Geoscience Canada
Journal of the Geological Association of Canada
Journal de l'Association Géologique du Canada

Earth Science Education 7. GeoTrails: Accessible Online Tools for Outreach and Education

Katie M. Maloney, Alexander L. Peace, Joe Hansen, Keira L. Hum, Julia P. Nielsen, Kate F. Pearson, Shania Ramharrack-Maharaj, Deana M. Schwarz, Elli Papangelakis and Carolyn H. Eyles

Volume 50, Number 3, 2023

URI: https://id.erudit.org/iderudit/1107231ar
DOI: https://doi.org/10.12789/geocanj.2023.50.198

See table of contents

Publisher(s)

The Geological Association of Canada

ISSN

0315-0941 (print)
1911-4850 (digital)

Explore this journal

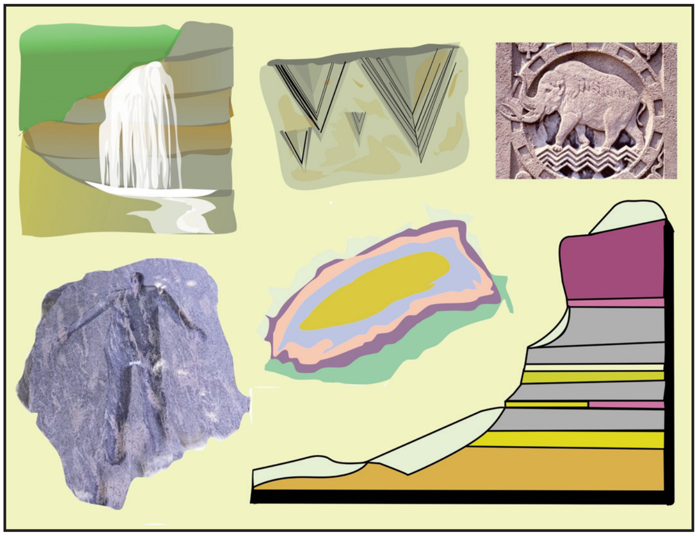
Cite this article

Maloney, K., Peace, A., Hansen, J., Hum, K., Nielsen, J., Pearson, K., Ramharrack-Maharaj, S., Schwarz, D., Papangelakis, E. & Eyles, C. (2023). Earth Science Education 7. GeoTrails: Accessible Online Tools for Outreach and Education. *Geoscience Canada*, *50*(3), 73–84. https://doi.org/10.12789/geocanj.2023.50.198

Article abstract

As geoscientists, we must prioritize improving our ability to communicate science to the public. Effective geoscience communication enables communities to understand how geological processes have shaped our planet and make informed decisions about Earth's future. However, geoscience research outputs have traditionally been published in peer-reviewed journals and presented at academic conferences. Consequently, essential information about local geology is rarely available in accessible, open access, and engaging formats. Here, we propose virtual field trips, or 'GeoTrails', as a possible solution to address the disconnect between geoscience research and public knowledge by improving our communication to the public. This initiative is largely driven by undergraduate students, who identify points of geological interest along selected hiking trails, write concise descriptions derived from scientific sources (e.g. longer peer-reviewed articles and government reports), and collect field data (e.g. 3-D LiDAR models, drone photography) to illustrate the characteristics of these geological features. The goal of the project is to communicate the importance of local geology on our environment and to raise awareness of how changing climates could affect us in the future; this information can empower communities to make better, more informed planning decisions. The creation of GeoTrails along the Niagara Escarpment offers a promising strategy to highlight the role of geoscientists and to engage the public in our ongoing research that aims to showcase Canada's geoheritage.

SERIES



Earth Science Education 7. GeoTrails: Accessible Online Tools for Outreach and Education

Katie M. Maloney[1,2], Alexander L. Peace[1], Joe Hansen[1], Keira L. Hum[1], Julia P. Nielsen[1], Kate F. Pearson[1], Shania Ramharrack-Maharaj[1], Deana M. Schwarz[3], Elli Papangelakis[1], and Carolyn H. Eyles[1]

[1]*School of Earth, Environment and Society, McMaster University*
1280 Main Street West, Hamilton, Ontario, L8S 4L8, Canada
E-mail: katie.maloney@mail.mcgill.ca

[2]*Department of Earth and Planetary Sciences, McGill University*
3450 University Street, Montreal, Quebec, H3A 0E8, Canada

[3]*APGO Education Foundation,*
Suite 704, One Yonge Street, Toronto, Ontario, M5E 1E5, Canada

SUMMARY
As geoscientists, we must prioritize improving our ability to communicate science to the public. Effective geoscience communication enables communities to understand how geological processes have shaped our planet and make informed decisions about Earth's future. However, geoscience research outputs have traditionally been published in peer-reviewed journals and presented at academic conferences. Consequently, essential information about local geology is rarely available in accessible, open access, and engaging formats. Here, we propose virtual field trips, or 'GeoTrails', as a possible solution to address the disconnect between geoscience research and public knowledge by improving our communication to the public. This initiative is largely driven by undergraduate students, who identify points of geological interest along selected hiking trails, write concise descriptions derived from scientific sources (e.g. longer peer-reviewed articles and government reports), and collect field data (e.g. 3-D LiDAR models, drone photography) to illustrate the characteristics of these geological features. The goal of the project is to communicate the importance of local geology on our environment and to raise awareness of how changing climates could affect us in the future; this information can empower communities to make better, more informed planning decisions. The creation of GeoTrails along the Niagara Escarpment offers a promising strategy to highlight the role of geoscientists and to engage the public in ongoing research that aims to showcase Canada's geoheritage.

RÉSUMÉ
En tant que géoscientifiques, nous devons donner la priorité à l'amélioration de notre capacité à communiquer la science au public. Une communication efficace des géosciences permet aux communautés de comprendre comment les processus géologiques ont façonné notre planète et de prendre des décisions éclairées sur l'avenir de la Terre. Cependant, les résultats de la recherche en géosciences ont traditionnellement été publiés dans des revues à comité de lecture et présentés lors de conférences académiques. Par conséquent, les informations essentielles sur la géologie locale sont rarement disponibles sous des formats accessibles, en libre accès et attrayants. Dans cette optique, nous proposons des excursions virtuelles, ou « GeoTrails », comme solution possible pour combler le fossé entre la recherche en géosciences et la connaissance du public en améliorant notre communication avec celui-ci. Cette initiative est en grande partie menée par des étudiants de premier cycle, qui identifient des points d'intérêt géologiques le long de sentiers de randonnée sélectionnés, rédigent des descriptions concises basées sur des sources scientifiques (par exemple, des articles à comité de lecture plus longs et des rapports gouvernementaux) et collectent des données sur le terrain (par exemple, des modèles LiDAR 3-D, des photographies par drone) pour illustrer les caractéristiques de ces caractéristiques géologiques. L'objectif du projet est de communiquer l'impor-

Geoscience Canada, v. 50, https://doi.org/10.12789/geocanj.2023.50.198 pages 73–84

tance de la géologie locale sur notre environnement et de sensibiliser aux façons dont les changements climatiques pourraient nous affecter à l'avenir; cette information peut permettre aux communautés de prendre des décisions de planification meilleures et plus éclairées. La création de GeoTrails le long de l'escarpement du Niagara offre une stratégie prometteuse pour mettre en valeur le rôle des géoscientifiques et pour engager le public dans notre recherche en cours qui vise à présenter le patrimoine géologique du Canada.

Traduit par la Traductrice

INTRODUCTION

The role of scientists has traditionally been to advance the state of knowledge by asking questions, seeking answers and publishing findings in peer-reviewed journals (Baron 2010; Stewart and Nield 2013). Geoscience societies, associations and surveys have created useful outreach materials (e.g. Geoscapes posters, *Four Billion Years and Counting* book) and workshops for teachers (e.g. National EdGEO Program) to promote accurate geoscience information to the public. However, press releases, news articles and online blogs are often the most publicly accessible sources of information to communicate research findings relevant to local communities (Bond and Paterson 2005; Colson 2011), and these may be sensationalized, politicized, or influenced by search engine algorithms (Brossard and Scheufele 2013). Over the last decade, undergraduate educators have started to emphasize the importance of teaching scientific communication to a variety of audiences (Brownell et al. 2013; Symons et al. 2017). At the same time, there has been an increased interest in outdoor activities during and after the COVID-19 pandemic. For example, Morse et al. (2020) studied the responses of over 3000 adults and found that participation in hiking, watching wildlife, and other outdoor hobbies in Vermont increased during the pandemic. This increased interest in outdoor activities presents a timely opportunity for new outdoor education initiatives.

Given the backdrop of intersecting global crises, many of which involve geoscientific issues (e.g. climate change, resource exploitation), geoscientists need to realize the benefit of effectively communicating scientific findings with the public to provide an opportunity for the sharing and exchange of knowledge (Stewart and Lewis 2017; Illingworth et al. 2018). By empowering our communities with geoscientific knowledge, we can also raise awareness about local environmental issues and the influence of changing climates on urban infrastructure and sustainability. Here, we seek to aid in addressing the disconnect between geoscientists and the public by introducing a new platform for geoscience communication. We outline the creation of a set of accessible and educational virtual trails called 'GeoTrails', which are integrated with digital field tools (3-D models, 360° images, drone imagery) to provide an immersive and informative virtual field experience. GeoTrails are constructed in collaboration with the APGO Education Foundation using ArcGIS™ StoryMaps™ by Environmental Systems Research Institute Incorporated (ESRI). This platform can be accessed through a variety of devices (e.g. cell phones, tablets and laptops) when walking the trail, or explored virtually from anywhere in the world, and has great potential to be used as an educational tool in the classroom.

Geoscientists will play an important role in building a sustainable future for Canada; however, decreasing enrollment trends demonstrate a lack of interest by students to pursue geoscience careers (Center for Geoscience and Society 2018; Mosher and Keane 2021). Today, many students are driven by altruism (Carter et al. 2021) and want to learn how to address problems in the real world (Disbrow-Monz et al. 2023). GeoTrails could provide a recruitment strategy by highlighting geoscience research and its importance in the community. Hence, to enhance the communication of important geoscientific information to members of the diverse, predominantly urban communities in southern Ontario, we targeted sites along the Bruce Trail and Niagara Escarpment to create informative GeoTrails on an openly accessible, user-friendly platform.

The Niagara Escarpment is a steep cliff, stretching from southern Ontario to northern Michigan, that formed primarily by differential erosion processes during the late Cenozoic and now exposes a variety of Paleozoic sedimentary rocks (Fig. 1, Brunton 2009; Brett et al. 2018; Brunton and Brintnell 2020). The escarpment geology influences multiple aspects of the local environment including soil quality (Kingston and Presant 1989; Haynes 2000) and the movement of groundwater and contaminants (Brunton and Brintnell 2020). Much of the Niagara Escarpment is located in southern Ontario, which has a population of over 7.5 million (Statistics Canada 2023) and is frequently visited by international tourists who come to see famous sites along the escarpment such as the Niagara Falls. Most public hiking trails that follow the Niagara Escarpment in southern Ontario are part of the Bruce Trail, Canada's longest and oldest marked footpath which is managed by the Bruce Trail Conservancy. The Bruce Trail Conservancy (BTC) has over 10,000 enthusiastic members who lead hikes, maintain trails, and can provide a wealth of knowledge about the trails. However, despite this obvious interest in the natural environment along the trails very little accessible geological information is available to BTC members or the public. Restrictions resulting from the COVID-19 pandemic have also taught us the value of experiences that can be obtained or augmented virtually to increase accessibility (Evelpidou et al. 2021; Whitmeyer and Dordevic 2021; Aaisyah et al. 2021; Peace et al. 2021; Gregory et al. 2022).

Motivations

Several motivations are involved in the development of the GeoTrails including: 1) the integration of scientific information from a variety of expert sources not usually accessible to the public, 2) geoscientific outreach to local communities, 3) recruitment of geoscience students, and 4) building leadership skills in students at all stages of their careers. Our GeoTrails incorporate a variety of geoscience perspectives from geologists, paleontologists, hydrogeologists, geomorphologists, and engineers, showcasing the benefit of using integrated approaches to better understand our environment. This multifaceted approach also allows the GeoTrails to engage an audience with diverse backgrounds and interests. Overall, the main

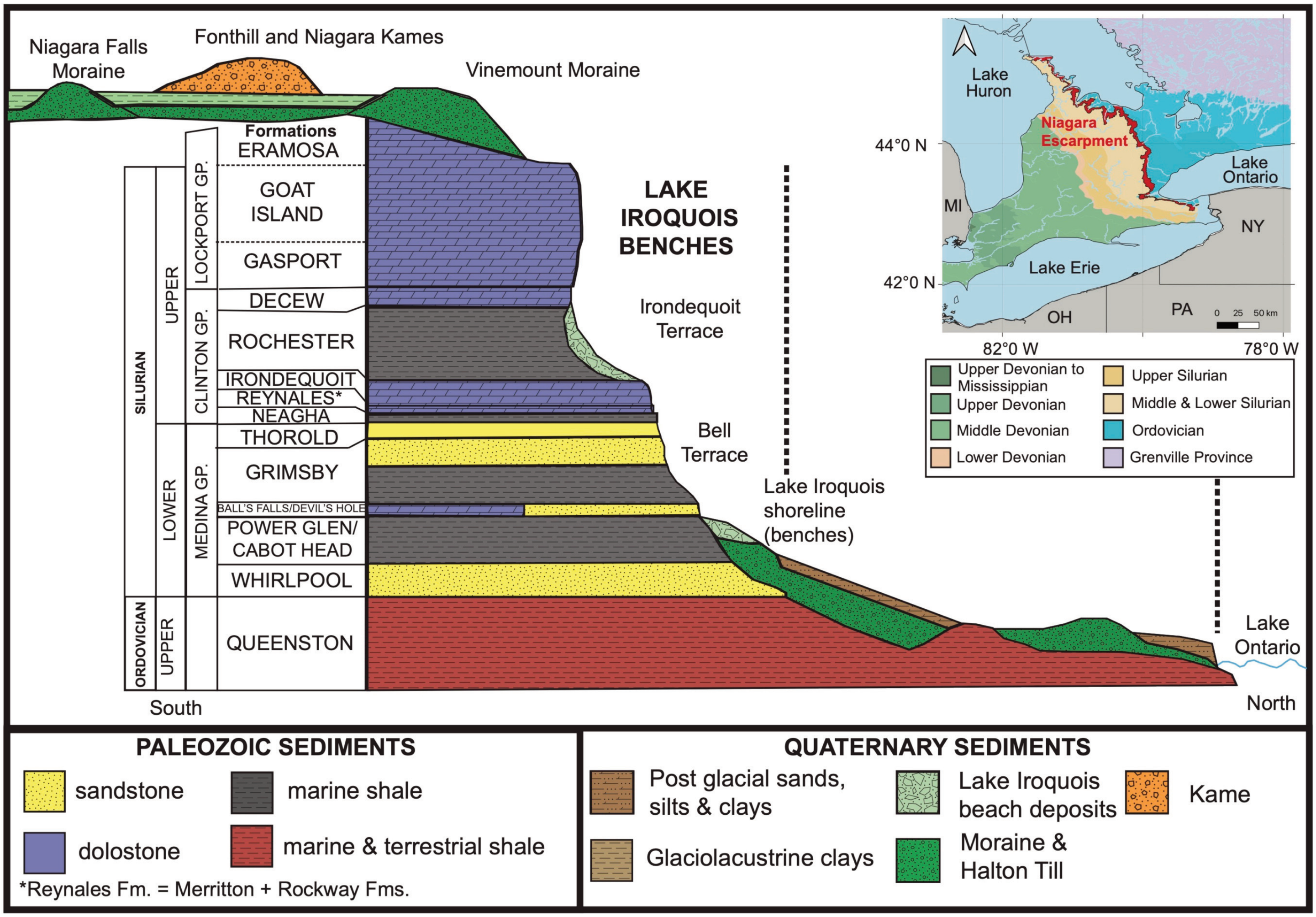


Figure 1. Niagara Escarpment general stratigraphy in Niagara Region, Ontario, Canada (adapted from Steele and Haynes 2000; Brunton and Brintnell 2020). Inset Map shows the Niagara Escarpment in southern Ontario and an overview of the Paleozoic geology (Armstrong and Dodge 2007).

goal of the GeoTrails is to provide geoscience information to the public in an exciting and inclusive format. GeoTrails also inform members of the local community about the types of geoscientific investigations and research projects being conducted in the area and why these are important. This information can empower community members and allow more informed decisions to be made about critical environmental issues. As natural disasters related to climate change increase in Canada (Weber 2023), members of the geoscience community are obliged to become leaders in ensuring that accurate information about Earth processes is available to educators and the public.

GeoTrails can also serve as a recruitment tool to attract students into geoscientific professions. The earth science curriculum is not mandatory in local high schools and these GeoTrails allow students to not only learn about the fascinating story of the formation of our planet but also about relevant career opportunities. The creation of the GeoTrails is student-driven, with undergraduate students conducting much of the field data collection independently while mentored by graduate students, postdoctoral fellows, and faculty. Students take on leadership roles by identifying points of geological interest along each trail and managing field data (e.g. GPS points, photos, videos, notes). These experiences provide students with valuable field training, practice in communicating geoscience to different audiences, and an opportunity to explore their own research interests.

Study Site

The Niagara Escarpment is bordered by Lake Ontario and Lake Erie and the Niagara River marks the international border between Canada and United States (Tovell 1992; Steele and Haynes 2000; Brett et al. 2018; Fig. 1). In the Niagara Region, urban and industrial expansion has, to some extent, been controlled by its geographic setting (Haynes 1995). The Great Lakes moderate the local climate (Scott and Huff 1996), making the region an appropriate place to grow various fruits (e.g. peaches, grapes) and even allow the growth of Carolinian forests which are typically restricted to the southern United States. Land use planning along the Niagara Escarpment is complex because it must respect Indigenous traditional territory (Hayward 2021; Ryan-Davis and Scalice 2022) while also

Table 1. GeoTrails (for map, see https://geoscienceinfo.com/geotrails/).

	Distance (km)	Duration (hours)	Description
Ball's Falls GeoTrail (Lincoln, Niagara)	1.5	1.5	Take a short hike from Upper Ball's Falls to Lower Ball's Falls and learn about an early settlement that utilized the local geological resources.
Cave Springs GeoTrail (Campden, Niagara)	1	1	Visit the trails here to see the famous Ice Cave and search for hidden rivers that appear at the surface as springs.
Niagara Gorge GeoTrail (Niagara Falls)	1	1	Hike the trail near the Niagara Gorge to learn how the powerful Niagara River changed the landscape we see today.
Chedoke Radial Trail GeoTrail (Hamilton)	1	1	Explore this section of the Bruce Trail to see how the Niagara Escarpment has helped shape the city of Hamilton as both an obstacle to development and important resource.
Sulphur Springs GeoTrail (Dundas, Hamilton)	3.4	1.5	Located in the Dundas Conservation Area, following this trail will lead you to the famous sulphur spring, the Hermitage, and the Griffin House.
Tiffany Falls GeoTrail (Ancaster, Hamilton)	0.35	0.5	Take a short walk to the spectacular Tiffany Falls and learn about active slope and valley processes along the way.

considering the requirements for industry, urbanization, agriculture, tourism, outdoor recreation and nature conservation (Haynes 1995). Over 1.3 million people live near the Niagara Escarpment and require effective geoscience information to help evaluate these competing interests in an age of increasing urbanization (UNESCO 2018). The Niagara Escarpment has also become a popular recreational attraction with hiking trails (e.g. the Bruce Trail) leading to conservation areas and the many waterfalls that cross its face, and offering seasonal opportunities for downhill and cross-country skiing. Hence, the Bruce Trail and its side trails along the Niagara Escarpment have provided exceptional study sites to develop and test the first series of GeoTrails. Bruce Trail hike leaders have been able to provide valuable feedback on the first GeoTrails to help us improve their construction and accessibility. We are open to suggestions for improvement of the GeoTrails and will continue to seek opportunities for feedback from trail users, teachers, geoscience educators and conservation experts.

The Niagara Escarpment is well suited for geoscience education based on its proximity to major urban centres and the rocks exposed along its length have been well documented since the mid 1800s (Hall 1852; Grabau 1908; Williams 1919; Bolton 1957; Brett 1983; Brett et al. 1990; Brunton 2009; Brett et al. 2018; Brunton and Brintnell 2020). Rocks exposed along the escarpment formed from the Late Ordovician to the middle Silurian periods when the Niagara region was covered in a shallow sea that extended across much of Laurentia and was home to a diverse number of invertebrate species (Brett 1983; Brett et al. 1990; Brunton 2009; Brett et al. 2018; Brunton and Brintnell 2020). Hence, a mixed siliciclastic–carbonate succession of sedimentary rocks accumulated in the basin creating a stratigraphy that continues to shape the modern landscape with the rock types providing a primary control on the topography of the region.

The Niagara Escarpment is vulnerable to differential erosion with fractured dolostone units overlying recessive shale layers which are exposed along major roads that cross the escarpment in the city of Hamilton, Ontario (Formenti et al. 2022; Gage et al. 2022). These differential erosion processes are not well understood and are the focus of ongoing research by undergraduate students at McMaster University. The GeoTrails we have created showcase this active research to the local community, including research constraining fracture patterns (e.g. distribution, conductivity; Formenti et al. 2022) and thermal change influencing winter weathering of fractured dolostone (Gage et al. 2022). Researchers are also investigating the influence of expanding urbanization and climate change on active processes along the Niagara Escarpment, which can put pressure on local rivers, increasing flooding and erosion risks (Ramharrack-Maharaj and Davies 2023). Identifying, evaluating and mitigating these risks is important since the Niagara Escarpment is an area of considerable ecological importance and was designated as a UNESCO World Biosphere Reserve site in 1990 (Niagara Escarpment Biosphere Reserve).

DEVELOPMENT OF GEOTRAILS

A total of six GeoTrails (Table 1) along the Niagara Escarpment were developed and released to the public on the geo-

Table 2. Urban GeoTrails (for map, see https://geoscienceinfo.com/urban-geotrails/).

Urban GeoTrail	Created by	Description
University of Toronto	University of Toronto team	Discover how the University of Toronto and the city of Toronto grew together from the historic building stones on campus.
Downtown Toronto: Union Station to the Royal Ontario Museum	University of Toronto team	Explore downtown Toronto and learn about the building stones that shaped the city.
McMaster Building Stones	McMaster team	View the historic buildings and architecture to learn about the beginnings of the campus and its expansion over the last century.
McMaster Rock Garden	McMaster team	Visit the rock gardens on the McMaster campus to learn about the different rock types and campus history.
Laurentian Campus	Laurentia team and Ontario Geological Survey	Wander through campus to explore local rocks with out-of-this-world features, including shatter cones and the Sudbury Breccia.

scienceINFO.com website between April 2022 and January 2023. This was done in partnership with the APGO Education Foundation, whose mandate is to support students and internationally trained geoscientists, and to promote a greater understanding of geoscience to the public (APGO: https://www.apgoedfoundation.ca/). The APGO Education Foundation provided technical support for the construction and publication of the StoryMaps and consulted with community groups to identify how the GeoTrails could aid in meeting their mandates. Collaborations with members of the Bruce Trail Conservancy and the Niagara Peninsula Aspiring Global Geopark helped guide site selection by identifying sites that are accessible, popular with the public and geologically significant. We have also launched an urban equivalent to our Niagara Escarpment GeoTrails called "Urban GeoTrails" (Table 2), which offer short geologically themed tours in urban settings, showcasing the geologic history of features of 'urban outcrops' such as building stones, rock gardens, and local parks.

Data Collection, Materials, and Resources

Data collection was led by teams of undergraduate students, who did multiple reconnaissance trips along selected trails to identify sites of geological interest and potential GeoTrail stops. Field data collection included digital photos, 3-D LiDAR models (Scaniverse using iPad Pro), digital 360° images, drone imagery, GPS points, and other field-based observations. Several logistical considerations had to be addressed during GeoTrail development, including site selection, time of data collection and accessibility. Site selection was based on numerous factors including accessibility, safety, geological points of interest, proximity to population centres and proximity to public transportation hubs. Data collection was significantly limited by seasonal time constraints; snow-covered outcrops and icy trails rendered sections of the trails unsafe until April. By mid-July, many of the outcrops were again covered by extensive vegetation, therefore the most useful imagery was captured in May and June.

GeoTrail text was developed based on field observations, peer-reviewed journal articles (e.g. Brett 1983; Cramer et al. 2011) and detailed reports by the Ontario Geological Survey, New York State Geological Survey, Niagara Parks, Hamilton Conservation Authority and the Bruce Trail Conservancy. Innovative research from these reports was integrated with research published in academic journals and knowledge from experts in the community. For example, a retired McMaster professor, Dr. Gerry Middleton, published a series of open access articles related to building stones and urban geology for a local publication called "Raise the Hammer" (Middleton 2011). This resource was particularly useful as it provided reliable information about local features that are not usually documented in textbooks or academic journals. In addition, historical records were investigated to provide perspective about how early settlers utilized the local geology to establish viable settlements starting in the 18th century (Haynes 1995). These settlements, which mostly lie below the Niagara Escarpment, were protected from extremely cold climate conditions and used natural hydropower created by waterfalls formed by rivers flowing over the Niagara Escarpment. Preserving community geoscience knowledge, including traditional ecological knowledge from Indigenous communities (Gewin 2021), and making that information accessible to the public is a major goal of these GeoTrails. For example, Indigenous peoples were the first to recognize the importance of natural resources including chert nodules found in the capstone dolostone beds that were used to create early tools. The GeoTrails will continue to improve as we build stronger relationships by listening to and learning from local Indigenous communities.

Choice of Dissemination Medium

Virtual field data can be hosted on many different platforms including ArcGIS and Google Earth (Whitmeyer et al. 2012 and references therein; De Paor et al. 2016; Bitting et al. 2018; Whitmeyer and Dordevic 2021). We chose to build the GeoTrails using ArcGIS StoryMaps as it is a user-friendly platform

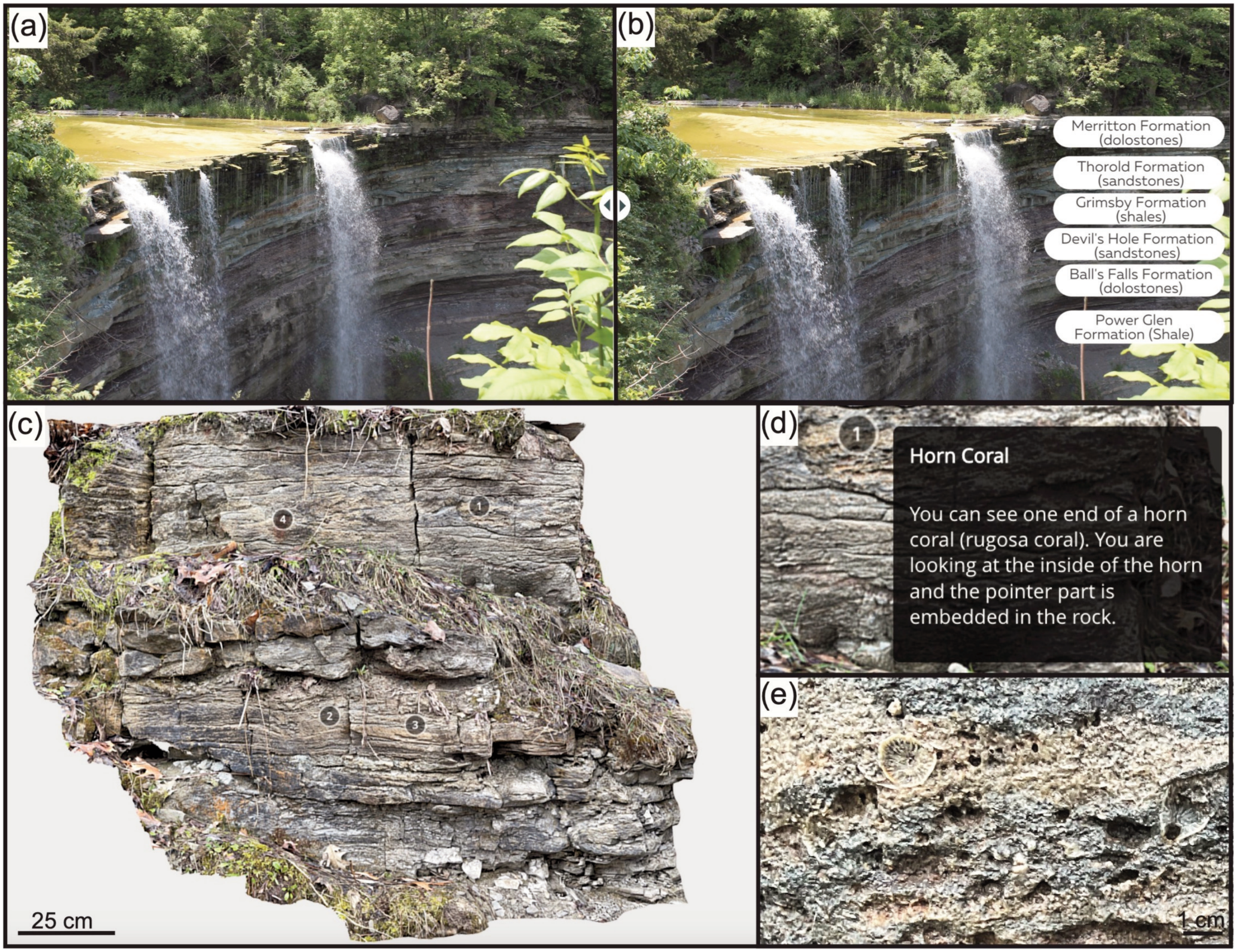


Figure 2: GeoTrails Data. (a) The lower waterfall at Balls Falls is presented in the GeoTrail using a slider. (b) GeoTrail users can move the slider to reveal the stratigraphic nomenclature and lithology of exposed units (e.g. parts of the Medina Group in Figure 1). (c) Example of a 3-D model hosted in Sketchfab; the numbers represent interesting features described using pop-up text boxes (see (d)). (d) Description of feature 1, a horn coral identified on the 3-D model shown in c. (e) High resolution photograph of fossils that can be viewed in the 3-D model. (a, b) Ball's Falls GeoTrail link: https://experience.arcgis.com/experience/c39fea16e5994697844239ba5a2f2e84/. (c–e) Chedoke Radial Trail GeoTrail link: https://experience.arcgis.com/experience/e8ffe313977d489aa91134b881c5f1df/.

and compatible with a variety of devices including phones, tablets, and desktop computers. The flexibility and ease of updating ArcGIS StoryMaps allows the GeoTrails to be living documents that can be updated as we learn more about the geology of our region and showcase active research. In order to ensure that they may be enjoyed by as many people as possible, numerous display methods are used to ensure that these GeoTrails are accessible and appeal to different learning styles. As users scroll down the page, each brief section of text is accompanied by a media component to better illustrate what is being discussed. Types of media used are still photos, figures, 360° interactive photos, slide bars to allow for easy comparison between two photos (Fig. 2a, b), video clips, drone footage, and interactive 3-D LiDAR imaging (Fig. 2c–e). Audio bars are also included that narrate all text to accommodate users with visual impairment. By providing a diverse array of interactive learning materials, we hope to stimulate interest in the reader and promote further learning.

GeoTrail Structure

The GeoTrails follow a consistent structure to make it easy for users to find similar information at each site (Fig. 3). Each GeoTrail contains a summary page that includes an introduction to the site with logistical considerations including safety warnings, parking information and costs, and trail accessibility. The introductory text includes a description of the site, a connection between the area and the regional geology of the Niagara Escarpment, a brief overview of each stop and an interactive map showing the location of each stop (Fig. 3b). Land acknowledgements are included to recognize the meaningful history and connection Indigenous people have with the land as well as to emphasize the lessons we can learn from Indige-

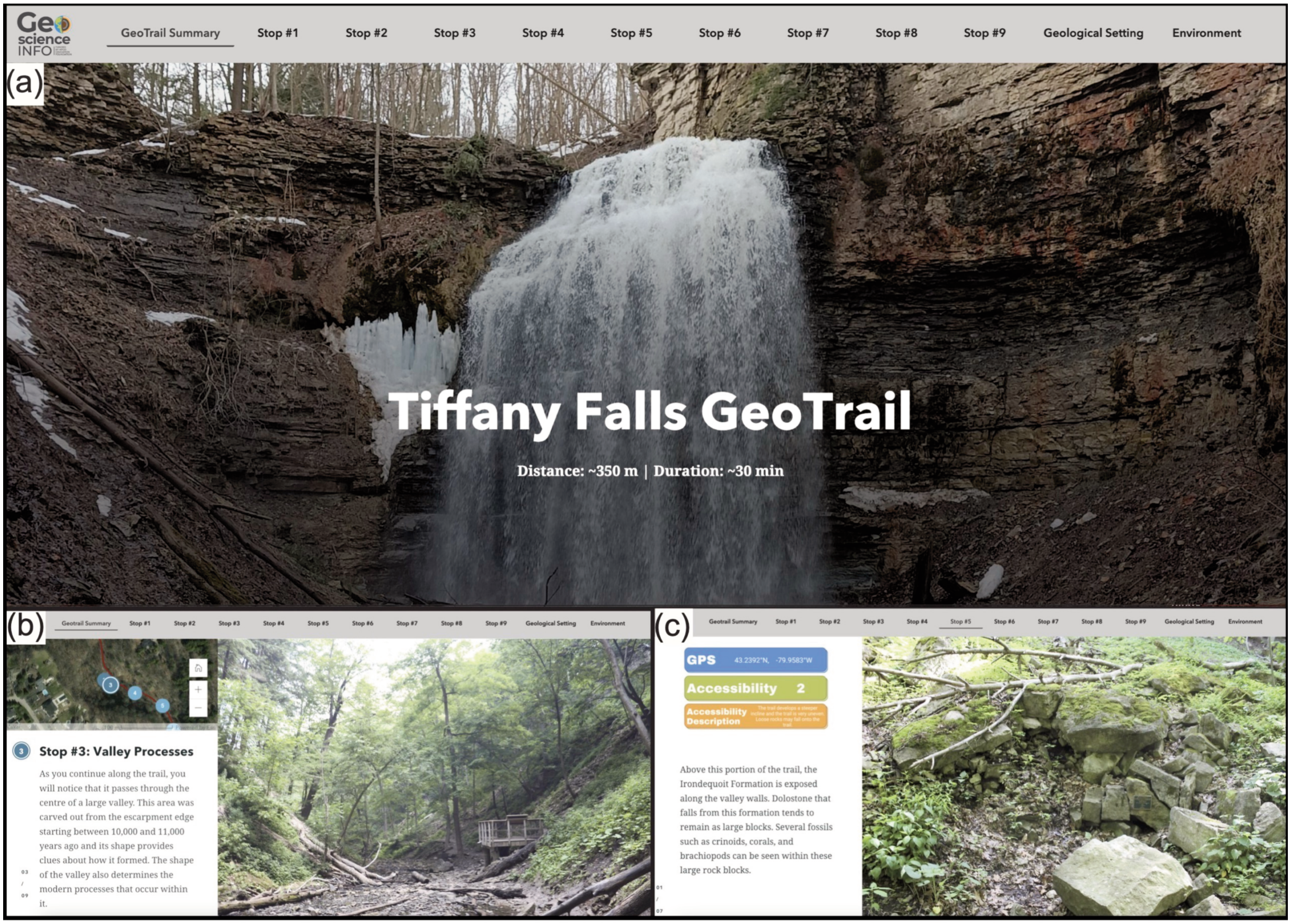


Figure 3. GeoTrail layout construction. (a) Example of a summary page for Tiffany Falls with the stops, geological setting and environment tabs shown across the grey bar at the top of the page. (b) A map on the summary page shows the location of each stop along the trail with a short summary of features and a photograph. (c) Each stop starts with information about the location (e.g. GPS coordinates), accessibility and an accessibility description. The text beside it describes the corresponding media while the number of slides is indicated in the bottom corner. Tiffany Falls GeoTrail link: https://experience.arcgis.com/experience/c0b10d68480444ebacde08432b5076b8/.

nous worldviews about sustainability and stewardship (Whitmore and Carlson 2022). A land acknowledgement is included at the beginning of every GeoTrail to remind users that we are on the traditional territory of the Indigenous communities. For example, the Hamilton and Niagara Regions are located on the traditional territory shared by the Haudenosaunee Confederacy and the Anishinaabe nations, which was acknowledged in the Dish with One Spoon Wampum belt. This Wampum belt uses the symbolism of a dish to represent the territory, and one spoon to represent that the people are to share the resources of the land and only take what they need (Seneca College 2022). In this spirit, in all of our GeoTrails, we strongly encourage the public to treat these lands with respect and to leave them in their natural state.

Each stop along a GeoTrail has its own page (Fig. 3c), which can be accessed via a series of tabs at the top of the page when using a laptop, or a drop-down menu when using a mobile device. Every stop begins with an accessibility rating and access description for the location. Accessibility was ranked for each stop along the GeoTrail from 1 (fully accessible for wheelchairs and strollers) to 3 (limited accessibility including stairs and uneven paths). Descriptions for the accessibility of each site are also provided with detailed information about the trail conditions. For example, an accessibility description could include whether the path is paved or unpaved, steep, or gently sloping, and the presence of rocky terrain and/or tree roots.

As you scroll down the page for each stop, you will find relevant geological, environmental and historical information depending on the point of interest. In addition, every GeoTrail includes a geological setting and environment page. The text in these two pages remains consistent among GeoTrails and provides additional information about the formation of the Niagara Escarpment as well as its influence on the modern environment. The geological setting page describes the geology of southern Ontario as an informal series of 4 units including Precambrian, Paleozoic, Pleistocene glaciations and present-day landscape. The history and formation of the Niagara

Escarpment rock units during the Paleozoic is described by characterizing each of the formations and briefly describing how each represents changes in the paleoenvironment through time reflecting tectonic events. The process of differential erosion is discussed in relation to the formation of the Niagara Escarpment and its many waterfalls including Niagara Falls. The Pleistocene glaciations are documented through glacial landforms that shape the modern landscape above and below the Niagara Escarpment.

The environment page of each GeoTrail focuses on answering the following question: "Why do we need to understand the local geology?" in a series of short paragraphs with corresponding figures. These sections feature examples of how the Niagara Escarpment and local geology influence people's daily lives including agriculture, groundwater, rivers, climate, ecology, economy, transportation and tourism. For example, the construction of the Welland Canal was necessary to bypass Niagara Falls and connect the St. Lawrence Seaway to the rest of the Great Lakes, allowing access to major ports in Cleveland, Detroit, Milwaukee and Chicago. Another example is the thriving wine industry in Niagara that is possible due to a combination of diverse glacial soils and the unique climate controlled by the Great Lakes and the Niagara Escarpment (Shaw 2005).

Urban GeoTrail Structure

Urban GeoTrails follow a similar structure to the GeoTrails, however, the formatting is more flexible based on the available information and targeted audience. For example, the University of Toronto campus and Downtown Toronto Urban GeoTrails feature two new pages - Building Stones and Rock Descriptions. The Building Stones page provides a map with the locations and descriptions of quarries where the building stones were sourced (Hewitt et al. 1964; Kemp et al. 1998) while the Rock Description page provides an overview of the rock types featured on the Urban GeoTrail. This is valuable information to help users understand how far some of the stones have been transported; however, clear documentation of the quarries where building stones were sourced is often unavailable. On the McMaster campus, local stones from the Niagara Escarpment are easy to spot, but the sources of metamorphic or igneous stones remain unknown. The Laurentian Campus Urban GeoTrail describes building stones, rock gardens, and outcrops on and near campus demonstrating another method to showcase Ontario's rich and complex geologic history.

DISCUSSION

The process of creating GeoTrails in collaboration with the APGO Education Foundation has led to numerous learning opportunities, not only for the public who use them, but also for geoscientists at various career stages who helped create them. Early career faculty (following the Natural Sciences and Engineering Research Council of Canada (NSERC) definition of individuals holding their first independent academic position within the last five years) had the opportunity to engage in science communication for the public and to network with community environmental leadership. Postdoctoral fellows and senior graduate students had the opportunity to improve their writing, field supervision and mentorship abilities. Undergraduate students scouted field sites, collected data and presented GeoTrails to community members during guided hikes. These opportunities enriched their careers by providing field and research experiences to students as early as during their first year of study. Students were also encouraged to practice their presentation skills to become effective scientific communicators to different audiences (e.g. their peers, scientists, community stakeholders). Future research could continue to assess students' perspectives on how involvement in the GeoTrails project has influenced their career trajectory.

Developing Opportunities for Geoscience Teaching

Fieldwork is fundamental to understanding the processes that have shaped our planet (Elkins and Elkins 2007; Petcovic et al. 2014; Whitmeyer and Dordevic 2021; Evelpidou et al. 2021). Field activities are understood to increase students' interest and enjoyment in a topic compared to traditional labs (Kern and Carpenter 1984), while they also enhance students' ability to understand and use the acquired information (Kern and Carpenter 1986; Elkins and Elkins 2007). Digital field tools (e.g. virtual field trips, virtual outcrops) allow educators to bring the field into the classroom, complementing fieldwork (Arthurs 2021; Peace et al. 2021; Whitmeyer and Dordevic 2021; Marshall and Higley 2021; Gregory et al. 2022). Many of these tools are not new (De Paor 2016), but their usage has skyrocketed with remote learning conducted during the COVID-19 pandemic (Peace et al. 2021; Evelpidou et al. 2021; Larsen et al. 2021; Arthurs 2021; De Paz-Álvarez et al. 2022; Gregory et al. 2022). Additional usage of digital field tools highlighted their importance in making the field more accessible and inviting to all students as geosciences continue to strive to improve diversity, equity and inclusivity (Arthurs 2021; Peace et al. 2021).

Urban GeoTrails in cities and on campuses can be utilized in undergraduate courses (Peebles and Johnson 1984; Wetzel 2002; Guertin 2005; Perez-Monserrat et al. 2013) and published for community outreach (Hannibal and Schmidt 1991; Horenstein 2008). These virtual tours can provide information about environmental, engineering, architectural and geoheritage influences that direct the type of stone used for these applications (Peebles and Johnson 1984; Hannibal and Schmidt 1991; Brocx and Semeniuk 2019). For example, Indiana limestone was selected for ornamental trimmings on Knox College (University of Toronto St. George Campus) while most of the building stones are of local Whirlpool sandstone that can be observed in outcrop along the Bruce Trail (Rogers 2019). Limestone better preserves the sharp edges and ornate details of the masonry work based on its crystalline structure, instead of individually cemented grains. Additionally, building stones reflect the history of the city and its resources with many buildings relying on local stones, which were often more affordable (Peebles and Johnson 1984; Eyles 2002). Examining building stones (Hoskin 2000; Wetzel 2002; Guertin 2005; Perez-Monserrat et al. 2013) and rock gardens (Dillon et al.

2000; Waldron et al. 2016) in urban settings helps students make connections between geology and social drivers, as well as gain confidence and understand geological processes recorded in more rural field areas (e.g. GeoTrails along the Niagara Escarpment). Urban GeoTrails make the field more accessible to students who feel more comfortable in, or are restricted to, urban settings (Birnbaum 2004; d'Alessioa 2012) and place-based learning has been shown to be remarkably effective in urban undergraduate student populations (Kirkby 2014).

Strategies to Make the Geoscience Accessible to the Public

The GeoTrails we have created thus far are an example of effective collaboration between a registered charity (e.g. APGO Education Foundation) and university students and faculty (e.g. McMaster University, University of Toronto) to promote geoscience and its environmental influence on the community. The non-profit partner benefits from the universities' expertise while the universities gained support to fund students and access to resources (e.g. online platforms, staff support). In addition, the non-profit partner provides a user-friendly website that permanently hosts the GeoTrails and Urban GeoTrails, and regularly promotes the website at public events across Ontario. These partnerships are essential to build on the work community organizations have initiated (e.g. conservation efforts by Bruce Trail Conservancy), to break down the image of the 'ivory tower' by showcasing active research that is being conducted at the local university and to increase transparency regarding government-funded research by sharing research findings with the public (Yin et al. 2022).

Improving the accessibility of popular local trails and conservation sites is one of the goals of the GeoTrails and Urban GeoTrails. It is necessary to ensure that the relevant geoscientific information is not only communicated in an accessible format that everyone can understand, but that the experience of exploring the trail is also inclusive. These GeoTrails provide a novel way to make geology more accessible for people with limited mobility as well as to those in the international community. The 360° images and 3-D models included in the GeoTrails allow the users to explore their virtual surroundings at their own pace. Labels on the 3-D models point out features of interest, and the high-resolution imagery supports further investigation of features such as fossils, vegetation, and sedimentary structures. By providing these GeoTrails virtually, anyone can access the information to learn more about Canadian geoscience and explore famous tourist destinations such as the Niagara Gorge that might otherwise be cost prohibitive.

GeoTrails can provide educational opportunities for all ages and aid in the development of resources for conservation organizations (e.g. Bruce Trail Conservancy). Geotrails and Urban GeoTrails are useful learning tools for use in primary or secondary education classrooms. They are easily accessible guides that will allow teachers to take students into the field and learn about local geology without having to secure a trained geoscientist as a guide. Alternatively, teachers who cannot bring their students to the field (e.g. cost, location, accessibility) are encouraged to access these virtual tours in the classroom. Our multi-media approach is intended to provide as immersive an experience as possible, allowing students to get a feeling for what exploring the area is like without having to visit in person. GeoTrails and Urban GeoTrails, supplemented with educational materials for teachers, can help educators discover the potential of resources in their own backyards (Kean and Enochs 2001; Kean et al. 2004). We are hoping to reach more teachers with our upcoming Niagara Escarpment illustrated children's book and teacher's guide featuring activities involving the GeoTrails. In addition, these GeoTrails help to raise awareness about the impacts of climate change and/or land use on the local environment (Haynes 1995). The opportunity to learn about the environmental consequences of lifestyle choices can help community members understand their role in influencing global change.

FUTURE DIRECTIONS

The effectiveness of the GeoTrails to (1) build student leadership, (2) recruit students and (3) provide resources for local communities will continue to be assessed over the next five years. We plan to document the learning experiences of students who have participated in the development of the GeoTrails and to determine how their involvement has influenced their career choices. This will help identify which skills they developed during their work on the GeoTrails were most valuable to them. We would also like to host workshops aimed toward educators and community stakeholders (e.g. Curriculum Connections at GACMAC 2023) to showcase the GeoTrails and gain information about how to improve the GeoTrails to enhance student recruitment and better serve community needs. We are actively seeking feedback on the GeoTrails and look forward to creating additional resources (e.g. illustrated book, podcast, trail signs) to supplement these educational tools.

We will continue to create additional GeoTrails to showcase regional geological differences across southern Ontario and the influence of geoscience on our everyday lives. The involvement of additional university groups in the future will allow GeoTrails to expand to other regions of Ontario, such as the Rideau Trail (between Ottawa and Kingston, Ontario) and urban park trails within the City of Toronto. Ongoing testing of emerging digital field tools will allow us to determine their suitability and effectiveness to capture and present field data to a variety of audiences. Drone-based photogrammetry created using open-source software could also be incorporated in the GeoTrails to create 3-D surfaces for users to explore. The current GeoTrails feature drone photography, but drone-based photogrammetry will be necessary to provide perspective when access to parts of the trails may be problematic. Gamifying the GeoTrails to create additional opportunities for virtual reality engagement could also be a future direction for this project. Video game-style virtual field experiences provide an excellent opportunity to improve field accessibly for both the public and students (Mani et al. 2016; Needle et al. 2022).

https://doi.org/10.12789/geocanj.2023.50.198

Incorporating downloadable formats of the information including the audio descriptions provided in the GeoTrails is a future target.

The GeoTrails we have created would also benefit from the incorporation of additional opportunities for consultation with Indigenous leadership, community feedback and citizen science. Current feedback from community groups continues to help us enhance GeoTrail methodology and accessibility and inclusivity. However, the incorporation of user observations into the GeoTrails would help build local datasets for geoscientists and empower citizens to take ownership of their environment (Roche et al. 2020). There are logistical challenges to integrating public input into active research; however, this is an opportunity to generate new knowledge that needs to be explored. We are excited about the opportunities the expansion of the GeoTrails project provides and the potential to significantly enhance public awareness and appreciation of geoscience.

DATA AVAILABILITY

All GeoTrails are publicly available through Geoscienceinfo.com.

ACKNOWLEDGEMENTS

We would like to respectfully acknowledge that the GeoTrails in Hamilton and Niagara are on the traditional territories shared between the Haudenosaunee Confederacy and the Anishinaabe nation. This project was funded through Mitacs Accelerate grants IT30289 and IT30886 in partnership with the APGO Education Foundation. We thank A. Kerr, J. Bates and an anonymous reviewer for their constructive feedback and suggestions for improvement of the manuscript.

REFERENCES

Aaisyah, D., Sahari, S., Shah, A.A., Qadir, A., Prasanna, M.V., and Shalaby, R., 2021, COVID-19 as an opportunity to make field-based earth sciences and other similar courses easily accessible and affordable: Environmental Resilience and Transformation in Times of COVID-19, v. 29, p. 333–342, https://doi.org/10.1016/B978-0-323-85512-9.00030-9.

Armstrong, D.K., and Dodge, J.E.P., 2007, Paleozoic geology of southern Ontario: Ontario Geological Survey, Miscellaneous Release-Data 219.

Arthurs, L., 2021, Bringing the field to students during COVID-19 and beyond: GSA Today, v. 31, p. 28–29, https://doi.org/10.1130/gsatg478gw.1.

Baron, N., 2010, Escape from the Ivory Tower: A guide to making your science matter: Island Press, 272 p.

Birnbaum, S., 2004, Overcoming the limitations of an urban setting through field-based earth systems inquiry: Journal of Geoscience Education, v. 52, p. 407–410, https://doi.org/10.5408/1089-9995-52.5.407.

Bitting, K.S., McCartney, M.J., Denning, K.R., and Roberts, J.A., 2018, Conceptual learning outcomes of virtual experiential learning: Results of Google Earth exploration in introductory geoscience courses: Research in Science Education, v. 48, p. 533–548, https://doi.org/10.1007/s11165-016-9577-z.

Bolton, T.E., 1957, Silurian stratigraphy and palaeontology of the Niagara escarpment in Ontario: Geological Survey of Canada, Memoir 289, 145 p., https://doi.org/10.4095/101502.

Bond, R., and Paterson, L., 2005, Coming down from the ivory tower? Academics' civic and economic engagement with the community: Oxford Review of Education, v. 31, p. 331–351, https://doi.org/10.1080/03054980500221934.

Brett, C.E., 1983, Sedimentology, facies and depositional environments of the Rochester Shale (Silurian; Wenlockian) in western New York and Ontario: Journal of Sedimentary Petrology, v. 53, p. 947–971, https://doi.org/10.1306/212F82F1-2B24-11D7-8648000102C1865D.

Brett, C.E., Goodman, W.M., and LoDuca, S.T., 1990, Sequences, cycles, and basin dynamics in the Silurian of the Appalachian Foreland Basin: Sedimentary Geology, v. 69, p. 191–244, https://doi.org/10.1016/0037-0738(90)90051-T.

Brett, C.E., Brunton, F.R., and Calkin, P.E., 2018, Sequence stratigraphy and paleontology of the classic Upper Ordovician–Silurian succession in Niagara County, New York: Niagara Falls, NY, Field Guidebook, Association of Earth Science Editors Niagara Falls, 210 p.

Brocx, M., and Semeniuk, V., 2019, Building stones can be of geoheritage significance: Geoheritage, v. 11, p. 133–149, https://doi.org/10.1007/s12371-017-0274-8.

Brossard, D., and Scheufele, D.A., 2013, Science, new media, and the public: Science, v. 339, p. 40–41, https://doi.org/10.1126/science.1232329.

Brownell, S.E., Price, J.V., and Steinman, L., 2013, Science communication to the general public: Why we need to teach undergraduate and graduate students this skill as part of their formal scientific training: Journal of Undergraduate Neuroscience Education, v. 12, p. 6–10.

Bruce Trail Conservancy, 2020, The Bruce Trail Reference: Maps and Trail Guide, eds. Kirby, K., Langley, S., Tuohy, L., and Johnson, T., Queen's Printer Ontario, Dundas, 30th edition.

Brunton, F.R., 2009, Update of revisions to Early Silurian stratigraphy of Niagara Escarpment: Integration of sequence stratigraphy/sedimentology/hydrogeology to delineate hydrogeologic units (HGUs): Summary of Field Work and Other Activities, Ontario Geological Survey, Open File Report 6240, p. 25-1 to 25-20, https://doi.org/10.13140/RG.2.1.3109.5289.

Brunton, F.R., and Brintnell, C., 2020, Early Silurian sequence stratigraphy and geological controls on karstic bedrock groundwater-flow zones, Niagara Escarpment region and the subsurface of southwestern Ontario: Ontario Geological Survey, Groundwater Resources Study 13, 120 p.

Carter, S.C., Griffith, E.M., Jorgensen, T.A., Coifman, K.G., and Griffith, W.A, 2021, Highlighting altruism in geoscience careers aligns with diverse US student ideals better than emphasizing working outdoors: Communications Earth & Environment, v. 2, p. 1–8, https://doi.org/10.1038/s43247-021-00287-4.

Center for Geoscience and Society, 2018, Earth and space sciences education in U.S. secondary schools: Key indicators and trends 3.0: American Geosciences Institute, Alexandria, Virginia, 24 p.

Colson, V., 2011, Science blogs as competing channels for the dissemination of science news: Journalism, v. 12, p. 889–902, https://doi.org/10.1177/1464884911412834.

Cramer, B.D., Brett, C.E., Melchin, M.J., Männik, P., Kleffner, M.A., Mclaughlin, P.I., Loydell, D.K., Munnecke, A., Jeppsson, L., Corradini, C., Brunton, F.R., and Saltzman, M.R., 2011, Revised correlation of Silurian Provincial Series of North America with global and regional chronostratigraphic units and $\delta^{13}C_{carb}$ chemostratigraphy: Lethaia, v. 44, p. 185–202, https://doi.org/10.1111/j.1502-3931.2010.00234.x.

d'Alessioa, M.A., 2012, Schoolyard geology as a bridge between urban thinkers and the natural world: Journal of Geoscience Education, v. 60, p. 106–113, https://doi.org/10.5408/11-246.1.

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., Dordevic, M.M., Karabinos, P., Tewksbury, B.J., and Whitmeyer, S.J., 2016, The fold analysis challenge: A virtual globe-based educational resource: Journal of Structural Geology, v. 85, p. 85–94, https://doi.org/10.1016/j.jsg.2016.02.005.

De Paz-Álvarez, M.I., Blenkinsop, T.G., Buchs, D.M., Gibbons, G.E., and Cherns, L., 2022, Virtual field trip to the Esla Nappe (Cantabrian Zone, NW Spain): Delivering traditional geological mapping skills remotely using real data: Solid Earth. v. 13, p. 1–14, https://doi.org/10.5194/se-13-1-2022.

Dillon, D.L., Hicock, S.R., Secco, R.A., and Tsujita, C.J., 2000, A geologic rock garden as an artificial mapping area for teaching and outreach: Journal of Geoscience Education, v. 48, p. 24–29, https://doi.org/10.5408/1089-9995-48.1.24.

Disbrow-Monz, M., Ubeda, E.G., Greenberg, J., Metzger, E., and Wessel, G., 2023, Saving Earth, saving geoscience: GSA Today, v. 33, p. 52–53, https://doi.org/10.1130/GSATG565GW.1.

Elkins, J.T., and Elkins, N.M.L., 2007, Teaching geology in the field: Significant geoscience concept gains in entirely field-based introductory geology courses: Journal of Geoscience Education, v. 55, p. 126–132, https://doi.org/10.5408/1089-9995-55.2.126.

Evelpidou, N., Karkani, A., Saitis, G., and Spyrou, E., 2021, Virtual field trips as a tool for indirect geomorphological experience: A case study from the southeastern part of the Gulf of Corinth, Greece, Geoscience Communication, v. 4, p. 351–360, https://doi.org/10.5194/gc-4-351-2021.

Eyles, N., 2002, Toronto rocks: Geology in the city, *in* Eyles, N., Ontario Rocks: Three Billion Years of Environmental Change: Fitzhenry & Whiteside Limited, Markham, Ontario, p. 166–173.

Formenti, S., Peace, A., Eyles, C., Lee, R., and Waldron, J.W., 2022, Fractures in the Niagara Escarpment in Ontario, Canada: distribution, connectivity, and geohazard implications: Geological Magazine, p. 1–16, https://doi.org/10.1017/S0016756822000462.

Gage, H.J.M., Eyles, C.H., and Peace, A.L., 2022, Winter weathering of fractured sedimentary rocks in a temperate climate: Observation of freeze-thaw and thermal processes on the Niagara Escarpment, Hamilton, Ontario: Geological Magazine, p. 1–22, https://doi.org/10.1017/S0016756822000887.

Gewin, V., 2021, Respect and representation: Nature, v. 589, p. 315–317, https://doi.org/10.1038/d41586-021-00022-1.

Grabau, A.W., 1908, A revised classification of the North American Silurian: Science, v. 27, p. 622–623.

Gregory, D.D., Tomes, H.E., Panasiuk, S.L., and Andersen, A.J., 2022, Building an online field course using digital and physical tools including VR field sites and virtual core logging: Journal of Geoscience Education, v. 70, p. 85–100, https://doi.org/10.1080/10899995.2021.1946361.

Guertin, L.A., 2005, An indoor shopping mall building stone investigation with handheld technology for introductory geoscience students: Journal of Geoscience Education, v. 53, p. 253–256, https://doi.org/10.5408/1089-9995-53.3.253.

Hall, J., 1852, Palaeontology of New York: Van Benthuysen and Sons, Albany, NY, 362 p.

Hannibal, J.T., and Schmidt, M.T., 1991, Interpreting urban geology: Journal of Geoscience Education, v. 39, p. 272–278, https://doi.org/10.5408/0022-1368-39.4.272.

Haynes, S.J., 1995, Geology, landscape dynamics, and land-use of the southern Niagara Escarpment: Landplanning of a U.N. biosphere preserve: Minería y Geología, v. 12, p. 55–63, https://revista.ismm.edu.cu/index.php/revistamg/article/view/1605.

Haynes, S.J., 2000, Geology and Wine 2. A geological foundation for terroirs and potential sub-appellations of Niagara Peninsula wines, Ontario, Canada: Geoscience Canada, v. 27, p. 67–87, https://journals.lib.unb.ca/index.php/GC/article/view/4045.

Hayward, A., Sjoblom, E., Sinclair, S., and Cidro, J., 2021, A new era of Indigenous research: Community-based Indigenous research ethics protocols in Canada: Journal of Empirical Research on Human Research Ethics, v. 16, p. 403–417, https://doi.org/10.1177/15562646211023705.

Hewitt, D.F., 1964, Building Stones of Ontario, Part I Introduction: Ontario Department of Mines, Industrial Mineral Report No. 14, 72 p.

Horenstein, S., 2008, Building stone treasure troves: Evolution: Education and Outreach, v. 1, p. 520–530, https://doi.org/10.1007/s12052-008-0075-2.

Hoskin, P.W.O., 2000, Urban outcrops and the lunchtime petrology field trip: Journal of Geoscience Education, v. 48, p. 573, https://doi.org/10.5408/1089-9995-48.5.573b.

Illingworth, S., Stewart, I., Tennant, J., and von Elverfeldt, K., 2018, Editorial: *Geoscience Communication* - Building bridges, not walls: Geoscience Communation, v. 1, p. 1–7, https://doi.org/10.5194/gc-1-1-2018.

Kean, W.F., and Enochs, L.G., 2001, Urban field geology for K–8 teachers: Journal of Geoscience Education, v. 49, p. 358–363, https://doi.org/10.5408/1089-9995-49.4.358.

Kean, W.F., Posnanski, T.J., Wisniewski, J.J., and Lundberg, T.C., 2004, Urban earth science in Milwaukee Wisconsin: Journal of Geoscience Education, v. 52, p. 433–437, https://doi.org/10.5408/1089-9995-52.5.433.

Kemp, K.M., and Freeman, E.B., 1998, Field trip A5 building stones of Toronto: 17th General Meeting International Mineralogical Association, 12 p.

Kern, E.L., and Carpenter, J.R., 1984, Enhancement of student values, interests and attitudes in Earth Science through a field-oriented approach: Journal of Geoscience Education, v. 32, p. 299–305, https://doi.org/10.5408/0022-1368-32.5.299.

Kern, E.L., and Carpenter, J.R., 1986, Effect of field activities on student learning: Journal of Geoscience Education, v. 34, p. 180–183, https://doi.org/10.5408/0022-1368-34.3.180.

Kingston, M.S., and Presant, E.W., 1989, The soils of the regional municipality of Niagara: Report No. 60 of the Ontario Institute of Pedology, Land Resource Research Centre Contribution No. 89-17, https://sis.agr.gc.ca/cansis/publications/surveys/on/on60/on60-v2_report.pdf.

Kirkby, K.C., 2014, Place in the city: Place-based learning in a large urban undergraduate geoscience program: Journal of Geoscience Education, v. 62, p. 177–186, https://doi.org/10.5408/12-396.1.

Larsen, T., Tabor, L., and Smith, P., 2021, End of the field? Hacking online and hybrid environments for field-based learning in geography education: Journal of Geography, v. 120, p. 3–11, https://doi.org/10.1080/00221341.2020.1858325.

Mani, L., Cole, P.D., and Stewart, I., 2016, Using video games for volcanic hazard education and communication: An assessment of the method and preliminary results: Natural Hazards and Earth System Sciences, v. 16, p. 1673–1689, https://doi.org/10.5194/nhess-16-1673-2016.

Marshall, M.S., and Higley, M.C., 2021, Multi-scale virtual field experience: Sedimentology and stratigraphy of Grand Ledge, Michigan, USA: Geoscience Communication, v. 4, p. 461–474, https://doi.org/10.5194/gc-4-461-2021.

Middleton, G.V., 2011, Hamilton Building Stone: Raise the Hammer [website], https://raisethehammer.org/authors/197/gerard_v_middleton.

Morse, J.W., Gladkikh, T.M., Hackenburg, D.M., and Gould, R.K., 2020, COVID-19 and human-nature relationships: Vermonters' activities in nature and associated nonmaterial values during the pandemic: PLoS ONE, v. 15, e0243697, https://doi.org/10.1371/journal.pone.0243697.

Mosher, S., and Keane, C., (*editors*), 2021, Vision and change in the geosciences: The future of undergraduate geoscience education: American Geosciences Institute, Washington, DC., 178 p., https://www.americangeosciences.org/change/pdfs/Vision-Change-Geosciences.pdf.

Needle, M.D., Crider, J.G., Mooc, J., and Akers, J.F., 2022, Virtual field experiences in a web-based videogame environment: Open-ended examples of existing and fictional field sites: Geoscience Communication, v. 5, p. 251–260, https://doi.org/10.5194/gc-5-251-2022.

Peace, A.L., Gabriel, J.J., and Eyles, C., 2021, Geoscience fieldwork in the age of COVID-19 and beyond: Commentary on the development of a virtual geological field trip to Whitefish Falls, Ontario, Canada: Geosciences, v. 11, 489, https://doi.org/10.3390/geosciences11120489.

Peebles, P.C., and Johnson, G.H., 1984, A field trip guide: The geology of building stones in metropolitan areas: Science Activities, v. 21, p. 19–26, https://doi.org/10.1080/00368121.1984.9957990.

Perez-Monserrat, E.M., de Buergo, M.A., Gomez-Heras, M., Muriel, M.J.V., and Gonzalez, R.F., 2013, An urban geomonumental route focusing on the petrological and decay features of traditional building stones used in Madrid, Spain: Environmental Earth Sceinces, v. 69, p. 1071–1084, https://doi.org/10.1007/s12665-012-2164-3.

Petcovic, H.L., Stokes, A., and Caulkins, J.L., 2014, Geoscientists' perceptions of the value of undergraduate field education: GSA Today, v. 24, p. 4–10, https://doi.org/10.1130/GSATG196A.1.

Ramharrack-Maharaj, S., and Davies, E., 2023, Linking surface hydrology and geology: A case study of the Niagara Escarpment (Hamilton, Ontario) (Abstract): Geoscience Canada, v. 50, p. 205, https://doi.org/10.12789/geocanj.2023.50.200.

Roche, J., Bell, L., Galvão, C., Golumbic, Y.N., Kloetzer, L., Knoben, N., Laakso, M., Lorke, J., Mannion, G., Massetti, L., Mauchline, A., Pata, K., Ruck, A., Taraba, P., and Winter, S., 2020, Citizen science, education, and learning: Challenges and opportunities: Frontiers in Sociology, v. 5, 613814, https://doi.org/10.3389/fsoc.2020.613814.

Rogers, C., 2019, Guide to some of the building stones at the University of Toronto: 17th Euroseminar on Microscopy Applied to Building Materials, Toronto.

Ryan-Davis, J., and Scalice, D., 2022, Co-creating ethical practices and approaches for fieldwork: AGU Advances, v. 3, e2022AV000762, https://doi.org/10.1029/2022AV000762.

Scott, R.W., and Huff, F.A., 1996, Impacts of the Great Lakes on regional climate conditions: Journal of Great Lakes Research, v. 22, p. 845–863, https://doi.org/10.1016/S0380-1330(96)71006-7.

Seneca College, 2022, A dish with one spoon (Chapter 3), *in* Skoden: Teaching, Talking, and Sharing About and for Reconciliation: Open Library, https://ecampusontario.pressbooks.pub/skoden/.

Shaw, A.B., 2005, The Niagara Peninsula viticultural area: A climatic analysis of Canada's largest wine region: Journal of Wine Research, v. 16, p. 85–103, https://doi.org/10.1080/09571260500327630.

Statistics Canada, 2023, 2021 Census of population geographic summary: Statistics Canada, https://www12.statcan.gc.ca/census-recensement/2021/search-recherche/productresults-resultatsproduits-eng.cfm?Lang=E&GEOCODE=2021A00033518.

Steele, K.G., and Haynes, S.J., 2000, Mines and wines: Industrial minerals, geology and wineries of the Niagara Region - Field Trip Guidebook: Ontario Geological Survey Open File Report 6029, 25 p.

Stewart, I.S., and Lewis, D., 2017, Communicating contested geoscience to the public: Moving from 'matters of fact' to 'matters of concern': Earth-Science Reviews, v. 174, p. 122–133, https://doi.org/10.1016/j.earscirev.2017.09.003.

Stewart, I.S., and Nield, T., 2013, Earth stories: Context and narrative in the communication of popular geoscience: Proceedings of the Geologists' Assocation, v. 124, p. 699–712, https://doi.org/10.1016/j.pgeola.2012.08.008.

Symons, S.L., Colgoni, A., and Harvey, C.T., 2017, Student perceptions of staged transfer to independent research skills during a four-year honours science undergraduate program: The Canadian Journal for the Scholarship of Teaching and Learning, v. 8, 6, https://doi.org/10.5206/cjsotl-rcacea.2017.1.6.

Tovell, W.M, 1992, Guide to the geology of the Niagara Escarpment with field trips, *in* Brown, L., *ed.,* The Niagara Escarpment Commission with the Assistance of the Ontario Heritage Foundation: Ashton-Potter Limited, Concord, ON, p. 150.

UNESCO, 2018, Niagara Escarpment Biosphere Reserve: Available at: https://en.unesco.org/biosphere/eu-na/niagara-escarpment#:~:text=Socio-Economic%20Characteristics.

Waldron, J.W.F., Locock, A.J., and Pujadas-Botey, A., 2016, Building an outdoor classroom for field geology: The geoscience garden: Journal of Geoscience Education, v. 64, p. 215–230, https://doi.org/10.5408/15-133.1.

Weber, B., 2023, 'Something's changed': Summer 2023 is screaming climate change, scientists say: CBC News Calgary, updated 6 August 2023, 1.6929271, https://www.cbc.ca/.

Wetzel, L.R., 2002, Building stones as resources for student research: Journal of Geoscience Education, v. 50, p. 404–409, https://doi.org/10.5408/1089-9995-50.4.404.

Whitmeyer, S.J., and Dordevic, M., 2021, Creating virtual geologic mapping exercises in a changing world: Geosphere, v. 17, p. 226–243, https://doi.org/10.1130/GES02308.1.

Whitmeyer, S.J., Bailey, J.E., De Paor, D.G., and Ornduff, T., (*editors*), 2012, Google Earth and Virtual Visualizations in Geoscience Education and Research: Geological Society of America Special Papers, v. 492, 468 p., https://doi.org/10.1130/SPE492.

Whitmore, C., and Carlson, E., 2022, Making land acknowledgements in the university setting meaningful and appropriate: College Teaching, https://doi.org/10.1080/87567555.2022.2070720.

Williams, M.Y., 1919, The Silurian geology and faunas of Ontario Peninsula, and Manitoulin and adjacent islands: Geological Survey of Canada, Memoir 111, 195 p., https://doi.org/10.4095/101651.

Yin, Y., Dong, Y., Wang, K., Wang, D., and Jones, B.F., 2022, Public use and public funding of science: Nature Human Behaviour, v. 6, p. 1344–1350, https://doi.org/10.1038/s41562-022-01397-5.

Received May 2023
Accepted as revised August 2023