From Virtual Field Trip to Geologically-Reasoned Decisions in Yosemite Valley

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ABSTRACT

This study highlights a Geology of Yosemite Valley virtual field trip (VFT) and companion exercises produced as a four-part ~~module~~ educational activity to substitute for physical field experiences. The VFT is created as an Earth project in Google Earth Web, a versatile format that allows access through a web browser or Google Earth app with the sharing of an internet address. Many dynamic resources can be used for VFT stops through use of the Google Earth Engine (global satellite imagery draped on topography, 360° street-level imagery, user-submitted 360° photospheres). Images, figures, videos, and narration can be embedded into VFT stops. Hyperlinks allow for a wide range of external resources to be incorporated; optional background resources help reduce the knowledge gap between general public and ~~upper division~~ advanced undergraduate students, ensuring VFTs can be broadly accessible. Like many in-person field trips, there is a script with learning goals for each stop, but also an opportunity to learn through exploration as the viewer can dynamically change their vantage at each stop (i.e. guided discovery learning). This interactive VFT format ~~scaffolds~~ supports students' spatial skills and encourages attention to be focused on a stop's critical spatial information. The progression from VFT to mapping exercise to geologically-reasoned decision-making results in high quality student work; students find it engaging, enjoyable, and educational.

1. INTRODUCTION

The shifting landscape of the global COVID-19 pandemic in early 2020 brought unprecedented uncertainty and disruption to educators worldwide, particularly field educators (e.g. Arthurs, 2021; Phillips et al., 2021; Walker, 2021). To promote safety and minimize virus spread, many national agencies, local governments, and universities changed rules and guidelines on a near-weekly basis, often implementing drastic procedural changes with little notice. Against this backdrop a hundred-plus intensive capstone field geology ~~courses~~ educational experiences (i.e. "summer field" courses in the United States) hosted by universities around the world that were scheduled to run over the summer were forced to make a hard choice: Do we proceed? Some instructors held out hope of running their course (i.e. "module" in the European use) only to have their camping permits denied at the last minute or shifting regulations cancel their field course altogether. Although a very small minority did actually run in-person courses with clearances and modifications to safely limit COVID-19 exposure (e.g. Rotzien et al., 2021), most instructors shifted to offering alternative courses in a remote or virtual format that would attempt to instill some of the field skills considered essential by employers and graduate advisors.

34 Field geology educators across the globe began organizing and meeting virtually in March 2020 as a forum on
35 "Designing Remote Field Experiences" to assess resources readily available for use in remote field geology courses,
36 what could be adapted from instructors' courses, and what could be created new with enough lead time to be
37 implemented by others. Several working groups coordinated by affiliates of the National Association of Geoscience
38 Teachers (NAGT) sprung up with sub-interests (learning objectives, building a community-based virtual field camp,
39 virtual field trips, virtual worlds, virtual field geophysics, etc.). A clear challenge that repeatedly arose was how to
40 virtually deliver the same depth of learning that in-person field experiences provide.

41 For the preceding three years University of California- Riverside's summer field geology course, hosted in Owens
42 Valley, California, had a short one-day ~~module~~exercise where students were expected to use web-hosted lidar data to
43 map geomorphic features such as debris fans, rockfalls, and glacial moraines in Yosemite Valley. This exercise was
44 followed by a long day of driving over the Sierra Nevada to Yosemite Valley where students would participate in a
45 multi-stop walk highlighting natural hazards including floods, rockfalls, and rock avalanches. In post-course surveys
46 students cited the ~~module~~ Yosemite activity and visit as one of their favorite aspects of the course, and the students'
47 assessment results (scores) ~~instructor thought~~ indicate the mapping products ~~students~~ produced ~~in this module~~ were
48 some of the~~ir best~~ highest quality in the course. Out of this background familiarity and ~~potential~~ the possibility ~~for a~~
49 ~~long-lived module~~to create a long-lived teaching resource (i.e. with potential for broad international interest and usable
50 with a site visit once in-person field instruction resumed), we developed a four-part Geology of Yosemite Valley
51 educational activity~~module~~ (https://serc.carleton.edu/NAGTWorkshops/online_field/activities/237092.html; last
52 accessed: 11 October 2021), advertised through the main NAGT working group, and made this ~~module~~ activity
53 publicly available in May 2020 through the Science Education Resources Center (SERC) website hosted by Carleton
54 College (Figure 1). This paper is intended to provide an overview of the learning philosophies and technologies
55 employed, with the hope that it promotes the creation of high quality virtual field trips (VFTs) appropriate for the
56 general public, and highlights how VFTs can lead into advanced-level mapping and geologically-reasoned decision-
57 making exercises suitable for ~~upper-division~~ third-year or fourth-year undergraduate courses.

2. ~~MODULE~~ ACTIVITY DESCRIPTION

59 Geology of Yosemite Valley is a four-part educational ~~module~~activity that we intentionally designed to be flexible in
60 duration and student ~~grade~~knowledge-level
61 (https://serc.carleton.edu/NAGTWorkshops/online_field/activities/237092.html~~https://serc.carleton.edu/NAGTWork~~
62 ~~shops/online_field/ activities/237092.html~~; last access~~ed~~: 11~~24~~ ~~August~~October 2021). Full functionality requires a
63 computing device with internet connection, Google Chrome browser, Google Earth Pro desktop, and a trackpad or
64 mouse. The four parts are described in the suggested order of completion, as each part builds on the previous one.
65 Particular detail is given to the virtual field trip (Part I) created through the Projects feature of Google Earth Web, a
66 user-friendly and highly-adaptable format with advantages over many other VFT platforms. An overview of Parts II,
67 III, and IV are provided to illustrate how a VFT can be used as background material for more advanced-level mapping
68 and writing exercises.

2.1 Geology of Yosemite Valley Virtual Field Trip

2.1.1 Introduction to Google Earth Web Projects

The Geology of Yosemite Valley VFT (https://bit.ly/2Zbn3R7) was created as an Earth project using the *Creation Tools* available in Google Earth Web accessible via web browser. Google introduced *Tour Builder* as a beta tool in 2013 as a way to create shareable place-based narratives with images, text, videos and links hosted within their Google Earth engine; *Tour Builder* was discontinued in July 2021, but most of the functionality has been made permanent in Google Earth Web's *Creation Tools*, which launched in 2019. Creating with *Creation Tools* requires signing into the web version of Google Earth (preferred browser: Google Chrome) with a Google account (free); all projects are stored in the creator's Google Drive storage system. Much of the functionality will be familiar to users of other Google products (Docs, Sheets, Slides, etc.): a creator can make a project shareable or completely private, collaborate with other creators if they choose, and project changes are immediately saved and updated with an internet connection (i.e. real-time editing) (Figure 2).

All created features for a given project appear in a Table of Contents and can be reordered by the creator but not viewers. A publicly-shared project can be downloaded by a third-party user; it can also be copied such that a third-party creator can edit and adapt someone's project as their own (for example adding their own built-in quiz assessments for their students).

Three types of features can currently be added to projects: fullscreen slides, lines or shapes, and placemarks.

(1) Fullscreen slides fill the entire screen and are not geotagged. The creator can upload a background image or video and overlay text with hyperlinks. Because of the lack of geotagging, fullscreen slides work best as title slides or interstitial slides that intentionally pull focus away from the more interactive Google Earth environment (for example to highlight a figure or concept).

(2) Placemarks are geotagged points in Google Earth's global environment and are the most versatile feature that can be created. What makesA key advantage of placemarks in an Earth project truly standout is that not only is the viewer flown to the point on the globe, but the precise view (zoom level, look directionview orientation, imagery) that the creator selects. The view can be a top-down or oblique 3D vantage of Google Earth's elevation model-draped satellite imagery or pulled from Google Street View's extensive ground-level photosphere imagery (outward looking 360° zoomable imagery). User-submitted photosphere imagery can also be incorporated if the use is consistent with their Creative Commons license. VFT creators can use the Google Street View app on a smartphone or tablet to create and submit their own photospheres, which can be readily used as well. The creator can add text, hyperlinks, images, and videos into a sidebar that helps explain the particular view selected for the placemark. There is a more advanced option to directly edit the sidebar's html, which allows for custom widths, styles, and the addition of features like audio narration or embedded quizzes.

(3) Lines or polygons can be drawn on the standard 3D view of Google Earth with different widths, colors and transparencies, which may be helpful for highlighting a specific feature like a fault or landslide. Similar to

the placemark functionality, a sidebar box can have text or images describing the feature and a custom view can be tagged. Each line appears as an item in the Tables of Contents so this would be an unwieldy way to annotate many features in a small area (creating and embedding a figure would be more effective). It is not possible to create lines or polygons within a photosphere view.

2.1.2 VFT Walkthrough

When the viewer (student) clicks on the provided Geology of Yosemite Valley weblink (https://bit.ly/2Zbn3R7) on a computer, the default browser opens an uneditable "view only" version of the project (VFT) in Google Earth Web. On a tablet or smartphone, the Google Earth app is automatically opened if downloaded. The format dynamically adjusts to the size of the window. ~~screen; larger screens are able to convey more information and view at once and are probably ideal in most situations.~~

~~A Table of Contents appears with all of the tour items and a selectable "Present" button.~~ Clicking or tapping the "Present" ~~this~~ button takes you to the first item (i.e. first virtual field trip stop) in the Table of Contents and starts what is effectively an interactive slideshow. This VFT moves from the past towards the present, starting with a general overview of Cretaceous geology, bedrock joints, glaciations, and then moves on to active processes like rockfalls and debris fans. The VFT is designed in a format that could be a standalone overview of Yosemite Valley geology, but has the second purpose of preparing the student for additional exercises on geomorphic mapping; relatedly there is a particular emphasis on Quaternary deposits and hazards in the VFT.

At any point, navigation allows the student to go forward or backward or pull up the Table of Contents to revisit a past stop. To maximize accessibility to a wide variety of knowledge levels, text in the VFT is extensively hyperlinked to external web resources like Wikipedia or the U.S. Geological Survey. If a student is familiar with terms such as "subduction zones" or "partial melting" then they can read on, whereas another student who is not familiar with those terms readily has access to the information needed to understand. A student works through each of the 44 stops, reading the text and connecting the views to annotated figures and videos provided. In some places small exercises are suggested using the built-in measure tool (measuring area or distance). A student that needs to dive deeper into the hyperlinks and background information will need more time to complete the VFT (~3 hours), while a more knowledgeable student may be able to work through it in under 2 hours.

Yosemite Valley was a fortunate place to design a VFT, as the heavy visitation and high interest meant that many existing resources could be adapted rather than being created new. Google Earth's "3D Buildings" layer (photo-textured 3D models derived from low-flying aerial photogrammetry ~~derived elevation model) draped satellite imagery~~ in Yosemite Valley is of exceptional quality (for example, able to resolve individual trees or boulders), on par with current coverage in major cities and other popular outdoor recreation areas. The National Park Service has a wide variety of professionally-produced informative YouTube videos on Yosemite, including many on geology topics, that we incorporated with attribution. Similarly, most of the valley's main trails and viewpoints have Google Street View coverage. We created many new figures to best pair with specific vantages (Figure 3).

138 To be most broadly applicable, we designed this VFT without any assessment. Students get participation credit for
139 completing the VFT; if they are less diligent or skip stops they are more likely to need to revisit the VFT later to
140 complete the other ~~module~~ activity parts. Teachers could create their own quizzes hyperlinked at different stops, even
141 linking them directly to their ~~gradebook~~ records of scores if they had that functionality.

142 While the VFT could be conducted as a guided tour with an instructor leading the class through the field trip in a
143 lecture format (this would probably take less time), the simplicity of the format and opportunities for deeper learning
144 are greater if students are allowed to guide themselves (1-2 hours). Like many ~~good~~ in-person field trips, the Google
145 Earth Web project format strikes an ~~excellent~~ effective balance between purpose-driven stops with targeted learning
146 goals and opportunities for learning through exploration. While the particular vantages, text, images, and videos are
147 presented in a structured format to deliberately guide a student, at any point a student can break the script by zooming
148 in, rotating their view, walking a trail, or even searching for additional photospheres. Afterwards, the Table of Contents
149 allows the students to readily rejoin the tour. ~~It is a simple matter of continuing where they left off in the Table of~~
150 ~~Contents.~~ The mixture of medias and vantages allows for a particularly dynamic and engaging format. Peer reviewers,
151 students, and general public viewers all praised the VFT format. Creating a VFT using Google Earth Web *Creation*
152 *Tools* is intuitive and easily taught; students could create their own VFT as an alternative to an oral slide-based
153 presentation (e.g. Senger et al., 2021).

2.2 El Capitan Cross-Cutting Relationships Exercise

155 Part II of the ~~module~~ activity leverages the novel Geologic Map of the Southeast Face of El Capitan (Putnam et al.,
156 2014; 2015) as an advanced real-world relative dating exercise. El Capitan is one of the most famous landmarks in
157 Yosemite, an imposing, nearly kilometer-high vertical-walled monolith of exposed intrusive rock steeped in the
158 history of rock climbing. With the help of rock climbers and gigapixel photographs, geologists mapped intrusive units
159 with 8 different chemical compositions projected onto a vertical plane with great detail and precision (10 cm accuracy
160 for most contacts). While some of the units may be time-transgressive (e.g. multiple generations of pegmatite dikes)
161 or coeval (overlapping geochronologic ages and gradational contacts), relationships are consistent enough that
162 students can screenshot a particular region of the map and interpret the relationships to sort the 8 units from oldest to
163 youngest (Figure 4). A~~n~~ ~~instructor only~~ solution file is available through the SERC website ~~provided~~ with verified
164 instructor credentials.

165 With author permission, a version of the geologic map (Putnam et al., 2014) was edited to remove details such as the
166 geologic summary, correlation of mapped units, and geochronology so that students could focus on the mapped
167 relationships. An El Capitan stop on the VFT provides the necessary background that students need to understand the
168 basics of this geologic puzzle exercise. The concepts of cross-cutting relationships, gradational contacts, included
169 fragments, and magma mixing are introduced, using relatable examples where possible (a cracked phone screen for
170 cross-cutting relationships) and students are provided an embedded link to download the modified map. Because
171 students could search for the geologic map and companion journal article, this exercise works best as an in-session

172 group exercise with lenient grading. Emphasis should be placed more on the locations the students decide to
173 screengrab to highlight the least ambiguous relationships and their explanations provided.

174 Many cross-cutting relationship exercises given to students may involve sorting the timing of layered units,
175 unconformities, folds, faults, and dikes. This El Capitan exercise is made more challenging by focusing on eight
176 intrusive units with limited spatial layering and real world relationships of varying ambiguity.

2.3 Geomorphic Mapping of Yosemite Valley Exercise

178 In Part III of the ~~module~~ activity students are tasked with producing a geomorphic map of the Quaternary (mostly
179 Holocene) surficial deposits in Yosemite Valley using Google Earth Pro (desktop version)(Figure 5). Features to be
180 mapped include deposits of talus (i.e., rockfall), debris fans, rock avalanches, and glacial moraines, as well as river
181 terrace risers. The VFT highlights examples of each of these deposit types with additional background concerning
182 processes and linked hazards (rockfall, flooding, debris flows), including historic events. All the instructions and data
183 links needed for this mapping exercise are contained within the Google Earth KMZ provided to students. An example
184 of each deposit type or feature to be mapped is provided to students in the folder structure that they will use to submit
185 their final map (as a KMZ). Students create their geomorphic map ~~using~~ by interpreting web-served high-resolution
186 hillshades (greyscale NW-illuminated representation of surface) derived from unfiltered (i.e. includes trees and
187 buildings) and last return (i.e. bare-earth) airborne lidar data collected in 2006 (e.g.
188 https://doi.org/10.5069/G9GQ6VP3) and the internal web-served Google Earth satellite imagery built into the Google
189 Earth engine. The different Quaternary features (debris fans, rock avalanches, etc.) have very distinct textural and
190 slope styles readily distinguishable in the bare-earth lidar hillshade; once students gain an eye for it they can ~~fairly~~
191 efficiently map the 75 km^2 Yosemite Valley region.

192 This mapping exercise is most appropriate for an ~~upper division~~advanced undergraduate course (e.g. geomorphology,
193 applied geology, ~~summer~~ capstone field geology). The maps are ~~graded~~ scored based on correctness, completeness,
194 and neatness; the quality of the work is expected to be comparable to that produced by an entry-level professional
195 geoscientist~~students are held to a professional standard~~. An instructor-produced map is available through the SERC
196 website with verified instructor credentials. An entire class' KMZ maps can be added to the instructor's Google Earth,
197 allowing them to efficiently and objectively sort maps ~~from good to bad~~based on quality, check for cheating, and
198 identify obvious gaps in quality signifying ~~grade~~ score boundaries. From our experience in 2020 and 2021, these maps
199 are among the best products students have produced in UCR's remote summer field alternative courses. In the ~~course~~
200 ~~process~~ of mapping, most students (82%; 18 out of 22) recognize that nearly ~~100%~~all of the valley walls have talus or
201 debris flow deposits at their base; many (64%; 14 out of 22) recognize the variable density of river terrace risers along
202 the length of the valley.

2.4 Geologically-Reasoned Decision-Making in Yosemite Valley Exercise

204 Part IV of the ~~module~~ activity builds on the detailed geomorphic mapping the students did in Part III, which in turn
205 builds on the knowledge gained in Part I's VFT. In a KMZ file students are provided with two real-world hazard ~~lines~~

extents that Yosemite National Park uses for planning and preparedness: the known extent of the January 1997 flood in the valley, approximating a 100-year flood, and a rockfall hazard ~~line~~ extent that considers talus slopes and isolated boulders but not rock avalanches (Stock et al., 2014) (Figure 5). Students immediately recognize that some places in Yosemite Valley are expected to be susceptible to both floods and rockfall, and that most of the valley floor is susceptible to one of the hazards. Looking at the hazard ~~lines~~ extents overlain on the Google Earth satellite imagery, students can readily see what existing park infrastructure is within or near the hazard extents.

Students are tasked with using both their geomorphic mapping and the hazard ~~lines~~ extents to (1) provide recommendations for existing Yosemite Valley infrastructure that could be relocated to a less hazardous location, and (2) identify locations that would be suitable for additional development with varying levels of risk (e.g, a hotel, visitor center, storage facility, or parking lot). Students turn in a KMZ file indicating their recommendations and a technical report written as if they were consulting for the park (an oral presentation would be an effective format too). It is emphasized that the recommendations students provide must be well-reasoned and geologically-sound. Students should consider the nature of the respective hazards (e.g.~~,~~ rockfalls occur instantly and without warning and can be fatal, floods in the valley are predictable several days out and are rarely fatal) and the facility use (parking lots in flood zones can perhaps be evacuated with limited damage, a seldom-visited storage yard is better near a rockfall hazard zone than a campsite, etc.) when providing their recommendations. Students get particularly invested seeing how the numerous facilities are placed throughout the valley. By the end of the exercise they gain an appreciation of the ~~precious little~~limited real estate available for further development in the valley, that natural hazards are an active part of Yosemite Valley, and that there are considerable challenges associated with making decisions that affect the safety of over 4 million people a year.

3. DISCUSSION

3.1 Designing Virtual Field Trips with Google Earth Web

The Projects feature of Google Earth Web is a robust and adaptable format for semi-immersive virtual field trips that can be created with relative ease and presented intuitively. Instructors and students alike can learn the basics of project creation in about 15 minutes, making it an efficient format for instructors and also suitable for students to create their own VFT as part of a course's final project. The VFT can be made readily available on web-connected tablets (via Google Earth) or computer (via web browser such as Google Chrome) using a simple web link. The abundant fair-use imagery available through the Google Earth Engine (topography-draped satellite, 360° street-level, user-submitted 360° photospheres) often means VFT creators do not have to start from scratch. Using a 360° camera or the Google Street View app the VFT creator can also upload their own photospheres. The ability to not only geotag a field trip stop as a point on a map, but to curate a precise starting view for that stop (e.g. zoom level, oblique 3D vantage, particular ~~look direction~~view orientation in a photosphere) allows the creator to draw attention to the vantage most directly relevant to the learning goals for that stop. Text, images, and videos can be added to a sidebar supporting the stop's view; annotated photos of a similar or identical view can be particularly illustrative. However, each stop's view

240 is not fixed, allowing the viewer to explore "off-script", which can improve their situational awareness and
241 opportunities for independent learning. Advanced creators can customize the html for a given html stop, providing an
242 opportunity to add custom icons, narration, and built-in quizzes. Though less self-contained, hyperlinks offer an
243 opportunity to send students to external web addresses for background information (e.g. Wikipedia), quizzes or
244 surveys (e.g. Google Forms), and even web-hosted 3D models of outcrops or hand samples (e.g. Sketchfab, V3Geo).

245 As a result of the COVID-19 pandemic, Google Earth Web VFTs were created for several locations instructors would
246 otherwise be taking students on physical field trips, such as Greece (Evelpidou et al., 2021b) and Colorado (Mahan et
247 al., 2021). A notable pre-pandemic general public-focused implementation of Google Earth Web Earth projects as
248 VFTs is "Streetcar 2 Subduction" hosted by the American Geophysical Union (Rowe et al., 2020;
249 https://www.agu.org/streetcar2subduction). On their dedicated web page eight separate Earth projects are linked that
250 cover geological field trips in the San Francisco Bay Area, building on the classic field trip guidebook "A Streetcar to
251 Subduction and Other Plate Tectonic Trips by Public Transport in San Francisco" by Wahrhaftig (1984). While these
252 trips are fully functional as VFTs, they include information on transportation and safety logistics, and are designed as
253 self-guided walking tours. Because there is often cellular data reception is generally excellent in these urban-adjacent
254 field trip areas, a self-guided participant can use their GPS position (as a blue dot) to navigate from one stop to the
255 next within the VFT frame, and access the text, annotated images, and videos provided at each stop along the way.
256 There is a vast collection of existing field trip guidebooks that could be adapted into immersive VFTs to reach a
257 broader audience. Despite a global pandemic, United States national parks still hosted 237 million visitors in 2020;
258 the top ten visited parks all prominently feature geology (NPS Press Release, 25 February 2021). One could imagine
259 the value of linking immersive VFTs on park websites to help visitors plan their physical trips and phone-scannable
260 QR codes displayed outside visitor centers that would allow self-guided trips.

261 Currently there are several limitations of the Google Earth Web project format that are worth discussion. There is no
262 functionality to add georeferenced layers to a Google Earth Web project, such as a geologic map that could be turned
263 on or off over a landscape or a folder of data points that are distinct from field trip stops. Analysis is limited to
264 measuring distances and areas. Google Earth Web also currently does not have the ability to switch between different
265 imagery dates, a stellar feature on Google Earth Pro (desktop) that better highlights landscape changes (e.g. before
266 and after a wildfire). If there was a more straightforward way to cache all imagery and media related to a project, the
267 VFT could be taken to remote field locations and actually be used as more of an interactive field trip guide. At the
268 moment there does not seem to be a way to directly embed 3D models into Google Earth Web project sidebars; we
269 attempted to embed web-hosted Sketchfab, SketchUp, and 3D PDF models but were blocked by script or cookie
270 permissions. The ability to add an embedded 3D scan of a rock sample or a detailed outcrop model would likely add
271 to a VFT viewer's experience (these can still be hyperlinked though). Adapting the Google Earth Web project format
272 to Google Earth VR would certainly boost the immersiveness of a VFT, but at the cost of being a less accessible
273 format for many due to the specialized equipment currently needed for VR (e.g. Hagge, 2021). For public outreach
274 efforts and student engagement it would also be beneficial if statistics could be accessed about the number of viewers

275 and how long they viewed the VFT. Google Earth has been around for over twenty years and software development
276 continues to actively be supported, but as with any format, longevity is not guaranteed.

3.2 Comparison to Other VFT Formats

278 ArcGIS Online allows multiple layers of vector data to be viewed on a single customizable map interface (though
279 currently custom raster layers are not supported) and provides the ability to analyze and filter the data (e.g. West and
280 Horswell, 2018); however,this format does not really support a presented or guided structure and so additional
281 resources are needed to support a VFT. ArcGIS StoryMaps, best characterized as a map-centric dynamic webpage, is
282 another adaptable format suitable for geographically oriented tours or narratives (for VFT examples see Evelpidou et
283 al., 2021a; Senger et al., 2021); StoryMaps offers a more structured and less immersive VFT option than Google Earth
284 Web projects. Other more specialized formats exist on pay-to-create software platforms. StoryMaps GPS (e.g.
285 California State University Fullerton's Yosemite Fire & Ice tour accessed at
286 https://www.travelstorys.com/tours/154/Yosemite%20National%20Park) offers a similar presented format as Google
287 Earth Web with an overview map and field stops that can be selected from a table of contents, but lacks the key ability
288 of associating a discrete view with each stop.

289 Arizona State University hosts many publicly accessible VFTs built in the SmartSparrow software platform (Mead et
290 al., 2019; https://vft.asu.edu/https://www.vft.asu.edu). These trips are largely photosphere-centric with built-in links
291 to video and image pop-ups, and links to additional photosphere stops; the result is an immersive experience with high
292 production value (there are even ambient bird sounds) in a completely self-contained format. Several educators have
293 been experimenting with using videogame platforms (e.g. Minecraft, itch.io) to allow exploration-based field
294 simulations in both scanned real world sites and fictional environments (Needle et al., 2021; Rader et al., 2021); these
295 formats typically require more commitment on the part of the educators to design and implement but can be engaging,
296 allow interaction between students, and mimic the freedom of mapping a region for the first time. Virtual Reality (VR)
297 experiences offer the most immersive VFT possibilities by allowing the viewer to have the virtual environment
298 surround them (e.g. Peterson et al., 2020; Hagge, 2021; Métois et al., 2021); unfortunately, the specialist VR goggles,
299 software, and computer are likely unavailable to most students at home and students will almost certainly need to take
300 turns in a classroom setting. Arguably one of the more flexible formats for presenting VFTs remains a custom html
301 webpage; this format allows embedding of maps (e.g. ArcGIS Online, Google My Maps) and 3D outcrop or rock
302 sample models (e.g. Sketchfab), as well as external web links or links to download supporting materials (e.g. Bond
303 and Cawood, 2021).

3.3 Building Effective Learning Through VFTs

305 Undoubtedly a major advantage of VFTs is their immediate accessibility to locations around the globe and beyond.
306 Additionally, VFTs through Google Earth provides opportunities for students to participate in cognitively engaging
307 and interactive learning experiences, which have been found to improve student outcomes in STEM courses (Freeman
308 et al., 2014; National Research Council, 2011). In a recent meta-analysis synthesizing the findings from 225 studies,

309 FFreeman and colleagues (2014) found that interactive and active learning experiences, such as those provided by
310 VFTs, are better for students' STEM learning than pedagogical experiences that rely heavily on didactic instruction
311 (e.g. lecture-based instruction).

312 ~~synthesized the findings of 225 studies that reported data on examination scores or failure rates when comparing~~
313 ~~didactic instruction versus active learning on student performance in undergraduate STEM courses. Their results~~
314 ~~revealed that learning outcomes were significantly better for students whose experiences included active and~~
315 ~~interactive pedagogical practices.~~

316 VFTs using Google Earth allow for students to engage in guided discovery learning (Mayer, 2004). Virtual learning
317 environments based solely on discovery learning allow students to independently explore and solve problems with
318 little to no guidance (Lee and Anderson, 2013; Mayer, 2004). However, one drawback to this type of learning
319 environment is that it can be a source of extraneous cognitive load~~lead to excessive cognitive demands~~, especially
320 when it comes to users with limited ~~domain-specific expertise~~knowledge about geology and conducting fieldwork.
321 Cognitive load refers to the load that performing a particular task imposes on the cognitive system (e.g. Paas and Van
322 Merrienboer, 1994; Sweller, 2011). The amount of information one's cognitive system can process at a given moment
323 is limited. Thus, the presentation of too much information, some of which is unnecessary information when it comes
324 to solving the task, can result in artificially increasing the cognitive resources needed to process the relevant content.
325 This is referred to as extraneous cognitive load by Sweller (2010), and it results in decreasing the efficiency and
326 efficacy of the learner's cognitive system (see review of cognitive load theory by Paas et al., 2010). With the aim of
327 reducing the learner's cognitive load, T~~t~~he embedded instructional prompts that the Google Earth VFT format affords
328 enables the instructor to promote guided discovery of the environment by allowing ~~as it allows~~ for the integration of
329 direct instruction into discovery learning (e.g.~~,~~ Lee and Anderson, 2013; Mayer, 2004). This direct instruction
330 provides,~~ providing~~ students with the scaffolding (i.e. additional learning supports that can eventually be decreased
331 with increasing ability) necessary to navigate and learn from such a perceptually and informationally rich environment
332 (e.g. Lee and Dalgarno, 2011).

333 Google Earth-based VFTs are also an effective means to scaffold students' spatial skills. Spatial skills are a set of
334 cognitive skills that enable us to manipulate, organize, reason about, and make sense of spatial relationships in real
335 and imagined spaces (e.g. Atit et al., 2020; Newcombe and Shipley, 2015; Uttal et al., 2013). Field geology heavily
336 relies on the use of spatial skills as the goal is to use present day spatial properties to infer the geologic history of a
337 region (e.g.~~,~~ Atit et al., 2020; Shipley and Tikoff, 2016). In particular, identifying the relevant spatial properties in the
338 field requires the geologist to focus their attention on the critical spatial information (e.g.~~,~~ the orientation ~~of the rocks~~
339 ~~on~~of a bedding plane). Focusing attention on the important spatial information involves actively ignoring many other
340 aspects of the scene (e.g.~~,~~ ~~the orientation of the tree on the outcrop or~~ the size of the minerals, the fault slightly
341 offsetting the layers, the talus pile at the base of the outcrop - geologic features not pertinent to the problem at hand).
342 The spatial skills used to identify relevant information for further cognitive processing is called disembedding in the
343 geosciences (Manduca and Kastens, 2012; Reynolds, 2012) and selective attention in psychology (Moran and
344 Desimone, 1985). Novices find disembedding to be difficult (Coyan et al., 2010; Shipley and Tikoff, 2016). Google

345 Earth allows the user to remove the extraneous irrelevant information (e.g. vegetation) from the scene, bolstering
346 geologically-relevant disembedding tasks for novice users.

3.4 From General Public VFT to Geologically-Reasoned Decisions

348 Through our Geology of Yosemite Valley moduleactivity, we provide an example of how a VFT can be designed to
349 be approachable to a broad general public audience and at the same time serve as background information for an
350 upper divisionadvanced undergraduate student mapping project. Hyperlinking technical words to external resources
351 is an invaluable way of unobtrusively broadening the target audience. Distilling VFT stops to the most critical learning
352 goals (especially with annotated images and videos) and encouraging interaction with the immersive view at the stop
353 likely increases learning and engagement. Designing exercises that require students to utilize a combination of data
354 they create (e.g. mapping) and real world data (e.g. hazard data, stream gauge data) to justify decisions trains them to
355 develop professional skills and increases their investment in the task. The progression from VFT to mapping to
356 professional-style consultant report produced the highest quality work of any of the eight modules activities and
357 exercises covered in UCR's 2020 and 2021 virtual Summer Field Geology course offerings. SAnonymous student
358 feedback (n=10) collected through an anonymous web-survey from in the 2021 offering indicates that the Geology of
359 Yosemite Valley module activity garnered the most positive response. 50% of the class said the module activity was
360 their favorite component of the course and 60% said they learned the most from it; no students thought it was their
361 least favorite or that they learned the least from it (unfortunately no anonymous feedback was collected from students
362 in 2020).

4. CONCLUSIONS

364 The Projects feature of Google Earth Web is a robust and adaptable format to create rich and engaging virtual field
365 trips with relative ease. The abundant fair-use imagery built into the Google Earth Engine (satellite, 360° street-level,
366 user-submitted 360° photospheres) allows for immersive stops that enable creators to point to specific features, but
367 also encourages viewers to learn by exploration, mimicking an advantage of in-person field trips. Many media types
368 can be directly embedded (images, videos, narration) or hyperlinked (websites, 3D models, quizzes, etc.) to customize
369 the VFT presentation and adapt to a broad range of knowledge levels ranging from general public to upper division
370 major advanced undergraduate students. Where cellular coverage exists, this VFT format can also be used for self-
371 guided field trips. When properly implemented, a general public-oriented VFT can be used as background for mapping
372 exercises, which in turn can be used to encourage students to support geologically-reasoned decision-making.

CODE/DATA AVAILABILITY

374 All data relevant to the study are available via hyperlinks within the body of the text.

AUTHOR CONTRIBUTION

376 NCB conceived and created the teaching exercises; NCB led writing of the manuscript and created the figures. GMS
377 contributed content and expertise to the teaching exercise, and provided edits to the manuscript. KA contributed
378 pedagogical discussion (section 3.3) to the manuscript.

379 ## COMPETING INTERESTS

380 The authors declare they have no conflict of interest.

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388

Figure 1. From the field to the virtual. (**A**) Image of students learning about flooding in Yosemite Valley as part of an in-person field trip in 2017. Just to the left of the view is a ~1.5m tall sign marking the peak flood water level on January 2nd 1997 (seen in B), a striking location to discuss flood hazards as students look over the meadows, trails, and roads that would have been inundated. (**B**) A corresponding stop in the Geology of Yosemite Valley virtual field trip (https://bit.ly/2Zbn3R7) that utilizes a precisely chosen © Google Street View ~~look direction~~view orientation and zoom level to provide the same discussion of 1997 flooding. Students can pan the view to get a similar sense of flood inundation around them. Supporting t~~T~~ext and hyperlinks are in the sidebar at right. A historic photo of the flooding event, map of the flooding extent, and a NPS-produced video on Yosemite rain-on-snow flooding fill the full-screen

398 when clicked on. Virtual field trip is an Earth project created with © Google Earth Web viewed in © Google Chrome
399 web browser.

400

401   **Figure 2.** Creating a VFT Earth project in © Google Earth Web. (**A**) A view highlighting the interface for editing a
402   project (i.e. VFT). All changes are instantly saved to the cloud (the creator's Google Drive). (**B**) A view highlighting
403   the interface for editing a feature (i.e. virtual field trip stop). Many customizable options exist.

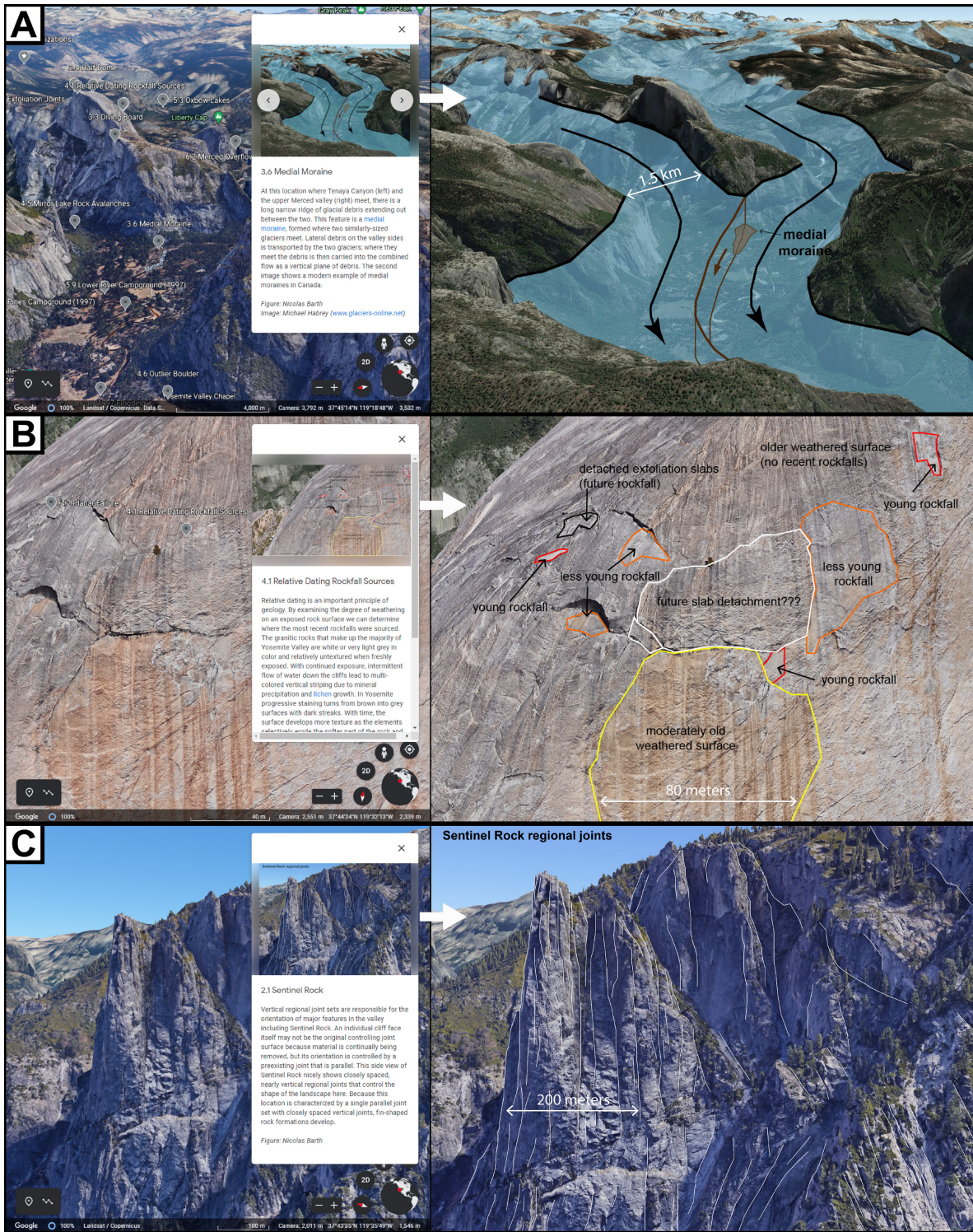
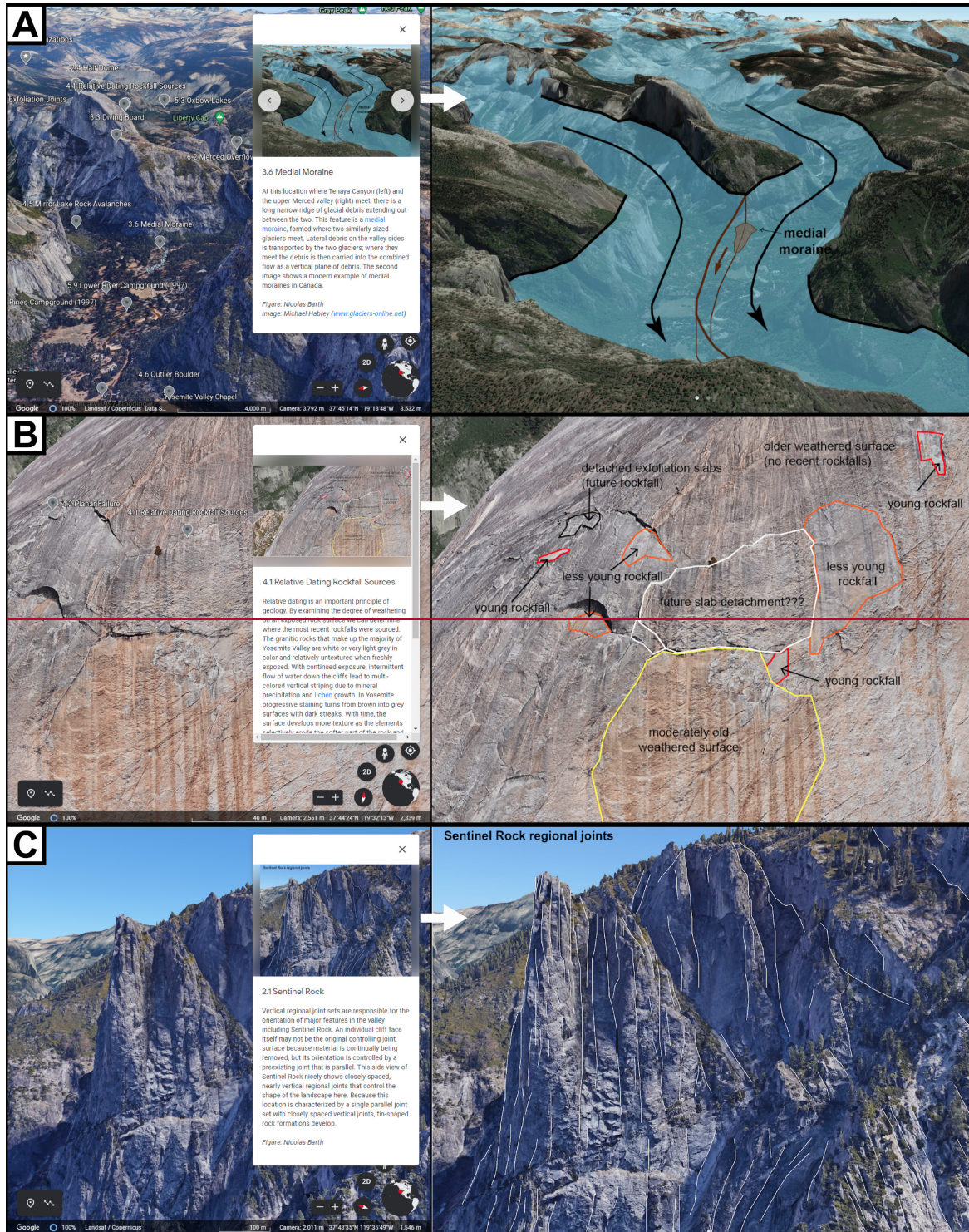
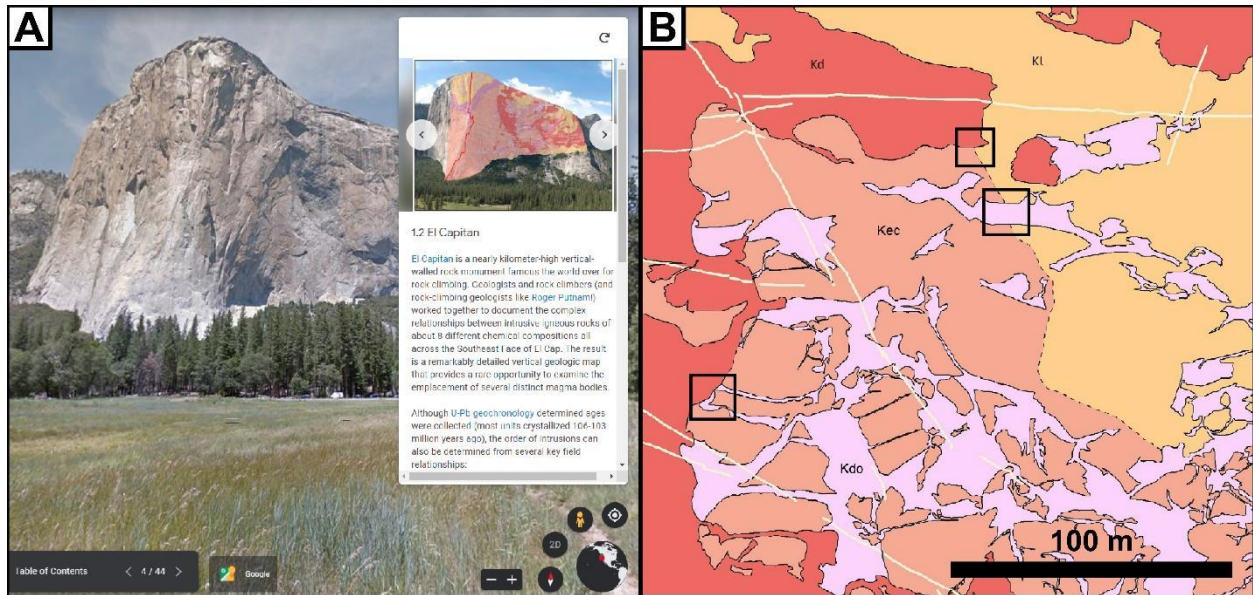
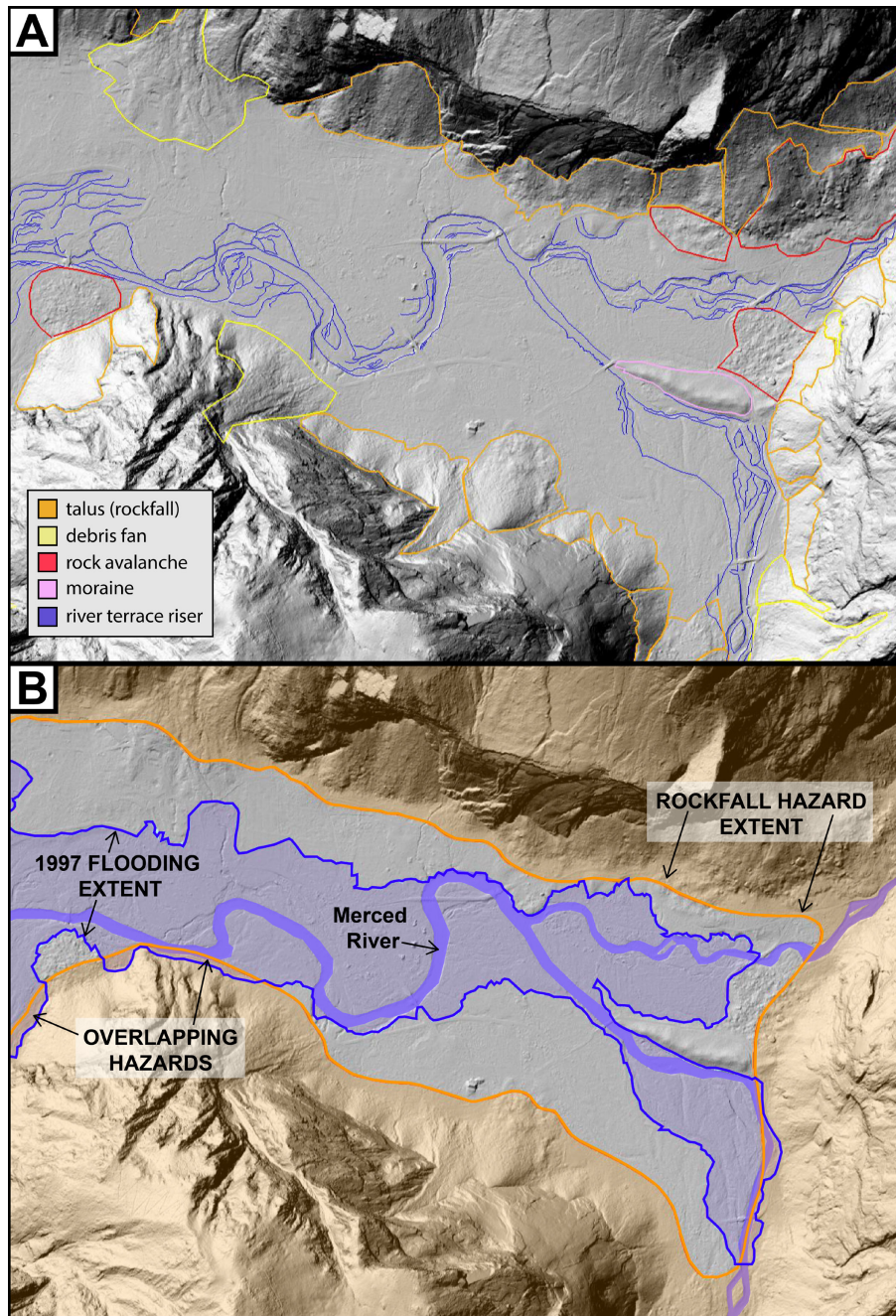



Figure 3. VFT stops highlighting learning through guided exploration. Left panels show the VFT stop view in © Google Earth Web; right panels show the corresponding annotated image embedded in the stop's description. VFT stops showcase (**A**) the medial moraine at the junction of Tenaya Creek and Merced River, (**B**) exfoliation-related rockfall sources of different ages on the slopes of Half Dome, and (**C**) regional joints exposed in the cliff faces of Sentinel Rock. By simulating the dynamic view in a figure, the viewer can better visualize the key features emphasized. In each instance the dynamic view encourages the viewer to zoom in closer to a feature or search the surrounding area for similar features.

414 **Figure 4.** Introducing a complex relative dating exercise. (**A**) Stop on the Geology of Yosemite Valley VFT (© Google
415 Earth Web) highlighting the vertical geologic map of El Capitan created by Putnam et al. (2014) and providing an
416 overview of the knowledge (cross-cutting relationships, law of included fragments, gradational contacts) necessary to
417 relatively date intrusive units. (**B**) An excerpt from the modified Putnam et al. (2014) El Capitan geologic map that
418 students use to determine the relative timing of eight intrusive units. Black boxes highlight three areas that provide
419 unambiguous relationships between two or more units.

420
421 **Figure 5.** From geomorphic mapping to hazard planning. (**A**) An excerpt from a virtual summer field student
422 geomorphic map ~~graded~~ scored "highly competent" (still room for improvement) submitted as a © Google Earth KMZ
423 file (final product of Part III of the ~~module~~activity). Basemap shown in both panels is a hillshade of bare-earth airborne
424 lidar data collected by NCALM (2006), web-served by OpenTopography (https://doi.org/10.5069/G9GQ6VP3~~, and~~
425 ~~funded by NSF (publicly accessible~~). Students use a combination of the lidar visualizations and satellite imagery
426 provided to map deposits based on texture, slope, and valley position. (**B**) A visualization of two hazard ~~lines~~ extents
427 utilized by Yosemite National Park and provided to students. Blue line indicates the maximum extent of January 1997
428 flooding (approximating a 100-year flood). Orange line indicates the expected extent of rockfall hazard within the
429 valley (i.e. beneath the valley walls) from Stock et al. (2014). In Part IV of the ~~module~~activity, students use their
430 geomorphic mapping and these hazard ~~lines~~ extents to examine the hazards posed to existing infrastructure and
431 identify areas of lower hazard suitable for further development. Geologically-based justifications are expected for all

432   of their recommendations. Location, scale, and orientation are deliberately excluded from this figure. Width of valley
433   floor here is ~1 km.

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