Teaching geology, from textbooks to the Earth: the potential of geological maps, a powerful but neglected educational tool

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Short Note

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ABSTRACT

Teaching geology is mostly limited to textbooks, so that classroom lectures are the primary educational method for students' training. Transition from listening to doing, more efficient in education, can be achieved with the use of rocks, minerals, and fossils (occasionally present in schools): it is an integration of classroom lectures, although simply representing punctual expressions of the geological complexity of the real world. A potential way to transfer geological concepts from books to everyday life is represented by the use of geological maps as educational tools: these technical and scientific documents (that in Italy cover the entire nation with different scale and detail) can be easily accessed from institutional websites. Digital images of these maps may be visualized in 3D digital environments using simple tools. By analyzing geological maps, it is possible to get familiar with concepts described in textbooks: rock types, faults, geological boundaries, geomorphological elements. Geological maps also represent an aid for outdoor geological activities, which can be followed by reports produced by students, migrating geology from books to real world: to achieve the best results, a training for teachers not acquainted with digital tools and geological maps should be considered and planned, either in presence or with digital supports.

KEYWORDS: geological maps, high school, education.

INTRODUCTION: GEOLOGICAL MAPS AS HISTORICAL, TECHNICAL, AND SCIENTIFIC DOCUMENTS

Since the publication, in 1815 (the same year of the Battle of Waterloo), of the first modern geological map by William Smith (Smith, 1815), geological maps have become the most important and powerful way to store and share geological information. Just like all the other types of thematic maps, geological maps provide the distribution of a specific theme on the topographic surface: geology. Distribution of rocks or deposits (i.e., geological units, different for age and composition) is represented as coloured areas, bordered by lines describing the nature of the contact between geological bodies (such as faults or lithological contacts). Other elements are also represented as points (e.g., caves, springs, bedding attitude) or lines (morphological elements such as ridges, terraces). Geological maps differentiate from other thematic maps as they strictly represent real features of the landscape, in terms of content and morphology, thus describing the physical 3D nature of the land, providing also information about the distribution of geological elements in the subsurface. Geological maps are actually produced with data directly collected in the field, with a process that has no counterparts in other thematic maps: most of them actually derive from the compilation of different types of data obtained with indirect investigations (such as density of population, age or any other type of "social" data) or with mixed information, such as in the case of land use. The production of geological maps is exclusive competence of geologists, as geological survey and the corresponding symbolic representation require a strong geological background (in terms of knowledge of processes, features and their interpretation) that no other professionals have. Geological maps are produced using a procedure that geologists from all over the world know and apply. They explore, walking across the investigated area, and collect in the field information and samples that, after analyses performed in laboratories with methods described in high school textbooks (such as radiometric dating, paleontological determinations, chemical and crystallographic analyses, petrographic microscope studies and so on), provide data reported in geological maps (Fig. 1). Producing a geological

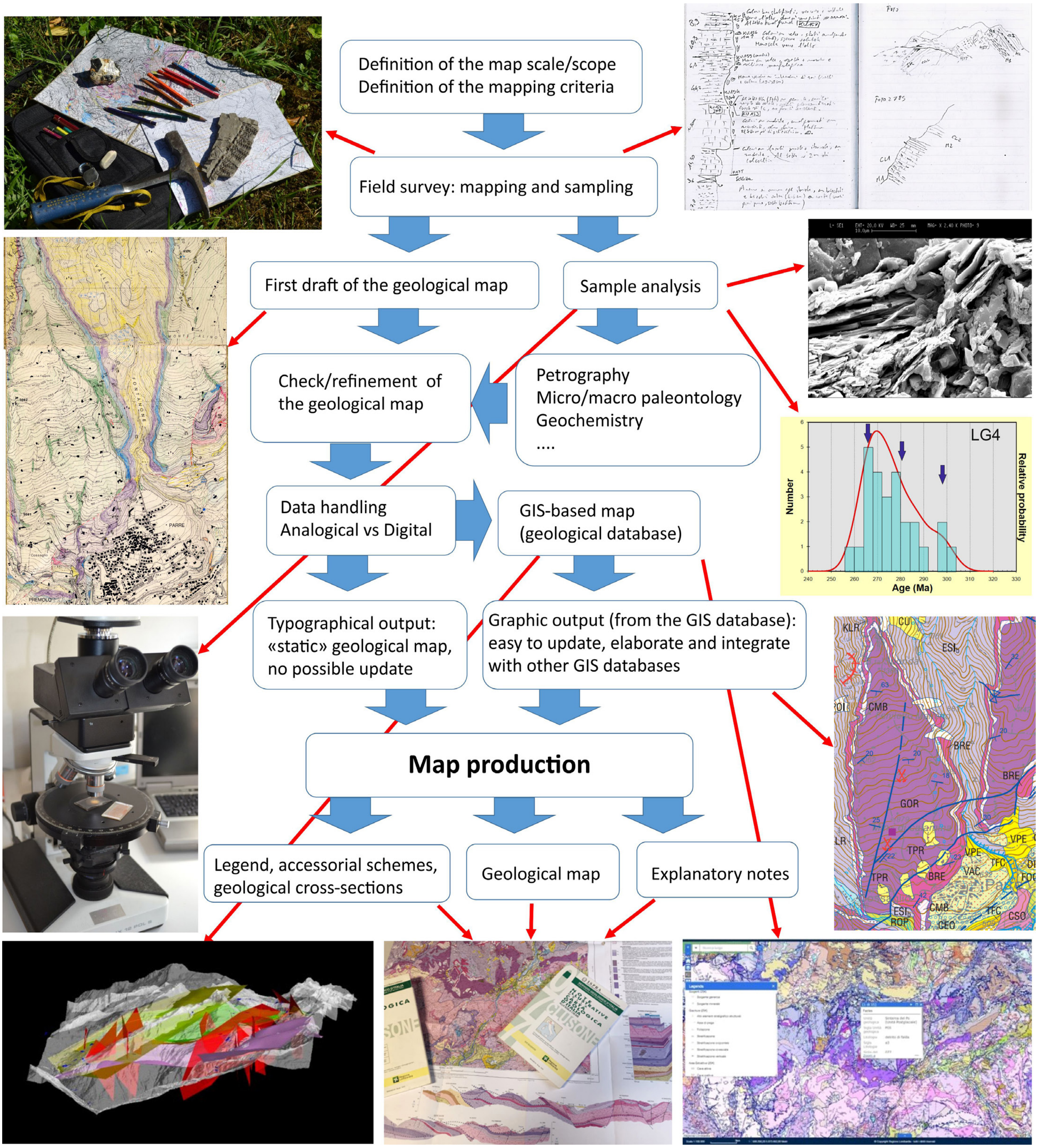

Fig. 1 - Conceptual steps in the production of a geological map: the entire process of mapping a 1:50,000 geological map (CARG Project) requires the work of a team of geologists for at least 4 years. All the data stored in the maps derive from a detailed field work (field survey) integrated with analytical results of the collected samples frequently integrated with digital data. The resulting map reports the intersection of geological objects with the topographic surface, providing constraints on the interpretation of the subsurface geology, essential for any land management activities (modified after Berra et al., 2024).

map is a very long process that requires, for each sheet, some years of work by a team of experienced geologists with different skills. The realization of geological maps is strongly influenced by the knowledge of geological processes: consequently, maps surveyed at different times reflect the geological knowledge at the moment of their realization. Therefore, besides storing physical data of specific territories, geological maps also reflect the geological knowledge at the time of their production. Geological maps thus have historical value as they document the advancements of geological sciences, but, on the other side, require a continuous update (Berra et al., 2024).

As geology is a relatively young science (for example, the plate tectonics theory dates back to only about 50 years ago, in the mid ‘70s of the last century), geological maps require updates for two main reasons: i) to include new geological knowledge and ii) because the analytical techniques, fundamental for the correct interpretation of rocks and geological processes, continuously improve allowing for a more detailed understanding of geological processes. Furthermore, tools available for field data collection and storage evolved too: modern geological maps are produced in digital format, a fact that favours their update with respect to previous typographical products. Digital tools also aid data collection in the field, as well as availability of high-resolution digital terrain models such as those produced with LIDAR (Laser Imaging Detection and Ranging) and data and elaboration of images collected with UAV (Unmanned Aerial Vehicles), increasing significantly in the last years the precision in georeferencing geological data.

Geological maps represent the most common way to store geological information related to a specific territory, in terms of composition, nature, age, resources and risks. To understand the context of geological maps, two main competences are required: one is related to the knowledge of the symbolic representation of geological objects and forms, the other to the familiarity with geological terminology and basic rules that govern our planet.

GEOLOGICAL MAPS AS 3D OBJECTS

Despite their importance in everyday life (geological maps are required by law, for example, for land management plans), their existence and use are mostly poorly known by most of the population although they represent the base for all the applications of geology (Berra et al., 2024).

Information stored in geological maps does not refer to a property with a simple geographical distribution (such as land use, density of population and so on) but instead provides data about the composition and nature of 3D geological objects that are cut by and interact with the topographic surface. This aspect is critical, as intersections among geological boundaries and topographic surface provide elements that, using simple geometrical rules, permit extrapolation of geological surfaces and objects in depth, returning the three-dimensional structure of a territory. This 3D nature of geological maps is documented by one of the accessory diagrams that are present in all modern geological maps: geological cross sections, always accompanying geological maps, provide data on the shallow interior of the Earth. The ability to decode information stored in a geological map requires basic geological competences as well as the ability to visualize in three dimensions the topography on which the geological data are placed. The 3D visualization of geological objects is today easily available thanks to software packages able to create models easily explorable with digital information tools. Several digital geological models are stored on web sites, including those from universities, institutions and research centres (see some examples at links at the end of the References).

GEOLOGICAL MAPS AND THEIR AVAILABILITY

Geological maps thus summarize the geological knowledge of a specific area at a certain time and are produced by geologists with a long process that, starting from data and sample collections in the field, ends up after detailed analyses in different laboratories and elaboration of the results. Modern geological maps are frequently associated with digital and georeferenced databases and provided with explanatory notes that integrate the data reported in the map. Geological maps provide physical information that is fundamental, for example, for correct land management. Due to the important applications of geological maps to everyday life, the realization of homogenous (in terms of methods, symbolic representations and common requirements) national geological maps in several countries is managed by national institutions. In Italy the first project of national geological mapping dates back to the first years after the unification of the nation: the ambitious project aimed to provide complete coverage of the Italian territory with maps at 1:100,000 scale. Starting in 1877 and ending in 1976, 277 1:100,000 geological maps were produced. Unfortunately, the time required was longer than expected (considering also two World Wars in the middle): about 100 years were necessary to complete the project, with the consequence that national territory, at the end of the process, was covered with maps of different age and quality, each produced with the available knowledge at the time, thus with extremely different reliability. To update the geological knowledge, a new project at 1:50,000 scale (the CARG Project, coordinated by ISPRA, “Istituto Superiore per la Protezione e la Ricerca Ambientale”, in collaboration with universities, research centres and administrations), started in 1989, with the goal to realize 636 sheets, entirely covering the Italian territory. The project is still ongoing: it stopped for 20 years due to the end of public financial support but it recently recovered, also due to the urgent need of updated geological maps that were absent for most of the zones affected by earthquakes in the last decade: in these areas, geological maps are fundamental to evaluate place by place the possible effects of amplification of seismic shocks (e.g., seismic microzonation). Approximately 50% of Italy is now covered by new, digitally produced 1:50.000 geological maps. ISPRA website provides easy and free access to published maps: institutional website of ISPRA stores all official 1:100.000 geological maps of Italy at http://sgi.isprambiente.it/geologia100k/; the CARG Project 1:50.000 maps that are currently available can be accessed at https://www.isprambiente.gov.it/Media/carg/index.html. CARG maps are also available on web sites of “Regioni” and “Province Autonome”. Maps are freely accessible online (but generally not downloadable); notes associated to the maps are available for download. The production of these maps is supported by public funding: printed maps with the explanatory notes (a book of 150-200 pages on average, rich in information that cannot be reported in the map) may be bought online form ISPRA (https://www.isprambiente.gov.it/it/servizi-del-sito/urp/faq-domande-piu-frequenti#Servizio_Geologico_Italia) at the production cost (less than 14 euros each). Every cm^2 of Italy is thus covered by at least one geological map, but frequently by two or more: beside the official 1:100,000 and 1:50,000 CARG geological maps of Italy, several local maps at different scales, created for research or land use purposes, exist but the access to these maps may is more complex and may require subscriptions. Similar situations exist in other countries.

GEOLOGICAL MAPS AS EDUCATIONAL TOOLS

Even if access to geological maps is frequently easy, free or cheap and public (especially for official geological maps), their existence and use is obscure to most of the population: generally, textbooks do not introduce students to the importance of geological maps as repository of geological data for a specific territory and to their fundamental role in land knowledge and management. Reading and understanding the content of geological maps requires basic geological knowledge, as is expected to be acquired by high-school students. To understand the symbolic representation of geological objects, as for any thematic map, a basic knowledge of the language of geology and of processes generating rocks and land morphology is required. To achieve geological awareness, use of geological maps as educational tools at school must postdate the acquisition of the terminology and knowledge of the most common geological processes, to understand the message provided by geological maps. Therefore, exercises on the ability to analyse geological maps may represent an important test on the abilities of pupils in understanding geological processes, stimulating the ability to interpret the history of a territory, with implications on the understanding of the role of geology for land knowledge, in terms of resources and risks. Despite this potential, geological maps are mostly neglected as tools for the education of high school students. The opportunity to "observe" the geological configuration of any place in Italy provides to teachers a fundamental chance to show the geological architecture of a specific area (in the school neighbourhood or during open-air excursions) and to explain the applications of concepts provided by textbooks. To illustrate the possible use of geological maps as educational tools, two examples are here presented.

1) *Geological maps to test the acquisition of knowledge*: on geological maps it is possible to organize a "quest" for geological situations. It is possible to involve the students, as in a board game, in a quest for different types of geological objects such as faults, folds, dykes, landslides, morphological elements (terraces, moraines and so on), possibly but not necessarily under the guidance of a teacher. Observation and discussion of the geological map describing the surroundings of the school (or of selected parts of Italy, as well as other countries) may help students to identify in the landscape geological objects represented in the map and elements described in textbooks, improving their familiarity with geological processes. Furthermore, outdoor activities can be easily organized, with the geological map representing a "treasure map" able to drive itineraries arranged in order to reach specific geological settings represented in the map. In addition, specific tasks can be assigned to single or groups of students, involving them directly in the application of the geological knowledge: short reports can be assigned, asking to integrate field observations (documented by pictures of outcrops and rocks) with their symbolic representation of the maps, with a learning-by-doing approach. Even without outdoor activities, the simple observation of the legend of a geological map is able to provide a real and tangible application of geological notions: reading legends of maps, students find names that mostly are known only from books. Showing the students how these terms are used in technical documents is essential to introduce the acquired notions in the physical world (Fig. 2).

2) *Geological maps as digital objects:* as geological maps are 3D representations of a territory, it is important to stimulate the ability to visualize in three dimensions relations between topography and geology (understanding the role of geology in shaping the Earth's surface). To stimulate the ability of 3D visualization, in the case of geological maps, digital tools may be extremely useful. Virtual land visualizations, such as those easily provided by Google Earth® (Lisle, 2006; Berra, 2018), represent an important support because they are able to provide more intuitive views of the geological characters of a territory than traditional paper maps (Bailey& Chen, 2011): the content is exactly the same, but the possibility to easily show together topography and its geology in 3D permits the understanding of aspects that can be appreciated only with specific training from printed geological maps. Draping geological maps on Google Earth® is a simple exercise that can be carried out without specific computer skills. A simple raster image of a selected territory (obtained, for example, by a screenshot of a geological map from the ISPRA web page by simply scanning a geological map) can be easily placed in its position (i.e., georeferenced) on Google Earth®. The process is relatively simple, and described on the Google Earth® support site (https://support.google.com/earth/answer/148099?hl=en): once Google Earth® has started, the image is added as overlay. The uploaded image needs to be adjusted (moving and stretching it) until it covers the corresponding area. After that, the image drapes the topography providing the possibility to visualize the landscape in 3D and virtually explore the area allowing for its visualization from different points of view. This simple exercise can be performed for any place on Earth where geological maps are available: from the closest places to the school, to iconic or exotic places in the different continents (Fig. 3). This simple exercise can be considered a virtual and digital "hands-on" activity, guiding the students from the analyses of the geological maps to their visualization in a virtual, 3D digital environment: with this activity it is possible to appreciate the "classical" approach of geology, related to field-data collection and laboratory analyses, with the use of digital tools, now representing a fundamental element for increasing the handlng of geological data. Satellite imagery alone is considered an important aid for teaching geology at high school (Monet & Greene, 2012), but its potential for the understanding of geological processes is strongly amplified by the use of geological maps, that permit to move from the morphology of a terrane (i.e., the surface) to its internal architecture (i.e., the subsurface). Understanding that geological maps are able to describe not only the surface but also the interior of our planet is a result that generally is

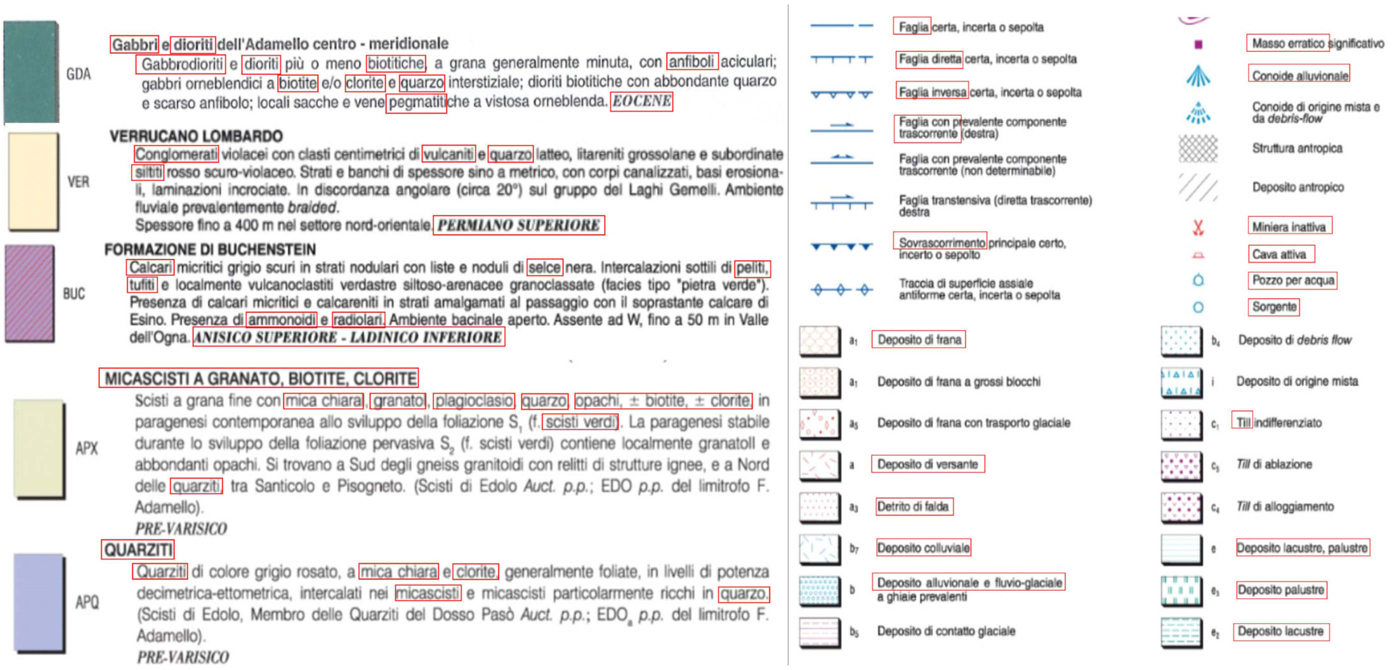

Fig. 2 - Legend of a geological map (CARG Project, in Italian): geological terms typically used in the high school textbooks commonly occur in the legend of geological maps, providing evidence of the use of these terms (and concepts) by professional geologists. CARG Project maps are in Italian language (also in German for the maps of the Provincia Autonoma di Bolzano/Bozen). The explanatory notes (in Italian) contain the English translation of the legend. The possibility to organize outdoor activities using geological maps provides the students with direct evidence of the tight link between what is learnt in classroom and what is its physical expression.

understated in the textbooks: the direct activity on real data with digital tools is able to present a poorly known science, as geology is, in a practical way.

OPERATIONAL CONSIDERATIONS

The use of geological maps as educational tool requires a positive and active approach by teachers on a topic that may appear challenging to those who do not have a specific geological training. Nevertheless, the use of geological maps is less complex than it can appear (the realization, instead, is very complicate): being geological maps physical objects, descriptive of the "real" world, it is possible to define a threshold of detail: this threshold can be limited to the lithological level (description and associations of rock types), to the individuation of elements related to geological processes (faults, folds, morphological features) or, more in detail, to the 3D geometry of geological objects (interpretation of the subsurface setting). These three levels of educational use of geological maps can be achieved with different activities and at different times on the same geological map.

The expertise for organizing this type of activity does not require specific training for teachers not familiar with geological maps: a non-specialist presentation of the main characteristics and applications of geological maps is provided, for example, by SGI (2015), with a set of panels where it is possible to find the basic requirements to be able to read a geological map, later presented in an open-access paper (Berra et al., 2024). The use of geological maps as educational tools allows students to shift from theory learnt on book to physical objects that they can observe and "touch" in the natural environment. To achieve this result, an integration of exercises on geological maps within the "classical" teaching of Earth Science in high school may require a specific training of high-school teachers. This can be achieved with different approaches: a) use of available (or to be prepared) on-line training prepared specifically for this scope; 2) group training led by geologists expert in the production and use of geological maps, with meetings focused on the use of these maps for educational purposes (for this point, several universities organize training for high-school teachers where a specific initiative on the use of geological maps for teaching geology can be added). Training for teachers not familiar with geological maps can be promoted also organizing teams of teachers, involving schoolteachers with specific geological education that can act as trainers for those with a basic level of geological knowledge. This can be organized with two approaches: among teachers from a single school or with the organization of specific working groups with teachers from different schools (for example, organized by teacher associations) possibly involving university geology professors as guides. The creation of mixed teams of teachers with different expertise is probably the best solution: in the last years, several networks have been created in Italy thanks to the PLS project (Progetto Lauree Scientifiche; Italian for "Scientific Degree Project") that involves high schools and universities on different science topics including geological subjects. The existence of these networks can promote definition and planning of selected activities, such as introduction of geological maps as an educational tool in high schools. The use of geological maps promotes a hands-on approach to geology: students became active players and not only passive subject of class lectures. Simple elaborations and realization of reports (with, better, or without outdoor activities) shift all the concepts normally provided by class lectures to a practical

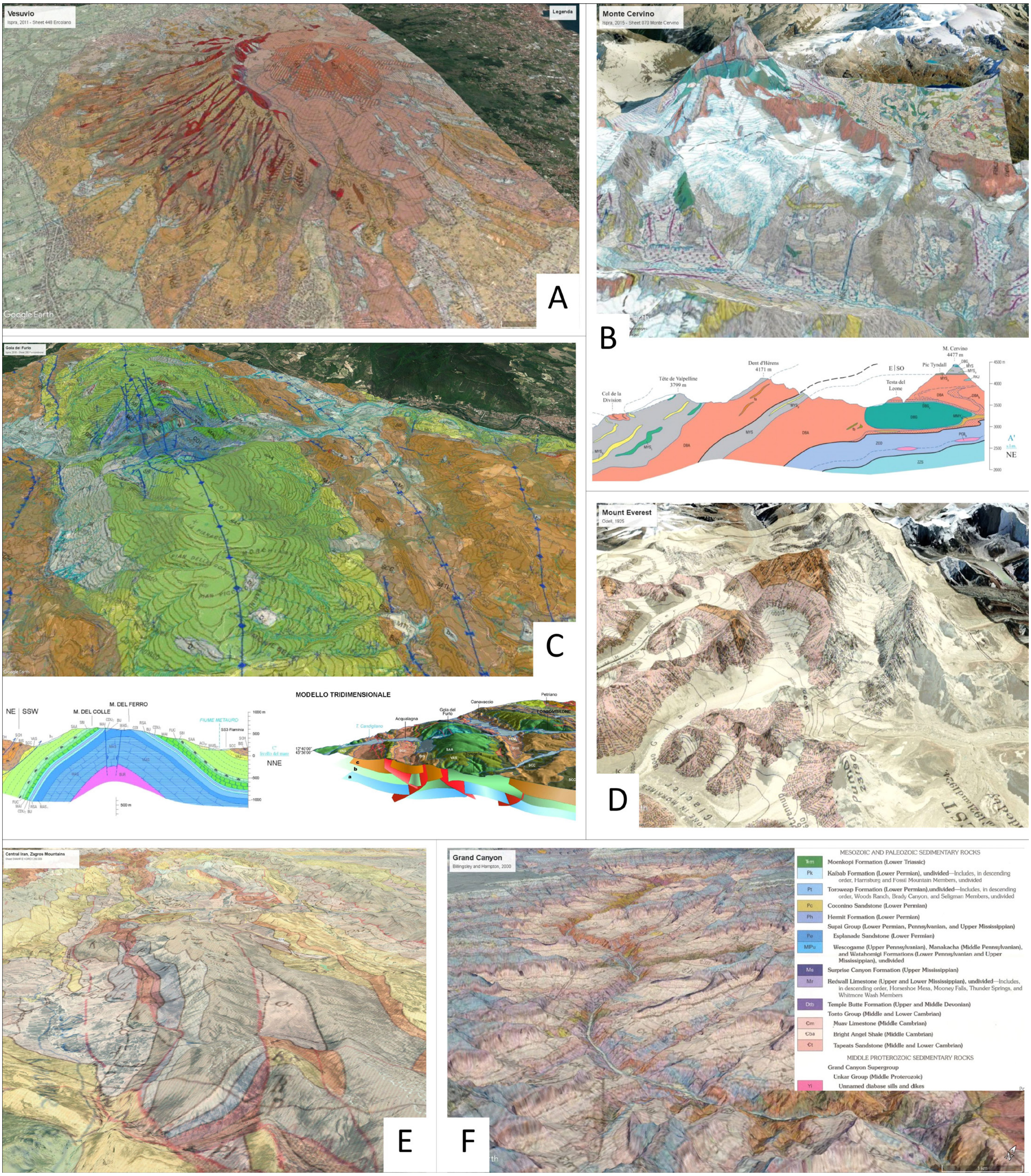

Fig. 3 - Examples of 3D visualization of raster images of geological maps draped on the topographic surface in different geological settings using Google Earth: A) Vesuvio (Mount Vesuvius; volcanic rocks), with the evident distribution of different lava flows on the volcano (Servizio Geologico d'Italia, 2011); B) Monte Cervino (Matterhorn; metamorphic rocks), geological map above and geological cross section, below: the same rocks (with the same colour) can be observed on the map and in the section, showing the relationship between surface and subsurface geology (Servizio Geologico d'Italia, 2015); C) Folded succession at the Gola del Furlo (Furlo Gorge; sedimentary rocks) above and geological cross section and geological 3D model of the subsurface: note the fold, with at the core older rocks (blue colours) eroded by the river (Servizio Geologico d'Italia, 2016); D) historical geological map of Mt. Everest (Odell, 1925), documenting the pioneering study of the highest peak of the Earth; E) 1:250,000 scale geological map Shahr-e-Kord, Zagros Mountains, Iran: the strong deformation of this area is clearly documented by the complex distribution of the different rocks (colours) and by the presence of faults; F) geological map of part of Grand Canyon, USA, where the simple geological structure (bedded sedimentary rocks of different composition and age) is clearly documented by the regular succession of the different colours all across the image (Billingsley & Hampton, 2000). Scale bar is 1 km. The file KMZ of images A to E can be downloaded at https://sites.unimi.it/fberra/didattica-per-insegnanti-in-italiano/, F at https://ngmdb.usgs.gov/Prodesc/proddesc_34288.htm.

level. This approach promotes active learning strategies, essential to consolidate knowledge, also promoting discussion among students ("doing rather than listening"; Matsushita, 2017). Engaging students in activities (e.g., reading, discussing, and writing) is fundamental to increase the efficiency of educational processes and to consolidate the acquired knowledge: involving students in doing things and thinking about things they are doing (Bonwell & Eison, 1991) is the basic rule of active learning. Furthermore, the creation of a network of teachers and schools could help to discuss the results of this approach, with a definition of the best practices to share among the different groups. In this view, geological maps become a fundamental tool for a "hands-on" approach to teaching geology at high schools, due to their easy accessibility, the possibility to organize outdoor activities directly involving the students. Geological maps, being real professional documents, can also be used to test and verify the acquired geological knowledge. The knowledge of the geological setting and history of the land we live in ultimately may help students to become informed citizens, aware of the complexity of the natural processes and, thus, of the world we inhabit. This is expected to provide a deep understanding of the consequences of the decision we have, as citizens, to make about land management, in terms of resources and risks. Students can also understand the role of geology as the science that can help us to be aware of the implications of the use of different energy sources on a changing planet, where eight billion *Homo sapiens* increasingly use the Earth's resources.

CONCLUSIONS

Geological maps are the most common and used way to store and disseminate the geological knowledge of any part of our planet. Their production requires competences that only geologists acquire during their education: nevertheless, practical work on geological maps by non-experts is possible and favours the application of geological concepts to the real world. The use of geological maps, covering in Italy the entire nation, as an educational tool needs to be promoted in high schools for classroom activities focused on the identification of geological objects and processes in the real world. Geological maps also represent a fantastic tool for outdoor activities, that can be associated with hands-on students' activities. Thanks to on-line availability and reduced cost of these professional documents, geological maps are easily accessible, helping teachers to link notions (acquired during classroom lectures) with concepts readable in the maps and, eventually, with the real world. The use of geological maps as education tools requires a limited training of high-school professors, which can be achieved by group activities with teachers familiar with the use of geological maps or with training organized with geologists from universities, research centres or institutions, possibly in the frame of existing collaborations (such as the PLS project in Italy). Hands-on activities on geological maps is surely one of the best ways to stimulate the curiosity of students toward the fascinating science of geology as well as the use of digital platforms: this is expected to make citizens aware of the need for geological knowledge for responsible decisions, both individually and as part of the vast and interconnected human community.

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