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Visualization and Sharing of 3D Digital Outcrop Models to Promote Open Science



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Structural and Thermal Evolution of the Himalayan Thrust Belt in Midwestern Nepal



By P.G. DeCelles, B. Carrapa, T.P. Ojha, G.E. Gehrels, and D. Collins

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Spanning eight kilometers of topographic relief, the Himalayan fold-thrust belt in Nepal has accommodated more than 700 km of Cenozoic convergence between the Indian subcontinent and Asia. Rapid tectonic shortening and erosion in a monsoonal climate have exhumed greenschist to upper amphibolite facies rocks along with unmetamorphosed rocks, including a 5–6-km-thick Cenozoic foreland basin sequence. This Special Paper presents new geochronology, multisystem thermochronology, structural geology, and geological mapping of an approximately 37,000 km² region in midwestern and western Nepal. This work informs enduring Himalayan debates, including how and where to map the Main Central thrust, the geometry of the seismically active basal Himalayan detachment, processes of tectonic shortening in the context of postcollisional India-Asia convergence, and long-term geodynamics of the orogenic wedge.

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SCIENCE

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Cover: Interactive 3D digital outcrop models (DOMs) can be shared and viewed on common devices (e.g., tablets, personal laptops, and smart phones) without specialty software. Video game engines can export customized applications for touch screen devices (top); web-based viewers can be used to stream large datasets without the need to transfer files (bottom left and right) and can be used to make measurements and interpretations directly on the DOM. See related article, p. 4–10.

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Visualization and Sharing of 3D Digital Outcrop Models to Promote Open Science

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ABSTRACT

High-resolution 3D data sets, such as digital outcrop models (DOMs), are increasingly being used by geoscientists to supplement field observations and enable multi-scale and repeatable analysis that was previously difficult, if not impossible, to achieve using conventional methods. Despite an increasing archive of DOMs driven by technological advances, the ability to share and visualize these data sets remains a challenge due to large file sizes and the need for specialized software. Together, these issues limit the open exchange of data sets and interpretations. To promote greater data accessibility for a broad audience, we implement three modern platforms for disseminating models and interpretations within an open science framework: Sketchfab, potree, and Unity. Web-based platforms, such as Sketchfab and potree, render interactive 3D models within standard web browsers with limited functionality, whereas game engines, such as Unity, enable development of fully customizable 3D visualizations compatible with multiple operating systems. We review the capabilities of each platform using a DOM of an extensive outcrop exposure of Late Cretaceous fluvial stratigraphy generated from uninhabited aerial vehicle images. Each visualization platform provides end-users with digital access and intuitive controls to interact with large DOM data sets, without the need for specialized software and hardware. We demonstrate a range of features and interface customizability that can be created and suggest potential use cases to share interpretations, reinforce student learning, and enhance scientific communication through unique and accessible visualization experiences.

INTRODUCTION

High-resolution 3D digital models are becoming increasingly common data sets in academic and commercial applications. In the geosciences specifically, digital outcrop models (DOMs), or virtual outcrops, can provide geoscientists with photorealistic models that preserve spatial precision, dimensionality, and geometric relationships between geologic features that are inherently 3D and susceptible to distortion and/or loss of information when rendered in 2D (Bellian et al., 2005; McCaffrey et al., 2005; Jones et al., 2009). Digital 3D mapping approaches using DOMs have enabled geoscientists to perform supplemental measurements, correlations, and interpretations that are difficult or impossible to obtain with traditional methods (Figs. 1–2; Pavlis and Mason, 2017; Nesbit et al., 2018).

Until recently, however, collection and use of digital data sets has been limited to specialists, due to hardware and software limitations. A number of methods are now available for collecting and processing 3D models (Hodgetts, 2013; Carrivick et al., 2016). In particular, structure-from-motion and multi-view stereo (SfM-MVS) photogrammetry software, commonly paired with uninhabited aerial vehicles (UAVs), enables geoscientists to produce photorealistic DOMs through a highly streamlined UAV-SfM workflow (Chesley et al., 2017; Nieminski and Graham, 2017; Pavlis and Mason, 2017; Nesbit and Hugenholtz, 2019).

Related efforts have centered on the development of 3D software solutions with tools for geoscience applications. Custom software packages, such as Virtual Reality Geology Studio (VRGS; Hodgetts et al., 2007) and LIME (Buckley et al., 2019), offer users lightweight executable tools and

opportunities to analyze and revisit data at multiple scales. Open source programs, such as Blender and CloudCompare, can be used for data exploration and measurement and have also integrated specific geoscience toolsets (e.g., Brodu and Lague, 2012; Dewez et al., 2016; Thiele et al., 2017).

Although acquiring DOMs has become more straightforward, and various 3D analysis programs are available, dissemination of DOMs, interpretations, and results has remained a challenge due to software and file-size barriers. Specialty 3D programs are often hindered by product licensing and can involve a considerable learning curve to understand controls, file formats, and integrated tools. Furthermore, DOMs can easily exceed multiple gigabytes (GB) in size, which can be taxing on computational resources for rendering, file storage, and data transfer. With the growing collection of high-resolution DOMs and similar 3D data sets, there is a need for dedicated, intuitive, and accessible 3D visualization platforms.

Given the challenges outlined above, we examined existing visualization solutions that could potentially enable sharing of DOMs and support open science through increased data accessibility. To provide a functional introduction to modern visualization platforms, we illustrate the capabilities and functionality of two web-based interfaces (Sketchfab and potree) and a cross-platform videogame engine (Unity) using a geologic case study. A DOM was produced through a UAV-SfM workflow for an extensive outcrop (1 km²) exposed within the badland landscape of Dinosaur Provincial Park (Alberta, Canada). Each visualization platform provides access to the large DOM through an intuitive lightweight interface without the need for high-end hardware,



Figure 1. Geologic interpretations (line drawing on 2D field photograph), a common conventional method to highlight stratigraphic architecture and distribution of related units. Mudstones are gray to light brown; sandstones are light gray to white. This process is often performed on photos or a photomosaic acquired in the field.

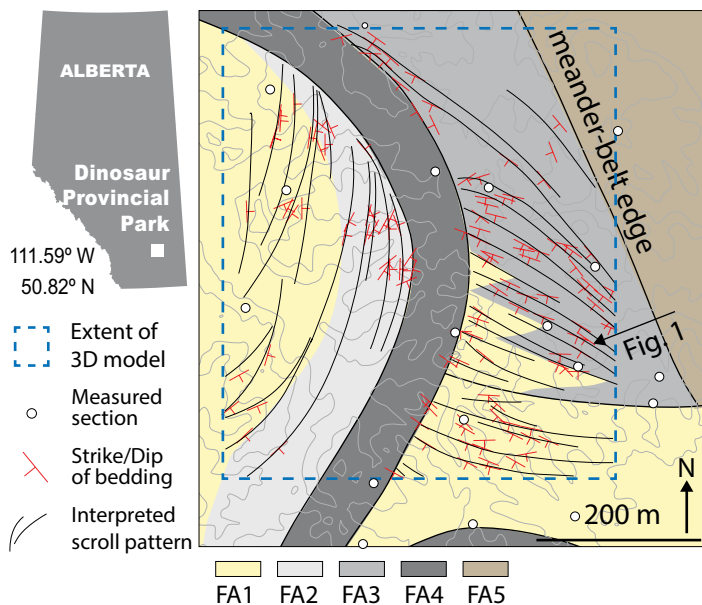


Figure 2. Traditional geologic map used to share field measurements, observations, and interpretations in 2D plan-view. This geologic map was constructed from the integration of traditional fieldwork methods (measured sections as well as paleoflow and bedding measurements) with digital outcrop model mapping to characterize heterolithic channel-belt deposits exposed at Dinosaur Provincial Park, southeastern Alberta, Canada. Field-based Facies Associations (FA)1—sandy point bar; FA2—heterolithic point bar; FA3—Counter-point bar; FA4—abandoned channel; FA5—mudstone. Bedding surfaces, noted in Figure 1 (red), were digitally mapped on the 3D model and yield a more refined and detailed interpretation of accretion surface orientation and stratigraphic architecture. These methods are being widely applied, yet the results are difficult to disseminate and share in 3D.

specialized software, or transfer and storage of large files. This prompts an increased ability to share data sets, interpretations, and results with a wider community, expanding opportunities for scientific communication and open science education.

RELATED WORK

Visualization of digital 3D models has been practical for more than two decades; however, early geoscience applications were typically restricted to dedicated geovisualization labs and required specialized software (e.g., Thurmond et al., 2006; Jones et al., 2009; Bilke et al., 2014). Today, visualization of large 3D data sets is no longer limited to sophisticated labs, but rather an average computer can render 3D models efficiently, due in large part to inexpensive hardware, such as dedicated graphics processing units (GPUs). Despite the capabilities of modern computing hardware,

bottlenecks remain, with a lack of accessible visualization software and the need to transfer large files.

Though separate 3D viewers are available to supplement proprietary software (e.g., Trimble RealWorks, FugroViewer), they typically require local storage of large files, learning curves, and have associated licensing restrictions. Alternative applications, such as digital globes (e.g., Google Earth) are a popular method for disseminating spatial and non-spatial data in an interactive, semi-immersive environment, with intuitive controls (Goodchild et al., 2012). Digital globes have been used to create “virtual field trips” (McCaffrey et al., 2010; Simpson and De Paor, 2010; De Paor and Whitmeyer, 2011) and present 3D data sets (Blenkinsop, 2012; De Paor, 2016). Although digital globes provide tremendous benefits, displaying DOMs within digital globes requires a significant reduction of detail and results in overlay

issues relative to underlying base layers (Tavani et al., 2014).

Web-based dissemination may be one of the most promising and practical means for rapidly streaming 3D digital data sets without transferring raw data (Turner, 2006; von Reumont et al., 2013). Advances of application programming interfaces (APIs), such as WebGL, allow modern Internet browsers to access the local GPU to improve rendering of 2D and 3D graphics, without the need for plug-ins or extensions (Boutsi et al., 2019). Though not guaranteed, WebGL enables GPU functionality on various operating systems and devices (Schuetz, 2016). Several proprietary web viewers, such as Sketchfab (<https://www.sketchfab.com>), use WebGL for sharing 3D models. Proprietary web-based viewers have recently been used by geologic databases (e.g., Safari Database, <https://www.safaridb.com>; Howell et al., 2014; eRock; Cawood et al., 2019).

Web viewers based on open source code, such as potree (Schuetz, 2016), use WebGL API to efficiently render massive point clouds (>10⁹ points) in standard Internet browsers. Potree does not require end-users to install software or download large data sets (Schuetz, 2016) and has been adopted by various organizations, including the USGS, for sharing and visualizing national topographic LiDAR data sets (USGS, 2019). Similarly, OpenTopography and Pix4Dcloud provide online viewers, similar to potree, allowing subscribers to share point clouds through standard web browsers.

Alternative methods have incorporated the use of game engines to create customized geovisualizations compatible with various operating systems. Unity and Unreal Engine are two popular game development platforms that are well-documented, have vast online programming communities, and are available for free to developers producing revenue below a defined threshold. Recently, game engines have been used in the geosciences for the gamification and sharing of 3D data sets in immersive virtual reality (VR) (Bilke et al., 2014), translating ArcGIS data into a 3D environment using Unity (Robinson et al., 2015), and presenting virtual archaeological sites (Martinez-Rubi et al., 2016; Boutsis et al., 2019).

CASE STUDY: FLUVIAL STRATIGRAPHY, DINOSAUR PROVINCIAL PARK

Geological Overview

Dinosaur Provincial Park is a UNESCO World Heritage Site in southeastern Alberta, Canada, recognized for an abundance of well-preserved dinosaur fossils and characteristic badland topography (Dodson, 1971; Currie and Koppelhus, 2005). This case study presents a 1 km² subsection within the northeastern portion of the park containing extensive 3D exposures of the Late Cretaceous Dinosaur Park Formation (Wood et al., 1988; Eberth and Hamblin, 1993). Contrasting layers of siltstone and fine- to medium-grained sandstone along with the stratigraphic architecture are representative of successive meandering channel belts cutting through adjacent floodplain mudstones (Figs. 1–2; Smith et al., 2009; Nesbit et al., 2018; Durkin et al., 2020). Most of the park is a natural preserve accessible only through research permits or guided programs. The digital model provides a viewing window into a small section

of the park without disrupting wildlife and the natural landscape.

Data Collection and DOM Processing

Images were collected through eight flights with a sensefly eBee fixed-wing UAV equipped with a Sony WX220 18.2 megapixel camera, resulting in 1760 images. Images were recorded at a pitch angle of 10° off-nadir to increase point visibility along sub-vertical surfaces and increase precision of final models within the high-relief topography (Nesbit and Hugenholtz, 2019). Images were processed using Pix4Dmapper v4.3 following a similar workflow described by previous authors (Küng et al., 2012; Nesbit et al., 2018). Following initial processing, the model was divided into four quadrants and processed into a dense point cloud and 3D textured mesh. Mesh outputs were exported as Autodesk Filmbox (.fbx) format, which generally results in smaller file sizes than commonly used 3D polygon (.ply) and wavefront (.obj) formats.

Visualization Approaches

DOMs are presented in textured mesh and dense point cloud formats, using three different visualization platforms (Sketchfab, potree, and Unity). Although other platforms are available, these were intentionally selected for their ability to provide end-users with access to 3D data sets without specialty software or transfer of large data sets and are representative of the current capabilities of modern viewers.

Web-Based 3D Mesh (Sketchfab)

Using a web-based interface, Sketchfab allows authors to intuitively upload models, define rendering options (e.g., lighting, material properties), and provide supplementary annotations (Fig. 3A). Upload limitations of 200 MB, including all mesh and texture components, prevented rendering of the complete 1 km² field area within a single viewer without significant texture distortion. To preserve detail within the field area, we present each quadrant separately. Multiple texture resolutions and VR compatibility are automatically generated during upload to provide end-users with different level of detail (LoD) rendering options based on the capabilities of their viewing device. Location-specific annotations describing geologic features and concepts to end-users were added to models using the upload interface. Additional data sets could not be integrated within 3D model space.

Web-Based 3D Point Cloud (potree)

Viewers using potree code can render raw point clouds and integrate multiple data sets into a single viewer with customizable options. The dense point cloud for the 1 km² field area is ~25.5 GB and contains more than 805 million points (Fig. 3B). Point cloud data sets can be compressed (from .las to .laz format) to reduce file size and converted into a potree file and folder structure for efficient tile-based rendering using the potree converter (Schuetz, 2016), with a final size of 3.5 GB. By default, the potree code includes an interactive overview map that displays the viewer's location and view direction, various navigation options and settings, and several measurement tools allowing end-users to record simple measurements, including distances, areas, volumes, and topographic cross sections. Following conversion, the files and folder structure can be added to a web host and dispersed through a standard web domain. Information on getting started can be found on the potree GitHub page or homepage (<http://www.potree.org>). An example is presented in Figure 3B using the Pix4Dcloud viewer, which implements the potree library.

Videogame Engine (Unity)

Videogame engines allow the production of unique end-user experiences through customized data visualization and presentation (Fig. 4). Unity provides a platform to design and develop videogames and is well documented through user manuals, community forums, and online tutorials (e.g., <https://unity.com/learn/get-started>). The program interface contains simple “drag and drop” functions for creation of simple scenes, but also allows fully customizable objects and interaction through scripting. Unity supports various formats, including point clouds, meshes, and 2.5D digital elevation models (DEMs). However, point cloud rendering through Unity can be challenging (Fraiss, 2017), and DEM interpolations are susceptible to distortion along slopes (Bellian et al., 2005; Pavlis and Mason, 2017). Therefore, we used 3D meshes (.fbx files) and associated textures (.jpg), which made up much of the final videogame file size (~1 GB).

Navigation within the scene was programmed through a first-person movement script, in which the camera is controlled by directional keys on the keyboard and orientation based on the mouse. Camera movement was restricted within the scene boundaries by enabling the “mesh collider” option

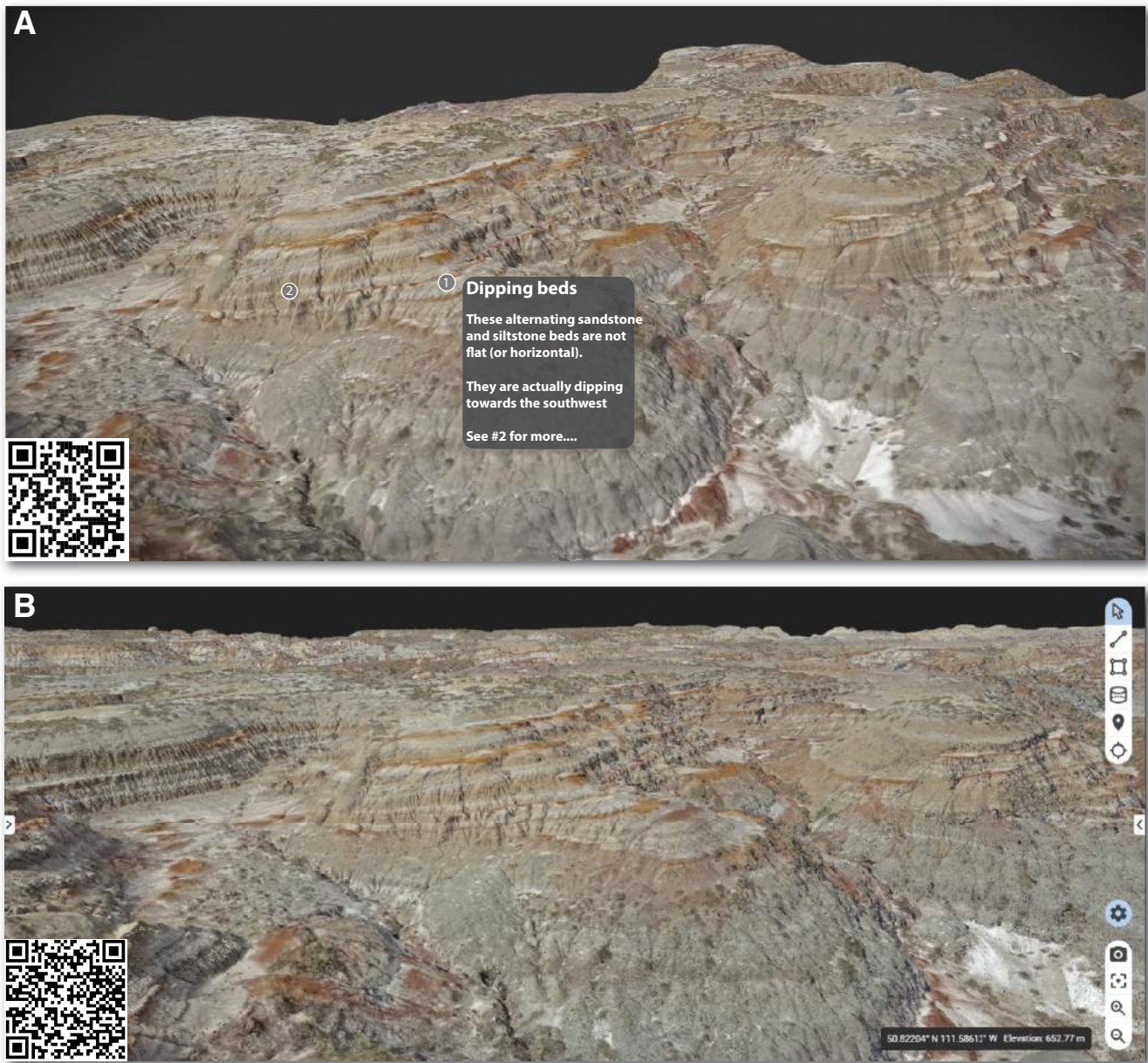


Figure 3. Digital outcrop models (DOMs) of the heterolithic channel-belt deposits in Figure 1, presented in two different viewers. (A) Sketchfab viewer contains 3D textured mesh DOM, but is limited by resolution and only supports text annotations to provide supplemental information; note the limited field area loaded to preserve detail in texture and topography—additional interactive models of the field area are online at <https://sketchfab.com/paulnesbit> or by following the QR code. Additional proprietary web viewers include Euclidean Vault (<https://www.euclidean.com/vaultinfo/>), and voxlr (<https://www.voxlr.com/>). (B) Visualization of the 3D dense point cloud DOM of the entire 1 km² field area (>805 million points) in a standard web browser using potree code applied in customized web viewer from Pix4D. QR code provides digital access to the fully interactive viewer, also available at <http://tiny.cc/Pix4DpotreeViewer>.

within the mesh options panel. Various components were added to the scene, such as the sky background, surrounding topography, and interactive features. Sky textures were adapted from the Unity Asset Store (assetstore.unity.com). Surrounding topography was added by creating a terrain object within Unity, defining height values by importing a 10 m DEM (AltaLIS, 2017), textured with a 10-m true-color satellite image (Copernicus, 2018). Interactive features were added to a dropdown menu

within the user interface (UI) and included several “points of interest” that automatically transport end-users to areas with educational information within the scene. The UI menu allows users to navigate between integrated data sets and associated information panels within the scene and can be exited at any time to return to free fly mode.

DISCUSSION

Sharing of large 3D data sets without specialist software is possible through modern

viewers; however, a host of challenges remain with current solutions before the full potential can be realized. Data acquisition technologies continue to offer higher resolutions and larger file sizes. Contrastingly, visualization platforms commonly limit file sizes, forcing a compromise between field area extent and detail. As demand increases for sharing larger 3D data sets, more advanced multi-resolution rendering solutions, such as LoD in Sketchfab and LIME or tiled approaches similar to potree, will be essential. Options for end-

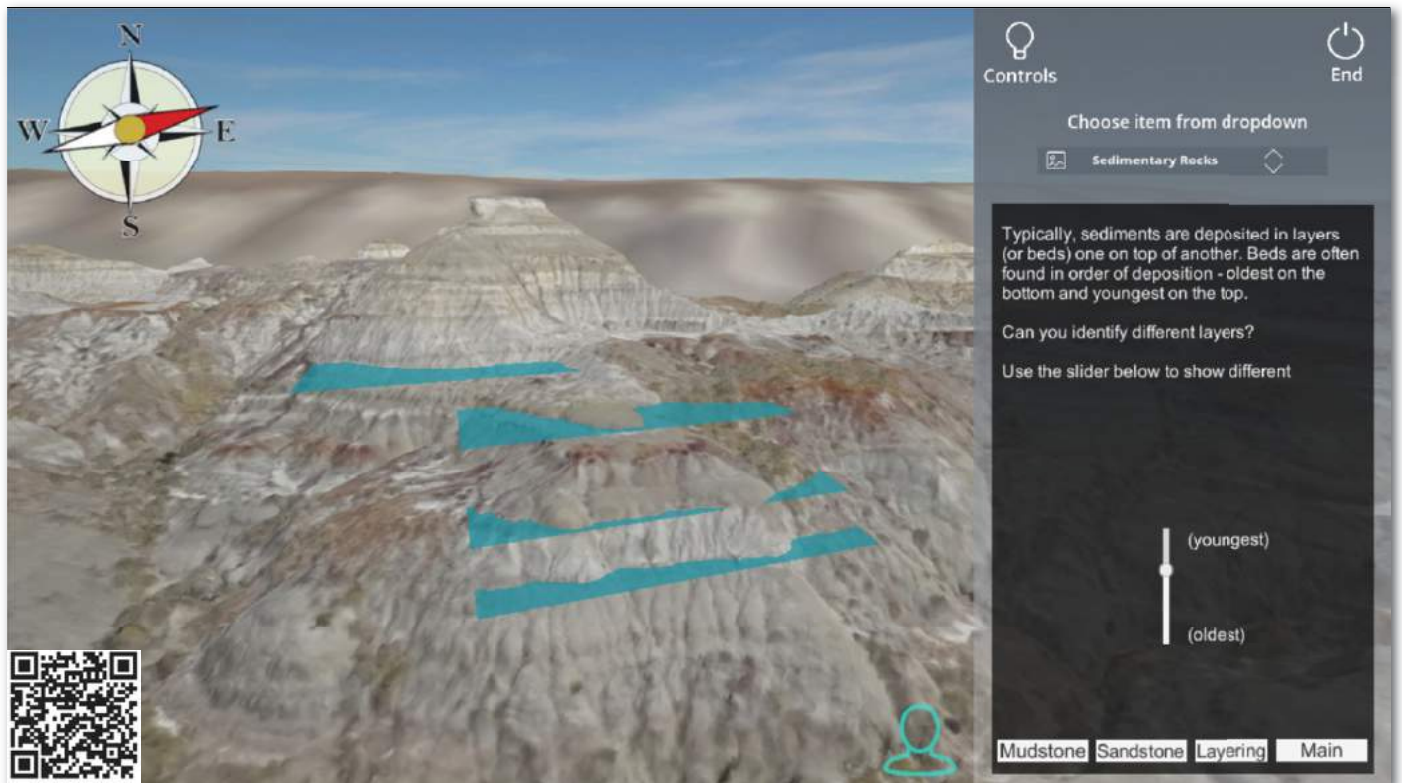


Figure 4. Videogame viewer (executable application) of the entire 1 km² field area rendered as a textured mesh and created with Unity. Note the dynamic orientation arrow in the upper left corner of the game, the options menu to the right of the screen, and interpretations of geologic surfaces turned “on.” Drop-down menu in the side panel provides end-users with options to navigate to predefined “points of interest” throughout the field area, simulating virtual field-trip stops. Note the resolution difference between the foreground (uninhabited aerial vehicle [UAV]) model and the peripheral topography and landscape, created with a digital elevation model draped with a 10 m satellite image. End-users can also select “free fly” mode in order to navigate throughout the field site on their own. A fully interactive viewer is available in GSA’s Data Repository¹ (also accessible from the QR code). Both data repository supplemental files are interactive videogame visualizations presenting a “virtual field trip” that introduces basic geology concepts using a UAV-Structure from Motion textured mesh model within Dinosaur Provincial Park (Alberta, Canada). One is a standalone application (.exe file) for machines running Windows (no software required). The other is a standalone application (.app file) for machines running macOS (no software required). Note the README.txt file after unzipping prior to running.

users to select display quality based on the capabilities of their machine provides additional avenues to smoothly render large data sets; for example, the Unity UI offers *Quality* and *Screen Resolution* settings upon startup, and potree code provides adjustable options for *Point Budget* and *Quality*.

Capabilities of 3D viewers can be expanded through incorporation of basic interpretation tools, the ability to integrate multiple data sets, and customizable interfaces. There are various levels of customizability in modern platforms. Sketchfab, for example, currently permits addition of text and web-linked photo annotations, but does not support integration of additional 3D objects, shapefiles, or drawings. Open source platforms (e.g., potree and Unity) contain support to integrate meshes, shapefiles, and custom objects within a scene (Fig. 4) but require additional coding to convert and

render data properly. The default potree code supports basic measurement tools (see Fig. 3B), but further customization within potree or Unity requires significant upfront programming efforts.

Compatibility and design considerations may also emerge as issues for visualization platforms. Although potree code is currently compatible with standard web browsers, future updates to browsers may impede performance. Similarly, users who rely on third-party applications are subject to decisions made by suppliers. On the other hand, formats supported by Unity (e.g., Windows [.exe], Apple [.app], mobile device [iOS, Android], Sony PlayStation 4, Microsoft Xbox, and WebGL) have been standard for their respective platforms and are likely to maintain functionality through updates, as backward compatibility is often built into new versions.

Cartographic principles will become increasingly important as 3D visualizations are used to disseminate spatial data layers with 3D DOMs. This technique has the potential to extend models beyond simple visuals into scientific visualizations designed to aid the understanding of data, provide new perspectives, and provoke individual knowledge construction (MacEachren and Kraak, 1997). Delivering data in this way requires consideration of cartographic design as it relates to the purpose of a model, intended audience, and how to best present data. For example, use of these platforms as geospatial data viewers still requires basic map components (e.g., scale, orientation, legend, metadata, etc.), which are not currently available in some 3D viewers, but are essential for extending these 3D models to spatially meaningful 3D geovisualizations.

¹GSA Data Repository item 2020176, supplemental file 1—virtual field trip videogame for Windows (.exe—no software required); supplemental file 2—virtual field trip videogame for MacOS (.app—no software required), is available online at <https://www.geosociety.org/datarepository/2020>.

CONCLUSIONS AND RECOMMENDED USE

Tools for collecting high-resolution 3D data sets have recently become commonplace in both commercial and academic fields; however, sharing 3D data sets typically requires end-users to have specialty software, high-end processing computers, and/or locally store large files. Through the presentation of a large UAV-SfM derived DOM, we introduce three representative visualization platforms that harness potential to advance 3D data dissemination and promote open science communication to end-users without the need for specialized software and hardware.

Web-based viewers, such as Sketchfab and potree, provide practical options for sharing data sets with end-users without cumbersome transfer and storage of large files. Web-based viewers typically provide an easy solution to share 3D visualizations without the need for programming, though customizability and file sizes are limited. The default potree code has extended capabilities, such as measurement tools, display options, and the ability to integrate multiple file types within a single viewer. Open-source code allows capable programmers to customize the potree viewer and could potentially be used as a raw data viewer or educational supplement. A web domain and web storage are required to host potree visualizations, which may limit uptake for educational purposes, but it remains promising for sharing raw data sets with collaborators or commercial partners.

Game engines require more significant coding knowledge for customized visualizations and measurement tools and may therefore be less practical as raw data viewers. However, videogames create opportunities to broaden scientific communication and education beyond conventional 2D maps and photo-based line drawings (e.g., Figs. 1–2) by contextualizing 3D information within a 3D, immersive, and realistic environment (Fig. 4). Videogame visualization could be used for engaging museum displays, presentation of course material, or virtual field experiences, in which “participants” can follow guided prompts or explore the scene freely in self-navigation mode.

Although virtual platforms provide exciting potential for enhanced student learning and improved scientific communication to the broader public, their efficacy as a learning tool necessitates future research. Regardless, emerging visualization platforms provide

access to 3D data sets without the need for advanced software and hardware. Though often limited by logistical constraints, we encourage authors to share high-resolution DOM data sets whenever possible. Methods of 3D data dissemination and visualization are still in their infancy behind the relatively recent rise in 3D mapping applications and acquisition techniques; as the latter continue to grow, we expect the former to develop in new and unique ways to facilitate open science initiatives through communication and democratization of photorealistic 3D models.

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REFERENCES CITED

- AltaLIS, 2017, Alberta 20K Digital Elevation Model (DEM).
- Bellian, J.A., Kerans, C., and Jennette, D.C., 2005, Digital outcrop models: Applications of terrestrial scanning lidar technology in stratigraphic modeling: *Journal of Sedimentary Research*, v. 75, p. 166–176, <https://doi.org/10.2110/jsr.2005.013>.
- Bilke, L., Fischer, T., Helbig, C., Krawczyk, C., Nagel, T., Naumov, D., Paulick, S., Rink, K., Sachse, A., Schelenz, S., Walther, M., Watanabe, N., Zehner, B., Ziesch, J., and Kolditz, O., 2014, TESSIN VIS-Lab—Laboratory for scientific visualization: *Environmental Earth Sciences*, v. 72, p. 3881–3899, <https://doi.org/10.1007/s12665-014-3785-5>.
- Blenkinsop, T.G., 2012, Visualizing structural geology: From Excel to Google Earth: *Computers & Geosciences*, v. 45, p. 52–56, <https://doi.org/10.1016/j.cageo.2012.03.007>.
- Boutsis, A., Ioannidis, C., and Soile, S., 2019, Interactive online visualization of complex 3D geometries: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, v. XLII-2, W9, p. 173–180, <https://doi.org/10.5194/isprs-archives-XLII-2-W9-173-2019>.
- Brodu, N., and Lague, D., 2012, 3D terrestrial lidar data classification of complex natural scenes using a multi-scale dimensionality criterion: Applications in geomorphology: *ISPRS Journal of Photogrammetry and Remote Sensing*, v. 68, p. 121–134, <https://doi.org/10.1016/j.isprsjprs.2012.01.006>.
- Buckley, S.J., Ringdal, K., Naumann, N., Dolva, B., Kurz, T.H., Howell, J.A., and Dewez, T.J.B., 2019, LIME: Software for 3-D visualization, interpretation, and communication of virtual geoscience models: *Geosphere*, v. 15, p. 1–14, <https://doi.org/10.1130/GES02002.1>.
- Carrivick, J.L., Smith, M.W., and Quincey, D.J., 2016, Structure from Motion in the Geosciences: Oxford, UK, Wiley-Blackwell, <https://doi.org/10.1002/9781118895818>.
- Cawood, A.J., and Bond, C.E., 2019, eRock: An open-access repository of virtual outcrops for

- geoscience education: *GSA Today*, v. 29, p. 36–37, <https://doi.org/10.1130/GSATG373GW.1>.
- Chesley, J., Leier, A., White, S., and Torres, R., 2017, Using unmanned aerial vehicles and structure-from-motion photogrammetry to characterize sedimentary outcrops: An example from the Morrison Formation, Utah, USA: *Sedimentary Geology*, v. 354, p. 1–8, <https://doi.org/10.1016/j.sedgeo.2017.03.013>.
- CloudCompare, 2019, Version 2.9. GPL Software. Available online: <http://www.cloudcompare.org> (accessed 7 Feb. 2020).
- Copernicus, 2018, Sentinel data: Retrieved from USGS, Earth Explorer 15 August 2019, processed by ESA.
- Currie, P.J., and Koppelhus, E.B., editors, 2005, Dinosaur Provincial Park: A Spectacular Ancient Ecosystem Revealed: Bloomington, Indiana, Indiana University Press, 648 p.
- De Paor, D.G., 2016, Virtual rocks: *GSA Today*, v. 26, p. 4–11, <https://doi.org/10.1130/GSATG257A.1>.
- De Paor, D.G., and Whitmeyer, S.J., 2011, Geological and geophysical modeling on virtual globes using KML, COLLADA, and Javascript: *Computers & Geosciences*, v. 37, p. 100–110, <https://doi.org/10.1016/j.cageo.2010.05.003>.
- Dewez, T.J.B., Girardeau-Montaut, D., Allanic, C., and Rohmer, J., 2016, Facets : A CloudCompare plugin to extract geological planes from unstructured 3D point clouds: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences—ISPRS Archives*, v. 41, p. 799–804, <https://doi.org/10.5194/isprsarchives-XLI-B5-799-2016>.
- Dodson, P., 1971, Sedimentology and taphonomy of the Oldman Formation (Campanian), Dinosaur Provincial Park, Alberta (Canada): *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 10, p. 21–74, [https://doi.org/10.1016/0031-0182\(71\)90044-7](https://doi.org/10.1016/0031-0182(71)90044-7).
- Durkin, P.R., Hubbard, S.M., Holbrook, J.M., Weltschuk, Z., Nesbit, P.R., Hugenholtz, C.H., Lyons, T., and Smith, D.G., 2020, Recognizing the product of concave-bank sedimentary processes in fluvial meander-belt strata: *Sedimentology* (in press).
- Eberth, D.A., and Hamblin, A.P., 1993, Tectonic, stratigraphic, and sedimentologic significance of a regional discontinuity in the upper Judith River Group (Belly River wedge) of southern Alberta, Saskatchewan, and northern Montana: *Canadian Journal of Earth Sciences*, v. 30, p. 174–200, <https://doi.org/10.1139/e93-016>.
- Fraiss, S.M., 2017, Rendering Large Point Clouds in Unity [B.S. thesis]: Vienna, University of Technology (TU Wien), 38 p.
- Goodchild, M.F., Guo, H., Annoni, A., Bian, L., de Bie, K., Campbell, F., Craglia, M., Ehlers, M., van Genderen, J., Jackson, D., Lewis, A.J., Pesaresi, M., Remetej-Fülöpp, G., Simpson, R., Skidmore, A., Wang, C., and Woodgate, P., 2012, Next-generation Digital Earth: Proceedings of the National Academy of Sciences of the United States of America, v. 109, p. 11,088–11,094, <https://doi.org/10.1073/pnas.1202383109>.
- Hodgetts, D., 2013, Laser scanning and digital outcrop geology in the petroleum industry: A review: *Marine and Petroleum Geology*, v. 46, p. 335–354, <https://doi.org/10.1016/j.marpetgeo.2013.02.014>.
- Hodgetts, D.L., Gawthorpe, R., Wilson, P., and Rarity, F., 2007, Integrating Digital and Traditional Field Techniques Using Virtual Reality Geological Stu-

- dio (VRGS): 69th EAGE Conference and Exhibition incorporating SPE EUROPEC 2007, p. 11–14, <https://doi.org/10.3997/2214-4609.201401718>.
- Howell, J.A., Martinius, A.W., and Good, T.R., 2014, The application of outcrop analogues in geological modelling: A review, present status and future outlook, *in* Martinius, A.W., Howell, J.A., and Good, T.R., eds., *Sediment-Body Geometry and Heterogeneity: Analogue Studies for Modelling the Subsurface*: Geological Society, London, Special Publication 387, p. 1–25, <https://doi.org/10.1144/SP387.12>.
- Jones, R.R., McCaffrey, K.J., Clegg, P., Wilson, R.W., Holliman, N.S., Holdsworth, R.E., Imber, J., and Waggott, S., 2009, Integration of regional to outcrop digital data: 3D visualisation of multi-scale geological models: *Computers & Geosciences*, v. 35, p. 4–18, <https://doi.org/10.1016/j.cageo.2007.09.007>.
- Küng, O., Streach, C., Fua, P., Gurdan, D., Achtelik, M., Doth, K.-M., and Stumpf, J., 2012, Simplified building models extraction from ultra-light UAV imagery: *ISPRS—International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, v. XXXVIII-1, p. 217–222, <https://doi.org/10.5194/isprsarchives-XXXVIII-1-C22-217-2011>.
- MacEachren, A.M., and Kraak, M.J., 1997, Guest editorial exploratory cartographic visualization: Advancing the agenda: *Computers & Geosciences*, v. 23, p. 335–343, [https://doi.org/10.1016/S0098-3004\(97\)00018-6](https://doi.org/10.1016/S0098-3004(97)00018-6).
- Martinez-Rubi, O., de Kleijn, M., Verhoeven, S., Drost, N., Attema, J., van Meersbergen, M., van Nieuwpoort, R., de Hond, R., Dias, E., and Svetachov, P., 2016, Using modular 3D digital earth applications based on point clouds for the study of complex sites: *International Journal of Digital Earth*, v. 9, p. 1135–1152, <https://doi.org/10.1080/17538947.2016.1205673>.
- McCaffrey, K.J.W., Jones, R.R., Holdsworth, R.E., Wilson, R.W., Clegg, P., Imber, J., Holliman, N.S., and Trinks, I., 2005, Unlocking the spatial dimension: Digital technologies and the future of geoscience fieldwork: *Journal of the Geological Society*, v. 162, p. 927–938, <https://doi.org/10.1144/0016-764905-017>.
- McCaffrey, K.J.W., Hodgetts, D., Howell, J.A., Hunt, D., Imber, J., Jones, R.R., Tomasso, M., Thurmond, J., and Viseur, S., 2010, Virtual fieldtrips for petroleum geoscientists: *Geological Society, London, Petroleum Geology Conference Series*, v. 7, p. 19–26, <https://doi.org/10.1144/0070019>.
- Nesbit, P.R., and Hugenholtz, C.H., 2019, Enhancing UAV-SfM 3D model accuracy in high-relief landscapes by incorporating oblique images: *Remote Sensing*, v. 11, <https://doi.org/10.3390/rs11030239>.
- Nesbit, P.R., Durkin, P.R., Hugenholtz, C.H., Hubbard, S.M., and Kucharczyk, M., 2018, 3-D stratigraphic mapping using a digital outcrop model derived from UAV images and structure-from-motion photogrammetry: *Geosphere*, v. 14, p. 1–18, <https://doi.org/10.1130/GES01688.1>.
- Nieminski, N.M., and Graham, S.A., 2017, Modeling stratigraphic architecture using small unmanned aerial vehicles and photogrammetry: Examples from the Miocene east coast basin, New Zealand: *Journal of Sedimentary Research*, v. 87, p. 126–132, <https://doi.org/10.2110/jsr.2017.5>.
- Pavlis, T.L., and Mason, K.A., 2017, The new world of 3D geologic mapping: *GSA Today*, v. 27, p. 4–10, <https://doi.org/10.1130/GSATG313A.1>.
- Robinson, A., Gordon, C.E., Houghton, J., Lloyd, G.E., and Morgan, D.J., 2015, ArcGIS to Unity: A design pipeline for creation of 3D terrain in serious egames for geology: *Geology Today*, v. 31, p. 237–240, <https://doi.org/10.1111/gto.12121>.
- Schuetz, M., 2016, Potree [Thesis]: Rendering Large Point Clouds in Web Browsers: Vienna University of Technology, 84 p.
- Simpson, C., and De Paor, D.G., 2010, Restoring maps and memoirs to four-dimensional space using virtual globe technology: A case study from the Scottish Highlands: *Geological Society, London, Special Publication 335*, p. 429–441, <https://doi.org/10.1144/SP335.20>.
- Smith, D.G., Hubbard, S.M., Leckie, D.A., and Fustic, M., 2009, Counter point bar deposits: Lithofacies and reservoir significance in the meandering modern Peace River and ancient McMurray Formation, Alberta, Canada: *Sedimentology*, v. 56, p. 1655–1669, <https://doi.org/10.1111/j.1365-3091.2009.01050.x>.
- Tavani, S., Granado, P., Corradetti, A., Girundo, M., Iannace, A., Arbués, P., Muñoz, J.A., and Mazzoli, S., 2014, Building a virtual outcrop, extracting geological information from it, and sharing the results in Google Earth via OpenPlot and Photoscan: An example from the Khaviz Anticline (Iran): *Computers & Geosciences*, v. 63, p. 44–53, <https://doi.org/10.1016/j.cageo.2013.10.013>.
- Thiele, S.T., Grose, L., Samsu, A., Mickelthwaite, S., Vollgger, S.A., and Cruden, A.R., 2017, Rapid, semi-automatic fracture and contact mapping for point clouds, images and geophysical data: *Solid Earth*, v. 8, p. 1241–1253, <https://doi.org/10.5194/se-8-1241-2017>.
- Thurmond, J.B., Løseth, T.M., Rivenæs, J.C., Martinsen, O.J., and Aiken, C.L.V., 2006, Using outcrop data in the 21st century—New methods and applications, with example from the Ainsa Turbidite System: *Deep-Water Outcrops of the World Atlas*, CD-ROM.
- Turner, A.K., 2006, Challenges and trends for geological modelling and visualisation: *Bulletin of Engineering Geology and the Environment*, v. 65, p. 109–127, <https://doi.org/10.1007/s10064-005-0015-0>.
- USGS, 2019, 3D Elevation Program (3DEP): <https://www.usgs.gov/news/usgs-3dep-lidar-point-cloud-now-available-amazon-public-dataset> (accessed 11 Feb. 2020).
- von Reumont, F., Arsanjani, J.J., and Riedl, A., 2013, Visualization of geologic geospatial datasets through X3D in the frame of WebGIS: *International Journal of Digital Earth*, v. 6, p. 483–503, <https://doi.org/10.1080/17538947.2011.627471>.
- Wood, J.M., Thomas, R.G., and Visser, J., 1988, Fluvial processes and vertebrate taphonomy: The upper cretaceous Judith River formation, South-Central Dinosaur Provincial Park, Alberta, Canada: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 66, p. 127–143, [https://doi.org/10.1016/0031-0182\(88\)90085-5](https://doi.org/10.1016/0031-0182(88)90085-5).

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Photo by Matthias Mullie on Unsplash.



Coronavirus Update

GSA continues to monitor the ongoing coronavirus pandemic. Our goal is to deal with the challenges of COVID-19 as proactively, thoroughly, and thoughtfully as we can. The safety and well-being of our communities across the United States, and the entire globe, remain our highest priorities.

The information in this publication is current as of press time; however, we are evaluating the feasibility of hosting the GSA 2020 Annual Meeting in Montréal, Québec, Canada, and considering alternatives, such as a virtual format.

Opening of the abstracts submission system, housing, and registration have been pushed back to 1 July to give everyone involved as much time as possible to gauge how circumstances are developing with regard to closures, travel restrictions, and so forth.

We encourage you to visit the annual meeting website (<https://community.geosociety.org/gsa2020/>) for updates. If you have questions or concerns about the meeting, contact meetings@geosociety.org.

IMPORTANT DATES

4 August: Abstracts deadline

Early August: Student volunteer program opens

21 September: Early registration deadline

21 September: GSA Sections travel grants deadline

28 September: Registration and student volunteer cancellation deadline

30 September: Housing deadline for discounted hotel rates

Registration

Registration at <https://community.geosociety.org/gsa2020/registration> will open in July.

Early registration deadline: 21 September

Cancellation deadline: 28 September

REGISTRATION FEES

	Early registration July–21 Sept.	Standard/ onsite after 21 Sept.
Professional Member— Full Meeting	US\$440	US\$520
Professional Member— 1 Day	US\$275	US\$315
Professional Member— 70+ Full Meeting	US\$315	US\$400
Professional Member— 70+ One Day	US\$215	US\$240
Professional Nonmember— Full Meeting	US\$635	US\$710
Professional Nonmember— One Day	US\$380	US\$455
Early Career Professional— Full Meeting	US\$280	US\$350
Early Career Professional— One Day	US\$175	US\$209
Student Member— Full Meeting	US\$155	US\$190
Student Member— One Day	US\$110	US\$125
Student Nonmember— Full Meeting	US\$210	US\$245
Student Nonmember— One Day	US\$145	US\$165
High School Student	US\$60	US\$60
K–12 Professional— Full Meeting	US\$75	US\$85
Field Trip or Short Course Only	US\$55	US\$55
Guest or Spouse	US\$110	US\$120
Low Income Country**	50%	50%

**Participants from countries classified as “Low or Lower Middle Income Economies” by the World Bank need only pay 50% of the category fee for full meeting or one day registration. Online registration is not available for “Low or Lower Middle Income Economy” registrants. Please fill out a printable version of the registration form and mail it to GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA

GSA strives to create a pleasant and rewarding experience for every attendee. Let us know in advance of the meeting if you have needs that require further attention. Most dietary considerations can be met without any extra charge. Be sure to check the box when registering online and describe your need in the space provided.

DON'T FORGET TO...

- Check your passport to make sure it's valid
- Register for tours, special events, field trips, and short courses
- Bring a copy of your meeting confirmation with you
- STUDENTS: Be sure to apply for the travel grant program by 21 Sept.
- Make your hotel reservation
- Book your travel

TRAVEL GRANTS

Do you need assistance with travel to the meeting? GSA Sections, Divisions, and Associated Societies are ready to help. Various groups are offering grants to help defray your costs for registration, field trips, and travel. Check out the meeting website (<https://community.geosociety.org/gsa2020/>) for application and deadline information. Eligibility criteria and deadline dates may vary by grant. For meeting attendees who reside outside of North America, check the International Travel Grant webpage.

STUDENT TRAVEL FUND

Interested in helping students participate in the meeting? Help them participate by donating to the student travel fund when you register. Every year, a large percentage of students apply for travel grants for the meeting but do not receive an award due to a limited number of funds. You can help reduce this number by donating as little as US\$10 when you register. 100% of the funds collected go to students.

STUDENT VOLUNTEER PROGRAM

The student volunteer program will open in early August. Work at least ten hours and get complimentary registration, plus get an insider's view of the meeting.

CONTINUING EDUCATION CREDITS (CEU)

The annual meeting offers an excellent opportunity to earn CEUs toward your continuing education requirements for your employer, K–12 school, or professional organization. Please check the meeting website *after the meeting* to download your CEU certificate.

MEDIA REGISTRATION

Complimentary meeting registration is available to journalists from bona fide news organizations and public information officers from geoscience-related organizations. Media registration provides access to all scientific session, the GSA Resource and Innovation Center, and the newsroom. Get information about eligibility, and request media credentials at <https://community.geosociety.org/gsa2020/connect/press>.

Organizing Committee



General Chair: Felix Gervais,
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Technical Program Vice Chair:
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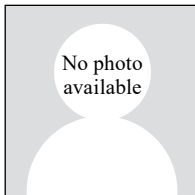
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**Students and Early Career Professionals
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Local Geology Program Chair:
Galen Halverson, McGill University,
galen.halverson@mcgill.ca

Event Space Requests

Request event space for meeting rooms to hold your non-technical events (i.e., business meetings, town halls, luncheons, receptions, etc.) via our online event space & event listing database: <https://community.geosociety.org/gsa2020/connect/events>. Space is reserved on a first-come, first-served basis. Deadline: 8 June.

Meet with Us on Social Media (follow hashtag #GSA2020)

-  twitter.com/geosociety
-  instagram.com/geosociety
-  facebook.com/GSA.1888
-  community.geosociety.org

Tips for Students on How to Make the Annual Meeting Affordable

Teresa Baraza and Allie Nagurney

GSA Annual Meetings are great opportunities to learn, share your research, and network with other students and scientists. Here are some ideas on how you can find funding to support your travel and tips for saving money while you're at the meeting.

University Funding Opportunities for Travel

Travel awards are often available through your university. Do some research and consult with your advisor, and email or set up meetings with individuals at the administrative, department, and faculty levels. Be sure to look into extracurricular associations on campus as well.

Home Department: This should be the first place you go to look for funding. First, have a conversation with your advisor and lay out expectations. Do they have research grant funding for you to go to a conference? Even if your advisor has research funding they may want you to seek out other opportunities. Many departments have money for students to travel to meetings, but sometimes these awards are dependent on you submitting an abstract or attending a short course or field trip.

Research Office, Graduate Division Office, or Graduate School staff can help you write a proposal or letter and draft a budget for research, travel costs, and dissemination of your results. Sometimes these grants are semester-based, and you can't apply for them until after the conference, so just keep that in mind when planning.

Undergraduate and Graduate Student Associations and Offices for Giving and Donations often offer financial scholarships and fellowships. Some funds are set aside for career services to help students reach their occupational goals through networking, connecting with employers, and exploring graduate programs. These could all be accomplished by attending a professional meeting. If you need help locating these awards, visit your career services and financial aid offices.

Student Affairs and Other University Offices embrace diversity and inclusion, international, LGBTQ+, people with disabilities, married with children, undocumented people, and veterans. These departments may offer workshops and tutorials, and their staff could help you meet your travel goals.

Non-Profit Association Funding Opportunities for Travel

GSA's Sections, Divisions, and Associated Societies offer travel grants. Many of these require you to apply in the spring and summer to attend the annual meeting in the fall, so be sure to check deadlines early.

GSA Sections offer financial assistance to GSA student members to attend the annual meeting. Deadlines are usually in August or September.

GSA Divisions offer grants, especially when students attend a short course or field trip.

GSA International provides travel grants to international scientists and students. The deadline is in early June.

Many GSA Associated Societies meet at the GSA Annual Meeting. Groups such as the Association for Women Geoscientists offer travel grants to attend conferences.

GSA Student Volunteer Program: In return for working at least ten hours during the meeting, GSA grants you complimentary registration. These jobs cover a wide spectrum of opportunities, from working at the registration desk, helping to run short courses and career programs, to assisting in technical sessions to ensure everything runs smoothly. Hundreds of students are needed at each annual meeting. This program opens in early August and normally fills up quickly, so sign up early. Volunteering is also a great way to see the behind the scenes of the meeting and learn what it takes to make a GSA Annual Meeting happen.

The **On To the Future** program offers travel awards to students and recent graduates from diverse backgrounds who have never attended a GSA Annual Meeting.

Other Money-Saving Opportunities

- Visit the GSA Roommates & Rides Community to share housing, airport shuttles, and/or carpool.
- Attend events for students and early career professionals. You will receive important career advice, and some of these programs offer coffee, light snacks, or lunch.
- Stock your hotel room refrigerator with snacks and fruit.

GSA Annual Meetings are great opportunities to network, learn, and disseminate your research. Start looking for funding opportunities in late spring/early summer, and if you apply for a variety of funding opportunities, you should be able to cover the cost of your travel to the meeting.

Teresa Baraza is a Ph.D. student at Saint Louis University and is the Soils Division Representative of the GSA Student Advisory Council. Allie Nagurney is a Ph.D. Candidate at Virginia Tech and is the Chair of the GSA Student Advisory Council.

Travel & Transportation

PASSPORT AND VISA REMINDER

Passports will be required for entry into Canada for all attendees. Passports should be valid for at least six months. Participants are invited to consult the visa office website <https://www.cic.gc.ca/english/visit/visas.asp> to determine whether they will need a visa as well. As a general rule, the validity of a Canadian visa cannot go beyond the validity of the passport. The passport must have at least two blank pages.

YUL, MONTRÉAL-TRUDEAU INTERNATIONAL AIRPORT: ACCESSIBLE AND EFFICIENT

Located 20 km from downtown Montréal, the YUL, Montréal-Trudeau International Airport (<https://www.mtl.org/en/transport/yul-aeroport-international-montreal-trudeau>), is connected via direct flight to some 150 destinations offered by 30 carriers and welcomes over 18 million passengers annually.

- The 747 shuttle bus (<https://www.mtl.org/en/transport/747-aeroport-p-e-trudeau-centre-ville>) from the airport to downtown Montréal is an economical choice at just C\$10 per person. Tickets may be purchased at the airport with a credit card or cash. The ticket is valid for 24 hours. For details on the bus and metro (subway) network, go to <http://www.stm.info/en>.



© Aéroports de Montréal.

- Taxis are an inexpensive and comfortable way to get around. To the downtown core of Montréal, taxis are a flat fee of C\$41. For more details on taxis go to <https://www.admtl.com/en/access/taxis-limousines>.
- Uber drivers' cars are now available at Montréal-Trudeau airport. Pick up is at door 7 on the departure level.

Childcare by KiddieCorp

Location: Palais des congrès de Montréal

Hours: Sun.–Wed., 7 a.m.–6 p.m. daily

Cost: US\$10 per hour per child for children two years or older and US\$12 per hour per child for children under two with a one-hour minimum per child. 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.



More info: www.kiddiecorp.com/parents-guide/
Register securely: <https://form.jotform.com/KiddieCorp/gsakids>
Contact: +1-858-455-1718; info@kiddiecorp.com

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. Deadline: 28 Sept.

Cancellations: For a full refund, cancellations must be made to KiddieCorp prior to 28 Sept. Cancellations made after 28 Sept. will incur a 50% fee. No refunds after 7 Oct.

About: KiddieCorp is a nationally recognized company that provides onsite 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.

Hotels

RESERVATION OPTIONS

Housing will open in July. Check for updates at <https://community.geosociety.org/gsa2020/travel/hotels>.

CRITICAL DATES

21 Sept.: Last day to cancel rooms without penalty.

30 Sept.: Reservations must be received by this date in order to guarantee rooms at special meeting rates.

15 Oct.: All changes, cancellations, and name substitutions must be finalized through Orchid.Events.

After 15 Oct.: You must contact the hotel directly with any changes or for new reservations.

ROOMMATES & RIDES

Use the GSA Travel & Housing Bulletin Board at <https://community.geosociety.org/gsa2020/travel/rooms-rides> to share housing, airport shuttles, and/or carpool. You can also use this service to make arrangements to meet up with your colleagues.



© DoubleTree by Hilton Montreal.

Hotel Rates

Hotel	Single Rate* (tax not included)	Add'l Adult	Distance to Palais
Doubletree by Hilton Montréal	\$239	\$25	<5 min. walk
Embassy Suites by Hilton Montréal**	\$229	\$35	<5 min. walk
Hôtel Delta Montréal by Marriott	\$173	\$20	<5 min. walk
Hôtel Faubourg Montréal**	\$159	\$20	<5 min. walk
Hôtel Le Dauphin Montréal**	\$178	N/A	<5 min. walk
InterContinental Montréal	\$199	\$20	<5 min. walk
Le Centre Sheraton Montréal	\$215	\$30	<10 min. walk
Le Westin Montréal	\$255	\$30	<5 min. walk
Marriott Springhill Suites Old Montréal**	\$195	\$15	<10 min. walk

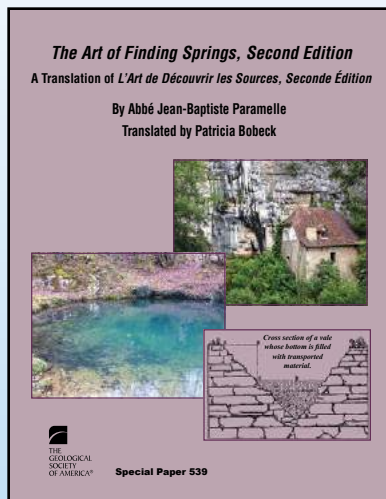
Rates are in Canadian dollars and do not include the current applicable tax of 18.475% per room, per night.

*Rates based on single occupancy/one bed; check the GSA website (<https://community.geosociety.org/gsa2020/travel/hotels>) for additional rate information.

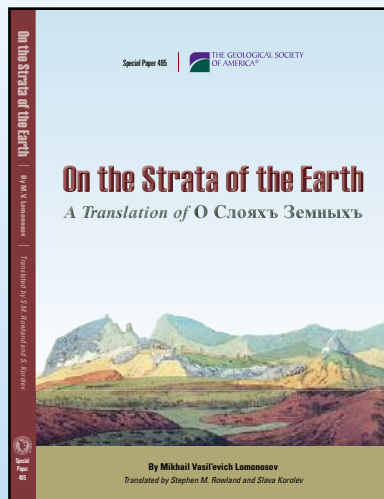
**Rate includes breakfast (varies from continental to full buffet depending on hotel).

Evolution of the Geosciences

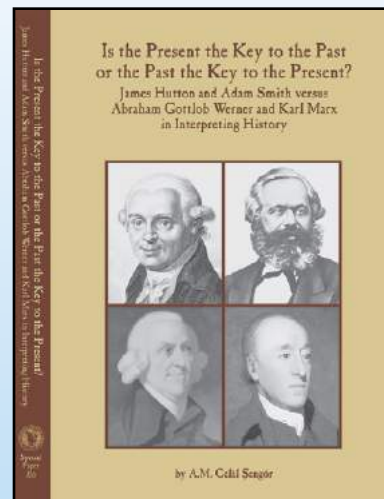
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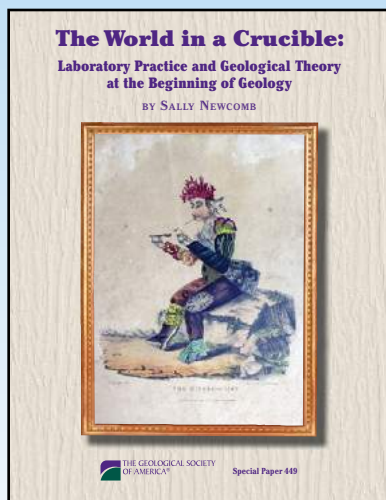
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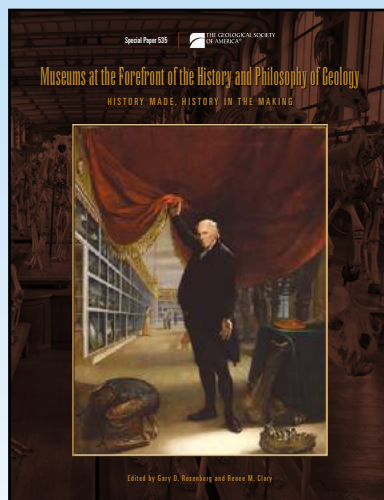
On the Strata of the Earth
A Translation of *О Слояхъ Земныхъ*
By Mikhail Vasil'evich Lomonosov;
translated by Stephen M. Rowland and Slava Korolev
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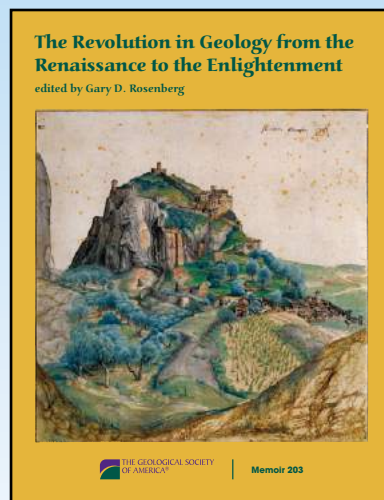
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Keep the Meeting Safe and Inclusive

GSA is committed to providing a safe, inclusive, and professional environment for all of our events, including meetings, field trips, short courses, mentorships, and other GSA-supported programs. Maintaining safe, inclusive events is critical to GSA's success because it promotes full participation and a sense of belonging, which in turn fosters open dialogue, networking, and the productive exchange of scientific ideas.

EVENTS CODE OF CONDUCT

GSA's Events Code of Conduct provides examples of acceptable and unacceptable conduct for all of our events, including our expectation that all GSA events will be free of discrimination, harassment, and bullying. The code of conduct applies to everyone who attends GSA events, including, but not limited to, registrants, guests, volunteers, exhibitors, staff, and service providers. Attendees are required to read and sign the Events Code of Conduct before registering for GSA meetings.



RESPECTFUL INCLUSIVE SCIENTIFIC EVENTS (RISE)

GSA established RISE in 2016. Under this program, GSA uses conspicuous posters to remind meeting participants of our Events Code of Conduct and whom to call to report concerns. GSA takes all concerns seriously and has established procedures to ensure that

appropriate follow-up occurs. Typically, GSA's ethics & compliance officer has an on-site RISE office at the annual meeting. We also have trained dozens of GSA members and staff as RISE liaisons. These individuals attend all major GSA events and have been coached on what to do if they receive a complaint or witness a potential code of conduct violation.

To read the Events Code of Conduct and learn about GSA's other ethics initiatives, go to <https://www.geosociety.org/ethics>.

MAP AND CHART 92

An Earth Scientist's Periodic Table of the Elements and Their Ions

by L. Bruce Railsback, 2015

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Pardee Keynote Symposia



Joseph Thomas Pardee
(1871–1960)

Pardee Keynote Symposia are named in honor of GSA Fellow and benefactor Joseph Thomas Pardee (1871–1960) via a bequest from Mary Pardee Kelly. Pardee is perhaps best known for his work on Glacial Lake Missoula. These symposia consist of invited presentations covering a broad range of topics.

P1. Assembling Laurentia: Turning Points in the Geologic Evolution of the North American Continent

Endorsed by *GSA Structural Geology and Tectonics Division; Mineralogical Society of America; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Sedimentary Geology Division; GSA Geophysics and Geodynamics Division*

Disciplines: Tectonics/Tectonophysics, Geophysics/Geodynamics, Geochemistry

Advocates: Dawn Kellett; Basil Tikoff; Michael L. Williams

The North American continent (Laurentia) records the evolution of tectonic processes from the earliest Archean to modern times. This Pardee Keynote Symposium will initiate a meeting-wide series of sessions focusing on “turning points” in the tectonic evolution of Laurentia. The goal is to integrate the broad range of geologic disciplines in order to scrutinize key periods in the long history of Laurentia when the character, rate, or style of tectonic processes changed or when the plate tectonic process itself may have changed in some fundamental way, and to identify potential drivers for these changes.

P2. Frontiers of Research, Discovery, and Societal Impact in the Hydrologic Sciences

Endorsed by *GSA Hydrogeology Division; GSA Geology and Society Division; GSA Environmental and Engineering Geology Division; GSA Karst Division; GSA Limnogeology Division; Geochemical Society; GSA Quaternary Geology and Geomorphology Division*

Disciplines: Hydrogeology

Advocates: Ingrid Y. Padilla; William L. Cunningham; Elizabeth Eide

The fields of hydrology and hydrogeology address how water interacts with the landscape and ecosystem as well as how hydrologic systems are altered by land use and climate. Hydrologic science research is often interdisciplinary and multidisciplinary, involving expertise from physical and ecosystem sciences, engineering, and/or mathematics, and integrates observational, experimental, theoretical, modeling, and field approaches. The field has changed rapidly due to new discoveries, technological advances, societal needs, and the data revolution. This session will include presentations from leaders in the field that highlight opportunities for research and societal impact in the hydrologic sciences, followed by a panel discussion.

P3. Our Coastal Futures: Working Together to Understand Hazards and Mitigate Disasters

Endorsed by *GSA Marine and Coastal Geoscience Division; GSA Geology and Society Division; GSA Quaternary Geology and Geomorphology Division; GSA Limnogeology Division*

Disciplines: Marine/Coastal Science, Geoscience and Public Policy, Geoscience Information/Communication

Advocates: Rónadh Cox; Robert Weiss

As sea level rises and storm intensity increases, the coastal zone bears the brunt. As we work to understand the science of coastal hazards, we must also consider the human and societal aspects as part of effective mitigation strategies. This symposium convenes a transdisciplinary group of experts in coastal and marine geoscience, policy, anthropology, and history, to discuss the multiplex aspects of coastal hazards in the twenty-first century. This includes cutting-edge scientific approaches as well as attention to social justice and inclusivity.

P4. The Next Generation of Geoscience Leaders: Strategies for Excellence in Diversity and Inclusion

Endorsed by *GSA International; Mineralogical Society of America*

Disciplines: Geoscience Education

Advocates: Raquel Bryant; Benjamin Andrew Keisling

Scientists who make significant diversity, equity, and inclusion (DEI) contributions are often not rewarded, and may even be penalized for their additional efforts. In order to make real strides in achieving DEI goals, we must reframe scientific and academic excellence to include the rigorous pursuit of equity in the geoscience community. This Pardee Symposium will feature (A) speakers who are leaders and role models with demonstrated records of excellence in DEI, (B) a leadership exercise to develop targeted community-relevant solutions, and (C) a panel of non-scientist experts that can provide additional resources to support DEI efforts.

P5. Challenges and Solutions for a Changing Climate: New Directions for GSA

Endorsed by *GSA Geology and Society Division; GSA Geology and Health Division; GSA Sedimentary Geology Division; GSA Structural Geology and Tectonics Division; GSA Karst Division; GSA Geochronology Division; GSA Quaternary Geology and Geomorphology Division; GSA Energy Geology Division; GSA Environmental and Engineering Geology Division; GSA Marine and Coastal Geoscience Division; GSA Soils and Soil Processes Division; GSA Mineralogy, Geochemistry, Petrology and Volcanology Division; GSA Continental Scientific Drilling Division; GSA Hydrogeology Division; GSA Limnogeology Division; GSA Geoscience Education Division; GSA Geology and Public Policy Committee; GSA International*

Disciplines: Environmental Geoscience, Energy Geology, Geoscience Information/Communication

Advocates: Beth Bartel; Malcolm Siegel; Candace L. Kairies-Beatty; Luke J. Bowman; Sinjini Sinha

Responding to a 2019 challenge from GSA president Don Siegel, this symposium in turn challenges GSA leadership and membership to think creatively, critically, and constructively about our role in climate change solutions. The year is 2020. Looking back, what will we wish we had done? This session looks forward, exploring visions and viewpoints in the themes of assessment, mitigation, adaptation, and engagement, with a focus on North America. As a society of geoscientists, it is our responsibility to drive the solutions that will ensure a sustainable existence on our favorite planet.



Feed Your Brain *Lunchtime Enlightenment*



J. Douglas Walker

Sun., 25 Oct., noon–1:30 p.m.

GSA Presidential Address: J. Douglas Walker, “Doing Geology in an Online World.”



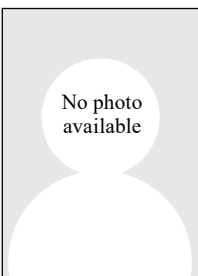
Tom Gleeson

Mon., 26 Oct., 12:15–1:15 p.m.

Tom Gleeson, 2020 Michel T. Halbouty Distinguished Lecture, “Is Groundwater a Local and Global Resource? New Sustainability Ideas and Tools across Scales.”



Ken Lambla



June Lambla



Marek Ranis



Missy Eppes

Tues., 27 Oct., 12:15–1:15 p.m.

Ken Lambla, June Lambla, Marek Ranis, Missy Eppes, “Bringing Art to Your Science and Thus Your Science to the People: Joining Visual Culture and Scientific Evidence.” *Endorsed by GSA Geology & Society Division; GSA Geoscience Education Division; GSA History and Philosophy of Geology Division; and Quaternary Geology and Geomorphology Division.*



Jill Heinerth

Wed., 28 Oct., 12:15–1:15 p.m.

Jill Heinerth, “Science and Mapping of Underwater Caves.”



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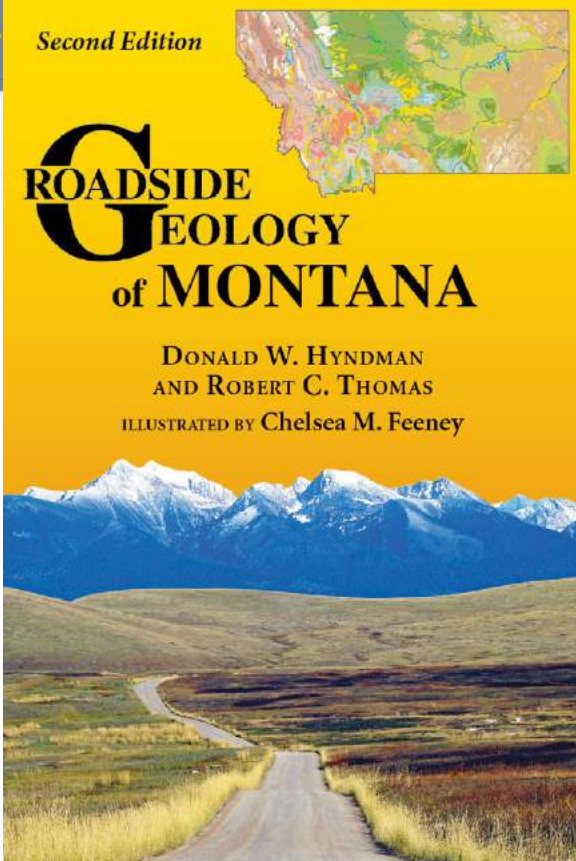
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Scientific Field Trips

Descriptions and leader biographies are online at <https://community.geosociety.org/gsa2020/program/field>.

-  401. **Trace the Steps of 19th-Century French Hydrogeologists Henry Darcy and Jean-Baptiste Paramelle.** Wed., 14 Oct.–Wed., 21 Oct. Cost: US\$1,500. **Leader:** Patricia Bobeck.
402. **Transect of a Hot, Long Orogen: The Grenville Province of Western Québec.** Wed.–Sat., 21–24 Oct. Cost: US\$464. **Leaders:** Christopher W. Lambert, Stellenbosch University; Félix Gervais; Charles Kavanagh-Lepage.
403. **From Obduction to Collision: A Transect across Ordovician to Devonian Sedimentary Basins of the Québec Appalachians.** Wed.–Sat., 21–24 Oct. Cost: US\$620. **Cosponsor:** *Université du Québec à Montréal*. **Leaders:** Stéphane De Souza, Université du Québec à Montréal; Morgann Perrot, Alain Tremblay.
407. **Ottawa & Gatineau Accessible Geoheritage Tour.** Fri.–Sat., 23–24 Oct. Application required. **Cosponsors:** *International Association for Geoscience Diversity (IAGD)*; *Canadian Geoscience Education Network (CGEN)*. **Leaders:** Anita M.S. Marshall, University of Florida; Beth McLarty Halfkenny; Jennifer L. Piatek; Jean Dougherty; Janice Aylsworth; Lesley Hymers.
-   408. **Kirk Bryan Field Trip: Pre-LGM Stratigraphic Record in the Central St. Lawrence Lowlands—How Much Ice in Southern Québec and Adjacent New England during MIS-3?** Sat., 24 Oct. Cost: US\$174. **Endorsed by** *GSA Quaternary Geology and Geomorphology Division*. **Leaders:** Michel Parent; Lamothé.
409. **Geoarchaeology of the Middle Saint Lawrence River Valley of Southern Québec, Canada.** Sat., 24 Oct. Cost: US\$230. **Leaders:** Laura R. Murphy, Kansas Geological Survey; Brendan Fenerty; L.M. Joyce Seals; Adrian Burke.
-  410. **The Hydrology, Biogeochemistry, and Mineralogy of a Montregian Hill: Mont Sainte Hilaire.** Sat., 24 Oct. Cost: US\$235. **Leaders:** Peter M. Douglas, McGill University; Greg Langston.
411. **Geological Field Trip in the Mount Royal Park.** Thurs., 29 Oct. Cost: US\$360. **Leader:** Pierre Bédard, Polytechnique Montréal.
-    413. **Cambrian–Lower Ordovician of SW Québec–NE New York.** Thurs.–Sat., 29–31 Oct. Cost: US\$642. **Leaders:** Osman Salad Hersi, University of Regina; Ed Landing; David G. Lowe; James Hagadorn; David Franz.
-   414. **Geology and Wine: What Grows Together, Goes Together.** Sat., 24 Oct. Cost: US\$221. **Leader:** Kristyn Jessica Rodzinyak, McGill University; Chimira Andres.
-     415. **Canada's Role in Space.** Thurs., 29 Oct. Cost: US\$211. **Endorsed by** *Canadian Space Agency*. **Leader:** Kristyn Jessica Rodzinyak, McGill University.
-   416. **Geology and Wine: What Grows Together, Goes Together.** Fri., 30 Oct. Cost: US\$221. **Leader:** Kristyn Jessica Rodzinyak, McGill University; Chimira Andres.

INDUSTRY TRACKS GSA's field trip program offers trips relevant to applied geoscientists. Look for these icons, which identify trips in the following areas:



Economic Geology



Energy



Engineering



Hydrogeology and
Environmental Geology

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GSA K–12 teacher members: You are welcome to take short courses without registering for the meeting or paying the nonregistrant 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 <https://community.geosociety.org/gsa2020/program/short> or contact Jennifer Nocerino, jnocerino@geosociety.org, for course abstracts and additional information.

Early registration is highly recommended to ensure that courses will run.





    **501. Field Safety Leadership.** Fri.–Sat., 23–24 Oct., 8 a.m.–5 p.m. US\$45. Limit: 24. CEU: 1.6. **Instructors:** Kevin Bohacs, ExxonMobil (retired); Kurt Burmeister, University of the Pacific; Greer Barriault, ExxonMobil Upstream Research Company. **Endorsed by ExxonMobil Upstream Research Company.**





  **502. Introduction to Petroleum Structural Geology.** Fri.–Sat., 23–24 Oct., 8 a.m.–5 p.m. US\$25. Limit: 30. CEU: 1.6. **Instructor:** Kellen Gunderson, Chevron Energy Technology Company. **Endorsed by GSA Structural Geology and Tectonics Division; GSA Energy Geology Division; AAPG Petroleum Structures and Geomechanics Division.**

    **503. Sequence Stratigraphy for Graduate Students.** Fri.–Sat., 23–24 Oct., 8 a.m.–5 p.m. US\$25. Limit: 55. CEU: 1.6. **Instructors:** Morgan Sullivan, Chevron Energy


Technology Company; Bret Dixon, Tall City Exploration.


Cosponsor: *Chevron Energy Technology Company.*





    **504. High-Resolution Topography and 3D Imaging I: Introduction to Terrestrial Laser Scanning.** Fri., 23 Oct., 8 a.m.–5 p.m. US\$60. Limit: 24. CEU: 0.8. **Instructor:** Christopher Crosby, UNAVCO. **Cosponsor:** *UNAVCO.*





    **505. Resistivity Surveying: Getting The Best and Making The Most From ERT and Induced Polarization Data.** Fri., 23 Oct., 8 a.m.–5 p.m. US\$105. Limit: 30. CEU: 0.8. **Instructors:** Jimmy Adcock, Guideline Geo Americas; Morgan Sander-Olhoef, Guideline Geo Americas. **Cosponsor:** *Guideline Geo.*

506. Quantitative Analysis, Visualization, and Modelling of Detrital Geochronology Data. Fri., 23 Oct., 8 a.m.–5 p.m. US\$100 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; Samuel Johnstone, U.S. Geological Survey.

 **507. From Airborne Electromagnetic Method Data to 3D Hydrogeological Conceptual Model.** Fri., 23 Oct., 9 a.m.–4 p.m. US\$103. Limit: 40. CEU: 0.7. **Instructors:** Tom Martlev Pallesen, I•GIS; Mats Lundh Gulbrandsen, I•GIS. **Endorsed by I•GIS.**

 **508. Petroleum Geochemistry for Basin Evaluation.** Sat., 24 Oct., 8 a.m.–5 p.m. US\$112. Limit: 25. CEU: 0.8. **Instructors:** Irene Arango, Chevron Energy Technology Company; Norelis Rodriguez, Chevron Energy Technology Company. **Endorsed by Chevron Energy Technology Company.**

    **509. Introduction to Drones (sUAS) in the Geosciences.** Sat., 24 Oct., 8 a.m.–5 p.m. US\$120. Limit: 24. CEU: 0.8. **Instructor:** Gregory Baker, Colorado Mesa University. **Endorsed by GSA Hydrogeology Division; GSA Geoarchaeology Division; GSA Quaternary Geology and Geomorphology Division.**

    **510. Three-Dimensional Geological Mapping and Modeling.** Sat., 24 Oct., 8 a.m.–5 p.m. US\$115. Limit: 55. CEU: 0.8. **Instructors:** Kelsey MacCormack, Alberta Geological Survey; Hazen Russell, Geological Survey of Canada; Harvey Thorleifson, University of Minnesota; Holger Kessler, British

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


Geological Survey; Richard Berg, Illinois State Geological Survey. **Endorsed by** *Association of American State Geologists*.


511. Get Your Science out There: Communicating with the Public, Understanding Reporters, Nailing Interviews, and Sharing on Social Media. Sat., 24 Oct., 8 a.m.–5 p.m. US\$119. Limit: 25. CEU: 0.8. **Instructors:** Paul Bierman, University of Vermont; Joshua Brown, University of Vermont; Christopher Halsted, University of Vermont; Basil Waugh, University of Vermont. **Endorsed by** *GSA Quaternary Geology and Geomorphology Division*.


 **512. High-Resolution Topography and 3D Imaging II: Introduction to Structure from Motion (SfM) Photogrammetry.** Sat., 24 Oct., 8 a.m.–5 p.m. US\$60. Limit: 24. CEU: 0.8. **Instructors:** Christopher Crosby, UNAVCO; J Ramon Arrowsmith, Arizona State University. **Cosponsor:** *UNAVCO*. **Endorsed by** *OpenTopography*.

513. Your Thesis is Software: Tools for the Geoscientist to Help Write Better Code, from Version Control to Test-Driven Development. Sat., 24 Oct., 8 a.m.–5 p.m. US\$10. Limit: 30. CEU: 0.8. **Instructors:** Simon Goring, University of Wisconsin; Amy Myrbo, Science Museum of Minnesota.

 **514. 3D Printing for Geoscience and Engineering: Emerging Technology in Education, Research, and Communication.** Sat., 24 Oct., 8 a.m.–5 p.m. US\$158. Limit: 40. CEU: 0.8. **Instructors:** Rick Chalaturnyk, University of Alberta; Sergey Ishutov, University of Alberta; Kevin Hodder, University of Alberta; Gonzalo Zambrano, University of Alberta. **Endorsed by** *GeoPrint; Petroleum Institute of Mexico*.


 **515. Ground-Penetrating Radar—Principles, Practice, and Processing.** Sat., 24 Oct., 8 a.m.–5 p.m. US\$80. Limit: 24. CEU: 0.8. **Instructor:** Greg Johnston, Sensors & Software. **Cosponsor:** *Sensors & Software*.


 **516. Medical Geology: The Earth's Impacts on Human Health.** Sat., 24 Oct., 8 a.m.–5 p.m. US\$10. Limit: 25. CEU: 0.8. **Instructors:** Laura Ruhl, University of Arkansas at Little Rock; Malcolm Siegel, University of New Mexico; Robert Finkelman, University of Texas at Dallas. **Cosponsor:** *GSA Geology and Health Division*.

 **517. A Practical Guide to Geophysics for Geotechnical Site Investigation.** Sat., 24 Oct., 8 a.m.–5 p.m. US\$105. Limit: 30. CEU: 0.8. **Instructors:** Jimmy Adcock, Guideline Geo Americas; Morgan Sander-Olhoft, Guideline Geo Americas. **Cosponsor:** *Guideline Geo*.


518. Geodynamic History of the Middle Part of Alpine-Himalayan Orogenic Belt. Sat., 24 Oct., 8 a.m.–5 p.m. US\$120. Limit: 40. CEU: 0.8. **Instructors:** Abdollah Saidi, deputy for the Middle East Sub-Commission; Akram Shahhosseini, Geological Survey of Iran.


519. Detrital and Petrochronologic Applications of U-Pb Geochronology and Lu-Hf and Trace/REE Geochemistry by Laser Ablation Inductively Coupled Plasma–Mass Spectrometry. Sat., 24 Oct., 8 a.m.–5 p.m. US\$40. Limit: 40. CEU: 0.8. **Instructors:** George Gehrels, University of Arizona; Kurt Sundell, University of Arizona; Sarah George, University of Arizona.

 **520. Exploring Surface Processes Using Community Surface Dynamics Modeling System Modeling Tools: How to Build Coupled Models.** Sat., 24 Oct. 8 a.m.–5 p.m. US\$50. Limit: 30. CEU: 0.8. **Instructors:** Gregory Tucker, University of Colorado; Tian Gan, University of Colorado; Benjamin Campforts, University of Colorado. **Cosponsors:** *National Science Foundation; Community Surface Dynamics Modeling System*.


 **521. 3D Hydrogeological Modeling. How to Build Them and Why.** Sat., 24 Oct., 9 a.m.–4 p.m. US\$103. Limit: 40. CEU: 0.6. **Instructors:** Tom Martlev Pallesen, I*GIS; Mats Lundh Gulbrandsen, I*GIS. **Endorsed by** *I*GIS*.

522. Teaching Quantitative Structural Geology. Sat., 24 Oct., 9 a.m.–5 p.m. US\$20 (a GSA store voucher for US\$20 will be given upon completion of the course). Limit: 30. CEU: 0.7. **Instructors:** David Pollard, Stanford University; Stephen Martel, University of Hawaii.

 **523. Introduction to Planetary Image Analysis with ArcGIS.** Sat., 24 Oct., 9 a.m.–5 p.m. US\$20 (a GSA store voucher for US\$20 will be given upon completion of the course). Limit: 30. CEU: 0.7. **Instructor:** Zoe Learner Ponterio, Cornell University. **Cosponsors:** *Spacecraft Planetary Imaging Facility; Cornell University*.

 **524. NASA Data Made Easy: Getting Started with Synthetic Aperture Radar.** Sat., 24 Oct., 8 a.m.–noon. US\$10. Limit: 24. CEU: 0.4. **Instructors:** Cynthia Hall, Goddard Space Flight Center; Lisa Grant Ludwig, University of California Irvine; Jay Parker, NASA; Heidi Kristenson, Alaska Satellite Facility; Sara Lubkin, NASA.

525. Everything You Wanted to Know about Open Science but Had No Time to Ask—Understanding Open Science. Sat., 24 Oct., 8 a.m.–noon. US\$50. Limit: 30. CEU: 0.4. **Instructor:** Laura Spence Kelleher, Taylor & Francis.

 **526. An Introduction to Stratigraphic Data Analysis in R (SDAR), A Quantitative Toolkit to Analyze Stratigraphic Data.** Sat., 24 Oct., 8 a.m.–noon. US\$100. Limit: 30. CEU: 0.4. **Instructor:** John Ortiz, Colombian Geological Survey and Corporación Geológica ARES.

527. Fostering GEO-STEM Learning Ecosystems: Creating More Diverse, Inclusive, and Resilient Communities Engaged in the Geosciences. Sat., 24 Oct., 1–5 p.m. US\$20 (a GSA store voucher for US\$20 will be given upon completion of the course). Limit: 40. CEU: 0.4. **Instructors:** Cheryl Manning, Northern Illinois University; Margaret Fraiser, American Geophysical Union.

GSA 2020 ANNUAL MEETING

528. Geosciences and Society: A Teaching Workshop. Sat., 24 Oct., 1–5 p.m. US\$90. Limit: 24. CEU: 0.4. **Instructors:** Anne Marie Ryan, Dalhousie University; Carl-Georg Bank, University of Toronto.

529. A New Future in Sedimentary Field Data Collection. Sat., 24 Oct., 1–5 p.m. US\$25. Limit: 40. CEU: 0.4. **Instructors:** Casey Duncan, University of Utah; Diane Kamola, University of Kansas; Elizabeth Hajek, Penn State University; Basil Tikoff, University of Wisconsin–Madison; Marjorie Chan, University of Utah. **Cosponsors:** National Science Foundation; GSA

Sedimentary Geology Division; GSA Geoinformatics Division; SEPM (Society for Sedimentary Geology).

530. Improving Workplace Climate: Strategies for Responding to Harassment. Sat., 24 Oct., 1–5 p.m. US\$20. Limit: 30. CEU: 0.4. **Instructors:** Andria Ellis, UNAVCO; Meredith Hastings, Brown University; Erika Marín-Spiotta, University of Wisconsin–Madison; Hendratta Ali, Fort Hays State University. **Cosponsors:** ADVANCEGeo Partnership; Association for Women Geoscientists; Earth Science Women’s Network; UNAVCO.



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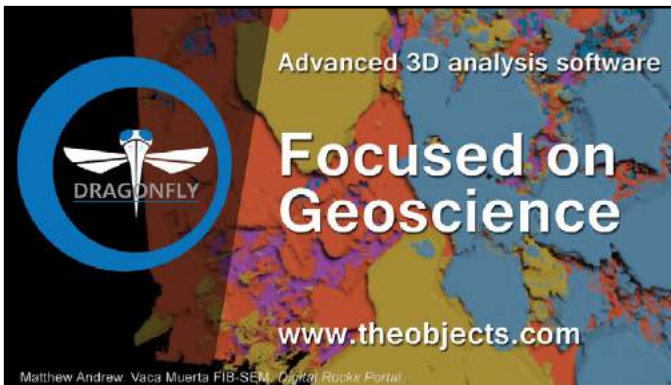
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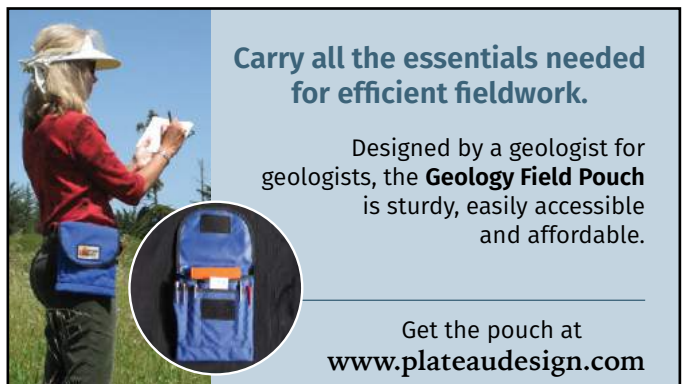
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Résumé Review Clinic
Drop-In Mentoring
Early Career Professionals Coffee
Geology Club Meet-Up
Networking Event
Women in Geology Program
Post or View Jobs

If you're not attending the meeting, consider registering for an upcoming webinar or viewing past career exploration webinars at <https://www.geosociety.org/webinars>.

Go to <https://community.geosociety.org/gsa2020/geocareers> for event details, dates, and times.

Be a Mentor—Share Your Experience

Become a mentor and help students navigate the meeting, introduce them to contacts, discuss career paths, and offer advice. Graduate students, early career professionals, professionals, and retirees are welcome to serve as mentors.

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.

Networking Event Mentor. The networking event is a gathering of students, early career professionals, and mentors. About 40 mentors are needed to answer questions, offer advice about careers plans, and comment on job opportunities within their fields.

On To the Future Mentor. About 75 On To the Future (OTF) mentors are needed. Each will be paired with a student who is part of the OTF program, which supports students from diverse groups to attend their first GSA Annual Meeting. Mentors will meet with their mentee each day of the meeting, introduce the mentee to five contacts, and share their professional experiences in the geosciences. Matching will be completed using an online platform. To learn more, go to <https://www.geosociety.org/OTF> and click on “mentorships.”



Résumé or CV Mentor. Résumé mentors are matched with students on-site to review the student’s résumé or CV. Consultations take place for 30 minutes in the GeoCareers Center in a one-on-one format. About 28 mentors are needed.

Women in Geology Mentor. About 30 mentors from a variety of sectors are needed to answer career questions and offer advice during the Women in Geology Program.

To serve as a mentor, please complete the mentor interest form at <https://forms.gle/bZeKibPue7BXEsyQ9>.



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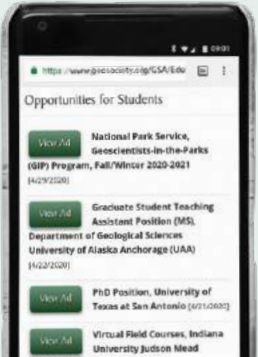
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On To the Future (OTF)

The OTF program supports students from diverse groups to attend their first GSA Annual Meeting. Now in its eighth year, here are some of the achievements so far:

647

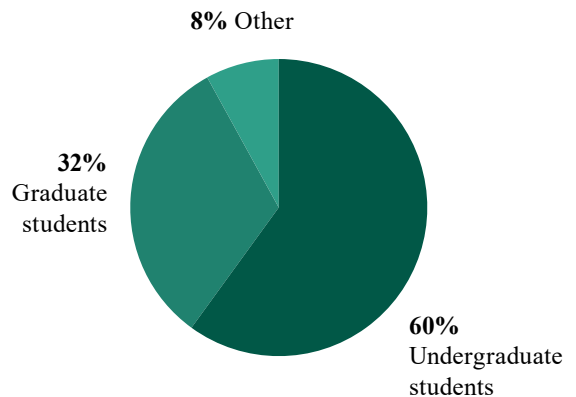
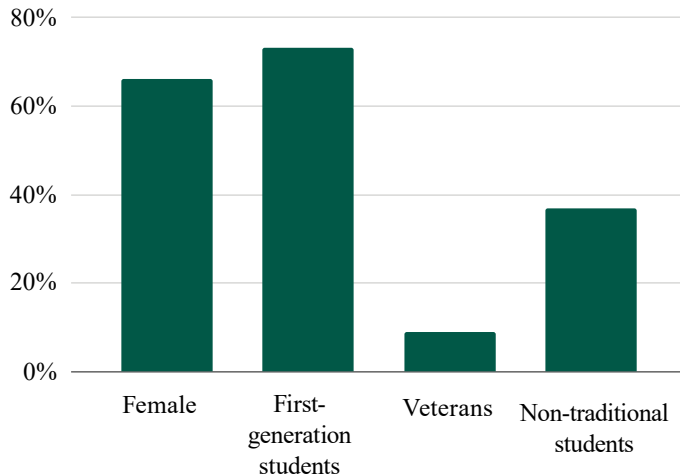
Supported **647** students and recent graduates since 2013.



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47% from groups underrepresented in the geosciences (American Indian/Alaska Native, African American, Hispanic/Latino, Native Hawaiian/Pacific Islander).



Learn more about this program and how you can help mentor a student at <https://www.geosociety.org/otf>.



GSA DIVERSITY IN THE GEOSCIENCES AND OTF ALUMNI RECEPTION

Tues., 27 Oct.

Everyone is welcome to socialize and share ideas at this informal gathering. OTF scholars, the OTF research grant awardee, and Expanding Representation in the Geoscience Scholarship recipients will be recognized, with a special presentation by the Bromery awardee.

Local Tours



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OLD MONTRÉAL WALKING TOUR

Sun., 1–4. Min.: 15; max.: 18. Cost: US\$32.

On this walking tour, your guide will lead you through a maze of narrow cobblestone streets, providing historic commentary and interesting facts about Old Montréal. The tour is designed to deliver an historic overview, and stops will be frequent but brief. There will be a lengthier stop for a guided visit of the Notre-Dame Basilica—a stunning example of neo-Gothic architecture and masterpiece of decorative art.

LUNCH AT AN AUTHENTIC SUGAR-SHACK

Mon., 11:30 a.m.–4 p.m. Min.: 35; max.: 50. Cost: US\$83.

Step back in time and experience a unique glimpse into Québec folklore at the Sucrerie de la Montagne—an official Québec heritage site. In a picturesque mountain setting, the Sucrerie is designed to resemble a typical rural Québec village of yesteryear, complete with a fieldstone sugar shack and bakery, barns where the dining rooms are located, a general store, a sawmill, and ancestral cabins. Your sugaring-off party will begin with a brief tour of the facilities. Guests are then welcomed into the dining room for a feast of traditional Québécois dishes, served family-style, all-you-can-eat. After lunch, drop by the general store for a souvenir, maple products, or local handicrafts. Don't forget a taste of maple taffy!

MONTRÉAL BREW TOUR

Tues., 1–4 pm. Min.: 15; max.: 18. Cost US\$79.

Montréal loves its beer! This informal tour gives you the opportunity to walk through a few off-the-beaten-path neighborhoods and visit three great local beer artisans—a unique experience since Québec doesn't export much of its liquid gold. You'll sample six products, along with a few local snacks, such as poutine, charcuterie, cheese, and chocolate.

MONTRÉAL FLAVORS TOUR

Wed., 10:30 a.m.–2:30 p.m. Min.: 15; max.: 18. Cost: US\$97.

Montréal has often been dubbed the North American capital for French cuisine and can certainly be considered an epicenter of gastronomy in general. You will discover the city from a different point of view while the tour guide provides a historical background, and you'll learn about the ethnic influences on this culinary community. From “Little Italy” to “Chinatown” and including the Greek, Portuguese, and Jewish neighborhoods, guests will visit some of the most popular food stops and try some of the local specialties.

Guest Program



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We warmly welcome all members of the GSA community to Montréal. As part of that welcome, we offer registered guests and Penrose Circle invitees a comfortable hospitality suite for rest and relaxation while technical sessions are happening. As a registered guest, you are welcome to attend your companion's technical session(s), and you will also have admittance to the Resource and Innovation Center. Activities in the suite include complimentary refreshments, entertaining and complimentary educational seminars, and local experts ready to answer your questions about Montréal. Local tours and activities will also be offered for an additional fee. We hope that you take advantage of the tours to learn about the area from one of the knowledgeable tour guides.

SEMINARS

Montréal's Architecture—Melding of Old & New

Sun., 10–11 a.m.

Montréal is an incredibly spectacular city with its own unique architectural style. It is not uncommon to see buildings hundreds of years old integrated with brand-new high-tech edifices. Join a Montréal tour expert on your virtual tour of some of the city's most captivating buildings. Learn a little about the city's unique style before heading out an exploratory tour on your own or on a guided city visit. However you decide to explore, la belle Métropole is a wonder to behold.

The Inner Game of Thriving

Mon., 10–11 a.m.

There are five principles to thriving: breathing, relaxation, exercise, nutrition, and mindfulness. In this seminar, presenter Bhaskar Goswami, an impactful speaker and a senior yoga and meditation teacher from Assam, India, will take you through these five key anchors. With practical examples and his engaging presentation style, Bhasgar will leave your group wanting to learn more. It is impossible not to feel more relaxed in his presence, and he is dedicated to your own practice of thriving going forward.

Getting to the Soul of the Matter

Tues., 10–11 a.m.

Many cultures and health practitioners use reflexology as a way to increase their sense of well being. If you have ever wondered about this ancient modality, here is your chance to learn a little about the theories behind how and why it is a favorite practice. Learn a few fabulous things to support your own sense of well-being and maybe even surprise others you love in your life too.

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WEDNESDAY

Open: 10 a.m.–2 p.m.



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Bringing Students and Schools Together

GSA's Campus Connection provides an excellent opportunity for students to meet face to face with representatives from top geoscience schools. This four-day event saves students time and travel expenses, giving the schools a chance to meet with some of the best student geoscientists in the world in a relaxed, informal setting.

EXHIBIT IN MONTRÉAL

Multiple rates are available to reflect a diverse range of GSA 2020 exhibitors. If you have questions or want to reserve your booth please contact David Gerhardt, Exhibit Manager, Corcoran Expositions Inc., +1-312-265-9664, david@corcexpo.com.

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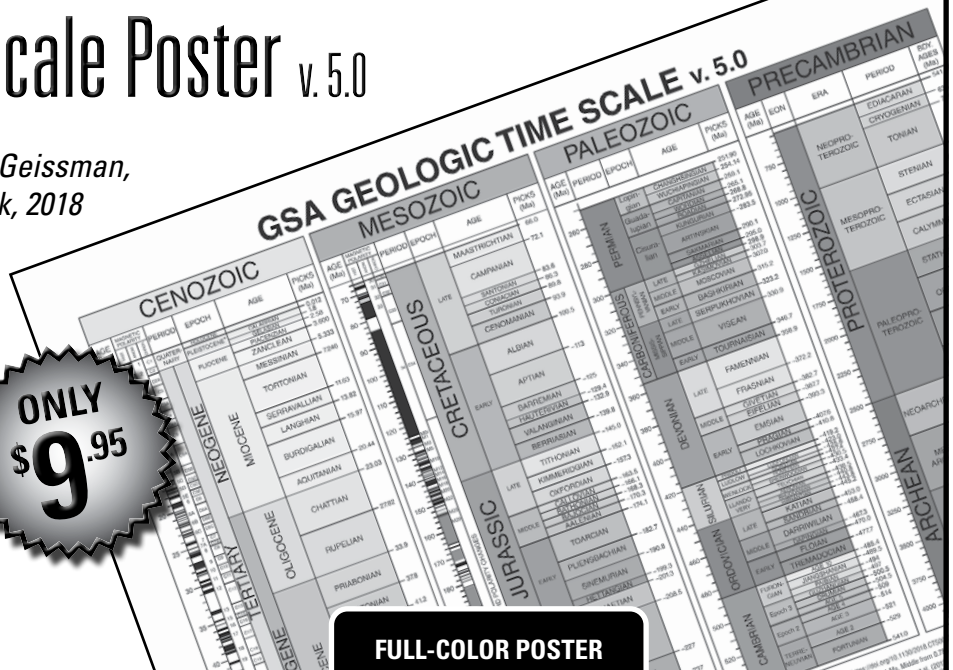
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Archibald Geikie (1835–1924): A Pioneer Scottish Geologist, Teacher, and Writer

Rasoul Sorkhabi, University of Utah, Salt Lake City, Utah 84108, USA; rsorkhabi@egi.utah.edu



Figure 1. Archibald Geikie as a young geologist in Edinburgh. (Photo courtesy of the British Geological Survey, probably taken in the mid-1860s.)

EARLY LIFE AND EDUCATION

Archibald Geikie was born into a middle-class family in Edinburgh in 1835. He was the eldest child of James Stuart Geikie (1811–1883), a chemist and musician, and Isabella Laing Thom (1808–1895), daughter of a captain in the merchant marines. The family was to welcome seven other children during the following seventeen years. His father owned a perfume shop and was also a church musician and later a music critic for *The Statesman*. He took his son to concerts in Edinburgh, which gave Geikie a taste for music.

Geikie entered Mr. Black's School at age seven and proved to be an outstanding student, and in 1845, he matriculated at the Edinburgh High School (now the Royal High School), which James Hutton had attended. Geikie enjoyed studying Latin and Greek classics as well as natural history and geology. His passion for geology was stimulated by finding Carboniferous fossils during Saturday trips south of Edinburgh. Later he recalled that he was impressed by the fact that the sedimentary rocks contained fossils of plants and animals never seen by humans. The rich geology of Scotland indeed attracted many minds, including Geikie's younger brother James Murdoch Geikie (1839–1915), who also became a geologist.

At age 15, Geikie apprenticed in a law office as preparation for a banking career. He found the legal work boring and left it two

years later, but there he learned how to write reports. Meanwhile, he read every geology book he could find, including John Playfair's *Illustrations of the Huttonian Theory*, Henry de la Beche's *Geological Manual*, Charles Lyell's *Principles of Geology*, and Hugh Miller's *The Old Red Sandstone*.

BECOMING A GEOLOGIST

In the summer of 1851, while the Great Exhibition in London was attracting so many people, Geikie decided instead to visit the Island of Arran in the Clyde estuary and study its geology, aided by a brief report by Andrew Ramsay of the British Geological Survey. Geikie came back with a report titled "Three weeks in Arran by a young geologist," published that year in the *Edinburgh News*. This report impressed Hugh Miller so much that the renowned geologist invited its young author to discuss geology over a cup of tea. Miller became Geikie's first mentor. In this period, Geikie became acquainted with local scientists and privately studied chemistry, mineralogy, and geology under Scottish naturalists, such as George Wilson, Robert Chambers, John Fleming, James Forbes, and Andrew Ramsay—to whom he confessed his desire to join the Geological Survey.

In 1853, Geikie visited the islands of Skye and Pabba off the coast of Scotland and reported his observations of rich geology, including finds of Liassic fossils. Hugh Miller arranged for him to exhibit these fossil finds at the Royal Physical Society's meeting that year—his first presentation at a professional gathering. Geikie's reports of Skye and Pabba were published in 1858 in *Quarterly Journal of Geological Society of London* and *Proceedings of the Royal Physical Society of Edinburgh*, respectively. Recently, Betterton (2019) has provided the unpublished reports of Geikie's early fieldwork, which demonstrate the literary, scientific, and painting skills of the young geologist.

In 1854, Geikie entered the University of Edinburgh but had to leave without graduation due to family financial problems resulting from Geikie's younger brother William's involvement in 1855 of stabbing a man. Shortly thereafter, when Sir Roderick Murchison, the director-general of the Geological Survey of Great Britain, asked Miller to introduce a young geologist to map the East Lothian district (a project begun by John Ramsay), Miller at once recommended Geikie. Thus, at age 20, Geikie began working at the Geological Survey, just a year after he had left the university.

Geikie's excellent fieldwork at the Survey as well as his first major publication in 1858, *The Story of a Boulder or Gleanings from the Note-book of a Field Geologist*, impressed Murchison, who became Geikie's second and most powerful mentor. When a separate branch of the Geological Survey for Scotland was founded in 1867, Murchison nominated Geikie (at age 32!) to become its director. Murchison also established a chair for professor of geology and mineralogy in 1871 at the University of Edinburgh and appointed Geikie the first professor. (Geikie held

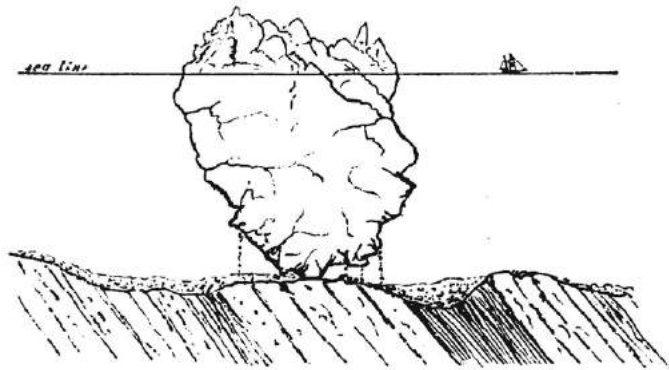


Figure 2. Iceberg grating along the sea-bottom and depositing mud and boulders—drawing by Geikie in his first book, *The Story of a Boulder* (London, Macmillan, 1858). Note the ship for scale.

both these positions until 1881.) Also in 1871, Geikie married Anna Alice Gabrielle Pignatel (1852–1918), a French-born musician (with an English mother and French father). The couple had four children: Lucy, Roderick, Elsie, and Gabrielle.

MANY-FOLD CONTRIBUTIONS

Geikie is reputed for his pioneering mapping of various parts of Scotland. In 1865, at age 30, he published *The Scenery of Scotland Viewed in Connection to Its Physical Geology* (360 pages) to accompany the geological map of Scotland (with Murchison). This seminal work was expanded to 540 pages in its third edition in 1901. Geikie's mapping of Scotland was not without blunders, however. In *The Highlands Controversy*, Oldroyd (1990) has shown how the simple Silurian mapping of a large part of the Scottish Highlands by the aging Murchison and his young protégé Geikie in 1860 turned out to be inaccurate, because the region was structurally complex and metamorphosed as revealed by the field mapping of Charles Lapworth in the 1880s. Geikie acknowledged his error much later, in 1907.

Geikie investigated volcanic terrains on British islands and attempted to understand the processes of volcanic eruptions. He particularly tried to categorize volcanic rock records based on their processes and in relation to specific igneous structures—vents, craters, fissures, dikes, plateaus basalts, and so forth. His two-volume treatises, *The Ancient Volcanoes of Britain*, published in 1897, summarized his 25-year work in this field.

Geikie made significant contributions to the study of glacial terrains, drifts, erratic boulders, and ice ages in Scotland, documented in his 1863 monograph, *On the Phenomena of the Glacial Drift of Scotland*. He pioneered the idea that rivers and glaciers were the main agents of denudation and sculpturing of landforms. To observe these phenomena first-hand in an active erosional setting, Geikie journeyed to Utah, Wyoming, and Yellowstone in 1879 (Sorkhabi, 2019).

TEACHER AND WRITER

Geikie was a popular teacher. At the end of each geology course, he would take students on a 10-day field trip. Geikie's classes included women students as well. His textbooks, especially *Textbook of Geology* (first published in 1882, with a fourth edition in 1905), were widely used in the UK and the USA. Geikie was also a prolific and influential popularizer of geology. He wrote a large number of essays explaining geologic features to the public; many



Figure 3. Geikie's landscape painting of Boulder Canyon, Colorado, USA, during his visit to the American West in 1879 (courtesy of Haslemere Educational Museum; for more artwork by Geikie, go to <http://www.haslemere-museum.org.uk/databases/geikiewebproject/geikie.php>).

of these essays are collected in *Geological Sketches at Home and Abroad* (1882) and *Landscape in History and Other Essays* (1898). His skills in landscape painting made his publications and reports more attractive. Cutter (1974) compiled Geikie's publications, listing 246 reports, articles, biographies, reviews, and books.

In 1881, Geikie resigned from Edinburgh University. In 1882, the Survey transferred him to London, where he succeeded Sir Andrew Ramsay as director-general of the Geological Survey of the UK as well as director of the Museum of Practical Geology. He retained these positions until his retirement in 1901.

Geikie corresponded with and met with many leading geologists of his day in the UK and overseas. Aside from two dozen obituaries published in *Nature* and book-length memoirs of Edward Forbes (1861), Sir Roderick Murchison (1875), Sir Andrew Ramsay (1895), and John Mitchell (1918), Geikie also delivered a series of lectures on *The Founders of Geology* at Johns Hopkins University in 1897, in which he summarized Hutton's principle of uniformitarianism in the famous maxim "the present is the key to the past" (Geikie, 1905, p. 299)

LATER LIFE

Geikie served as president of the Geological Society (London) from 1890 to 1892 and was reelected for a second term (1906–1908) to preside over the centenary celebrations of the Geological Society in 1907. Geikie was also closely associated with the Royal Society in London. He served as its secretary (1903–1908) and president (1908–1913)—the only geologist to serve as the president to this date.

Although not a college graduate, Archibald Geikie received honorary doctorates from 15 universities in Britain and continental Europe and several reputed scientific awards, including the Murchison Medal (1881) and Wollaston Medal (1895) of the Geological Society, and the Royal Medal of the Royal Society (1896). He was knighted by Queen Victoria in 1891, became a Knighted Commander of the Order of the Bath in 1907, and received the Order of Merit from Edward VII in 1913.

The most tragic event in Geikie's life was probably the early death of his only son Roderick who was killed in 1910 (aged 36) in an accident on the underground railway in London.

In 1913, Geikie went to live in his new house at Haslemere, Surrey. He collaborated with the Haslemere Educational (formerly Natural History) Museum, where his papers and collections are archived (Betterton et al., 2019). Geikie's autobiography, *A Long Life's Work*, was published in 1924, the same year he died. In his long and productive life, Archibald Geikie had mastered several fields of geology, working with his geologist's hammer as well as with his pen, ink, and field book.

REFERENCES CITED

Betterton, J., 2019, Unpublished manuscripts of Archibald Geikie, in Betterton, J., Craig, J., Mendum, J.R., Neller, R., and Tanner, J., eds., Aspects of the

Life and Works of Archibald Geikie: Geological Society, London, Special Publication 480, p. 255–316, <https://doi.org/10.1144/SP480.17>.
 Betterton, J., Craig, J., Mendum, J.R., Neller, R., and Tanner, J., eds., 2019, Aspects of the Life and Works of Archibald Geikie: Geological Society, London, Special Publication 480, 406 p.
 Cutter, E., 1974, Sir Archibald Geikie: A bibliography: *Journal of the Society of Bibliography of Natural History*, v. 7, p. 1–18, <https://doi.org/10.3366/jsbnh.1974.7.1.1>.
 Geikie, A., 1905, *Founders of Geology*, second edition: London, Macmillan, 498 p.
 Geikie, A., 1924, *A Long Life's Work: An Autobiography*: London, Macmillan, 438 p.
 Oldroyd, D.R., 1990, *The Highlands Controversy*: Chicago, Chicago University Press, 448 p.
 Sorkhabi, R., 2019, Sir Archibald Geikie: The North American connections, in Betterton, J., Craig, J., Mendum, J.R., Neller, R., and Tanner, J., eds., Aspects of the Life and Works of Archibald Geikie: Geological Society, London, Special Publication 480, p. 113–138, <https://doi.org/10.1144/SP480.12>.

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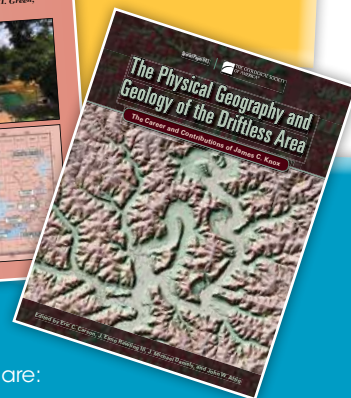
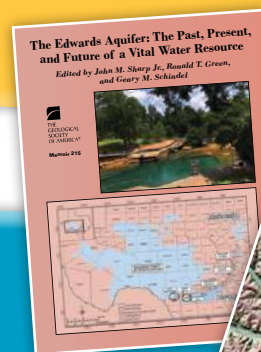
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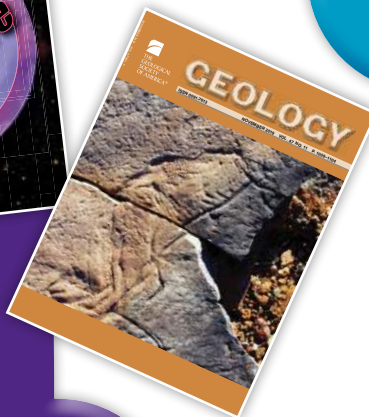
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REPORT

Climatic Controls on Continental Erosion and Sediment Transport (CLAST2019)

4–10 August 2019 | Juneau, Alaska, USA

CONVENERS

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INTRODUCTION AND CONFERENCE DETAILS

Although tectonic forces are known to be a strong primary control on the generation of sediment, this conference assessed the dynamic role of global and regional climate in controlling the production, transport, and deposition of sediments over millennial to million-year time scales. However, study of climate and earth-surface process relationships is fundamentally problematic because many of these processes act both independently of and as a consequence of tectonic forcing. This conference sought to discuss how climatic forcing is translated to the sedimentary record and under what conditions the respective erosional signals can be observed and interpreted unambiguously in terms of paleoenvironmental and paleoclimatic change. This transdisciplinary meeting brought together researchers across a number of sub-fields to showcase the current state of research, demonstrate contemporary evidence and methods from studies worldwide, and summarize the research concerns remaining in our communities.

Hosted in Juneau, Alaska, USA, from 4–10 August 2019, CLAST2019 brought together 49 scientists from Australia, Brazil, Canada, France, Germany, Hong Kong, Israel, Italy, Switzerland, the U.K., and the U.S. The conference kicked off with an ice-breaker, was punctuated by a mid-week field trip and sunset dinner on Eagle Beach delta, and ended in Tracy Arm Fjord in the post-meeting field trip. Women scientists accounted for 46% of participants, and 23 of the participants were early career researchers (student and untenured researchers). Early career researchers presented one third of invited talks. Formalized one-on-one and informal peer mentoring was achieved throughout the week among researchers and across the wide range of disciplines.

Presentations were grouped into seven broad climate-erosion themes: (1) from source to sink: tracing erosional signals; (2) beyond the mainstream: continental deposition and erosion outside fluvial systems; (3) cycles, thresholds, and feedbacks: the evolving atmosphere and biosphere; (4) from ice to the ocean; (5) closing the gap: emergent tools and techniques for integrating

earth-surface processes and solid Earth datasets across time scales; (6) moving forward: innovations in data sharing, visualization, and modelling to understand landscapes and climate; and (7) history matters: reconciling tectonic, climate, and erosion histories.

PRESENTATIONS AND DISCUSSION

The major aims of the talks and focused group discussions were to (1) identify new and persistent knowledge gaps within our communities; (2) define major challenges in addressing these gaps; and (3) initiate conversations on the resources needed both within, between, and outside of our communities to effectively address these over the next five to ten years. Over the course of the week, participants identified three key areas:

Weather Erodes, Not Climate

Understanding the relative importance of event-scale and extreme events in controlling the sedimentary record has come to the forefront of several communities. What is the relative importance of extreme events over steady-state erosion processes? Are extreme events (mass-wasting, cyclones, wildfires, earthquakes, [flash-]floods) controlling the sedimentary record, or are these events the “noise”? At what scales are events detectable and at what scales do they matter?

To understand the immediate and lasting effects of seasonality and variability, efforts need to be made in not only obtaining measurements of *totals* but also in constraining *rates* and *durations*. This includes identifying records for environmental boundary conditions in the rock record (elevation, temperature, precipitation, wind speed, aridity, and seasonality) and improving our ability to measure them using novel (bio)geochemical markers, such as clumped isotopes.

Scale Matters, So Mind the Gap

The issue of comparing observations at varying temporal and spatial scales was identified as a key challenge. We have disparate proxies relevant at different spatiotemporal scales and are especially data limited at time scales that might matter. Improvement in geochronological techniques has in part addressed this data gap, but continued effort is needed. Future approaches looking to quantify transience or disequilibrium will need to allow for a holistic interpretation of disparate proxies and include development of proxies that are truly compatible with the scale of observation.



CLAST2019 attendees at the Mendenhall Glacier as part of the mid-week field trip. Back row (left to right): Sergio Andò, Niels Hovius, Karl Lang, Kelly Thomson, Mathieu Cartigny, Justin Lawrence, Daniella Rempe, Ian Delaney, Eva Enkelmann, Jane Willenbring, Ken Ferrier; Middle-back row (left to right): Pedro Val, Alexis Licht, Jan Blöthe, Glenn Sharman, Anna Clinger, Al Neely, Christian France-Lanord, Kristen Cook, Jessica Raff, Mitch D'Arcy, Hon-chim Chiu; Front-back row (left to right): Yani Najman, Xiaoni Hu, Claire Mastellar, Julia Carr, Kathleen Marsaglia, Nick Brilli, Anthony Maue, Eran Hood, Cathy Connor, Marguerite Toscano, Michal Ben-Israel, Duna Roda-Boluda, Steffi Tofelde; Front row (left to right): Tara Jonell, Donovan Dennis, Brian Yanites, Kalli Dubois, Yuting Li, Peter Clift, Adam Forte, Luca Malatesta, Veronica Prush, Sonia Nagorski, Nicole Gasparini, Udit Murkherjee. Photo credit: Tongass National Forest park ranger at Mendenhall Glacier.

Following on the key area above, the community highlighted the necessity for the development of *possible*, *plausible*, and *probable* models that can be appropriately upscaled from numerical and analog frameworks to test at the field scale. This includes developing coupled chemical and physical models that can be better applied when translating chemical fluxes (i.e., nutrients, carbon) along with records of physical erosion.

Landscape Connectivity (Buffers, Barriers, and Blankets)

The impact of landscape connectivity on source-to-sink dynamics has been an incredibly popular topic across geoscience fields for the past two decades and so consequently pervaded many discussions at the conference. Significant improvements have been made in understanding the role of signal shredding as a result of poorly connected landscapes, in how this process often biases sedimentary records, and over which spatiotemporal scales this process may inhibit accurate interpretation. Yet there are still issues in translating nonlinear behavior from erosional records, especially when non-unique responses are observed in both source and sink signals. Instead of viewing sedimentary systems as separate hillslope or fluvial systems, a nested perspective has proven useful for understanding landscape response and in identifying directionality of critical threshold behaviors. Recent work with community models has yielded interesting results and may continue to offer time- and energy-efficient ways in which to test hypotheses underpinned by empirical evidence from the field. Lastly, we recognized that necessary improvements are needed to identify the impact landscape legacy effects and how best to quantify “landscape memory” processes and rates.

ACKNOWLEDGMENTS

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Sedimentary Geology and Paleobiology Program, the Tectonics Program, and the Paleoperspectives on Climate Change Program. Supplementary sponsorship was provided by the International Association of Sedimentologists and the British Sedimentology Research Group of the Geological Society of London. We thank program directors Justin Lawrence and Marguerite Toscano at the conference for NSF representation and input, and we sincerely thank GSA meeting manager Becky Sundeen for organizational and administrative support. Considerable logistical support was provided by the University of Alaska Juneau and Forest Service staff of the Tongass National Forest.

Abstracts of presentations are available at www.geosociety.org/penrose (click the “archive” tab).

FIELD TRIPS AND GUIDES

An informal field-trip guide for the two field trips was compiled by the meeting conveners using text and figures compiled by UAS field trip leaders: Cathy Connor, Eran Hood, and Sonia Nagorski. This field trip guide is freely available at www.geosociety.org/penrose (click the “archive” tab).

Participants

Sergio Andò, Michal Ben-Israel, Jan Blöthe, Nicola “Nick” Brilli, Julia Carr, Matthieu Cartigny, Peter Clift, Anna Clinger, Cathy Connor, Kristen Cook, Mitch D'Arcy, Ian Delaney, Donovan Dennis, Roman DiBiase, Kalli Dubois, Eva Enkelmann, Ken Ferrier, Adam Forte, Christian France-Lanord, Nicole Gasparini, Eran Hood, Niels Hovius, Xiaoni Hu, Tara Jonell, Karl Lang, Justin Lawrence, Yuting Li, Alexis Licht, Luca Malatesta, Kathleen Marsaglia, Claire Mastellar, Anthony Maue, Udit Mukherjee, Sonia Nagorski, Yani Najman, Alexander Neely, Veronica Prush, Jessica Raff, Daniella Rempe, Duna Roda-Boluda, Glenn Sharman, Kelly Thomson, Stephanie Tofelde, Marguerite Toscano, Pedro Val, Jane Willenbring, Brian Yanites, Xiaoping Yuan, Peng Zhou.

GSA Participates in Initiative to Support Scientists Engaging with Policy Makers, Communities, and the Public



Rose Hendricks,
Kavli Civic Science
Fellow

Addressing many of the most complex and important problems we face—from climate change to global health threats—requires conversations and collaborations between scientists, decision makers, and the public. Many scientists are already involved in these interactions through interviews with the media, policy recommendations for their elected representatives, and collaborations with communities. These activities contribute to a culture of “civic science” (<http://ritaallen.org/civic-science/>), in which science both informs the broader

society and is informed by societal needs and priorities.

Scientific societies have traditionally supported their own members in this work. For example, GSA has extensive information for members on engaging in science policy (<https://www.geosociety.org/Policy>), provides fellowship opportunities to geoscientists to work more deeply with policymakers, organizes visits to congressional offices, and has issued a statement (https://www.geosociety.org/documents/gsa/positions/pos2_proContrib.pdf) on the importance of rewarding professional contributions in public spheres.

The Society Civic Science Initiative (<https://www.societycivicscience.org/>) provides an opportunity for GSA to expand on these programs by working more closely with other science societies. With support from the Kavli Foundation (<https://www.kavlifoundation.org>), societies have the opportunity to collaborate to advance their collective support of scientists’ civic science efforts. The initiative is led by the American Society for Cell Biology (ASCB), in partnership with the American Association for the Advancement of Science (AAAS), the American Geophysical Union (AGU), and Research!America. GSA has actively participated in this collaboration since it began in the fall of 2019.

The Society Civic Science Initiative began with an examination of societies’ civic science efforts. It documented common ways that organizations aim to equip, empower, and reward scientists who engage with broad audiences (the full report is available at <https://www.informalscience.org/scientific-society-civic-science-landscape>). The report uncovered some trends that will inform subsequent work.

- A number of associations have experienced increased interest among their members to get involved in advocacy, public engagement, and community science. Organizations have worked to meet this increased interest.
- Many organizations provide similar programs, such as webinars or conference sessions on science communication fundamentals. However, societies don’t have consistent practices for evaluating the effectiveness of these programs or sharing the lessons they learn with each other.

- At the same time, there are a number of programming areas that societies do not currently support, though their staff and members recognize their importance. These include supporting local and grassroots advocacy and facilitating collaborations between researchers and communities. Although some organizations do provide awards for scientists who engage in especially impactful civic science activities, there is room for greater recognition of this important work among societies, particularly because society recognition may contribute to more recognition among universities and other institutions.

Overall, the assessment provided insights into key opportunities for scientific societies to make a greater collective impact in their support. The group used this foundation to develop a collective vision and goals, which include:

- Creating opportunities for learning and collaboration among societies to scale up effective civic science programs;
- Encouraging more universities to offer greater support and rewards for scientists engaging in civic science; and
- Supporting more scientists in engaging more often and more effectively with policy makers and members of the public.

At the end of January 2020, staff from a number of societies (including GSA) convened to kick off specific projects toward those shared goals. The projects include developing a stronger learning culture among scientific societies, signaling the value of civic science to all entities in the science ecosystem, providing opportunities for scientists to engage in local and grassroots advocacy, and encouraging and facilitating collaborations between researchers and communities. As these projects expand and gain momentum, we will continue to monitor and measure our progress and seek additional opportunities for impact.

We are optimistic that this collaboration will create valuable opportunities for scientific societies to advance a culture of civic science. When science-society relationships are strong, we see scientific research that reflects public priorities and values, increased public interest in and support for science, the uptake of scientifically sound practices and policies, and the promise of a diverse and competent scientific workforce for years to come.

Please contact GSA’s director for geoscience policy, Kasey White (kwhite@geosociety.org), for more information about GSA’s involvement with the Society Citizen Science Initiative.

Rose Hendricks is the Kavli Civic Science Fellow, leading scientific societies in expanding their collaboration to support scientists who engage in civic science. She has conducted research to understand how to make science communications more effective at the FrameWorks Institute. She is also a leader of grassroots science communication training initiatives (ComSciCon and the Science Communication Trainers Network), and an active climate advocate with Citizens Climate Lobby. She earned her Ph.D. in cognitive science from the University of California San Diego.

Call for Committee Service

If you are looking for the opportunity to work toward a common goal, 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 [https://](https://rock.geosociety.org/Nominations/CS.aspx)

rock.geosociety.org/Nominations/CS.aspx. Open positions and qualification information is online at <https://rock.geosociety.org/forms/viewopenpositions.asp>. GSA headquarters contact: Dominique Olvera, P.O. Box 9140, Boulder, CO 80301-9140, USA; +1-303-357-1060; dolvera@geosociety.org.

Nomination deadline: 15 June. Terms begin 1 July 2021 unless stated otherwise.

COMMITTEE NAME	NO. OF VACANCIES	POSITION TITLE & SPECIAL REQUIREMENTS	TERM (YEARS)
Academic and Applied Geoscience Relations Committee	1	Member-at-Large: Industry	3
Annual Program Committee	3	Members-at-Large	4
		Member-at-Large: Student	2
Arthur L. Day Medal Award Committee	2	Members-at-Large	3
Council Officers	5	President-Elect	3
		Treasurer	1
		Councilors	4
Diversity in the Geosciences Committee	3	Members-at-Large	3
Education Committee	4	Members-at-Large	4
		Two-Year College Faculty Representatives	4
		Pre-College Educator (K–12) Representatives	4
		Graduate Student Representatives	2
Geology and Public Policy Committee	2	Members-at-Large	3
GSA International	2	Members-at-Large	4
Joint Technical Program Committee (terms begin Dec. 2020)	2	Members-at-Large: Marine/Coastal Geology	2
Membership and Fellowship Committee	1	Member-at-Large: Industry	3
Nominations Committee	1	Member-at-Large: Industry	3
North American Commission on Stratigraphic Nomenclature	1	GSA Representative	3
Penrose Medal Award Committee	2	Members-at-Large	3
Penrose Conferences and Thompson Field Forums Committee	2	Members-at-Large: Early Career Scientists	3
Professional Development Committee	1	Member-at-Large	3
Publications Committee	1	Member-at-Large	4
Research Grants Committee	15	Members-at-Large (various specialties)	3
Young Scientist Award (Donath Medal) Committee	1	Member-at-Large	3



Geoscience Videos and Animations: How to Make Them with Your Students, and How to Use Them in the Classroom

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We are in the midst of a “tectonic shift” in the way that undergraduate students want to learn. They will attend lectures and read assignments if they must, but they are especially interested in information that they can receive as videos on their cell phones and other mobile devices (Prensky, 2001; Thomas, 2011). The geosciences are uniquely well-suited to presentation via well-crafted, scientifically robust videos and animations. Geologic processes often take place over thousands to hundreds of millions of years and occur deep under water or within the Earth, where direct observation is not possible. Geology is synonymous with travel: Spectacular outcrops and Earth phenomena occur around the world, requiring photos and video to be accessible to most of us. Documenting natural disasters and the realities and impacts of climate change are highly amenable to presentation via videos and animations. Finally, videos and animations about the Earth allow these experiences to be shared with more diverse audiences. Sharing high-quality videos and animations about Earth systems may stimulate student interest in the earth sciences and help address longstanding concerns about enrollments in geoscience degree programs. However, in spite of these considerations, the number of high-quality geoscientific videos to use for these purposes continues to be inadequate. We hope through this article to spark discussion about how to encourage more geoscientists to create scientifically accurate and engaging videos and animations of Earth processes.

Historically, generating video content and animations for education has been the purview of publishers, television producers, and videography professionals. However, with the advent of inexpensive video production

equipment (including tablets and smartphones) and software (i.e., Adobe Creative Suite applications, Camtasia, iMovie, etc.), the tools for making good-quality video and animations have become widely accessible, and platforms such as YouTube make it easy to disseminate videos. Most geoscientists are not trained in storyboarding, making animations, recording sound, or editing video. Companies like Pixar and TV channels like National Geographic and Discovery have staff with much stronger technical skills in these areas than any geoscientist will likely have, and have the budgets to do longer, high-production-value geoscientific videos. However, what we geoscientists have that videography professionals lack is more important than big budgets: We know how the Earth works. We “tell the stories” of Earth processes and visualize them already, so with a basic understanding of video production—or, by leveraging our talented undergraduates, many of whom have been doing rudimentary video production and editing for years—we can produce our own scientifically accurate and visually engaging animations of important Earth phenomena.

It is easier and far cheaper for a motivated team of geoscientists to learn to make an educationally useful geoscience video than it is to get a videographer or animator knowledgeable enough in the geosciences to produce something of comparable educational value. Students involved in making geoscience video animations engage deeply and creatively with the content, learning our science better by making videos about it. Students interested in creating video on subjects they are learning aligns with the findings of the Speak Up Surveys and other longitudinal studies of change in STEM education on the

preferences of today’s “digital native” students to co-create content as a means of learning (i.e., Project Tomorrow, 2008; Rainie and Anderson, 2008).

Even if one agrees with the concept that geoscientists should be making educational videos and animations, *why* we would do so is less clear, as the drivers for faculty (tenure, promotion, a job, a graduate degree, etc.) are not obviously served via video-making in the way that writing grants and peer-reviewed papers are. Fortunately, making video animations of Earth processes is relatively cheap, and one can incorporate the modest costs of making educational videos into NSF-funded projects as “broader impacts” activities. It is easy to post videos and animations to YouTube and to disseminate them widely through Facebook and other social media, as well as via email communities (e.g., GSA Open Forum, AGU Member Community, AAAS Member Community), and it is also easy to post videos to a dedicated website (UTD Geoscience Studios, <https://utdgss2016.wixsite.com/utdgss>, hosts all of our geoscience videos and animations, and we also maintain a YouTube channel). There are no obvious outlets for papers discussing the production or educational potential of geoscience animations or videos; however, Stern et al. (2017) recently published a paper on an ≈9 min geoscience animated video, “Plate Tectonic Basics 1” (<https://www.youtube.com/watch?v=6wJBok9xjto&t=10s>), that explains how oceanic lithosphere is created at spreading ridges and destroyed in subduction zones. About 18,000 people have watched it on YouTube as of March 2020. No geoscience-specific recognition for outstanding videos has yet been estab-

lished, though, periodically, NSF posts competitions for innovative researcher or student videos related to its funded research (see as an example https://www.youtube.com/watch?v=g4iUTZ_XsU).

The educational impacts of student use of video animations of geoscience phenomena as compared to traditional instructional modalities have not been well studied. We obtained IUSE-EHR Program Exploratory grant funding to assay both how to make effective video animations of tectonic processes and to see if using these videos in geoscience courses leads to improved student understanding of these natural phenomena. Our project has leveraged the interests of University of Texas at Dallas (UTD) undergraduate and graduate students, affording them an opportunity to develop basic videography and animation skills in the context of a UTD course, “Geoscience Videos and Animations” taught by the first author. A nine-minute video about this course is at <https://www.youtube.com/watch?v=k2LYe9DqGx0&t=9s>. The course targets upper-division geoscience majors, who by this stage know a lot of geology, and gives them the means to explore a geologic topic of interest via making their own video animation about it. The class does not depend on the video-making or animation skills of the first author (which are extremely limited!), as the students are eager to learn and teach each other the use of videography and animations software. We use Adobe Creative Suite applications to make video animations, Illustrator (AI) for figures and animation elements, Premiere Pro for editing, and After Effects for animation and special effects. The ability to make a video or animation is a job skill, and students like being able to add this to their résumés.

Assessing the instructional benefits of a geoscience animation can take different directions depending on what one wants to know. In our project, we are most interested in whether students can accurately recall the workings of dynamic, deep-Earth processes,

and whether the video format is a comfortable and effective way for them to learn that content. We are using the ConceptSketch assessment approach (Johnson and Reynolds, 2005) along with written responses to measure learning, and short interviews with students to assay their views on the videos and gather formative data for refining the videos. We’ve collected classroom data on two UTD videos (Three Great Ways to Melt the Mantle: <https://www.youtube.com/watch?v=LqWVXRtcSiA&t=90s>; Continental Rifts, Ocean Basins and Passive Continental Margins: Plate Tectonics Basics 2: <https://www.youtube.com/watch?v=W6oJKsSiLEI&t=26s>). Student responses to the animations as instructional tools have thus far been uniformly positive, and their written and sketched responses point to improvements in learning, with some interesting complexities related to the recall of visual content.

Some pointers to keep in mind to start making your own geoscience videos or animations include:

1. Use animation sparingly. Video is much easier to do than animation: one minute of video can be made in 1% of the time it takes to generate one minute of a simple animation. Geoscience expertise plays a big role in making scientifically correct animations and largely decides how quickly one can make a geoscience educational animation.
2. Good sound is the most important part of any video. Recording good sound quality is a challenge, and good sound quality is critical to making videos and animations that students will want to use and that you will want to share.
3. Avoid lecturing. Try to tell a story about the topic of the video—a good storyboard is the first step in video making. Good stories make viewers want to learn more about the topic at hand.
4. People have short attention spans and will “click away” when they get bored. Most of the UTD geoscience videos are three to five minutes long; our 10-minute videos are more ambitious and target only upper-level

students, who have longer attention spans for geoscience content.

5. Always include “closed captions.” Closed captioning makes an animation or video accessible to the hearing-challenged, and it is also useful in noisy environments or when viewers don’t want to disturb those around them. YouTube offers a closed-captioning service for videos, but you will need to edit the captions before posting.
6. Guide viewers to where they can learn more. Use textbooks and peer-reviewed literature for the video content, and list these references at the end of the video.
7. Give credit generously, wherever it is due, for images downloaded from the Internet, for experts interviewed, and to those who helped put the geoscience animation or video together: the best videos are ultimately team efforts.

REFERENCES CITED

- Johnson, J., and Reynolds, S., 2005, Concept sketches—using student and instructor generated annotated sketches for learning, teaching, and assessment in geology courses: *Journal of Geoscience Education*, v. 53, p. 85–95, <https://doi.org/10.5408/1089-9995-53.1.85>.
- Prensky, M., 2001, Digital Natives, Digital Immigrants Part 1: On the Horizon, v. 9, no. 5, p. 1–6, <https://doi.org/10.1108/10748120110424816>.
- Project Tomorrow, 2008, Speak Up 2007 for Students, Teachers, Parents & School Leaders: Selected National Findings: <http://www.tomorrow.org/speakup/> (last accessed 10 Mar. 2020).
- Rainie, L., and Anderson, J., 2008, The Future of the Internet III: Pew Internet and American Life Project, <https://www.pewresearch.org/internet/2008/12/14/the-future-of-the-internet-iii/> (last accessed 20 Mar. 2020).
- Stern, R.J., Lieu, W., Manley, A., Ward, A., Fechter, T., Farrar, E., McComber, S., and Windler, J., 2017, A new animation of subduction zone processes developed for the undergraduate and community college audience: *Geosphere*, v. 13, p. 628–643, <https://doi.org/10.1130/GES01360.1>.
- Thomas, M., 2011, *Deconstructing Digital Natives*: New York, Routledge, Young People, Technology, and the New Literacies, <https://doi.org/10.4324/9780203818848>.

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Seeing Like a Geologist: How Expertise and Context Impact Frame-of-Reference Judgments

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SEEING LIKE A GEOLOGIST, MEASURING LIKE A PSYCHOLOGIST

Frame of reference is vital to the interpretation of geologic data (e.g., plate motion), strike and dip, navigation, and visualization with diagrams and outcrops (Kastens and Ishikawa, 2006; Groom et al., 2015). For example, when viewing a map of plate motion relative to the United States, you will observe a different pattern than a map of absolute plate motion (Groom et al., 2015). Geologists use frame-of-reference thinking when interpreting geologic scenes, such as examining structural changes (i.e., fault movement) within an outcrop. Presently, there is a lack of empirical data to understand the impact of frame of reference in the geosciences. This study offers preliminary data on the impact of geologic expertise on frame-of-reference thinking with and without geologic context.

Psychologists describe two distinct frames of reference for diagram interpretation: environmental (i.e., describing objects' locations based on the axis of the environment or scene) and object (i.e., describing an object's location based on the intrinsic features of another object) (Carlson-Radvansky and Irwin, 1993). Psychological literature demonstrates that most people will use an environmental frame of reference (Friederici and Levelt, 1990; Carlson-Radvansky and Irwin, 1993). Friederici and Levelt (1990) support the idea that situational conditions can impact the frame of reference that a person uses, suggesting that frame-of-reference thinking is context dependent.

We propose that geologic training influences a geologist's frame-of-reference judgments and may be a predictor of geologic expertise. Geologic training focuses on the object level of the scene, putting equal importance on the parts as the whole. For

example, introductory geology students learn that the top and bottom contact of an individual sedimentary layer has meaning, even when the layer is folded or tilted. In other words, the term "above" has special geologic meaning in context and does not always refer to the top of a diagram. For example, when discussing "above," advanced stratigraphic features, including overlapping or offlapping layers and topset, foreset, and bottom beds may cause miscommunication. The draped manner of these layers and unique patterns that emerge may change the understanding of "above" for novices or experts. We also propose that expert geologists will prefer an object frame of reference when interpreting geologic diagrams. Novices' recent training with introductory concepts, such as Steno's laws, may cause equal rates of object responses for geologic and non-geologic settings.

These proposed ideas imply that frame-of-reference judgments may be a predictor of geologic expertise and could be used to evaluate where people fall on the expert-novice spectrum. Understanding the relation between expert and novice frame-of-reference judgments has implications for the classroom and

field; students and faculty may utilize the same terminology to discuss different features, causing a misunderstanding.

Here, we report the results of a pilot study that examines the proposed impact of geologic training on frame of reference by asking the following questions: (1) does geologic expertise impact the frame of reference geologists use when deciding where "above" is in a scene?; and (2) does the context of the scene impact frame-of-reference thinking?

METHODS

A survey was administered at the 2017 Geological Society of America Annual Meeting at the Michigan State University Geocognition Research Laboratory booth. The survey included four frame-of-reference questions and a demographic survey. The demographic survey collected data on geologic experience. The frame-of-reference questions included two geologic scenes and two non-geologic scenes. The non-geologic scenes were modeled after Carlson-Radvansky and Irwin (1993), with a donkey on a hill with two flies, one placed in each reference frame (Fig. 1A). Participants were prompted: "Circle the fly above the donkey."

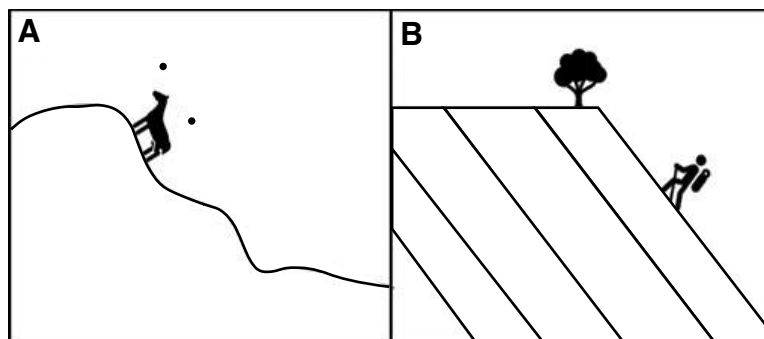


Figure 1. Diagrams with the non-geologic (A) and geologic (B) scenes have objects placed in the object and environmental reference frame.

To evaluate whether context influences frame of reference, a parallel item depicted a geologic scene with tilted sedimentary beds exposed on the side and top. A hiker and tree were placed above the limestone layer in the object and environmental frames of reference, respectively (Fig. 1B). Participants were prompted: “Circle the object that is above the limestone layer.”

Participant responses were categorized as an object or an environmental reference frame. For example, if the participant selected the fly perpendicular to the donkey’s back or the hiker, then they were coded as the object reference frame. The demographic survey was scored based on participants’ number of undergraduate courses, graduate courses, degrees, and years worked. An expert is a typical geology faculty member or senior-level employee, an intermediate is equivalent to a graduate student or early-career employee, and a novice is a typical undergraduate student.

RESULTS

The results focus on the use of an object frame of reference for two reasons: (1) we proposed that geologic training would focus geologists on the objects within the scene, and (2) a high rate of use of an object frame of reference will show a deviation from the expectations of the psychological literature.

Testing research question 1, our study divided frame of reference use by geologic expertise, then by the type of scene. Our results show that all levels of expertise used an object frame of reference at least 35% of the time (Fig. 2). For the geologic scenes, experts and intermediates used an object frame of reference to answer the prompts over 75% of the time. Novices answer ~60% of the time for both scenes.

For research question 2, we tested each level of expertise using a chi-square test. No significant difference was found in novice responses based on the context of the scene, $X^2(1) = 0.254$, $p = 0.614$. Context is important at higher levels of expertise. Intermediates [$X^2(1) = 20.422$, $p = 0.000$] and experts [$X^2(1) = 6.798$, $p = 0.009$] both switch from an object reference frame for the geologic scenes to an environmental reference frame for the non-geologic scenes.

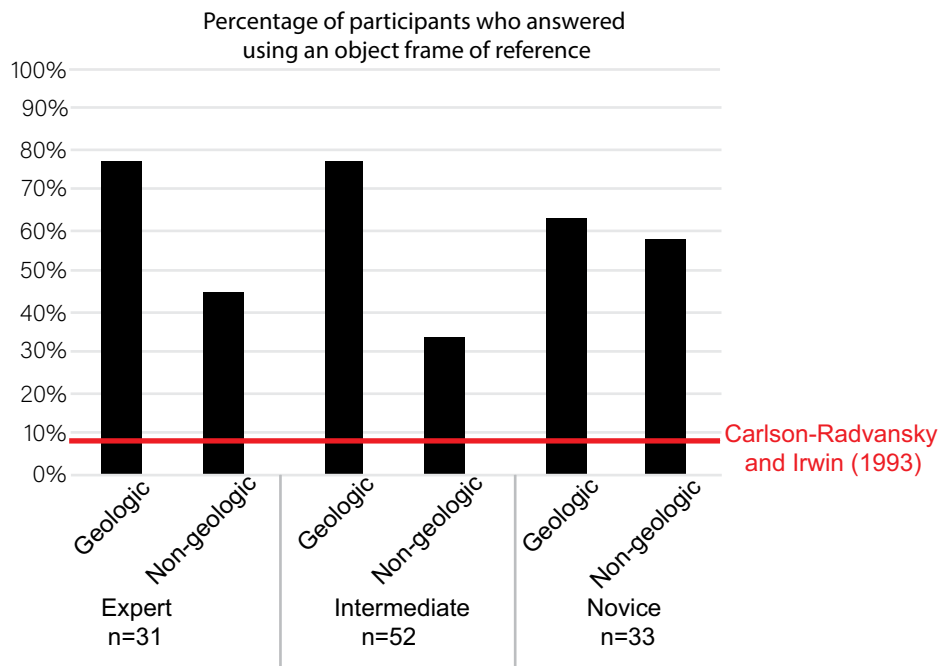


Figure 2. Percentage of participants who responded using an object frame of reference by expertise and context. The red line represents Carlson-Radvansky and Irwin’s 1993 object response rate.

FUTURE WORK AND LIMITATIONS

This pilot study is limited by a small number of survey items. However, we gathered data with a higher number of participants compared with the cited literature (Carlson-Radvansky and Irwin, 1993). Comparison with previous studies is limited, because modern use of technologies (e.g., GPS) may yield poorer frame-of-reference thinking (Ishikawa et al., 2008). Future work should test if the forced-choice response format in this study primed participants and yielded a higher object-centered response rate than an open-ended task. Since frame of reference is a component of spatial thinking, expanding the study to include other science, technology, engineering, and math disciplines and a general audience would be valuable to understanding the context of these findings. This study concludes that explicit frame-of-reference training may prevent confusion between faculty and students, increasing the rate novices move along the expert-novice spectrum, and provides the basis for continued research to further understand its relationship with geology.

REFERENCES CITED

- Carlson-Radvansky, L.A., and Irwin, D.E., 1993, Frames of reference in vision and language: Where is above?: *Cognition*, v. 46, no. 3, p. 223–244, [https://doi.org/10.1016/0010-0277\(93\)90011-J](https://doi.org/10.1016/0010-0277(93)90011-J).
- Friederici, A.D., and Levelt, W.J.M., 1990, Spatial reference in weightlessness: Perceptual factors and mental representations: *Perception & Psychophysics*, v. 47, no. 3, p. 253–266, <https://doi.org/10.3758/BF03205000>.
- Groom, R., Fox-Lent, C., and Olds, S., 2015, Measuring Plate Motion with GPS: UNAVCO, 21 p.
- Ishikawa, T., Fujiwara, H., Imai, O., and Okabe, A., 2008, Wayfinding with a GPS-based mobile navigation system: A comparison with maps and direct experience: *Journal of Environmental Psychology*, v. 28, no. 1, p. 74–82, <https://doi.org/10.1016/j.jenvp.2007.09.002>.
- Kastens, K.A., and Ishikawa, T., 2006, Spatial thinking in the geosciences and cognitive sciences: A cross-disciplinary look at the intersection of the two fields, in Manduca, C.A. and Mogk, D.W., eds, *Earth and Mind: How Geologists Think and Learn about the Earth*: Geological Society of America Special Paper 413, p. 53–76, [https://doi.org/10.1130/2006.2413\(05\)](https://doi.org/10.1130/2006.2413(05)).

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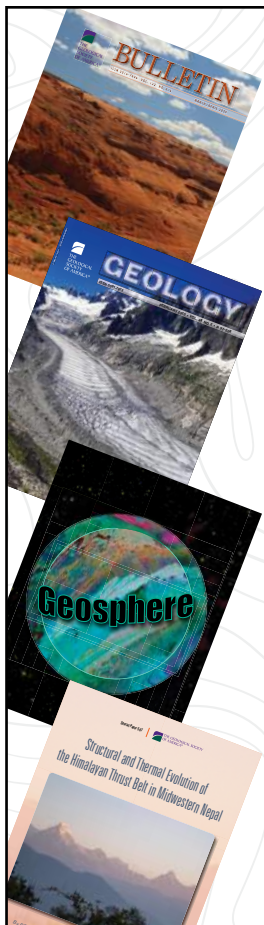
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GSA FOUNDATION

Update

John W. (Jack) Hess, *GSA Foundation President*

A Positive Way to Invest in the Future of our Field

We at the GSA Foundation sincerely hope that you and your families remain healthy and well during this unprecedented time. In awareness of the current and evolving situation, we also wish to sustain the hope of days ahead and the promise of developing careers and livelihoods, including those in the ever-vital geosciences. During this time, we would like to help our geoscience community continue to prepare geoscientists of the future, and we offer a positive way to invest in the future of our field.

We have a meaningful opportunity to double the impact of your support. A longtime GSA Foundation donor is issuing a matching gift challenge. Any gift made to GSA's diversity initiative, On To the Future (OTF), between now and 30 June will be matched 1:1, up to US\$11,000.

The goal of OTF is to help students from traditionally underrepresented groups become the geoscientists of the future. Recipients of OTF scholarships are provided a one-year membership in GSA along with full meeting registration and travel support to attend their first GSA Annual Meeting.* They are also paired with a mentor who helps them navigate the meeting, make decisions about future education opportunities, and prepare for their future geoscience careers. OTF also provides students with space where they can experience a sense of community and belonging.

Make a gift today at <https://gsa-foundation.org/fund/on-to-the-future-fund/> and double your impact on the future leaders of the geosciences.



On To the Future students at GSA 2019 in Phoenix, Arizona, USA.

*Keeping in mind the uncertainty surrounding COVID-19, gifts made to the OTF fund at this time will be applied to the OTF program based on the status of GSA programming over the coming months. Your gift may help provide registration and mentorship for in-person or virtual GSA meetings, or expand the fund so that future student participants can be supported at a greater level.

www.gsa-foundation.org



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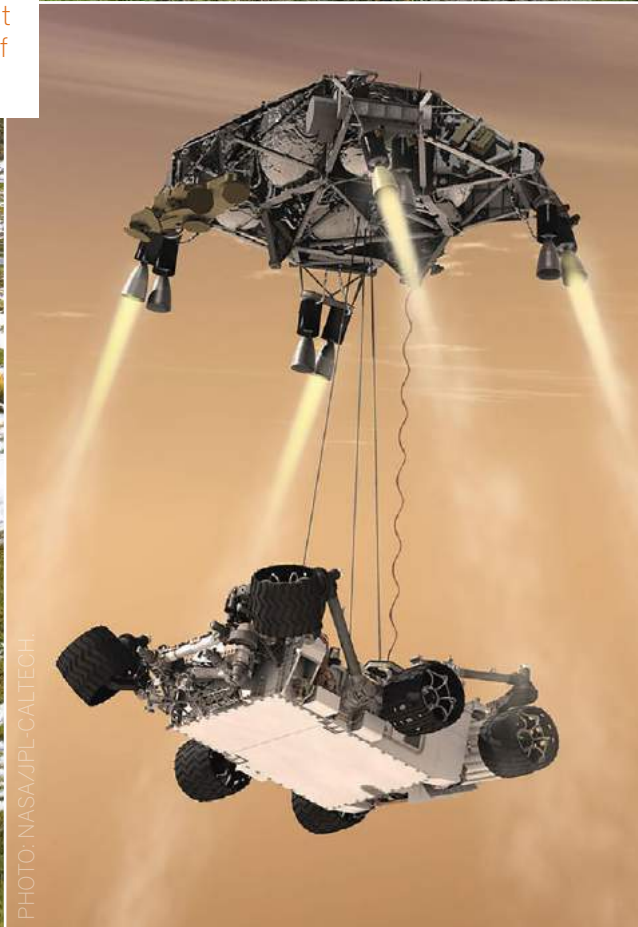


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