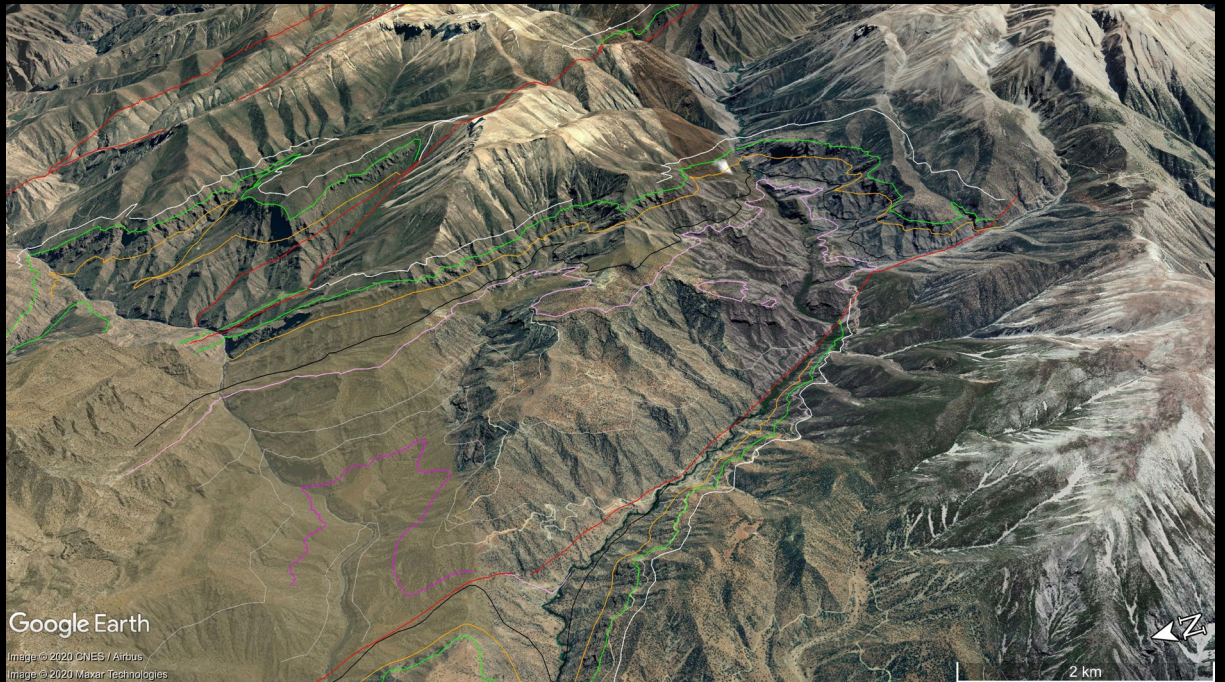


Geological *Field Trips* *and Maps*



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Virtual geological mapping in the Lurestan region of the Zagros (NW Iran) with Google Earth

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Cover page Figure

View in Google Earth of a detail of the area of interest with geological limits traced.

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Abstract

In this work, we present a Google Earth (GE) based virtual field mapping exercise, designed for master's and bachelor's students of geology and aimed at supporting or replacing field mapping training courses. The exercise consists of mapping geological limits and faults in a poorly vegetated area of the Lurestan region (Zagros thrust and fold belt). The occurrence of cliff-forming and recessive formations allows students to recognise directly on GE the first order geological structures of the area, which include faults and folds with wavelengths of many kilometers. The provided input data includes a stratigraphic description of the exposed formations, field photographs, and a set of field checkpoints. The material can be provided entirely or partly, depending on the students' level and workload required. The full dataset is intended for undergraduate students with little or no field experience, while master students are expected to complete the exercise with limited input data. Additionally, the exercise can be limited/focused on sub-areas or extended on the entire area.

This virtual mapping exercise is expected to empower students' ability to visualize, understand and reconstruct 3D geological surfaces; providing an essential tool for future scholars and practitioners.

Keywords: virtual field mapping, Google Earth, Zagros.

Introduction

Google Earth (GE; <https://www.google.com/earth/>) is by far the most commonly used digital tool for research and teaching in geosciences (Butler, 2006; Patterson, 2007; Chen et al., 2009; De Paor and Whitmeyer, 2011; Blenkinsop, 2012; De Paor et al., 2012; Triantafyllou et al., 2017; Liang et al., 2018), from geodynamic processes down to the scale of fracturing, including geological mapping (e.g. Martinez-Graña et al., 2015; von Hagke et al., 2019). Released in 2005, GE has been immediately recognised as a powerful tool for geoscientists, allowing them to interpret landforms and structures in 3D across different scales (Lisle, 2006). Among the others, the tremendous success of GE is due to the coupled availability of high-resolution composite satellite or aerial images draped onto a medium resolution terrain model, which is easily rendered in consumer-grade devices, such as computers, tablets, and smartphones. The free release of the Pro version of GE in 2015 and the availability of basic drawing features, such as placemarks and polylines, together with the possibility of overlaying images (such as geological maps) and placing photos, hyperlinks, and 3D models, made GE a versatile tool that has become the standard digital environment for virtual field trips.

In particular, field experience in geological mapping is nowadays reinforced in the digital environment via GE-based field trips or mapping exercises (e.g. McCaffrey

et al., 2010). Their use, however, has been quite limited in the past years, mostly to help students with limited mobility and/or to overcome budget limitations or travel restrictions. Nonetheless, the availability of digital field trips and/or digital geological mapping training exercises has become a critical issue for most universities during the 2020 Covid-19 lockdown period. Therefore, the need for providing fieldwork activities calibrated to different levels, to replace days/weeks of field mapping, has boosted the demand for virtual field mapping exercises.

Here we provide a virtual field mapping exercise from the Lurestan region of the Zagros fold and thrust belt. The area corresponds to a roughly 50x50 km box, in which excellent exposure of outcrops is favoured by a successful combination of poor vegetation and lithologies with strong erodibility contrast. The outcrop conditions, the relatively simple geometry of the structures, and the field check performed by our research team, allowed us to set up an effective virtual field mapping exercise. In the following sections, we briefly describe the geology of the study area, then we describe the available material, and finally, we present the expected mapping methods and expected results.

Geological setting

The study area is located in the Lurestan arc of the Zagros mountain belt, a Late Cretaceous to Cenozoic NW-SE striking belt of the Alpine-Himalayan orogenic system. The Zagros belt extends for almost 2000 km, from Turkey to SE Iran. It started to develop in Late Cretaceous with the closure of the Neo-Tethys ocean and evolved, during the late Eocene-Oligocene, in the continental collision between the Arabian and Eurasian plates (e.g. Berberian and King, 1981; Alavi, 1994; Agard et al., 2005; Vergés et al., 2011; Koshnaw et al., 2018). The Zagros belt is bounded to the NE by the Main Recent Fault and the Main Zagros Thrust, together forming the suture zone of the belt (e.g. Berberian and King, 1981). To the SW, the High Zagros Fault and the Mountain front flexure are the two major structures of the Zagros belt. In particular, the Mountain Front Flexure (MFF) consists of a topographic and structural step that divides the belt from its foreland basin (Falcon, 1961). The trend of the Mountain Front Flexure is characterised by a sinusoidal shape defined by salients and recesses (Fig. 1) and this virtual field mapping interests an area located in the Lurestan arc, one of the two major salients of the Zagros. The area of interest is roughly 50x50 km in size, and it is characterised by the occurrence of NW-SE trending folds having wavelengths of a few kms (Fig. 1). Faults

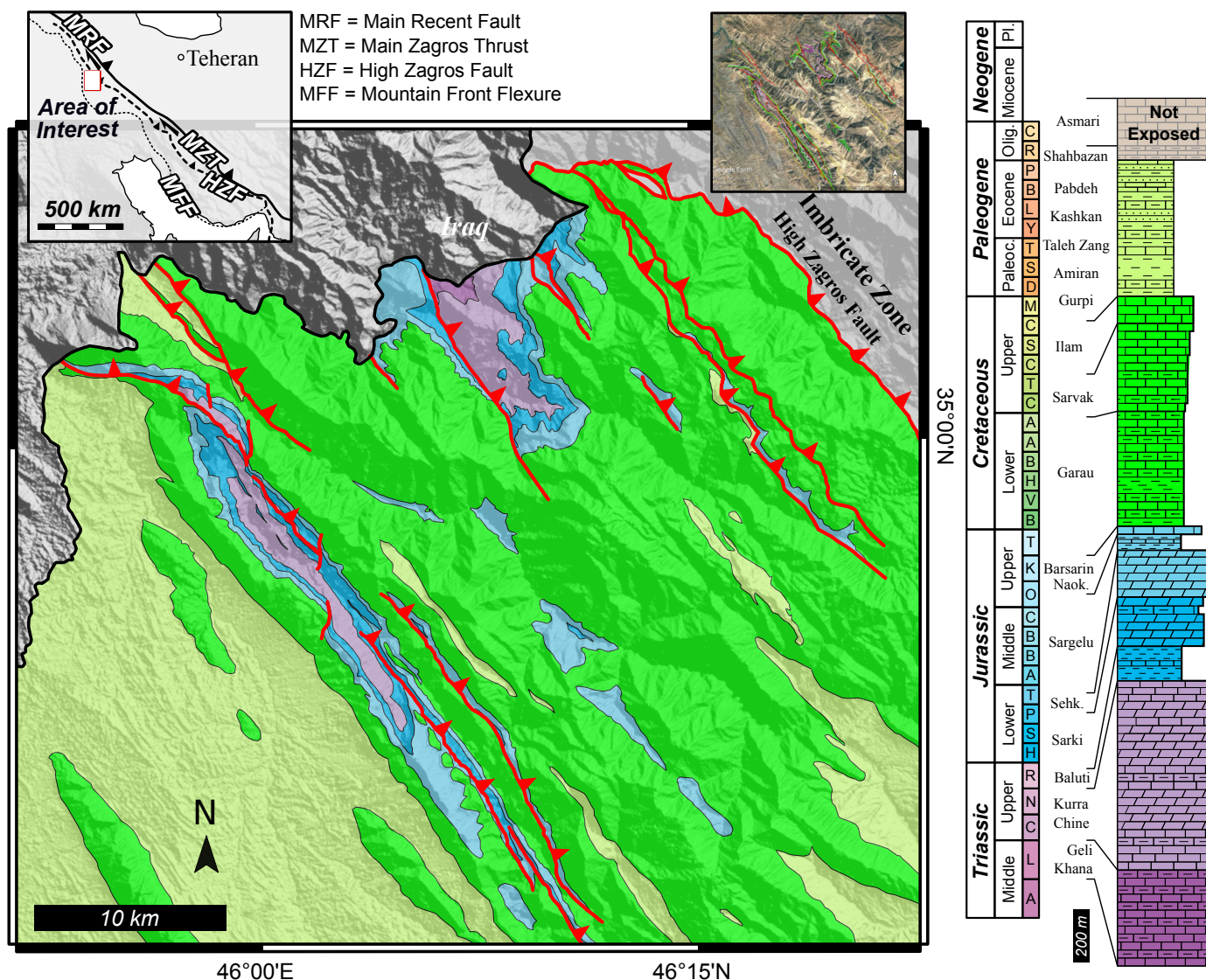


Fig. 1 - Geological map and stratigraphic succession of the NW portion of the Lurestan area (after Tavani et al., 2018). The two insets show the simplified structural scheme of the Zagros and the Google Earth extracted map with digitised geological limits.

are NW-SE striking too. The main fault of the area is the High Zagros Fault, one of the major structures of the Zagros (e.g. Verges et al., 2011), which has in its hanging wall the “Imbricate Zone”. Both the fault and its hanging wall are not part of this exercise. To the SW of this fault, the exposed multilayer includes formations spanning in age from Triassic to Cretaceous (Fig. 1). From the oldest to the youngest, the formations that crop out are:

- The 400 to 500 m thick Anisian-Ladinian Geli Khana Fm., consisting of thin-bedded shallow-water limestones, calcareous shales and dolostones.
- The 600 to 700 m thick Carnian-Norian Kurra Chine Fm., made of thick-bedded shallow-water dolostones and limestones, with intervals made

of thin-bedded marls, argillaceous limestones and dolostones.

- The 30 to 100 m thick Norian-Rhaetian? Baluti Shale Fm., which consists of dark grey to black shales, with some tens of centimeter-thick intercalations of dolomitic limestones.
- The 100 to 200 m thick upper Norian?-Rhaetian to Pliensbachian Sarki Fm., made of limestones and dolostones.
- The 100 to 200 m thick upper Pliensbachian-Toarcian Sehkaniyan Fm., consisting of coarsely bedded dolostones.
- The 20 to 100 m thick Toarcian?-Callovian Sargelu Fm., consisting of shales, marls and marly limestones. The overlying Callovian-Kimmeridgian Naokelekan Fm. is 10 m thick and includes thin-bedded pelagic limestones

- sandwiched between two beds of oil shales. On top of this, the 20 m thick Kimmeridgian-Tithonian Barsarin Fm., made of stromatolitic dolostones and dolomitic breccias. Due to their limited thickness, The Sargelu, Naokelekan, and Barsarin formations are not expected to be differentiated by students.
- The Lower Cretaceous Garau Fm., made up of deep-water well-bedded marls, shales and limestones. The overlying Sarvak and Ilam Fms. in the northern portion of the Lurestan are mostly made of well-bedded pelagic limestones. In the study area, the stratigraphic boundaries between the Garau, Sarvak and Ilam Fms. entail only subtle and gradual lithological changes and are not expected to be mapped. The cumulative thickness of these three formations is highly variable, spanning from less than 400 m up to more than 1 km.
 - The youngest exposed rocks of the area belong to the Upper Cretaceous to lower Paleocene Gurpi Fm., which is made of a thick sequence of gray marls with thin intercalations of marly limestones.
 - Description and photos of these rocks are provided in the supplementary material, with emphasis on the lithological contrast and cliff-forming boundaries that can be followed on GE images.
- The folder “Stratigraphy” includes two interpreted panoramic photographs, aimed at showing the key features of the exposed multilayer.
 - The folder “Checkpoints” contains placemarks with the exposed formation at the indicated placemark site, as checked in the field. The names of all the formations are illustrated in the stratigraphic column of Figure 1. The Barsarin and Naokelekan, which due to their limited thickness are lumped together, are named “Bars-N”.
 - The folder “Photos” includes uninterpreted panoramic photographs of key structures, such as monoclines, folds, thrusts, normal faults (Fig. 2).
 - The last folder, “Limits”, is not meant to be provided to students, and includes our result of the mapping (Fig. 3). Notice that due to the above-mentioned motivations, the Garau, Sarvak and Ilam formations and the Sargelu, Naokelekan, and Barsarin formations have been grouped respectively together. Only the top Ilam and Top Barsarin are expected to be recognised. Notice that limits are affected by some small-scale irregularities. These relate with the problem of draping different orthophotos used to digitize the limits (i.e. historical Google Earth maps and Bing maps) on high-slope topography. Accordingly, a tolerance of some meters (up to 20 m for near-vertical cliffs) should be taken into consideration during the mapping exercise. A similar tolerance of some meters should be taken into account for checkpoints, which have been geolocalised in the field using smartphone and tablet GPS.

Data & methods

This virtual mapping exercise is based on data collected during several fieldworks, conducted in the 2015-2017 period, which led to the construction of the geological map in figure 1. The input data for carrying out the virtual mapping is provided in the supplementary material and consists of (i) a PowerPoint file and (ii) a KMZ file. The “Photo&stratigraphy.pdf” file includes field photographs illustrating the key features of the exposed formations. The core of the exercise is the “Lurestan2020.kmz” file, which is made of five folders, four of them being input data and one with the expected result. In practice:

The folder “Areas of interest” includes three polygons defining three areas of increasing difficulty. In the area “Exercise 1” information is dense and the structures are quite simple. This area is an entry-level exercise for bachelor’s students. The area “Exercise 2” has less information and more complex structures. The whole area, i.e. “Exercise 3” includes the entire region and it is designed for master’s students.

- The folder “Bedding” includes some sparse bedding data visualised as disks of uniform size (see Blenkinsop, 2012).

Students are expected to create a folder with subfolders for each geological limit. Geological limits should be then traced as polylines, combining landform, bedding data, and checkpoints. In this sense, students are encouraged in using the historical imagery tool to select, at each site, the best lighting conditions. Bing maps overly, available at <https://ge-map-overlays.appspot.com/map-overlays-for-google-earth-combined.kmz>, represents also a useful option at many sites where the GE imagery has lower resolution. This last resource, however, should be used with caution as in the case of low network speed it can significantly slow down the rendering.

Specifically, to assist students in the geological mapping exercise, teachers should follow these steps: (i) Provide a brief introduction to the key geological elements of the area, namely the occurrence of NE-SW trending folds and NW-SE striking thrusts affecting an about 3 km-thick exposed carbonate multilayer made of alternating stiff and weak levels. (ii) Using the PPT file in the supplementary material and the interpreted panoramic photographs in the “stratigraphy” folder,



Fig. 2 - Selection of panoramic photos included in the exercise with line drawing.

illustrate the cliff-forming and recessive formations. In this sense, the top Kurra Chine Fm. and the top Sehkaniyan Fm. are easily recognisable limits and should be introduced first. After, the Barsarin and Naokelekan fms., which form a 20-30 m-thick package

of stiff material sandwiched between the weak Sargelu and Garau fms., should be introduced as an additional key horizon for mapping. (iii) Before proceeding with mapping, it is highly recommended to provide information about the mapping tools in Google Earth.

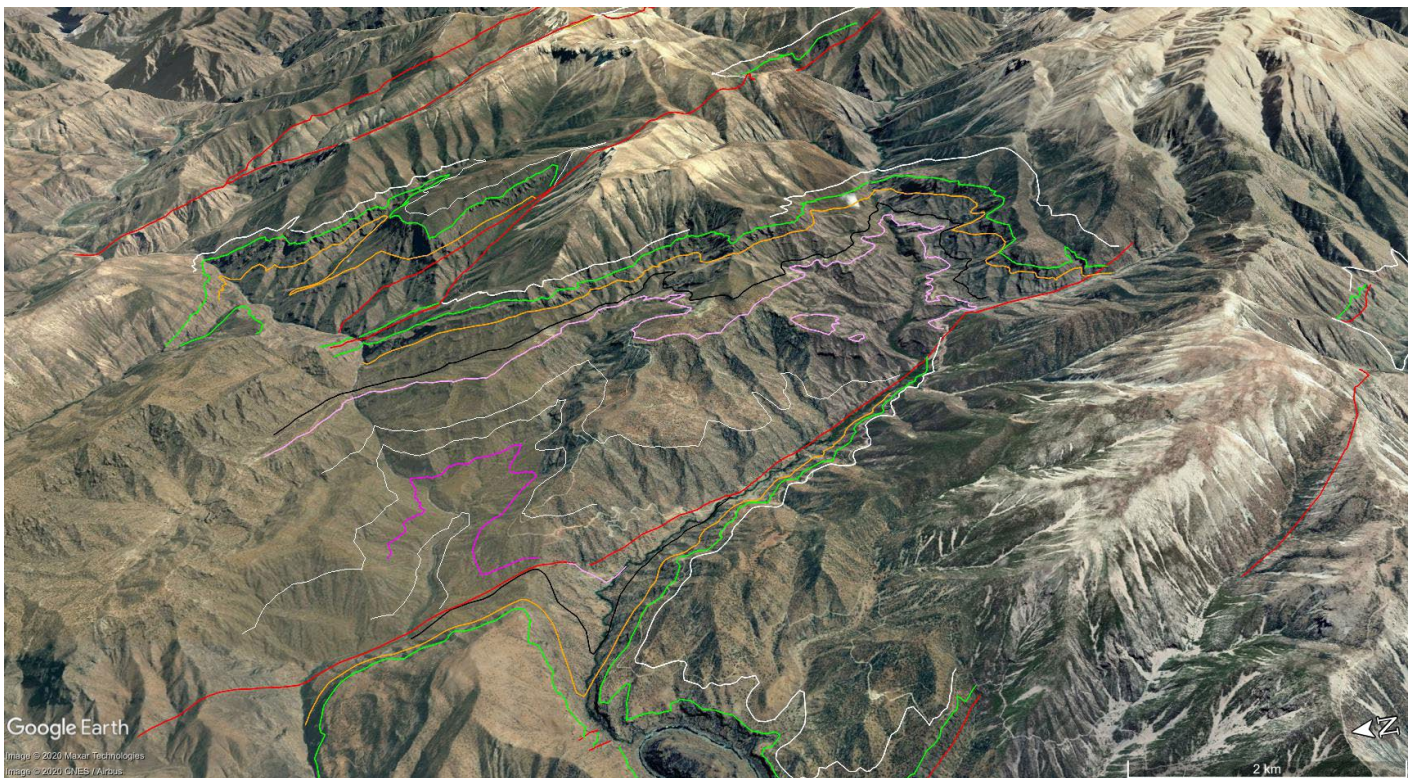


Fig. 3 - View in Google Earth of a detail of the area of interest with geological limits traced.

The “add path” tool is used to trace the geological limits and teachers should briefly explain how to create and edit paths. The organisation in folders of the digitised paths and the selection of the correct folder when adding a path are also critical issues. (iv) To trace the geological limits, we highly recommend to start with the northern area of the “exercise 1” polygon of the KMZ file. This is the simplest and best-constrained area. Some basic geometric rules of geological mapping, such as the “V” rule, can be illustrated to the students in this area.

Benefits of virtual geological mapping and expected learning outcomes

In the last years, virtual reality has become increasingly used in most fields of geosciences, firstly as a powerful research tool via virtual outcrops models (Xu et al., 2000; Pringle et al., 2001; McCaffrey et al., 2005; Corradetti et al., 2018), and more recently in training projects (e.g. Houghton et al., 2018). Virtual outcrop models and virtual field trips are nowadays employed in the training of geoscience students (e.g. Dolphin et al., 2019). Open-source repositories of virtual outcrops have been made available to the scientific community (e.g. <https://www.e-rock.co.uk/>; <https://v3geo.com/>) and software specifically designed to the visualisation and

analysis of virtual outcrops have been developed (e.g. Hodgetts et al., 2007; Tavani et al., 2011; Buckley et al., 2019). Despite the availability of the above mentioned geology-oriented software tools, GE is still to be regarded as one of the best available options in virtual field trips and entry-level mapping exercises due to: its versatility, ease of use, high rendering performance, and availability for free; all these features allow to mitigate the digital divide issue, i.e. the different hardware, software, and internet connection speed availability. The proposed exercise, indeed, requires a consumer-grade computer, and it is affordable with basic digital skills and has thus a great potential for use in training. In detail, by taking advantage of an outstanding geology and the proper combination of vegetation and erodibility contrast, students should be able to recognise and map the different geological structures of the area and, more generally, to improve their ability in understanding geological structures in a 3D environment. Plunging synclines and anticlines, reverse and normal faults, thrusts that laterally die out in folds occur in the area. Students are expected to recognise them and improve their ability to map them, by interpolating in the proper way the provided sparse and diverse information. In conclusion, this exercise is intended to integrate field mapping experience by improving the 3D understanding of structures. This exercise of virtual geological mapping has been already provided to students in the courses of

Structural Geology (2nd year bachelor, course 2019/20) and Balanced Cross Sections (1st year master, courses 2018/19 and 2019/20), at the Department of Earth Sciences of the Federico II University of Naples. Bachelor's students were able to complete the exercise 1 area in about 12 hours, including moderate to high teaching support. The general impression is that, regardless of the need for smart working solutions caused by the 2020 pandemic situation, this interactive exercise is extremely useful for understanding the 3D aspects of geology and to illustrate the basic relationships between limits and topography. Based on these experiences, teachers need to keep in mind that students (particularly bachelors) may be novices not only to geological concepts, but also to the software and, in general, to the 3D environment. Indeed, a common error was to think that the "smartphone and tablet" digital native generation had strong software skills, which was not the case for all the students. Master's students completed the whole area (exercise 3) in about 30/40 hours with much less support. The exercise for master's students in balanced cross-sections

included a further step. This consisted of importing the digitised limits in Move software and projecting them onto a 30 m-resolution digital elevation model, and finally to construct a balanced geological cross-section (which generally takes additional 10-15 hours). The description of this part, however, is out of the scope of this mapping exercise.

Supplementary material

Lurestan2020.kmz: Google Earth file containing the input data and the expected results of the virtual geological mapping exercise.

Photo&stratigraphy.pdf: Field photos and a short description of the exposed formations.

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