number of majors to the program.

Working with advisors and departmental and college curriculum committees, we put together and received approval for four-year plans for each of these programs, fulfilling all primary major requirements while adding the geology core courses as a secondary major. Since this is a different approach than the one developed in physics, and there are no other examples at ISU, the validation process for these double majors required approval in each college involved.

Some characteristics that make this pathway to geology attractive to students include the ability to graduate in four years with two majors, the added professional benefit of a geology degree in a competitive job market, and the opportunity to pursue a career or graduate degree in geology. It is not unusual for geology graduate programs to admit students with degrees in biology, chemistry, physics, civil engineering, or environmental science. Completing the core geology courses in addition to their primary major's requirements would make the transition into a geology graduate program relatively smooth. Also, the M.S. geology degree has historically been the preferred professional degree for private-sector jobs in geoscience (Wilson, 2019), whereas the Ph.D. is the graduate degree of choice for some programs like materials engineering.

GROWING GRADUATE PROGRAM THROUGH CONCURRENT B.S./M.S. DEGREES

Increasing numbers of students enter university with college credits earned in high school through dual enrollment programs, advanced placement courses, or credits transferred from two-year institutions. ISU offers 30 concurrent B.S./M.S. or B.S./MBA programs that allow students to earn a B.S. and M.S. or MBA in five years in engineering, agronomy, chemistry, and more.

The ability to earn concurrent B.S. and M.S. degrees within five years is motivated in part by the M.S. becoming the degree of choice in many disciplines, including the geosciences (e.g., in oil and gas, federal government) (Levine, 2011; Wilson, 2019). Taken sequentially, it takes on average >6.5 years to earn both degrees (Wilson, 2018). This extended time could discourage students interested in a STEM career from pursuing a degree in geosciences in favor of a degree in engineering, for example, where starting positions require only a B.S.

We developed B.S./M.S. and B.S./MBA geology programs aimed at students pursuing a career in industry or as consultants. To our knowledge, there are only three other B.S./M.S. geoscience programs in the U.S. (two at Penn State and one at the University of Texas at El Paso), and none that include the MBA. While the primary goal is career preparation, the B.S./M.S. program might be a potential mechanism to increase the number of students who pursue a Ph.D. in geosciences (~18% of B.S. graduates in 2017; Wilson, 2018).

Students apply to the graduate program in their junior year after identifying a graduate advisor and complete graduate courses in their fourth and fifth years. Using this as a recruiting tool for students transferring from two-year institutions that tend to have a higher percentage of underrepresented minorities would potentially provide an opportunity to increase a program's diversity (Wilson, 2018). As for the traditional M.S. geology degree, there is a thesis and a rarely pursued non-thesis (creative component) option. Students are eligible for graduate teaching and research assistantships in their fourth and fifth years and reduced or free tuition as part of the graduate assistantship package.

CONCLUSIONS

We started accepting students into the geology+ program in fall 2019, and there are currently eight students from civil engineering, biology, meteorology, and environmental science who have declared geology as a secondary major. So far, there are a handful of students pursuing the B.S./M.S. option. However, we foresee this as an attractive recruiting tool and an opportunity to diversify the student body through partnerships with university programs to attract women and underrepresented minorities to STEM fields.

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GSA FOUNDATION Update

Meaningful Support: Honoring Field Camp Excellence

Each year since 2011, the GSA/ExxonMobil Field Camp Excellence Award has granted US$10,000 to a traditional six-week geology field camp that teaches the fundamentals of geologic mapping and field methods. Based on safety awareness, diversity, and technical excellence, the award is intended to assist with the summer field season. Recently, a past recipient took part in the GSA Foundation's virtual chat, *Field Camp in Changing Landscapes*. Miriam Barquero-Molina, Director of University of Missouri's (MU) Geology Field Program, spoke about the continued importance of in-person field training and noted the relieving impact of the Excellence Award for her camp. We asked her to expand on the Branson camp and award.

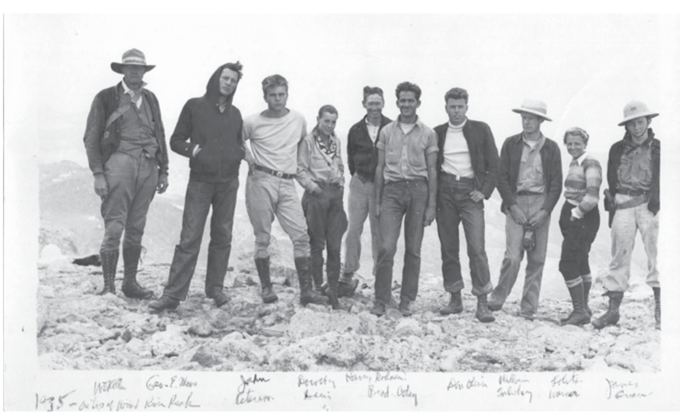
The University of Missouri Geology Field Camp, founded in 1911 by Edwin B. (E.B.) Branson, is the longest continually running geology field camp in the United States. Prof. Branson had undertaken extensive fieldwork around Wyoming's Wind River Ranges during his dissertation work. An early believer in the power of hands-on learning, Branson realized that this part of Wyoming would be an ideal setting to teach field skills to geology students, and he set out to make his dream a reality. What started as white canvas tents along the shores of the Popo Agie River in Sinks Canyon and nearby areas in the early years evolved into a bona-fide field station of log structures built by students and staff during the 1930s and 1940s.

Maintenance and upkeep of a permanent field camp facility in a remote location are not for the faint of heart. The finances of large state universities have changed dramatically, and many geology field camps have been left to their own devices. MU's Branson Field Laboratory is no stranger to this pain.

A permanent infrastructure provides very different learning conditions for students than those of a more mobile camp. For permanent camps, infrastructure emergencies are unexpected and potentially crippling. Since the late 1970s, MU's geology field camp has had the incredible fortune of the financial support of the MU Geology Development Board. The board has always recruited into their fold MU geology alumni fiercely devoted to the camp who have risen to the occasion every time the camp has needed financial help.

In 2014 the camp was dealing with the financial aftermath of extensive renovations (to the tune of over a half million dollars), including building two bridges. Unexpectedly, about a month before the start of the summer season, the camp additionally faced the need to bear-proof the trash and recycling system due to sudden U.S. Forest Service regulations. This is the year MU's geology field camp was awarded the GSA/ExxonMobil Field Camp Excellence Award. This is a very competitive program, proving that, as a geoscience community, we are lucky to have such a large number of excellent field programs in our midst. For MU's camp, the award was, therefore, very much a surprise, and the unexpected US$10,000 proved to be an unexpected and much needed lifeline that allowed for the mandated bear-proofing to be done as required prior to the start of the 2014 summer season. The camp director could stop worrying about money and could focus on the camp's mission: to provide a high-quality hands-on learning experience for geoscience students across the nation.

The Society recognizes that formal geology field camp training is vital to the development of capable, well-rounded geoscientists who are prepared to contribute to society through the many diverse career paths available. GSA and GSAF are proud to support existing field camps with often challenging, changing needs, and corporate partnerships make this possible. If your company or organization would like to learn more about how you can be involved, please contact Debbie Marcinkowski at +1-303-357-1047 or dmarcinkowski@geosociety.org.



Walter Keller and University of Missouri field camp students atop Wind River Peak, 1935.

Miriam Barquero-Molina, students, and teaching assistants atop Wind River Peak, 2018.

gsa-foundation.org

TAKING ON 21ST CENTURY CHALLENGES CREATING 21ST CENTURY LEADERS

From the Earth's core to outer space, research at The University of Texas at Austin's Jackson School of Geosciences is advancing the understanding of our world and beyond for the benefit of humankind.

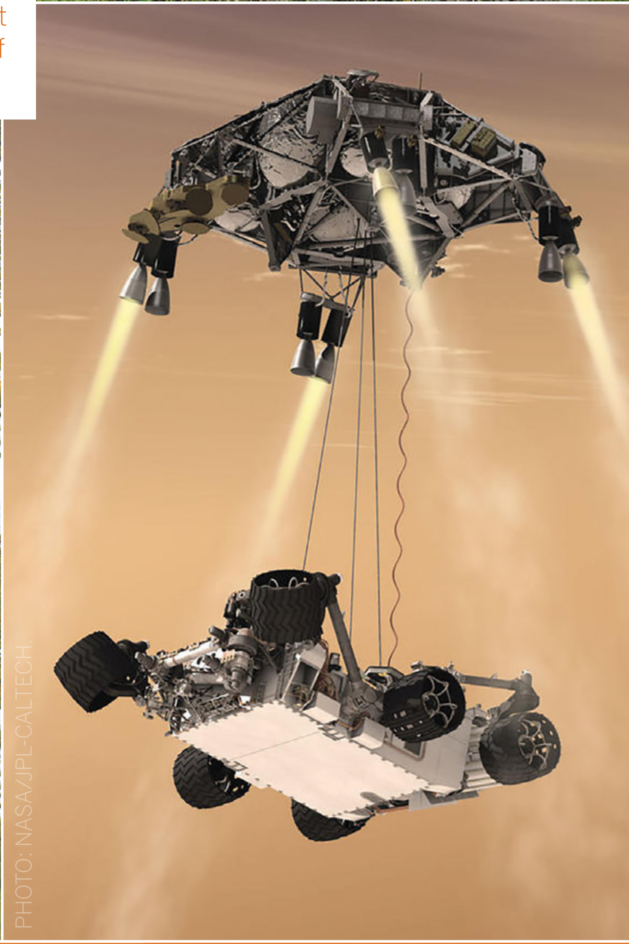


PHOTO: NASA/JPL-CALTECH