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SCIENCE

Cover: View of Hole in the Mountain Peak in the Ruby Mountain–East Humboldt Range metamorphic core complex, Nevada, USA. This cliff face is comprised of strongly sheared and attenuated Neoproterozoic (lower benched cliffs) through Ordovician (upper white cliffs) metasedimentary rocks, heavily intruded by Cenozoic intrusions (large dark bodies, such as in the upper left). For the related article, see p. 4–11.

GSA NEWS

Metamorphic Core Complex Dichotomy in the North American Cordillera Explained by Buoyant Upwelling in Variably Thick Crust

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ABSTRACT

Metamorphic core complexes (MCC) in the North American Cordillera exhibit a strong dichotomy. Those in the north formed in a thickened orogenic plateau during Paleogene Farallon subduction, are widely spaced (~200 km), and young SW. Conversely, those in the south formed in thinner crust, are closely spaced (~50 km), developed during the Oligocene-Miocene transition to regional transtension, and young NW. Synthesis of magmatism and cooling ages, modeling, and plate reconstructions demonstrate that MCCs could have initiated as buoyant domes driven by lower-crust heating caused by asthenospheric upwelling after Farallon slab rollback. These domes were later exhumed by Miocene extension. The widely spaced Paleogene hinterland domal upwellings and associated mylonites were temporally decoupled from Miocene detachments, manifesting a two-stage development. The closely spaced Oligocene-Miocene foreland MCCs show almost synchronized doming and detachment faulting. The spacing dichotomy of the MCCs reflects the characteristic wavelength of the doming process that was in turn controlled by the thickness and thermal state of the crust.

INTRODUCTION

Vertical material advection in Earth's lithosphere impacts heat transport, rheology, crustal differentiation, and planetary cooling (Gans, 1989; Rey et al., 2009; Moore and Webb, 2013; Whitney et al., 2004, 2013). The formation of continental metamorphic core complexes (MCCs) is one such process, where mid-lower crust rocks are exhumed as arched domal structures with spatially coexisting ductile shear zones and brittle faults (Coney, 1980; Yin, 2004; Whitney et al., 2013; Platt et al., 2015) (Fig. 1).

MCCs comprise a belt stretching across the North American Cordillera (Fig. 2A) (Coney, 1980). They may have formed from the thermally induced buoyant ascent of migmatitic or plutonic cores as gneiss domes (e.g., Eskola, 1949; Whitney et al., 2004) (Fig. 1B) or during regional crustal extension via detachment faulting coupled with isostatic exhumation of footwall rocks (e.g., Wernicke, 1981; Wernicke and Axen, 1988) (Fig. 1A). Here we show how this long-held discussion reflects a distinct dichotomy between MCCs formed in the hinterland of the Sevier thrust front versus those in its foreland (Fig. 2A). Using compiled records of magmatism and MCC evolution, plate reconstructions, and numerical models, we argue that MCCs originally initiated as buoyant domes whose formation and spacing was controlled by the thermal state and thickness of the crust. Farallon slab dynamics and plate-boundary conditions influenced the timing of doming and contributed to their final exhumation via detachment faults. Our study highlights how thermal structure controls mass and heat transport across the lithosphere.

METAMORPHIC CORE COMPLEXES OF THE NORTH AMERICAN CORDILLERA

The North American Cordillera involved Mesozoic east-dipping oceanic subduction, arc magmatism, and retro-arc thrusting (e.g., Yonkee and Weil, 2015). The Late Cretaceous Sevier thrust front stretches north across western North America, defining the eastern limit of a thickened orogenic plateau (i.e., the Nevadaplano; DeCelles, 2004). Subduction of the conjugate Shatsky Rise (CSR) ca. 80–40 Ma caused the subducting Farallon slab to flatten eastward, which resulted in underplating of forearc sediments and the cessation of magmatism (e.g., Livaccari et al., 1981; Copeland et al., 2017; Chapman et al., 2020). Subsequently, due to slowed plate convergence and its own negative buoyancy, the Farallon slab steepened rapidly, which resulted in SSW-sweeping Eocene-Oligocene volcanism from Idaho to southern Nevada and WNW-sweeping Oligocene-Miocene volcanism across Arizona into California-Nevada (Coney and Reynolds, 1977; Humphreys, 1995; Copeland et al., 2017; Lund Snee and Miller, 2022) (Fig. 2A). A preceding

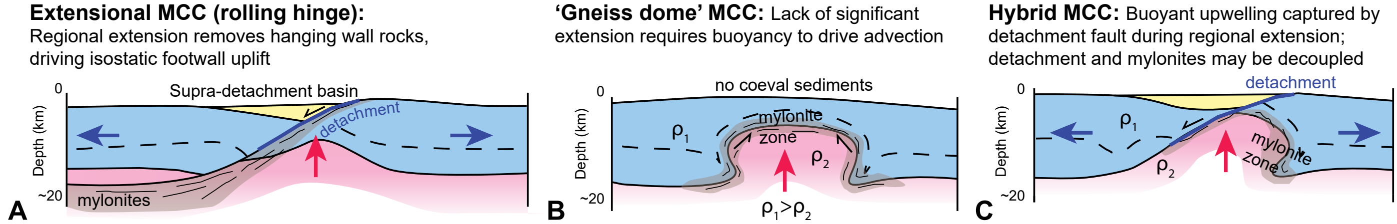

Figure 1. Spectrum of metamorphic core complex models: ρ_1 and ρ_2 are the density of the upper and lower crust, respectively. MCC—metamorphic core complex.

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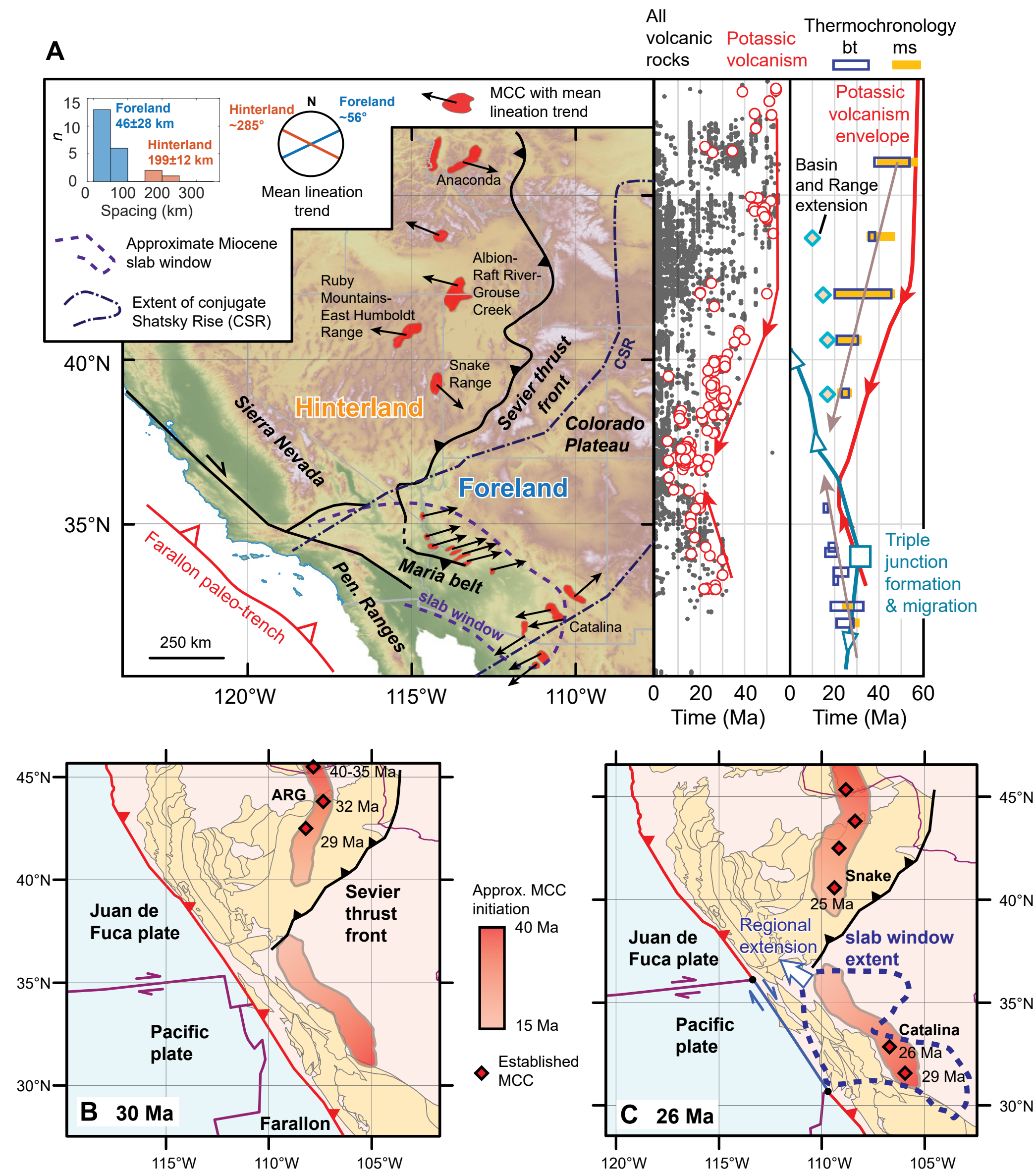

Figure 2. (A) Metamorphic core complexes (MCCs) in the hinterland and foreland of the Sevier thrust front in the North American Cordillera. Right graph shows NAVDAT volcanic (black) and potassic rocks (red), MCC and regional extension timing constraints (Supplemental Material [see text footnote 1]), and reconstructed triple-junction formation (square) and migration (arrows). (B, C) Plate reconstructions of Oligocene western North America (Clennett et al., 2020). Hinterland MCCs initiate prior to triple-junction formation and migration, decoupled from these tectonic events, whereas the foreland MCCs develop during triple-junction migration and slab-window development. ARG—Albion–Raft River–Grouse Creek; bt—biotite; ms—muscovite.

correlative sweep of potassic volcanism may reflect melting of an enriched mantle source, indicating asthenospheric upwelling (e.g., Manley et al., 2000) following slab removal (Fig. 2A).

After, or potentially overlapping with, the phase of migrating Eocene-Miocene volcanism, MCCs developed across western North America as two distinct sets. In the north, Paleogene MCCs formed in the hinterland of the Sevier thrust front (Armstrong, 1968; Yonkee and Weil, 2015), from British Columbia, Canada, down to southern Nevada (Fig. 2). Conversely, in the south, Oligocene-Miocene MCCs formed in Arizona, eastern California, and southern Nevada, in the foreland region of the Sevier thrust front (Fig. 2). The hinterland MCCs have characteristic spacing of ~200 km, whereas the foreland MCCs are spaced ~50 km (Fig. 2A), defining an ~4:1 spacing ratio. Hinterland MCCs initiated while the Juan de Fuca plate was still subducting beneath North America, which was not yet in an extensional state (e.g., Stevens et al., 2017), whereas foreland MCCs developed during triple junction migration and regional extension (Atwater and Stock, 1998; Jepson et al., 2022) (Figs. 2B and 2C). Based on their locations relative to the Sevier thrust front, hinterland MCCs likely developed in thicker crust than the foreland MCCs. The timing and spacing represent a distinct dichotomy between the hinterland and foreland MCCs, which has not been satisfactorily explained with existing tectonic models.

RAYLEIGH-TAYLOR INSTABILITY MODEL FOR METAMORPHIC CORE COMPLEXES

To explain the MCC dichotomy, we propose a simple model that links MCC formation with the thermal state and thickness of crust. Our model is reminiscent of buoyant diapirism (i.e., Rayleigh-Taylor instability, RT) in a two-layer medium with a denser upper layer. Dimensional analysis (Selig, 1965) and analog models (Marsh, 1979) show characteristic diapir spacing, λ, is related to the viscosity contrast $R = \frac{\mu_1}{\mu_2}$ between the upper (μ_1) and lower layers (μ_2) (where $\mu_2 \leq \mu_1$), and the thicknesses of the lower density lower crust layer, H_m. For a range of R, λ was plotted against H_m using analytical solutions to show the positive correlation between diapir spacing and H_m (Fig. 3A).

To further support the analytical solutions, we conducted two-layer numerical models (Fig. 4) using the MVEP2 thermo-mechanical modeling package (Kaus, 2010; Thielmann and Kaus, 2012). The models used fixed boundaries, $R = 1–100$, and a constant density difference ($\Delta\rho = 0.1$ g/cm^3) between the two layers (see Methods in the Supplemental Material[1]) (Fig. 4). These models reproduced the analytical curves with similar λ versus H_m correlations (Fig. 3A). The spacing dependence on R paralleled the analytical solutions of Selig (1965).

Our RT upwelling model suggests that distinct differences in thermal state and rheology between the hinterland and foreland regions of the North American Cordillera explain the observed MCC dichotomy (Fig. 2). Specifically, the model predicts that the wider-spaced hinterland MCCs developed with thicker H_m values, greater R values, or a combination of factors (Fig. 3A).

BUOYANT DOMING IN VARIABLY THICK CRUST

To test the RT model, we examined how H_m may have varied across the Cordillera, assuming H_m scales with the thickness of crust that might undergo partial melting above the solidus, say when $T > 700$ °C (e.g., Rey et al., 2009). In this framework, there are two parameters that affect H_m thickness: crustal thickness and the temperature at the base of the crust. Assuming similar thermal parameters in the crust, a thicker H_m will result from thicker crust or a hotter Moho.

The spatial location of the different MCCs in either the hinterland or foreland of the Sevier thrust front (Fig. 2A) implies that they developed in crust with variable thickness. Support for the Late Cretaceous Nevadaplano orogenic plateau (DeCelles, 2004) with relatively thick crust (~60+ km) in the Sevier hinterland includes observed deeply incised paleovalleys (Henry et al., 2012), geochemical thickness proxies (Chapman et al., 2015), moderate-to-high magnitudes of Mesozoic crustal shortening in the Sevier thrust belt and its hinterland (e.g., Long et al., 2014; Yonkee and Weil, 2015; Zuza et al., 2021), Late Cretaceous deep burial (~7–8 kbar) of supracrustal rocks in exhumed MCCs that supports substantial crustal thickening (Lewis et al., 1999; Hallett and Spear, 2014), reconstructions of Cenozoic extension that imply thickened pre-Cenozoic crust (Coney and Harms, 1984), and stable-isotope paleoaltimetry (e.g., Snell et al., 2014).

Conversely, direct evidence for substantial Mesozoic-Cenozoic crustal thickening in the foreland region is lacking. The region is southeast of the Sevier thrust-front and northeast of the Maria fold-thrust belt (e.g., Knapp and Heizler, 1990) (Fig. 2A). Structural reconstructions of Cretaceous–early Cenozoic contractional deformation do not suggest substantially thickened crust (e.g., Davis, 1979; Clinkscales and Lawton, 2018). Geochemical proxies suggest thickened crust across Arizona in the late Cretaceous (~60 km) but relatively thinner crust (~40 km) at 40–30 Ma (Jepson et al., 2022). Therefore, prior to the initiation of Oligocene-Miocene MCCs, we assume the foreland region was relatively thin at ~40 km.

Assuming a thicker hinterland (~60 km) and thinner foreland (~40 km) at the time of Cenozoic MCC generation, steady-state geotherms were plotted to examine the thickness of H_m above ~700 °C (Fig. 3B). We used an 800 °C Moho temperature to represent the hot lower crust heated via mantle upwelling after slab rollback. A set of numerical models simulating partial melting (Supplemental Materials [see footnote 1]) also support that the hinterland-type crust would have a thicker H_m than the foreland (right panel in Fig. 3B), H_{mh} versus H_{mf}, respectively. We estimate that the foreland lower crustal layer (H_{mf}) was ~7 km and the hinterland lower crustal layer (H_{mh}) was ~20 km, a ratio of ~3:1. With these estimates, a plot of MCC spacing versus H_m fits well on analytical curves, demonstrating a predictable positive correlation (Fig. 3A).

In this framework, observed MCC spacing overlap curves for diapirism with reasonable viscosity contrasts of 2–3 orders of magnitude

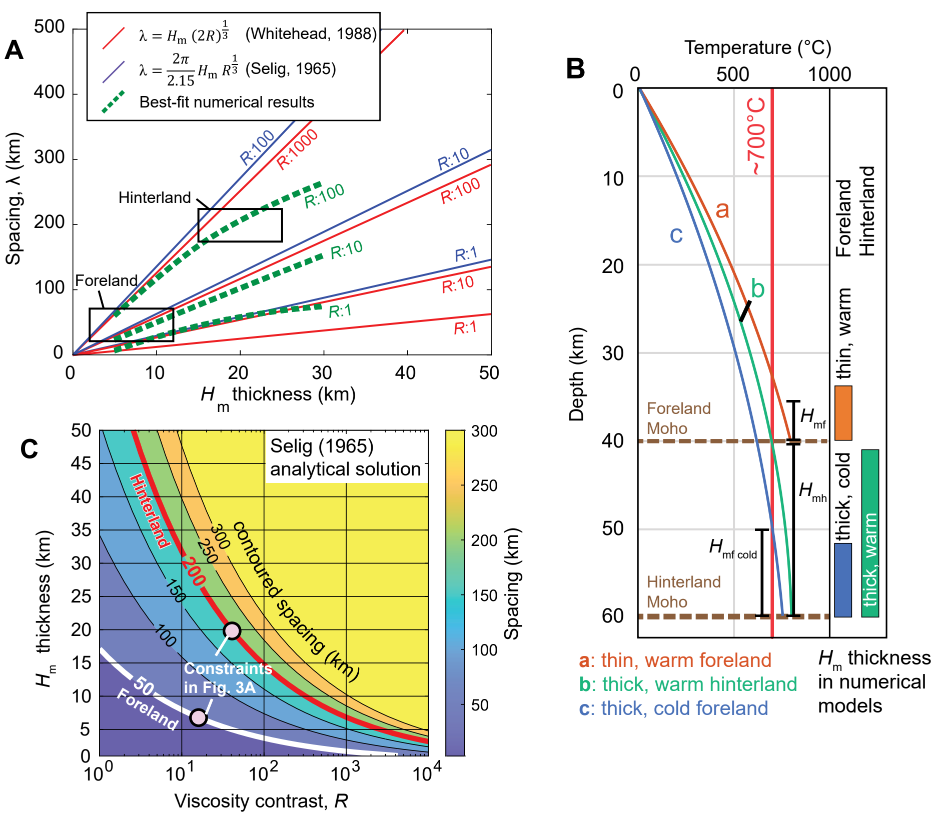

Figure 3. (A) Analytical and numerical predicted diapir spacing vs. the thickness of the lower density lower layer (H_m) for different viscosity contrasts (R), plotted with hinterland and foreland metamorphic core complex spacing (±1σ) and estimated H_m (±5 km) (from B). (B) Estimates of lower-layer thickness (above ~700 °C), assuming ~800 °C Moho, for the hinterland (H_{mh}), thin foreland (H_{mf}), or thick, cold (~750 °C Moho) foreland ($H_{mf\ cold}$). See text for explanation. Numerical models of partial melting confirm relative thickness differences (Supplemental Fig. 2 [see text footnote 1]). (C) Tradeoff between R and H_m for the Selig (1965) curve, with observed spacing contours emphasized.

[1]Supplemental Material. A synthesis of timing constraints for the North American Cordillera metamorphic core complexes, a brief discussion of the conjugate Shatsky Rise, details of zircon Hf compilation, and methods and results of numerical simulations. Go to https://doi.org/10.1130/GSAT.S.21253911 to access the supplemental material; contact editing@geosociety.org with any questions.

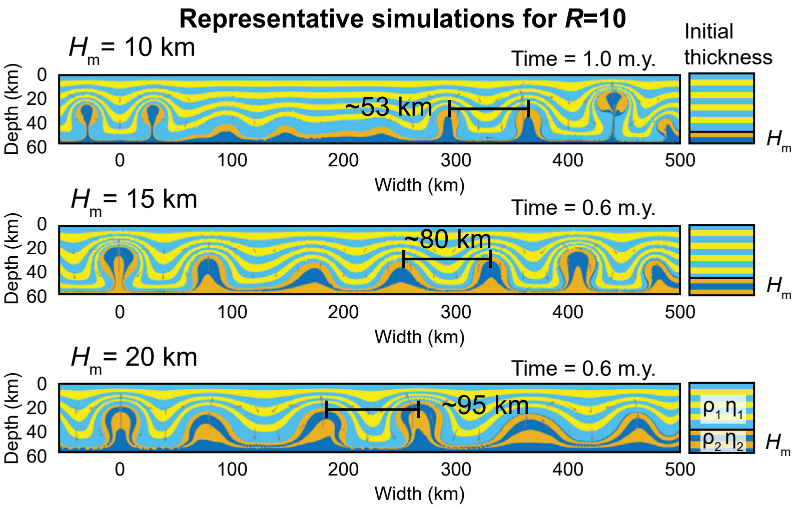

Figure 4. Representative numerical model results showing increased diapir spacing with increasing H_m. The upper layer is denser and ten times more viscous (R = 10); colored layers are passive to show strains. Complete simulation setup and results are in the Supplemental Materials (see text footnote 1).

between the partially melted lower crust and colder, more viscous upper crust (Fig. 3A) (Whitney et al., 2004; Rey et al., 2009). There is a tradeoff between viscosity contrast (R) and the thickness of the lower crustal layer (H_m), which we explored for Selig's (1965) solution (Fig. 3C): observed spacing dichotomy may result from (1) nearly constant R in both the hinterland and foreland, which implies variable H_m (~3:1 ratio); (2) generally similar H_m, which implies substantial R variations between hinterland and foreland (~100:1 ratio); or (3) some intermediate scenario. We argue that variable H_m, modulated by thermal state or thickness discussed above (Fig. 3B), may be most responsible for spacing variations, which permits similar R values within each setting.

A potential caveat is that it has been postulated that Laramide flat-slab subduction could have refrigerated the upper plate to cool the Moho and thermal structure of the overlying crust (Dumitru et al., 1991). Reconstructions of the subducted CSR (Fig. 2A) show that it would have projected directly beneath the foreland MCCs but not the hinterland MCCs (Livaccari et al., 1981; Axen et al., 2018). This predicts that the foreland crust may have been colder than the hinterland, and therefore MCC diapirism in the colder foreland region would have emanated from an even thinner H_m layer than the hinterland. Although more complex, this scenario still satisfies our spacing arguments (Fig. 3). Furthermore, it is possible that Laramide thickening (Bird, 1984) of the Arizona region was more pronounced than we previously assumed (e.g., >45-km-thick crust), possibly driven by alternative thickening mechanisms beside crustal shortening that are hard to track in the geologic record, such as channel flow (Bird, 1991) or magmatic inflation (e.g., Chen et al., 2018). A potentially thicker foreland region would impact the MCC dichotomy model, but Laramide slab refrigeration may counteract this effect. That is, if the foreland was thick but relatively colder due to these combined impacts, a thinner H_m layer is predicted (Fig. 3A) to explain closer MCC spacing. Despite some uncertainties, thermal state through crustal thickness or basal temperature boundary conditions impact H_m (Fig. 3B) and thus diapir spacing (Fig. 3C).

FARALLON SLAB DYNAMICS DRIVE LOWER CRUSTAL HEATING

Buoyant MCC doming is driven by vertical density differences in the crust, rather than plate-boundary forces, regional extension, hanging wall removal, and isostasy (Fig. 1). Heating of the lower crust reduces its density and viscosity, for example as shown by numerical simulations and tectonic models for some of the MCCs in southwest Canada (Vanderhaeghe et al., 1999; Rey et al., 2009; Whitney et al., 2013). We envision the RT instabilities initiated with an increase of Moho temperature caused by post-Laramide slab rollback, potentially coupled with slab-window development, that allowed influx of hot asthenosphere that intensely heated the crust (Babeyko et al., 2002; Axen, 2020; Lund Snee and Miller, 2022). Thus, the timing of MCC generation should be strongly coupled with the timing of volcanism and crustal heating, and not necessarily correlated with kinematic shifts in plate-boundary conditions and the initiation of regional extension.

To test this hypothesis, we compiled biotite and muscovite $^{40}Ar/^{39}Ar$ ages (Supplemental Material [see footnote 1]), which track cooling through closure temperatures of ~300 °C and 400 °C, respectively (McDougall and Harrison, 1999). We interpret these dates to broadly constrain the late phases of mylonite development in quartz-rich rocks along the flanks of the evolving MCCs. Lower temperature thermochronometers track brittle normal faulting and related exhumation. Argon dates from hinterland MCCs young to the southwest, whereas those from foreland MCCs young to the northwest (Fig. 2). MCC doming age patterns parallel volcanic trends (Gans et al., 1989), but only Ar dates from the foreland MCCs show a correlation with the propagation of initial regional Basin and Range extension tracked by plate reconstructions, low-temperature thermochronology, and the extensional basin record (Miller et al., 1999; Colgan et al., 2010; Konstantinou et al., 2013; Lee et al., 2017; Jepson et al., 2022; Supplemental Material [see footnote 1]) (Fig. 2). Our compilation of volcanism, MCC doming, regional extension, and triple-junction migration suggests that MCC development is more strongly correlated with trends of rollback volcanism rather than the propagation of regional extension due to migrating triple junctions (Fig. 2).

The implied causal relationship between magmatism and MCC generation can be further tested by magmatic source characteristics. All MCCs involve pre-/syn-kinematic magmatism (e.g., Gans et al., 1989; Howlett et al., 2021). Available zircon εHf_T data from different but adjacent hinterland MCCs broadly overlap with parallel trends (Fig. 5A). εHf_T trend toward evolved values ($\varepsilon Hf_T \leq -20$) during Late Cretaceous anatexis followed by a juvenile excursion (εHf_T ~−10) during Eocene slab rollback reflecting mantle influx and melting (Howlett et al., 2021). An Oligocene evolution toward more evolved values ($\varepsilon Hf_T < -30$) can be interpreted as protracted crustal heating and melting (Konstantinou et al., 2013) (Fig. 5A). Foreland MCCs show more subdued isotopic trends (Fig. 5B), likely reflecting different melt sources compared to the hinterland region. Within uncertainty, the foreland trend is either flat or there is a juvenile excursion with the arrival of mantle-derived volcanism (Fig. 5B). In the hinterland, there is a pronounced

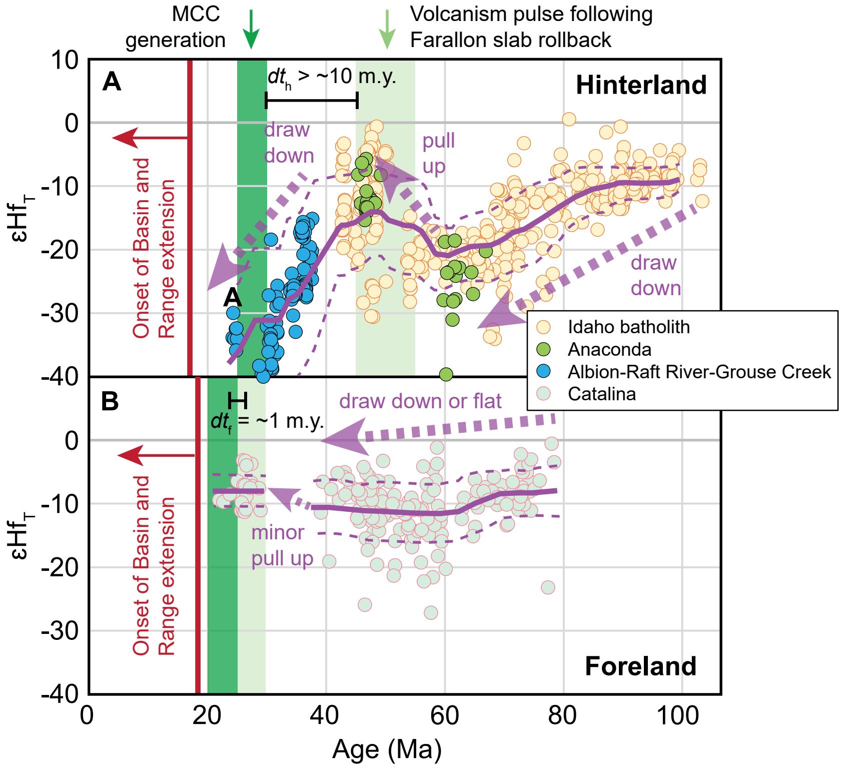

Figure 5. Zircon Hf compilation with 10-m.y. moving average (purple solid line) and standard deviation (dashed line). References in the Supplemental Material (see text footnote 1). (A) In the hinterland, note strong sawtooth pattern, with "pull up" correlated with Farallon slab removal and mantle-derived intrusions. Hf "drawn down" precedes mylonite generation after thermal incubation (dt_h > ~10 m.y.). (B) In the foreland, note the subdued sawtooth pattern with metamorphic core complex (MCC) generation shortly after upwelling volcanism (dt_f), such that dt_f << dt_h. Data: Gaschnig et al. (2011); Konstantinou et al. (2013); Fornash et al. (2013); Howlett et al. (2021).

~10-m.y. delay between juvenile magmatism and MCC doming (i.e., dt_h ~10 m.y., Fig. 5A) bracketed by Ar dates and cross-cutting relationships (e.g., Wright and Snoke, 1993; Konstantinou et al., 2013; Zuza et al., 2022) (Supplemental Material [see footnote 1]). Conversely, in the foreland, there is a much shorter delay between volcanism and MCC generation (i.e., dt_f <1 m.y., Fig. 5B), and therefore dt_f << dt_h (Fig. 5).

DECOUPLED MCC DOMING AND DETACHMENT FAULTING

Advances in field and geochronology studies reveal a decoupled two-phase deformation history for the hinterland MCCs. In the Albion–Raft River–Grouse Creek, the primary mylonitic shear zones formed in the Oligocene and Basin and Range extensional faulting started ca. 14 Ma (Konstantinou et al., 2013). In the northern Ruby Mountains–East Humboldt Range, Oligocene mylonites are crosscut by undeformed 17 Ma basalt dikes, which are cut by Miocene detachment faults that were associated with syn-kinematic extensional basin sedimentation (Wright and Snoke, 1993; Zuza et al., 2021, 2022). The Miocene detachment continues south along strike for ~150 km (Colgan et al., 2010), where its footwall is no longer mylonitic or migmatitic, thus suggesting the mylonites are not genetically or kinematically linked with detachment faulting. In the Snake Range, the Oligocene mylonitic shear zone was cut by ca. 22 Ma undeformed dikes (Lee et al., 2017), and a later phase of extensional exhumation is recorded by ca. 17 Ma fission track ages (Miller et al., 1999).

We posit that for hinterland MCCs, the earlier, temporally decoupled phase of buoyant doming established mechanical or thermal weaknesses that were exploited by Miocene detachment faulting, thus explaining the apparent connectivity between Paleogene doming and Miocene detachment faults (e.g., Konstantinou et al., 2013; Ducea et al., 2020; Zuza et al., 2021) (Fig. 2A). This also explains the perplexing observation that Paleogene MCCs did not generate syn-kinematic basins, whereas Miocene extensional basins were well developed (Colgan and Henry, 2009; Zuza et al., 2021). Domal upwarps in the mid-crust did not generate space for surface sedimentation, but hanging wall removal during detachment faulting allowed for supra-detachment basins (e.g., Friedmann and Burbank, 1995). Foreland MCCs may have similarly involved two phases that occurred on nearly overlapping time scales (Jepson et al., 2022) due to coeval slab-window development, magmatism, and extension initiation (Atwater and Stock, 1998) (Fig. 2).

Extension-related detachment fault models for MCC generation (e.g., Wernicke and Axen, 1988) (Fig. 1A) cannot satisfactorily explain MCC spacing, age trends, and generation prior to plate-boundary conditions switched to initiate regional extension (Fig. 2). MCC spacing has previously been interpreted in the context of elastic buckling (e.g., Yin, 1991), but this type of instantaneous solution does not uniquely constrain observed age trends across the Cordillera (Fig. 2) and diminishes the role of a viscous, partial-melt–rich mid-lower crust. The aforementioned two-phase deformation history of many MCCs complicates models of simple protracted detachment faulting. However, it remains possible that some MCC spacing is partially modulated by corrugations or elastic buckling that overprinted an established first-order buoyantly domed architecture.

A comprehensive summary model in Figure 6 unifies observations from across the Cordillera and provides testable predictions for future investigations. Mesozoic shortening thickened the hinterland region more than the foreland. Laramide flat-slab subduction underplated schists beneath the foreland region, potentially refrigerating the upper-plate lithosphere. In the hinterland, post-Laramide slab rollback drove SW sweeping juvenile magmatism that heated the crust. Thermal incubation over ~10 m.y. resulted in a hot, melt-rich lower crust that rose as buoyant diapirs to form hinterland gneiss dome MCCs with strong shearing along the upwelling margins (Fig. 1B). This style of MCC development resulted in pure-shear attenuation along the flanks and tops of the rising domes (Miller et al., 1983; Zuza et al., 2022). Paleogene doming would have overprinted and incorporated preexisting Mesozoic fabrics and structures, thus creating locally complex domal geometries. Detachment faulting during Miocene-present Basin and Range extension exploited the domal structures to exhume them in the detachment footwalls (Fig. 1C).

The spatial correspondence of the CSR and slab window beneath the foreland region may

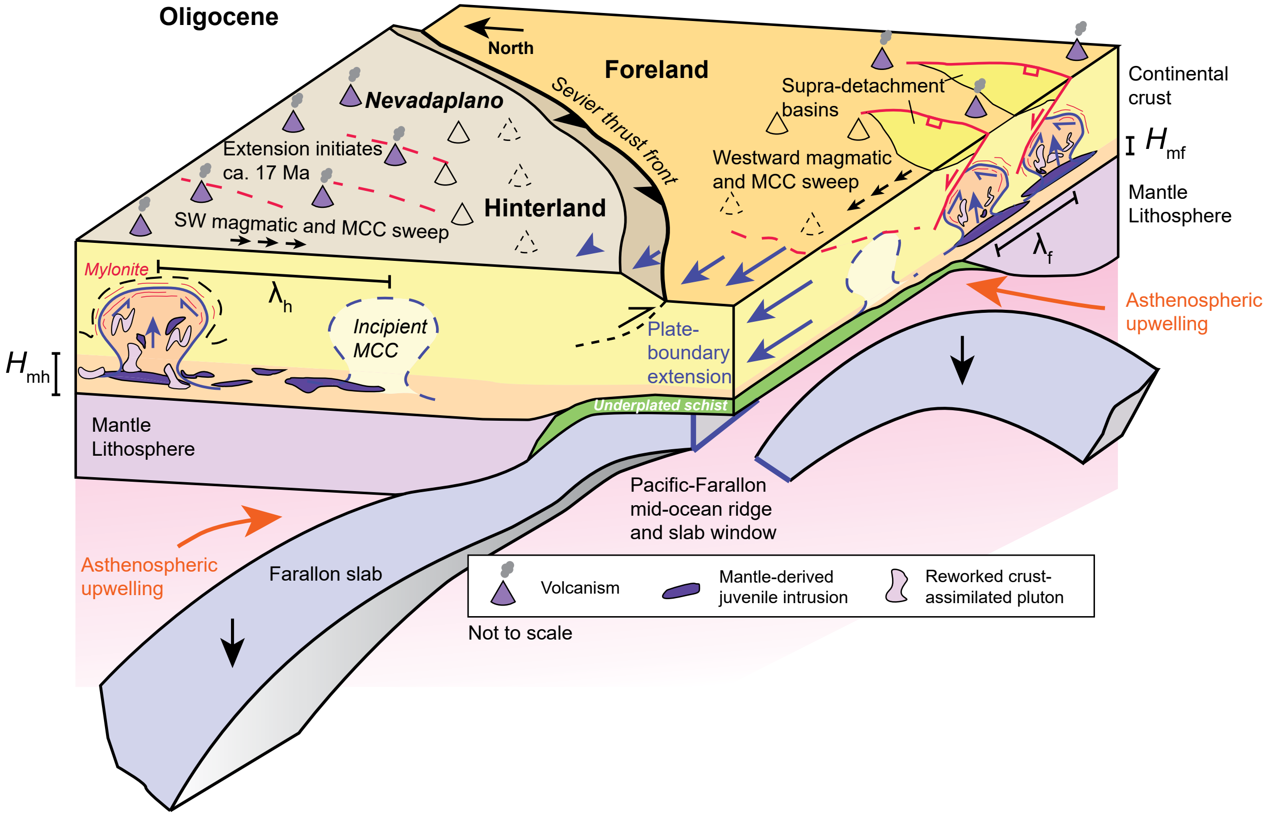

Figure 6. Model for metamorphic core complex (MCC) dichotomy in the North American Cordillera explained by buoyant upwelling in variably thick crust, including predictions for temporal trends, phases of thermal incubation, and connections with regional extension. H_{mh} and H_{mf}—thickness of the low density, lower crust layer in the hinterland and foreland, respectively; λ_h and λ_f—diapir spacing in the hinterland and foreland, respectively.

imply complex influence on MCC generation, including earlier lithospheric refrigeration and hydration followed by focused heating of the base of the crust. Coupled mantle upwelling through the slab window and a plate configuration conducive to regional extension drove diapiric upwellings that were almost immediately (within several m.y.) impacted by regional extension. Detachment faults captured the rising domes in their footwalls, resulting in more traditional kinematic evolution and geometries, with more stratigraphic omission and syn-kinematic basins (Fig. 1C).

The development of the classic North American Cordillera MCC belt was not uniquely and initially driven by regional extension because the hinterland MCCs developed before mid-Miocene plate-boundary conditions drove regional extension (Colgan and Henry, 2009). Instead, we argue that Farallon slab dynamics and subsequent mantle heating led to buoyant RT upwellings at characteristic spacings. Individual MCCs undoubtedly experienced differing Mesozoic-Cenozoic geologic histories, but as outlined here, the thickness and thermal state of the crust exerted a first-order control on the observed MCC dichotomy. Our model may be transferrable to other similar coupled subduction-intraplate settings. Mesozoic subduction in southeast China involved MCC generation following Jurassic-Cretaceous flat-slab subduction, rollback, and mantle-derived magmatism (Li and Li, 2007), similar to North America. The links between flat-slab events, subsequent rollback, magmatism, partial melting, and heat redistribution during MCC development require further evaluation.

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GSA Scientific Division Awards

ENERGY GEOLOGY DIVISION

Antoinette Lierman Medlin Scholarship

Nominations due 15 Mar.
Submit nominations to the first vice-chair.

This scholarship provides monetary support and recognition to deserving students in coal science. One award is for the completion of laboratory/analytical research (US$2,000), and a second award is presented for the completion of fieldwork (US$1,500). The fund, which is administered by the GSA Foundation, accepts contributions from personal and corporate sponsors.

Curtis-Hedberg Award

Nominations due 1 May.
Submit nominations to the Curtis-Hedberg Award chair.

The inaugural Curtis-Hedberg Award will be considered annually in accordance with the bylaws of the Society. The award will be made for outstanding contributions in the field of petroleum geology. Learn more at **community.geosociety.org/energydivision/awards/curtishedberg.**

ENVIRONMENTAL AND ENGINEERING GEOLOGY DIVISION

Distinguished Practice Award

Nominations due 31 Mar.
Submit nominations to the Division chair.

This award recognizes outstanding individuals for their continuing contributions to the technical and/or professional stature of environmental and (or) engineering geology. A nominee need not be a member of the EEGD, but must have made a major contribution to environmental and (or) engineering geology in North America. Each nomination must be accompanied by a written citation. Learn more at **community.geosociety.org/eegdivision/awards/new-item3.**

Meritorious Service Award

Nominations due 31 Mar.
Submit nominations to the Division chair.

This award recognizes outstanding service to the Environmental and Engineering Geology Division. Each nomination must be accompanied by a brief written statement indicating the outstanding service provided by the nominee.

GEOARCHAEOLOGY DIVISION

Claude C. Albritton, Jr., Award

Nominations due 15 Mar.
Submit nominations to gsa.agd@gmail.com.

The Albritton Award Fund, established with the GSA Foundation, provides scholarships and fellowships for research for graduate students in the earth sciences or archaeology. Recipients are students who have (1) an interest in achieving a master's or Ph.D. degree in earth sciences or archaeology, (2) an interest in applying earth-science methods to archaeological research, and (3) an interest in a career in teaching and academic research. Awards in the amount of US$650 are given in support of thesis or dissertation research, with emphasis on the field and/or laboratory aspects of the research. Learn more at **community.geosociety.org/geoarchdivision/home.**

Richard Hay Student Paper/Poster Award

Nominations due 1 Sept.
Submit nominations to gsa.agd@gmail.com.

The award is a travel grant for a student (undergraduate or graduate) presenting a paper or poster at GSA Connects. The grant is competitive and will be awarded based on the evaluation of the scientific merit of the research topic and the clarity of an expanded abstract for the paper or poster prepared by a student for presentation in the Division's technical session at the meeting. Learn more at **community.geosociety.org/geoarchdivision/home.**

GEOLOGY AND HEALTH DIVISION

Distinguished Career Award

Nominations due 8 Mar.

This award recognizes the recipient's lifetime contributions to the field of geology and health. The awardee does not need to be a member of the Division. Learn more at **community.geosociety.org/geologyhealthdivision/events32/upcoming-awards.**

HISTORY AND PHILOSOPHY OF GEOLOGY DIVISION

History and Philosophy of Geology Student Award

Nominations due 15 June.
Submit nominations to the Division's secretary/treasurer.

An award of US$1000 will be given to a student for a paper to be given at GSA Connects. Awards may also be given for second place. Oral presentations are preferred. Faculty advisors may be listed as second author, but not as the lead author of the paper. The proposed paper may be (1) a paper in the history or philosophy of geology, (2) a literature review of ideas for a technical work or thesis/dissertation, or (3) some imaginative aspect of the history or philosophy of geology we have not thought of before. Students should submit a n abstract of their proposed talk and a 1,500–2,000-word prospectus for consideration. Monies for the award are administered by the GSA Foundation. Learn more at **community.geosociety.org/histphildiv/awards/student.**

MINERALOGY, GEOCHEMISTRY, PETROLOGY, AND VOLCANOLOGY (MGPV) DIVISION

MGPV awards emphasize achievements in geologic and multidisciplinary approaches. Geologic work is by nature generalistic and has an important field component, with Earth as the natural laboratory. Learn more at **community.geosociety.org/mgpvdivision/home.**

MGPV Distinguished Geologic Career Award

Nominations due 31 Mar.

This award goes to an individual who, throughout their career, has made distinguished contributions in one or more of the following fields of research: mineralogy, geochemistry, petrology, volcanology, with emphasis on multidisciplinary, field-based contributions. Nominees need not be citizens or residents of the United

States, and GSA membership is not required. Learn more at **community.geosociety.org/mgpvdivision/awards/dgca.**

MGPV Early Career Award

Nominations due 31 Mar.

This award will go to an individual near the beginning of their professional career who has made distinguished contributions in one or more of the following fields of research: mineralogy, geochemistry, petrology, volcanology, with emphasis on multidisciplinary, field-based contributions. Nominations are restricted to those who are within eight years past the award of their final degree. Extensions of up to two years will be made for nominees who have taken career breaks for family reasons or caused by serious illness. Nominees need not be citizens or residents of the United States, and GSA membership is not a requirement. Learn more at **community.geosociety.org/mgpvdivision/awards/earlycareer.**

PLANETARY GEOLOGY DIVISION (PGD)

Ronald Greeley Award for Distinguished Service

Nominations due 30 June.

This award may be given to those members of the PGD, and those outside of the Division and GSA, who have rendered exceptional service to the PGD for a multi-year period. Nominations for the award, which should include a description of what the nominee has given to the PGD community, may be made by any PGD member to the management board. Learn more at **community.geosociety.org/pgd/awards/greeley.**

Shoemaker Award

Nominations due 19 Aug.

This award is for undergraduate or graduate students, of any nationality, working in any country, in the disciplines of geology, geophysics, geochemistry, astronomy, or biology. The award, which will include US$2500, is to be applied to the study of impact craters, either on Earth or on the other solid bodies in the solar system. Areas of study may include but shall not necessarily be limited to impact cratering processes; the bodies (asteroidal or cometary) that make the impacts; or the geological, chemical, or biological results of impact cratering. Learn more at **community.geosociety.org/pgd/awards/shoemaker.**

QUATERNARY GEOLOGY AND GEOMORPHOLOGY DIVISION

Farouk El-Baz Award for Desert Research

Nominations due 1 Apr.

Submit nominations to Anne Chin, ann.chin@ucdenver.edu.

This award recognizes excellence in desert geomorphology research worldwide. It is intended to stimulate research in desert environments by recognizing an individual whose research has significantly advanced the understanding of the Quaternary geology and geomorphology of deserts. Although the award primarily recognizes achievement in desert research, the funds that accompany it may be used for further research. Any scientist from any country may be nominated. Neither nominators nor nominees need be GSA members. Monies for the award are administered by the GSA Foundation. Nominations should include (1) a statement of the significance of the nominee's research; (2) a curriculum vitae; (3) letters of support; and (4) copies of no more than five of the nominee's most significant publications related to desert research. Learn more at **community.geosociety.org/qggdivision/awards/el-baz.**

Distinguished Career Award

Nominations due 1 Apr.

Submit nominations to the Division secretary.

This award goes to a Quaternary geologist or geomorphologist who has demonstrated excellence in their contributions to science. Neither nominators nor nominees need be GSA members. Nominations should include (1) a brief biographical sketch; (2) a statement of no more than 200 words describing the candidate's scientific contributions to Quaternary geology and geomorphology; (3) a selected bibliography of no more than 20 titles; and (4) a minimum of four letters from colleagues supporting the nomination. Learn more at **community.geosociety.org/qggdivision/awards/distinguished-career.**

SEDIMENTARY GEOLOGY DIVISION

Sedimentary Geology Division and Structural Geology and Tectonic Division Joint Award: Stephen E. Laubach Structural Diagenesis Research Award

Nominations due 1 Apr.

This award promotes research combining structural geology and diagenesis and curriculum development in structural diagenesis. It addresses the rapidly growing recognition that fracturing, cement precipitation and dissolution, evolving rock mechanical properties, and other structural diagenetic processes can govern recovery of resources and sequestration of material in deeply buried, diagenetically altered and fractured sedimentary rocks. The award highlights the growing need to break down disciplinary boundaries between structural geology and sedimentary petrology. Graduate students, postgraduate, and faculty-level researchers are eligible. Learn more at **community.geosociety.org/sedimentarygeologydiv/awards/Laubach.**

STRUCTURAL GEOLOGY AND TECTONIC DIVISION

Career Contribution Award

Nominations due 1 Mar.

This award is for an individual who, throughout their career, has made numerous distinguished contributions that have clearly advanced the science of structural geology or tectonics. Nominees need not be U.S. citizens or residents, and GSA membership is not required. Nominations should include the following: (1) name of nominee, present institutional affiliation, and address; (2) summary statement of nominee's major career contributions to the science of structural geology and tectonics; (3) selected key published works of the nominee; and (4) the name and address of nominator. Learn moire at **community.geosociety.org/sgt/awards/careercontribution.**

Outstanding Publication Award

Nominations due 1 Mar.

This award is given annually for a published work (paper, book, or map) of exceptional distinction that clearly advances the science of structural geology or tectonics. Nominations include (1) a full citation; (2) nomination (as short as a paragraph; letters or reviews may also be included); and (3) the name and address of the nominator. Learn more at **community.geosociety.org/sgt/awards/outstandingpublication.**

In Memoriam

The Society notes with regret the deaths of the following members (notifications received between 3 Oct. 2022 and 21 Dec. 2022). Memorials to deceased members are published open access at **www.geosociety.org/memorials.** Visit that page for links to information on how to honor someone with a memorial.

Charles S. Bartlett Jr.
Cary, North Carolina, USA
Date notified: 13 Oct. 2022

Robert O. Beringer
Ventura, California, USA
Date notified: 19 Oct. 2022

Paul R. Carlson
Palo Alto, California, USA
Date of death: 17 Feb. 2021

Kenneth L. Cole
Flagstaff, Arizona, USA
Date of death: 2 Oct. 2022

James F. Conley
Troy, Virginia, USA
Date of death: 4 Nov. 2021

Sarah E. Crump
Salt Lake City, Utah, USA
Date of death: 18 Nov. 2022

Edward J. Cushing
Saint Paul, Minnesota, USA
Date of death: 19 July 2022

Jerome J. Cuzella
Lakewood, Colorado, USA
Date of death: 24 Nov. 2022

Stefan H. Duerr
Mainz, Germany
Date of death: 27 Mar. 2022

Mary C. Eberle
Boulder, Colorado, USA
Date of death: 5 Nov. 2022

Olav Eldholm
Bergen, Norway
Date of death: 18 Mar. 2022

Dale L. Erlandson
The Woodland, Texas, USA
Date notified: 19 Oct. 2022

Andrew J. Flurkey
Richmond, Texas, USA
Date of death: 14 Sept. 2022

Richard J. Gentile
Kansas City, Missouri, USA
Date of death: 1 June 2022

Donald W. Groff
Brookfield, Connecticut, USA
Date of death: 19 Aug. 2022

Jutta Lore Hager
Woburn, Massachusetts, USA
Date of death: 14 Aug. 2022

Gilmor S. Hamill IV
Moraga, California, USA
Date notified: 28 Nov. 2022

B. Carter Hearn Jr.
Reston, Virginia, USA
Date of death: 2 May 2022

Richard C. Heathcote
Des Moines, Iowa, USA
Date of death: 21 Nov. 2022

Anne E. Henry
Dayton, Ohio, USA
Date of death: 6 Nov. 2022

Robert D. Higgins
Lakewood, Colorado, USA
Date notified: 10 Nov. 2022

Allan James
Lincoln, California, USA
Date of death: 3 Dec. 2022

E.A. Keller
Santa Barbara, California, USA
Date of death: 9 Sept. 2022

Les J. LaFountain
Monrovia, California, USA
Date of death: 13 Aug. 2022

Charles R. Lewis
Cazenovia, New York, USA
Date notified: 4 Oct. 2022

Gloria A. Linder
Gilroy, California, USA
Date of death: 6 July 2022

James M. Mattinson
Goleta, California, USA
Date notified: 7 Oct. 2022

Winthrop D. Means
Albany, New York, USA
Date of death: 7 Oct. 2022

Thomas Meixner
Tucson, Arizona, USA
Date of death: 5 Oct. 2022

Robert Calvin Milici
Charlottesville, Virginia, USA
Date of death: 18 Aug. 2022

Gerald A. Nicoll
Santa Ana, California, USA
Date of death: 17 Aug. 2022

Antony R. Orme
Woodland Hills, California, USA
Date notified: 7 Oct. 2022

H.C. Palmer
London, Ontario, Canada
Date of death: 1 July 2022

A.R. (Pete) Palmer
Boulder, Colorado, USA
Date of death: 24 Oct. 2022

Fred Peterson
Morrison, Colorado, USA
Date of death: 1 Mar. 2019

John R. Ritter
Gainesville, Florida, USA
Date of death: 1 Jan. 2022

Richard E. Schofield
Abilene, Texas, USA
Date of death: 19 Mar. 2022

William A. Thomas
Tuscaloosa, Alabama, USA
Date of death: 30 Sept. 2022

Spencer R. Titley
Tucson, Arizona, USA
Date of death: 18 Aug. 2019

Tracy L. Vallier
Coos Bay, Oregon, USA
Date of death: 28 Aug. 2022

Doug Yule
Northridge, California, USA
Date of death: 1 Oct. 2022

My Experience at the GSA Connects Meeting as an On To the Future (OTF) Awardee

Godspower Ubit

Winning the On To the Future (OTF) award three weeks before arriving to the United States to begin my graduate studies was the second most extraordinary moment of 2022. I can remember checking my email at about 10:30 p.m. (Nigerian local time) and reading the golden words "It is my pleasure to...." and screaming at the top of my voice with glee and waking my parents. At that point, I realized that my wait to attend my first conference in person was no longer a fairytale, but a reality. The plan to participate in the conference started by connecting with folks using the community tab on the GSA website for shared accommodation and rides. I linked up with numerous people during this time and made plans to meet them during the conference.

Fast-forward to the 7th of October: I arrived in Denver where I took a train ride (the first ever in my life). I had accommodations that I shared with two other people who are now good friends of mine. On the first day, I attended the OTF professional development workshop short course. I learned about the different trajectories people take to get to where they are in the geosciences. Through group work, hands-on exercises, and discussions, I realized that having a fulfilling geoscience career isn't always linear and everyone has a different story to tell. This short course reflected the full spectrum of diversity and inclusion and the attendees had different nationalities, ethnicities, and the mentors came from a variety of work sectors (academia and industry).

I got to meet and connect with numerous people with whom I still talk occasionally to this day. The OTF breakfast and networking sessions each morning were helpful as the presentations were well thought out and targeted toward our broad goals and interests. The icebreaker on the first day of the conference was terrific, and I ended the day with numerous business cards and contacts from consultants and professors.

The poster sessions were incredible for me because I got to make new friends and got updates about recent trends, techniques, and tricks within my research niche and the general world of geology. The GeoCareers Day, presidential dinner, research awards night, and reception were other events that I enjoyed immensely. I also learned how I could get involved as a student volunteer and I am currently in the process of serving in GSA's Continental Scientific Drilling Division.

The meeting was a very successful experience for me. It helped to clarify the academic trajectory I would expect as a graduate student and eventually as a university professor. So far, I can tell I received excellent advice on having a rewarding graduate school journey by using good time- and project-management skills, maintaining a work-life balance, and learning how frequently I should publish and/or present my research. I am also aware of other career opportunities available for doctorate students in the geosciences besides academia. At the meeting, I connected with a fellow graduate student and am currently exploring a future research collaboration. Also, I was made aware of information about fellowships and grants available to international students and how to access them.

I listened to both experts and students and learned about their life stories and how they navigated through their challenges. I connected and exchanged ideas with fellow students, postdocs, and experts. I now have mentors who periodically help me with advice, especially toward achieving my academic and professional goals. Thank you so much GSA for the OTF award. Attending GSA Connects 2022 has put me on the right path toward completing my Ph.D. and having a successful career.

ON TO THE FUTURE
Celebrating 10 years!

J. David Lowell Field Camp Scholarships

GSA and the GSA Foundation are proud to announce that J. David Lowell Field Camp Scholarships will be available to undergraduate geology students for the summer of 2023. These scholarships will provide students with US$2,000 each to attend the field camp of their choice. Additionally, awardees will be gifted with a Blue Standard Transit by Brunton.

Applications are reviewed based on diversity, economic/financial need, and merit. **Application deadline:** 31 Mar. 2023.

Learn more at **www.geosociety.org/field-experiences**.
Questions? Contact Jennifer Nocerino, jnocerino@geosociety.org.

Lauren Cannon, a 2022 J. David Lowell Field Camp Scholarship awardee.

GSA FOUNDATION

THE GEOLOGICAL SOCIETY OF AMERICA®

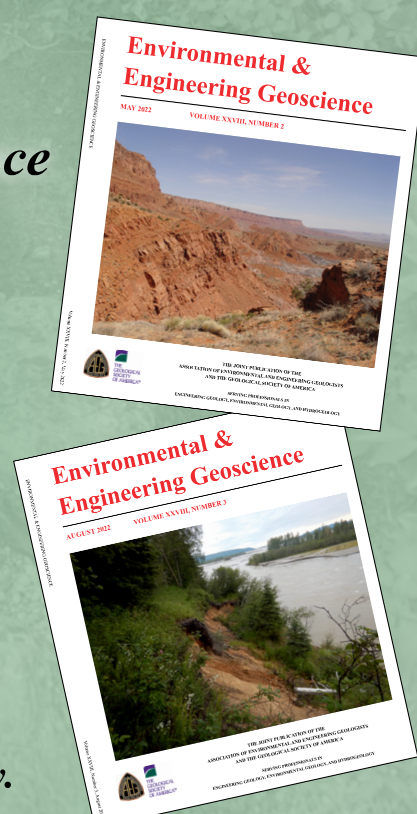
BRUNTON®

Submit Your Research to *Environmental & Engineering Geoscience*

Environmental & Engineering Geoscience (E&EG) is a joint publication of the Association of Environmental & Engineering Geologists (AEG) and the Geological Society of America. The journal is published quarterly and hosted at GeoScienceWorld (https://pubs.geoscienceworld.org/eeg).

E&EG publishes peer-reviewed, high-quality original research, case studies, and technical notes (manuscripts of fewer than 10 pages) on environmental geology, engineering geology, engineering geophysics, geotechnical engineering, geomorphology, low-temperature geochemistry, applied hydrogeology, and near-surface processes.

For more information and to submit your paper, visit the *E&EG* manuscript submission platform at **www.editorialmanager.com/eeg/.** Be sure to read the Style Guide for Authors, which contains valuable information about the topics and types of manuscripts they're looking for, as well as how to prepare your manuscript for submission and what to expect from the review, revision, and publication processes.



Make GSA Publications the next step on your journey.

Help Shape the Future of Geoscience— Serve on a Committee!

Deadline: 15 June 2023
Terms begin 1 July 2024

If you are looking for the opportunity to work toward a common goal, give back to GSA, network, and make a difference, then we invite you to volunteer (or nominate a fellow GSA member) to serve on a Society committee or as a GSA representative to another organization.

Learn more and access the nomination form at **www.geosociety.org/Committees.** Open positions and qualifications are online at **https://rock.geosociety.org/forms/viewopenpositions.asp.** GSA headquarters contact: Darlene Williams, dwilliams@geosociety.org.

COMMITTEE	NUMBER OF VACANCIES	POSITION TITLE & SPECIAL REQUIREMENTS	TERM LENGTH
Academic and Applied Geoscience Relations Committee	1	Member-at-Large Industry	3
Annual Program Committee	1	Member-at-Large	4
Arthur L. Day Medal Award Committee	2	Members-at-Large	3
Council Officers	5	President-Elect	3
		Treasurer	3
		Councilors	4
Diversity in the Geosciences Committee	3	Members-at-Large	3
Education Committee	1	Undergraduate Student Representative	2
Geology and Public Policy Committee	2	Members-at-Large	3
GSA International	4	Members-at-Large	4
		Member-at-Large, outside North America	4
		Member-at-Large Student	2
Membership and Fellowship Committee	1	Member-at-Large Industry	3
Nominations Committee	2	Members-at-Large	3
North American Commission on Stratigraphic Nomenclature	1	GSA Representative	3
Penrose Medal Award Committee	2	Members-at-Large	3
Penrose Conferences & Thompson Field Forums Committee	3	Members-at-Large	3
		Member-at-Large, Early Career Scientist	3
Professional Development Committee	1	Member-at-Large	3
Research Grants Committee	14	Members-at-Large (various specialties)	3
Young Scientist Award (Donath Medal) Committee	1	Member-at-Large	3

GSA Elections Begin 8 March 2023

GSA's success depends on you—its members—and the work of Officers and Councilors serving on GSA's Executive Committee and Council. Notice of the election will be posted on the secure GSA website with instructions for accessing the online ballot. You will receive an electronic voting reminder. When the ballot opens, information on the candidates will be available online for review. Paper versions of the ballot and candidate information are also available upon request. Please help continue to shape GSA's future by voting on these candidates. Ballots must be submitted electronically or postmarked by 7 April 2023.

We congratulate our incoming president who was elected by GSA membership in 2022.

PRESIDENT
(July 2023–June 2024)

Christopher (Chuck) M. Bailey
Professor, Dept. of Geology
William & Mary
Williamsburg, Virginia, USA

2023 Officer and Council Candidates

VICE PRESIDENT/ PRESIDENT-ELECT
(July 2023–June 2025)

Carmala N. Garzione
Professor and Dean, College of Science
University of Arizona
Tucson, Arizona, USA

TREASURER
(July 2023–June 2024)

Brian G. Katz
Environmental Consultant
Weaverville, North Carolina, USA

COUNCILOR POSITION 1
(July 2023–June 2027)

Craig H. Jones
Professor, Dept. of Geological Sciences
Fellow, Cooperative Institute for Research in Environmental Studies
University of Colorado
Boulder, Colorado, USA

Stephen E. Laubach
Senior Research Scientist, Bureau of Economic Geology
Jackson School of Geosciences
University of Texas
Austin, Texas, USA

COUNCILOR POSITION 2
(July 2023–June 2027)

Jessica Creveling
Associate Professor, College of Earth, Ocean, and Atmospheric Sciences
Oregon State University
Corvallis, Oregon, USA

Patricia Persaud
Associate Professor, Department of Geosciences
University of Arizona
Tucson, Arizona, USA

COUNCILOR POSITION 3—DIVISIONS LIAISON
(July 2023–June 2027)

Nicholas P. Lang
Discipline Scientist, NASA Planetary Science Division
Professor and Chair, Dept. of Geology
Mercyhurst University
Erie, Pennsylvania, USA

Gary E. Stinchcomb
Associate Professor, Dept. of Earth Sciences
The University of Memphis
Memphis, Tennessee, USA

GeoCareers Programs at the 2023 Section Meetings

GEOSCIENCE CAREER WORKSHOPS

Part 1: Career Planning and Networking. Your job-hunting process should begin with career planning, not when you apply for jobs. This workshop will help you begin this process and practice your networking skills. Highly recommended for freshmen, sophomores, and juniors—the earlier you start your career planning the better.

Part 2: Geoscience Career Exploration. What do geologists in various sectors earn? What do they do? What are the pros and cons of working in academia, government, and industry? Workshop presenters and professionals in the field will address these issues.

Part 3: Cover Letters, Résumés, and CVs. How do you prepare a cover letter? Does your résumé need a good edit? Whether you are currently in the market for a job or not, learn how to prepare the best résumé possible. You will review numerous examples to help you learn important résumé dos and don'ts.

MENTOR PROGRAMS

GSA student members will have the opportunity to discuss career prospects and challenges with applied geoscientists from various sectors. Not a member? Join at **www.geosociety.org/join** today!

South-Central Section Meeting
13–14 March, Stillwater, Oklahoma, USA
Shlemon Mentor Program: Monday, 13 March
Mann Mentors in Applied Hydrology Program: Tuesday, 14 March

Southeastern & Northeastern Joint Section Meeting
17–19 March, Reston, Virginia, USA
Shlemon Mentor Program: Friday, 17 March
Mann Mentors in Applied Hydrology Program: Saturday, 18 March

North-Central Section Meeting
4–5 May, Grand Rapids, Michigan, USA
Shlemon Mentor Program: Thursday, 4 May
Mann Mentors in Applied Hydrology Program: Friday, 5 May

Cordilleran Section Meeting
17–19 May, Reno, Nevada, USA
Shlemon Mentor Program: Wednesday, 17 May
Mann Mentors in Applied Hydrology Program: Thursday, 18 May

Rocky Mountain Section Meeting
23–25 May, Fort Collins, Colorado, USA
Shlemon Mentor Program: Tuesday, 23 May
Mann Mentors in Applied Hydrology Program: Thursday, 25 May

THE GEOLOGICAL SOCIETY OF AMERICA®

Mark Your Calendar for Meetings Closer to Home

South-Central Section

13–14 March
Stillwater, Oklahoma, USA
Todd Halihan, todd.halihan@okstate.edu
www.geosociety.org/sc-mtg

Edmon Low Library, Oklahoma State University.
Photo credit: rseigler0 from Pixabay.

Joint Southeastern & Northeastern Sections

17–19 March
Reston, Virginia, USA
Arthur Merschat, amerschat@usgs.gov; Patrick Burkhart, patrick.burkhart@sru.edu
www.geosociety.org/se-mtg

Reston Town Center water fountain.
Photo credit: J. Rodysill.

North-Central Section

4–5 May
Grand Rapids, Michigan, USA
Tara Kneeshaw, kneeshta@gvsu.edu; Ginny Peterson, petersvi@gvsu.edu
www.geosociety.org/nc-mtg

L.V. Eberhard Center at GVSU. Photo credit: Amanda Pitts, University Communications, Grand Valley State University.

Cordilleran Section

17–19 May
Reno, Nevada, USA
Stacia Gordon, staciag@unr.edu
www.geosociety.org/cd-mtg

Panorama from the Mono Lake South Tufa Area.
Photo credit: Dr. Philipp Ruprecht.

Rocky Mountain Section

23–25 May
Fort Collins, Colorado, USA
Rick Aster, rick.aster@colorado.edu
www.geosociety.org/rm-mtg

Pineridge Natural Area.
Photo credit: Jan Alexander from Pixabay.

2023

Celebrating 10 Years of OTF and Looking to the Future

On To the Future (OTF) creates shared joy, and a more certain future, for OTF Scholars, OTF Mentors, and GSA overall. The joy is generated the moment new OTF Scholars step into the GSA Annual Meeting space and begin to recognize what they are a part of …scientifically, personally, and through enduring opportunities to contribute to pressing needs. —Dr. George H. Davis, GSA Past-President.

This year we celebrate the ten-year anniversary of On To the Future, GSA's diversity initiative that began during the Society's 125th anniversary year. The program supports students from groups underrepresented in the geosciences to attend GSA Connects by offering partial travel funding, meeting registration, one-year GSA membership, one-to-one mentorship, and special sessions with leadership during the meeting.

Dr. Marjorie Chan, who was instrumental in establishing OTF, reflects: "It's hard to believe it was a decade ago that the On To the Future program started. I was chair of GSA's Diversity Committee, and we saw a need for positive actions to increase diversity in GSA. We were fortunate to have the convergence of a great committee, with the support of Wes Ward (GSA Foundation Board), George Davis (GSA President), GSA staff, and many others. We proposed the OTF program to coincide with GSA's 125th anniversary, and Wes Ward had the brilliant idea to use the first letters of the anniversary numbers (One Two Five), which we called On To the Future. I crafted the proposal to the GSA Foundation emphasizing the importance of this initiative to the future of GSA, and subsequently, George Davis invited me to present the program to the GSA Council. I distinctly remember turning to GSA Division reps during the presentation and saying: 'You've been saving money for a rainy day, and the rainy day is now! You need to open up those purses and spend it on supporting this program if you want to continue having a vital GSA membership in the future.' The Divisions and the Foundation responded positively, and OTF was launched."

Dr. Marjorie Chan addresses the first OTF group in 2013.

The 2019 OTF group.

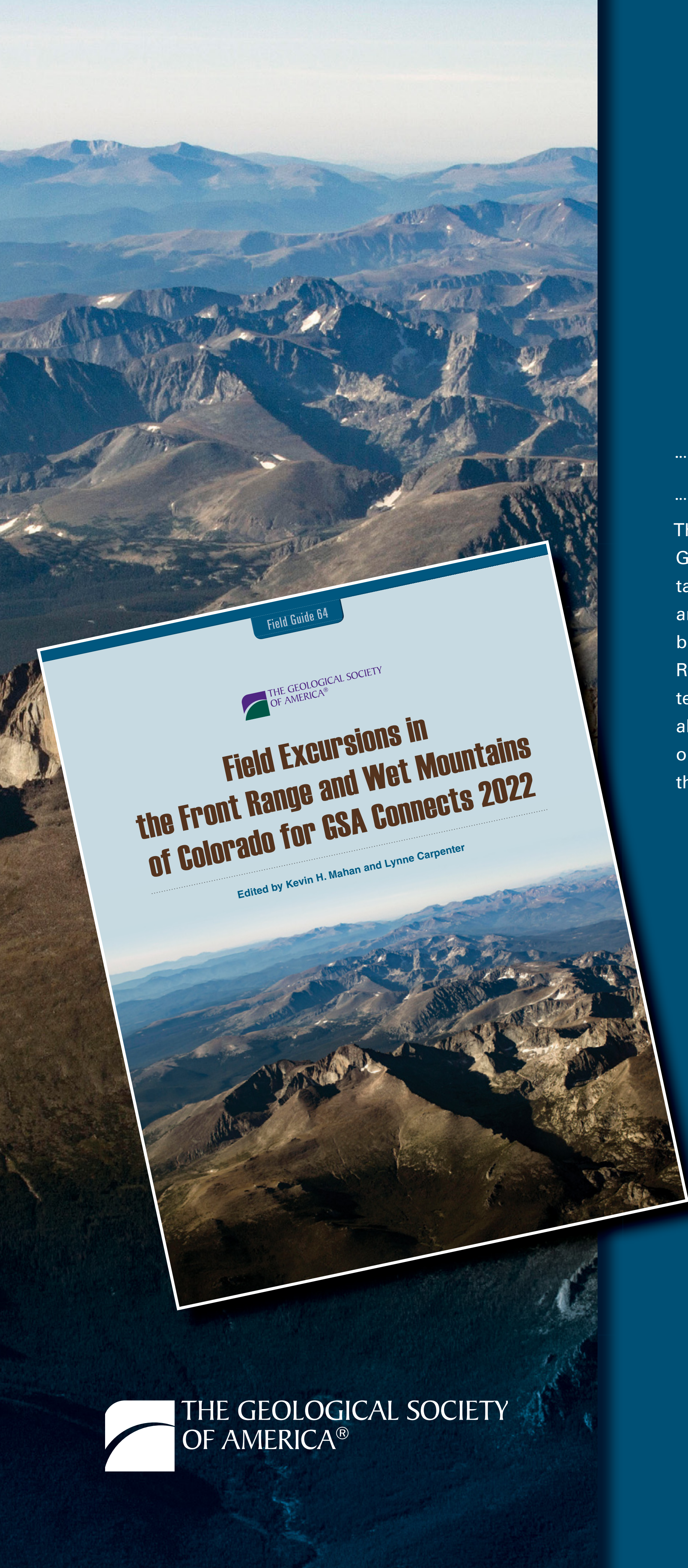
Marjorie also recalls two very moving experiences from the first OTF cohort: "I asked one of the OTF participants about their experience, and the response was: 'It has totally changed my perspective and I feel empowered!' Wow, that was exactly the response we wanted and I knew from that, OTF was destined for success. At the closing of that meeting, one of the Indigenous participants shared a traditional blessing for us with eyes closed and no cell phones or recordings. In the quiet of the early morning, his melodious voice reverberated in the hall where we were gathered. It was indeed unique and memorable!"

Every OTF cohort has had a special and impactful experience at GSA's annual meetings. You can read about many of these experiences on the Foundation blog: https://gsa-foundation.org/news-events/.

As we look back in celebration of ten years of OTF, we also look to the future. The impact of OTF extends far beyond the year students participate in the program. Since its inception, more than 700 students have received OTF scholarships. Many of these recipients have had their academic and career paths shaped by the experience, including the current chair of GSA's Diversity Committee, Dr. Angel Garcia, Jr., who was a participant in 2015. This large cohort of OTF alumni stay in touch with one another and often, with their mentors, support each other as they continue on their career paths. We are encouraged at the program's success when some even return as mentors.

Our vision for the future of OTF is superbly expressed by Marjorie: "It is my hope that we will continue to grow and expand OTF because it enriches GSA and is an investment in our future."

We hope you will help GSA enrich the geoscience profession and community by investing in the future with support of OTF. Please visit **https://gsa-foundation.org/fund/on-to-the-future-fund/** to make a gift online. If you would like to discuss ways you can make an even greater impact, please contact Debbie Marcinkowski at dmarcinkowski@geosociety.org or +1-303-357-1047.


Field Guide 64
THE GEOLOGICAL SOCIETY OF AMERICA®
Field Excursions in the Front Range and Wet Mountains of Colorado for GSA Connects 2022
Edited by Kevin H. Mahan and Lynne Carpenter
THE GEOLOGICAL SOCIETY OF AMERICA®

Bookmark the Geoscience Job Board at **www.geosociety.org/jobs** for up-to-the-minute job postings. Job Board ads may also appear in a corresponding monthly print issue of *GSA Today*. Send inquiries to advertising@geosociety.org, or call +1-800-427-1988 ext. 1053 or +1-303-357-1053.

POSITIONS OPEN

Position Profile for President and CEO of the Phillip and Patricia Frost Museum of Science, Miami

A Unique Opportunity. Frost Science ranks as one of the top cultural organizations and most widely attended attractions in Miami. The museum averages around 650,000 visitors annually.

About the Role of President & Chief Executive Officer. The President and CEO will lead Frost Science as a world-class science museum and ensure fiscal stability, growth, and relevant programming in all aspects of its operation. The CEO has delegated authority from the Board of Trustees [https://www.frostscience.org/board-of-trustees/] to conduct the day-to-day operations of the museum and to ensure the mission of the museum is maintained for the service to the community. The CEO will work with the Board to set the strategy for planning, growth, and changes to the mission that respond to the community needs and audiences for all museum operations and programs.

The salary for this position starts at $350,000. Frost Science provides generous executive-level employee benefits including medical benefits and personal time off. Salary is competitive and commensurate with experience.

Applications will be considered beginning in February 2023 and will continue until the position is filled. More information can be found at: https://www.frostscience.org/president-and-ceo/. Confidential inquiries, nominations/referrals, and applications (including resumes and letters of interest) should be sent electronically to executivesearch@frostscience.org.

Associate or Full Professor in Planetary Atmospheres or Planetary Geology, Indiana University Bloomington

Indiana University Bloomington Department of Earth & Atmospheric Sciences invites applications for a tenured hire in Atmospheric or Earth Science with applications to planetary science. Candidates should have research interests in planetary atmospheric modeling or planetary geology with links to our existing research strengths. This hire is made in concert with another in Astronomy in exoplanet science. Preference will be given to hires at the Associate or Full Professor levels, but outstanding candidates at the Assistant Professor level with a strong record of publication and external funding will also be considered.

You can learn more about the department of Earth and Atmospheric Sciences, and about IU Bloomington, here: https://earth.indiana.edu/. Bloomington is recognized as one of the best places to live in the US, with a vibrant, active community that benefits from the metropolitan qualities of a large city and the easy pace of a small town.

Diversity, equity, and inclusion are core values of our department and of the College of Arts & Sciences, and we are especially interested in candidates who are similarly committed to nurturing diversity and inclusion, sustaining a climate of mutual respect, and fostering a collaborative and supportive academic environment wherein everyone is empowered to succeed.

IU is committed to helping its faculty successfully grow their careers. Incoming faculty have access to a year-long series of orientation programs. All faculty at IU are encouraged to better support student success by engaging with the Center for Innovative Teaching and Learning. And all faculty have access to Proposal Development Services, which is staffed by Ph.D. researchers with track records of success in obtaining external funding, for in-depth support in the proposal writing process.

Apply online at http://indiana.peopleadmin.com with a cover letter, a CV a statement on research and teaching, and a statement on fostering diversity, equity, and inclusion in and out of the classroom, as well as contact information for three letters of reference. Review of applications will begin immediately and continue until the positions are filled. Queries can be sent to department chair David Polly (easchair@indiana.edu).

Before a conditional offer of employment with tenure is finalized, candidates will be asked to disclose any pending investigations or previous findings of sexual or professional misconduct. They will also be required to authorize an inquiry by Indiana University Bloomington with all current and former employers along these lines. The relevance of information disclosed or ascertained in the context of this process to a candidate, eligibility for hire will be evaluated by Indiana University Bloomington on a case-by-case basis. Applicants should be aware, however, that Indiana University Bloomington takes the matters of sexual and professional misconduct very seriously.

Indiana University is an equal employment and affirmative action employer and a provider of ADA services. All qualified applicants will receive consideration for employment based on individual qualifications. Indiana University prohibits discrimination based on age, ethnicity, color, race, religion, sex, sexual orientation, gender identity or expression, genetic information, marital status, national origin, disability status or protected veteran status.

OPPORTUNITIES FOR STUDENTS

Postdoctoral Researcher, Modeling CO_2 Storage in the Deep Aquifers of The Negev Desert (Israel), Geological Survey of Israel

We are looking for enthusiastic postdoctoral researcher for a funded project on modeling CO_2 storage in the deep aquifers of the Negev Desert (Israel).

In the research, we will use state-of-the-art numerical tools to simulate flow & transport of injected CO_2 to evaluate storage capacity, trapping efficiency and related properties.

Minimum Requirements:

- Ph.D. in geosciences (hydrology, geology, soil sciences, environment, etc.)
- Experience in modeling flow & transport in porous media or related fields

Please contact: Dr. Ravid Rosenzweig, The Geological Survey of Israel rravid@gsi.gov.il

Wilkes University Summer Geology Field Camp 2023

Wilkes University is offering a five-week, intensive, project-focused, international field camp located on the island of Newfoundland, Canada, open to upper-level geoscience students from any college or university. Newfoundland offers a unique cross-section of major crustal segments that comprise the Appalachian mountain belt. Field-camp curriculum is designed to meet the requirements of most undergraduate geology B.S. programs and many state professional licensure programs. For more information, or to apply, visit https://www.wilkes.edu/fieldcamp.

“Natural Disaster(s)”: Going Back to the Roots of Misleading Terminology. Insights from Culturomics

Fabrizio Terenzio Gizzi, *Institute of Heritage Science, National Research Council (ISPC-CNR), C.da S.Loja, 85050 Tito, Potenza, Italy*

MOTIVATIONS

The noun *disaster* (1590s) comes from the French *désastre* (1560s), from the Italian *disastro*, which derives from *dis-* (ill) and *astro* (star), literally “ill-starred”; the term *astro* results from the Latin *astrum*, which in turn arises from the Greek *astron* (Harper, 2001).

The United Nations Office for Disaster Risk Reduction (UNDRR, formerly UNISDR) defines a disaster as “a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts” (UNDRR, 2020). Furthermore, according to the World Bank “unnatural disasters are deaths and damages that result from human acts of omission and commission” (World Bank–United Nations, 2010). These statements clarify that disasters are the result of a complex interaction between hazardous events (e.g., earthquakes) and the vulnerability of the social system, due to *human choices*. Therefore, the adjective “natural” misrepresents the formal meaning of “disaster.”

The unnatural character of disasters has been dealt with at least since the mid-eighteenth century after the great 1755 Lisbon earthquake and downward through the discussion of the scientific community that began in the 1930s through the 1970s, and is still active today (Ball, 1975; Gaillard et al., 2007; Gould et al., 2016).

Nonetheless, the expression “natural disasters” is still used by politicians, media, international organizations, and scientists posing possible concrete implications, such as lowering the sense of human responsibility (Chmutina and von Meding, 2019) and influencing people to believe that (“natural”) disasters are ineluctable. That might adversely affect disaster preparedness. However, online initiatives and campaigns try to discourage the use of this expression (“#NoNaturalDisasters” web or Twitter campaigns). Additionally, the UNISDR banned the terminology from official communications in 2018 (Chmutina and von Meding, 2019).

Is it possible to infer when and how this (improper) lexicon developed? To try to answer this question, we asked for help from culturomics, a form of computational lexicology that studies human culture and human behavior based on the analysis of large digital data sets resulting from the collection, digitization, and indexing of a huge amount of words contained in printed works. We used the Ngram Viewer search engine, the free lexicometric tool developed by a team at Google Books (Michel et al., 2010).

GOOGLE NGRAM VIEWER (GNV): FEATURES AND SHORTCOMINGS

GNV allows anyone to make queries about the frequency and evolution of terms in several languages over time, based on the world’s most comprehensive index of books that is Google Books. However, the quality of the data set only becomes adequately large to be used for scientific purposes by the year 1800 (Michel et al., 2010).

GNV shows the frequency of words or phrases (n-grams) in a graph. A “1 g” is defined as a string of characters uninterrupted by a space and an n-gram as a sequence of 1 g. Therefore, the *x*-axis of GNV displays the year in which books from the selected language corpus were published, the *y*-axis represents the frequency with which GNV graphs the percentage of each word in each year by dividing the number of instances of the word in a particular year by the total number of words in that year (Michel et al., 2010). However, some shortcomings have to be considered, such as errors related to the optical scanning and metadata (e.g., date), unsystematic material, and doubles.

APPLICATION TO “NATURAL DISASTER(S)”

We searched for a 2 g *natural disaster(s)* [ND(s)] in the American English (2019) corpus from 1900 to 2019. Data was downloaded and analyzed on 9 Oct. 2021. Before 1900, GNV only provides a few results, most of which have inconsistent metadata. The oldest book is a sermon published in 1724.

Figure 1 shows that the two bi-grams begin to emerge since the 1930s and progressively increase over the entire period, especially NDs, even if with significant rises and falls. For NDs, the lowest peak is in the second half of the 1940s; the highest peak is in the second half of the first decade of the 2000s. Overall, the frequency of bi-gram(s) has decreased over the past decade and beyond.

The search results related to NDs were also analyzed to identify both the typology and authors of the books as well as the main topic of each document. The analysis was performed for each of the five periods in which GNV automatically groups the results: 1900–1967 (I period, includes the lowest peak), 1968–2006 (II, highest peak), 2007–2010 (III), 2011–2014 (IV), and 2015–2019 (V) (Fig. 1).

In the first time window (1900–1967), the results mostly (~60%) refer to official publications of international organizations (e.g., United Nations and its specialized agencies, such as UNESCO), institutions, different and short-lived U.S. civil defense agencies, documents of the legislative bodies of the U.S. (the Senate and the House of Representatives), and the related commissions still active or defunct, documents of the U.S. federal departments or the U.S. State Department, and codes of laws of both the U.S. and individual states.

The subject matter of these publications embraces annual statistics of disasters and their consequences in epidemiological, social, and economic terms; disaster relief in

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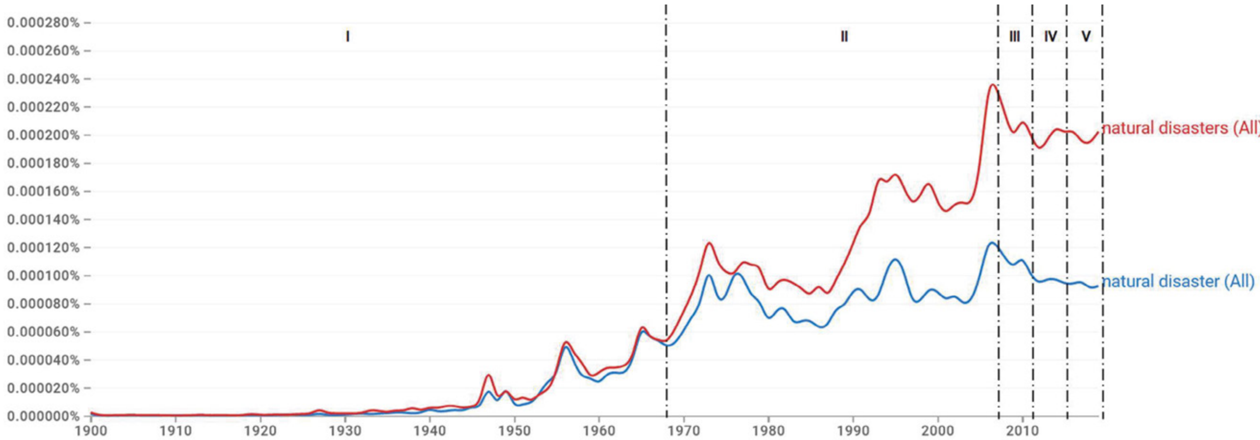

Figure 1. Frequency of "natural disaster(s)" (NDs) over time (smoothing is zero). The graph also shows the five periods in which Google Ngram Viewer (GNV) splits the NDs trend (modified from GNV). I—1900–1967; II—1968–2006; III—2007–2010; IV—2011–2014; V—2015–2019.

civil and agricultural sectors; disaster recovery and disaster prevention actions; and organization of civil defense systems. Among the remaining search results, we found magazines and articles published in scientific journals and conference proceedings as well as books whose topics are mainly history, geography, economy, and religion.

In the second period (1968–2006), the results include official publications and proceedings of conferences organized by institutions, governmental bodies or agencies, both U.S. and international organizations and associations, and so on. Again, among the issues of these publications there are statistics of disasters and their consequences. These items cover ~17% of the period, with a clear reduction compared to the first period. Indeed, most documents are books written by individual or multiple authors covering many areas such as natural science, philosophy, and religion. In the third period (2007–2010) and in the fourth and fifth periods (2011–2019), documents of official bodies and international organizations decrease further, being clearly a minority (between 4% and 7%) once compared to books, whose subjects are similar to those of the second period.

DEDUCTIONS

Culturomics can assist us in identifying the change in lexicon over time. Research points out that the terminology "natural disaster(s)" appears in books published in English in the U.S. since the 1930s, with an increase over time. Furthermore, the expression "natural disasters" seems to have had origin from institutions, bodies with public function, and international organizations. From the 1930s on, the terminology expanded, gaining importance in the lexicon of different fields of knowledge in which official documents (e.g., disaster statistics) probably played an important role as direct sources of disaster information. Over the past decade and beyond, the frequency of the expression has decreased, probably influenced by the growing skepticism about the (mis)use of the terminology and the long wave of reduced use of the phrase in official documents since the 1970s.

However, as the literature suggests (e.g., Brandt, 2018), the limitations of GNV imply that these findings have to be considered as a starting point of further research and not a landing point. Therefore, future research should involve other disciplines of social sciences and humanities, including business and administration (e.g., public and institutional administration, insurance) and the history of institutions.

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A New Tool for Producing 3D Orientation Symbology for Google Earth

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Modern methods for creating geologic maps feature a digital workflow, with dedicated mapping apps for mobile devices (e.g., ArcGIS Collector, FieldMove, StraboSpot), cloud storage of data in public repositories (e.g., strabospot.org), and preparation and presentation of maps and other deliverable products via geographic information systems (GIS), such as ArcGIS, QGIS, and Google Earth. Recently, the StraboSpot field data system (Walker et al., 2019) has provided a new standard for digital data collection and curation, and the StraboSpot app is increasingly used to collect field data. Data archived at strabospot.org can be downloaded in a variety of formats, including GIS shapefiles, KMZ files, XLS files, and image JPEGs. Mapping platforms, such as ArcGIS, FieldMove, and StraboSpot, can export field data in a variety of formats, including KMZ files that can be displayed in virtual 3D terrains. Viewing field data in a virtual 3D terrain can aid in the interpretation of planar and linear features, such as lithologic contacts, faults, and fold axes. However, field data points with orientation measurements are often not satisfactorily rendered when draped or positioned over a 3D surface that has notable topographic relief. Preferable is the depiction of orientation data as symbols in the correct 3D orientation at the virtual location equivalent to where it was mapped in the field. The depiction of 3D orientation symbols for bedding, foliation, lineation, etc. (Fig. 1), can now be easily achieved with a web-based tool called Symbols.

Our initial version of Symbols uploads generic CSV files of field data to produce 3D orientation symbols as a KML file for Google Earth (Whitmeyer and Dordevic, 2020). Recently, in order to interface more seamlessly with the StraboSpot field mapping system, we developed a new version: Symbols2 (https://educ.jmu.edu/~whitmesj/GEODE/symbols2/), which uploads an XLS file of field data. XLS files produced by the StraboSpot app or other sources will often include more columns of data than are necessary for creating 3D orientation symbols. Data columns that are relevant for generating orientation symbols include: Latitude and Longitude (to position a symbol in the correct virtual location in Google Earth), Strike, Dip, Planar Feature Type, Facing (upright or overturned), Trend, Plunge, Linear Feature Type, Name (for a field data point), Date (when the field data was collected) and Notes (field notes as recorded by the geologist). Symbols2 can handle an XLS file of field data from any source by assigning column headers to the type of data in the column. Field data is included within pop-up balloons in Google Earth, which are displayed by clicking on a symbol (Fig. 1).

StraboSpot records lithologic units for field data points as Tags, and thus a StraboSpot XLS file will include several columns with headers as Tag:*unit name*. Symbols2 assigns a nominal color to each of these unit Tags, so that the orientation symbols generated will be color coded. The user can change a unit Tag color using a graphical color selector or color hex code. If preferred, a user can select a master color for all unit Tags. Other adjustable parameters for the orientation symbols include Symbol length (size of the symbols), Symbol height (height of the symbols above the Google Earth ground surface or the specified Altitude), Symbol line thickness (thickness of the symbol lines), and the Filename for the KML file that the Symbols2 tool exports. Users can group data symbols in KML folders by Unit/Formation and/or by field Location (useful if some field locations have both planar and linear data recorded). A detailed instructions file is available via a button at the upper right side

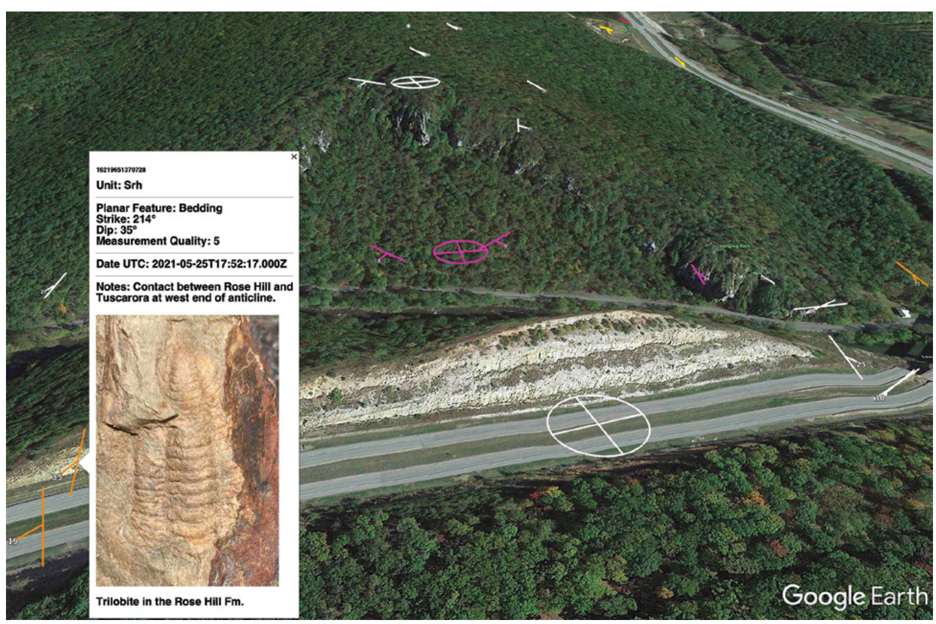

Figure 1. Oblique view in Google Earth of a hillside with 3D orientation symbols that document an anticlinal structure near Baker, West Virginia, USA. Orientation symbols depicted above the terrain were generated by StraboSpot for Symbols. Outcrop data and photos for a field location can be viewed by clicking a symbol, as shown in the rectangle at the left side of the figure.

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of the Symbols webpage and is included as a supplement to this manuscript[1].

A consideration for creating 3D symbology for Google Earth is the height (or altitude) of the symbols relative to the Google Earth ground surface. Symbols for StraboSpot defaults to positioning orientation symbols "relative to ground" at a height above the ground surface defined by the "symbol height" setting. This works well for areas with flat terrain. However, if symbols are plotted "relative to ground" in mountainous terrain, the symbols can look distorted. StraboSpot and other mapping apps can assign an elevation to point locations if the GPS tool in the mobile device is used to collect location information. Symbols2 includes an option to use elevation information in an XLS "Altitude" column, so that the orientation symbol is positioned at the "Absolute" elevation (instead of "relative to ground") plus the "symbol height" setting. If an altitude cell is blank, the orientation symbol is plotted "relative to ground." Lines and polygons are plotted "clamped to ground."

One consideration is that elevations collected by GPS receivers in mobile devices rarely match the elevation for a latitude and longitude location in the Google Earth digital elevation model (DEM). One way to correct for this discrepancy is to query Google Earth to find the DEM elevation for a specific latitude and longitude. You can do this by going to a desired location in Google Earth and reading the "elev" data from the bottom right corner of the window to update your XLS file with the altitude data for the location. This can be time consuming if you have many locations to query. Alternatively, you can automate the process in Symbols2 if you have a Google Maps API key. If "use altitude column" is selected, the user also has the option of entering their personal Google Maps API key in a field that appears below the "use altitude column" button. If a valid API key is entered, elevation data from the Google Maps DEM will be used for all points that have latitude and longitude information.

Once all parameters have been set in Symbols2 for an uploaded XLS file, a KML file with orientation symbols is generated by clicking the export button below the Tag Colors. It often takes several iterations of adjusting parameters and then evaluating the exported KML files in Google Earth to determine the preferred settings for a data set. Other outcrop information, such as field photos, can be added to the orientation symbols and placemarks in Google Earth. Images taken with the StraboSpot app can be downloaded from strabospot.org and have file names that indicate the name of the spot where the photo was taken. Photos and other imagery can be added to the pop-up balloon for a symbol in Google Earth Pro by editing the symbol placemark and adding the following text snippet to the description field:

<img src = "*URL for your image*" width = "400"></img>

Imagery added in Google Earth Pro will appear when the symbol is clicked in any version of Google Earth. However, images that are uploaded in the web version of Google Earth are stored differently and will not appear correctly in Google Earth Pro.

Once field data is represented in Google Earth by using the Symbols tools, it is fairly easy to create a digital geologic map using Google Earth's line and polygon tools. Both the web and desktop versions of Google Earth allow users to save draft/working geologic maps as KML files. Final versions of geologic maps can be exported from Google Earth Pro using the Save Image option from the file dropdown menu and from web Google Earth via a snapshot of the Google Earth window. A short guide for creating geologic maps in Google Earth is online at https://educ.jmu.edu/~whitmesj/GEODE/Creating_GE_Geologic_Maps.pdf, and an example of a virtual field mapping exercise that uses this workflow can be found at https://serc.carleton.edu/NAGTWorkshops/online_field/activities/237160.html.

We encourage readers to explore this new and easy-to-use option for displaying 3D orientation data in Google Earth, and we welcome feedback and suggestions from users for improvements to the Symbols tools.

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[1]Supplemental Material. Detailed instructions. Go to https://doi.org/10.1130/GSAT.S.21689390 to access the supplemental material; contact editing@geosociety.org with any questions.

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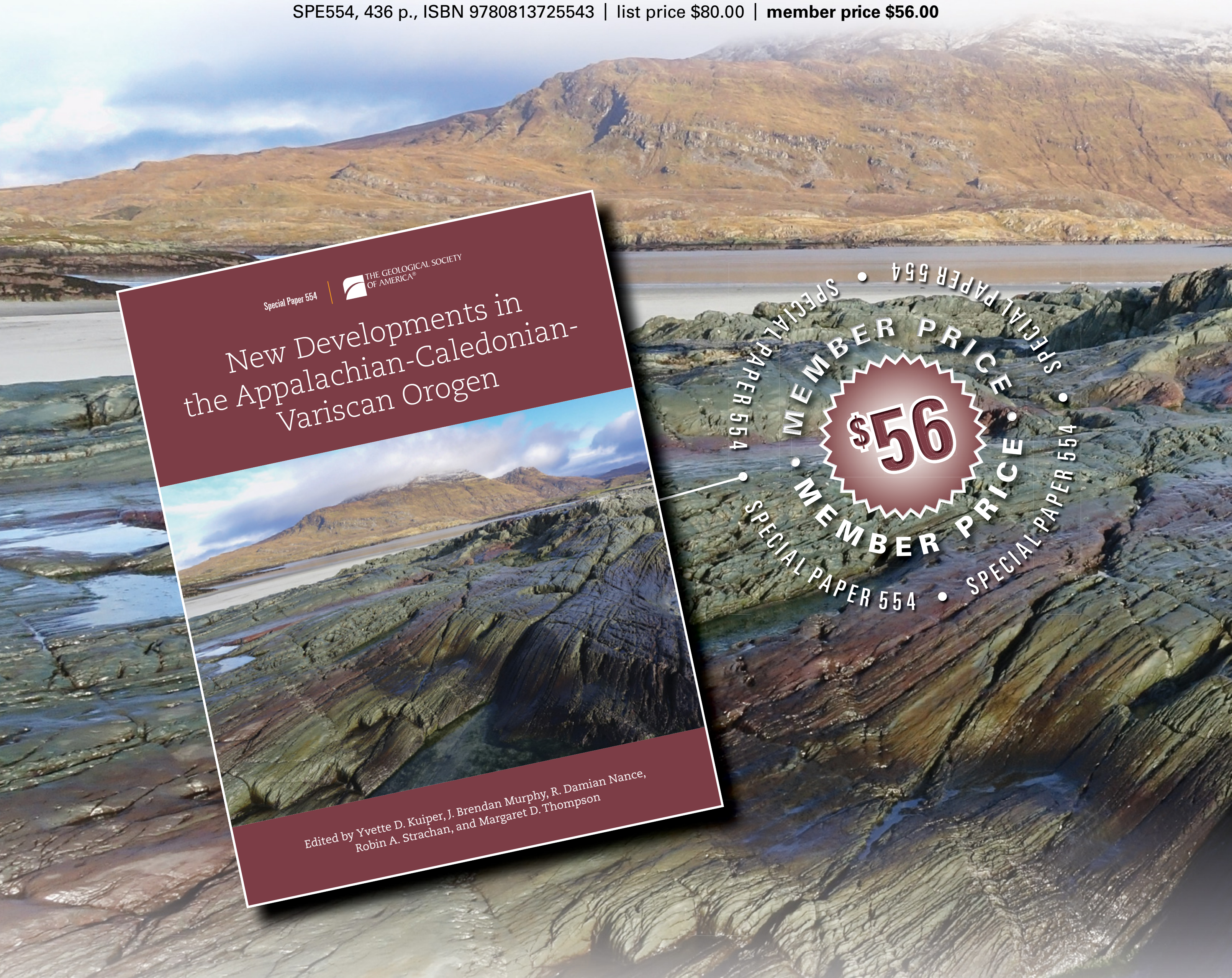

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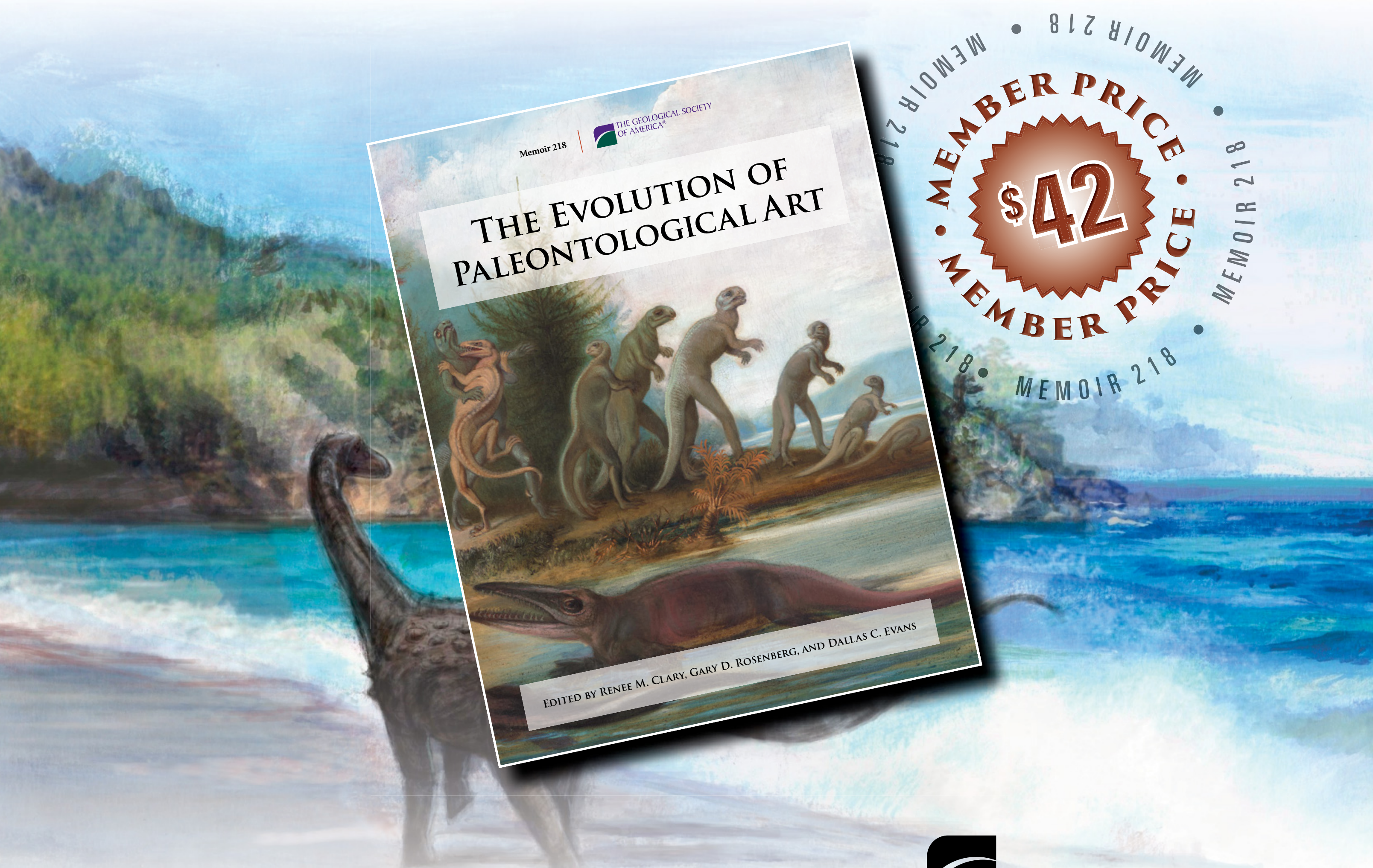

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