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Generalized digital lithological map of northern Mexico and southwestern United States of America☆

Mapa digital litológico generalizado del norte de México y suroeste de Estados Unidos de América

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Abstract

The compilation and generalization of the lithological units that crop out in northern Mexico and southwestern United States of America are important to understand the geology and evolution of this part of the North American continent. For this reason, we publish the first interactive digital lithological map with eleven surficial lithological units present in northern Mexico and southwestern United States of America, in which equivalent formations, sequences and igneous units of both countries were merged and generalized. This map shows the distribution of the main types of rocks that evolved in similar geological processes through time, therefore, researchers can use this new compiled map in the analysis and location of samples and geological evolution, or even during studies related to exploration of natural resources. The area covered by the map is comprised between Longitude of 123°10′W and 94°42′W and Latitude of 23°3′N and 36°57′N (Datum WGS-84).

Keywords: digital geological map; generalized map; northern Mexico; southwestern US

Resumen

La compilación de unidades litológicas que afloran en el norte de México y el suroeste de Estados Unidos de América es importante para entender la evolución geológica de parte del Continente Norteamericano. Por esta razón, en este trabajo se presenta el primer mapa litológico digital interactivo con 11 unidades litológicas presentes en el norte de México y sur de Estados Unidos, en el que se unieron y generalizaron formaciones, secuencias y unidades ígneas de ambos países. Este mapa muestra la distribución de los principales tipos de rocas que evolucionaron en procesos geológicos similares, por tanto, los investigadores pueden usar este mapa compilado en el análisis y/o la localización de muestras, la interpretación de la evolución geológica, o incluso para realizar estudios relacionados con la exploración de recursos naturales. El área que cubre el mapa está comprendida entre las longitudes 123°10′W y 94°42′W y las latitudes 23°3′N y 36°57′N (Datum WGS-84).

Palabras clave: Mapa geológico digital; mapa generalizado; norte de México; suroeste de Estados Unidos de América

1. Introduction

A prolonged Proterozoic to recent geological evolution is recorded in the rocks and landscape of northern Mexico and the southwestern United States, spanning a significant portion of Earth's history. The geological units recorded events such as the Rodinia and Pangea assembly and breakup, the Sevier and Laramide orogenies (metamorphism, magmatism and sedimentation), the Basin and Range extension and the opening of the

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Gulf of California. In addition, the area is the locus of abundant mineral deposits.

Numerous geological maps of the area have been published; however, most are small scale maps that include very detailed information and present a lot of geological units (polygons) that render it hard to recognize regional trends. Furthermore, every map presents a different scale depending on the research goal, which complicates the elaboration of larger scale maps. Further obscuring regional trends, geologic nomenclature is specific to each country and geologic correlations are not straightforward across the international boundary. Therefore, analyzing the relationships among rock types and events in the North American continent is challenging. One way to ease this analysis is merging formations, sequences or geological units with similar features and creating a single generalized and simplified map of both sides of the Mexico-US border. This is the purpose of the map presented in this article, that allows researchers to observe the distribution of the main types of rocks formed during a specific time period, which is important for both mineral exploration, and basic geologic studies. Additionally, this digital lithological map could be used by anyone with basic knowledge of Geographic Information System's (GIS's) because the related files could be downloaded from the journal website and modified according to each research purpose.

The original map information used was published by the geological surveys of Mexico and the US, and the lithological units were classified using lithological and chronological criteria. The software employed to merge formal units was Qgis, in view of being an easy to use, free open source and multiplatform GIS software. Furthermore, we used a digital elevation model and Google Earth Satellite imagery to facilitate matching between lithological units and topographic features.

2. Methods

The generalized lithological map presented in this publication is based on the compilation of geological maps at scale 1:250,000 prepared by the Mexican Geological Service (SGM) and the geological maps of California, Nevada, Arizona, New Mexico, Oklahoma and Texas states published by the United States Geological Survey (USGS) (Fig. 1).

A total of 70 vector maps (shapefiles) were prepared and loaded into the Qgis software. This GIS software is very versatile since it allows free manipulation of both raster and vector datasets. Subsequently, some maps were reprojected to the same coordinate reference system (Geographic coordinate system, WGS-84), in view of the fact that some of these had different datum references. All these maps were joined to produce a single map that covers an area between Longitude 123°10'W and 94°42'W and Latitude 23°3'N and 36°57'N (Datum WGS-84). Nevertheless, the resulting map of northern Mexico and southwestern US had many polygons that represented different formations, sequences, and igneous and metamorphic units; consequently, we made a re-classification of these formal units and merged them into simpler generalized units (polygons) using chronostratigraphic and lithological criteria. The final product is one generalized and simplified lithological map with eleven informal units, which provides geological information from a more regional perspective of this part of the North American continent.

Once the assembling of the units was made, the lithological contacts were adjusted aided by the hill-shade (digital elevation model) and Google Earth Satellite imagery. This approach improved the matching between relief and lithological units proposed in this publication. The digital elevation model was obtained from the GeoMapApp computer application (Ryan et al., 2009). The NASA-ASTER-USES elevation model was chosen since it provides both topographic and bathymetric information to add to the lithological map. Discrepancies on map boundaries were largely resolved during the process of reclassification and reshaping of the lithological units (polygons).

Eventually, the names of the geological formations and units in Mexican geology were obtained directly from the shapefile attribute table published by the SGM. However, for units in the US, it was necessary to download additional files (table format) containing the corresponding geological formation. Then, we compared the acronyms of the shapefile with the ones in the downloaded tables to complete the missing information in the shapefile. During this process, we were careful to review the merging results to make sure they were correct for each unit.

3. Lithological Map units

Informal lithological units presented here were established with the objective of observing the relationship between lithology and geological processes recorded in northern Mexico and southwestern US, and the idea of obtaining a far reaching view of the geology in this part of the continent.

The first unit, named "Precambrian rocks", includes sedimentary, igneous and metamorphic rocks located mainly in the northwestern part of the map, especially in the states of California, Arizona and Sonora. This lithological unit contains Paleoproterozoic and Mesoproterozoic basement-rock units related to the Paleoproterozoic orogens (Mojave, Yavapai and Matzatzal orogenies) and the Grenville orogen, as well as, Neoproterozoic passive margin sequences resulting after the rifting of this part of the Supercontinent Rodinia.

The second unit is named "Paleozoic rocks" and includes abundant sedimentary rocks with less amounts of metamorphic and igneous rocks. This unit is distributed in different zones of the map, but the majority of outcrops are in the northern part, where the Laurentian passive margin continental sequences were deposited through the Paleozoic in Nevada, Arizona, New Mexico and Texas, and in less proportion in Sonora, Baja California and Chihuahua.

The third unit, named "Triassic rocks", includes igneous and metamorphic rocks associated with the first stage of continental magmatism, and sedimentary rocks formed during that period.

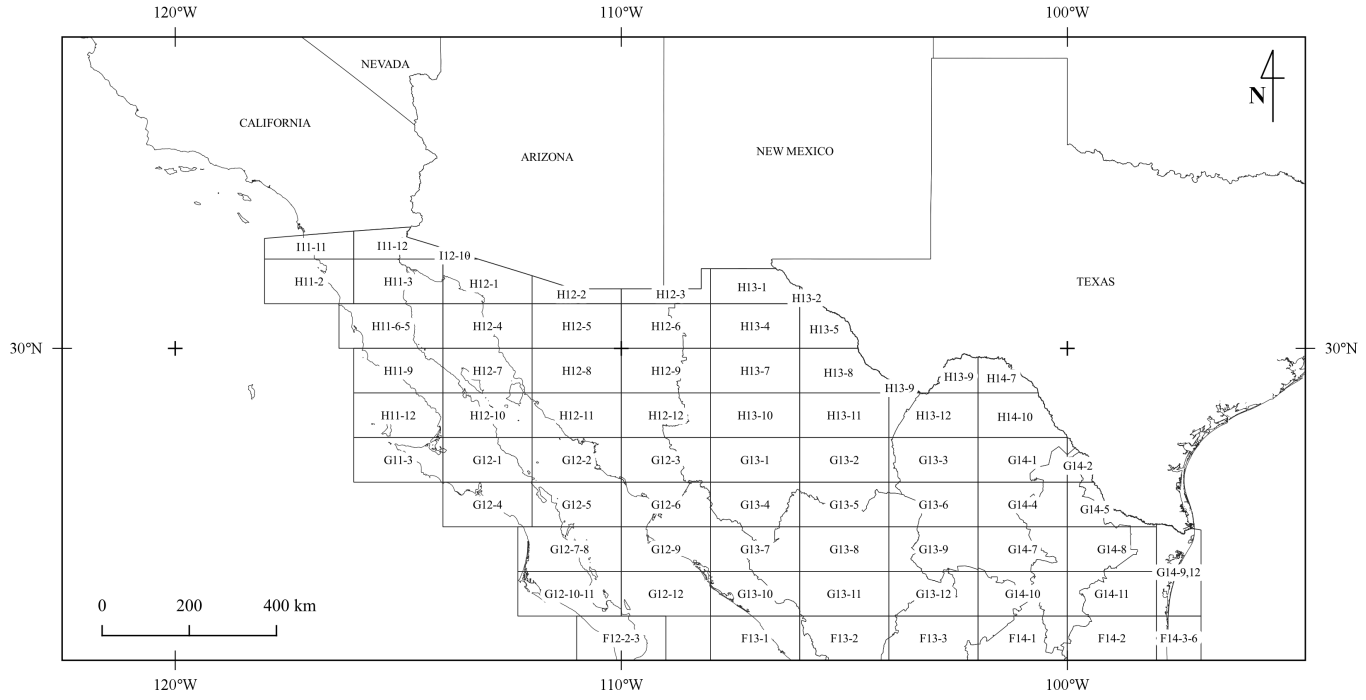

Figure 1: Geological information source / Fuente de la información geológica. **Mexico**: Álvarez-Arellano et al. (1999; 2000), Aparicio-Cordero y Ávalos-Zermeño (1997), Ávalos-Zermeño et al. (1998), Barbosa-Luna et al. (2008a, b), Carrasco et al. (2008a, b), Carrizalez-Aguilar et al. (2004), Castro-Escárrega et al. (2000; 2002a, b; 2003), Cedillo-Calvillo et al. (1998), Corral-Gastélum et al. (1999; 2000a, b; 2002; 2003), Escalante-Martínez et al. (2008), Escamilla-Torres et al. (1999a, b; 2000), García-Cortéz and Siqueiros-López (2002), García-Cortéz et al. (2000; 2002a, b; 2003), García-Padilla et al. (2000), González-Arroyo et al. (1998; 1999), González-Ramos et al. (2008), Guzmán-Espinoza et al. (1999), Hernández-Noriega et al. (2000a, b; 2003a, b), Hernández-Velázquez et al. (2002; 2003), Herrera-Monreal et al. (2008), Librado-Flores et al. (1999), Loaeza-García et al. (2008), Maldonado-Lee et al. (2000), Maraver-Romero et al. (2002a, b), Martínez-Gutiérrez et al. (2008), Martínez-Rodríguez et al. (2008), Minjaréz-Sosa et al. (2002), Montañez-Castro et al. (2000), Moreira-Rivera et al. (1996), Munguía-Rojas et al. (1998; 2000), Padilla-Palma et al. (1997), Palafox-Reyes et al. (1998), Peña-Leal et al. (1999; 2000), Pierre-Prian et al. (2000), Ramírez-Gutiérrez et al. (2008), Romero-Rojas and Moraver-Romero (1998), Romero-Rojas et al. (1997), Romo-Ramírez et al. (2008), Saldaña-Saucedo et al. (1997; 1999), Sánchez-Bermeo et al. (2004; 2008a, b), Santiago-Céspedes et al. (2000), Terán-Martínez et al. (1999), Terán-Ortega et al. (2003). **US**: Ludington et al. (2005) and Stoeser et al. (2005).

The fourth unit is named "Jurassic rocks" and includes sedimentary, igneous and metamorphic rocks located mainly in the western section of the map; this unit contains magmatic rocks related to the continental cordilleran magmatic arc and metamorphic rocks related to contractional tectonism that occurred in western Mexico and the southwestern US at this time.

The fifth unit, named “Cretaceous sedimentary rocks”, is distributed in the eastern part of the map (NE Mexico and Texas); it includes mainly rocks formed during different types of sedimentary processes associated with platform and basin development (mostly limestones).

Rocks related to the possible collision of exotic or fringing arcs to the North American continent were grouped in the sixth unit named "Cretaceous metamorphic rocks". Magmatic rocks associated with the Laramide magmatic arc (Late Cretaceous-Paleogene) and some mafic and ultramafic rocks were grouped in the seventh unit, named "Cretaceous and Paleogene igneous rocks", which are located in the western part of the map (California, Baja California, Arizona, Sonora y Sinaloa).

Rocks associated to Paleogene-Neogene siliceous and bimodal magmatism , mainly exposed in the Sierra Madre Occidental, the Comondu Group and Mongollon-Datil field, are included in an eighth unit named "Paleogene and Neogene volcanic and plutonic rocks", located mainly in the western part of the map. The ninth lithological unit was named "Paleogene and Neogene sediments and sedimentary rocks", which includes rocks that formed by drainage basins and coastal deposits and it is distributed in different zones of the map.

The Quaternary rocks were divided into two units; the tenth unit named "Quaternary volcanic rocks", mostly basaltic volcanic fields (Arizona, Sonora, New Mexico and Chihuahua), and the eleventh unit named "Quaternary sediments". The latter includes colluvium, alluvium, fluvial, eolian and glacial deposits.

Appendix A (Supplementary Material) summarizes the published lithological units that were combined and included in the map and geological details which can be found in the original maps published by the geological surveys of Mexico and the United States. On the next page there is a PDF version of the map.

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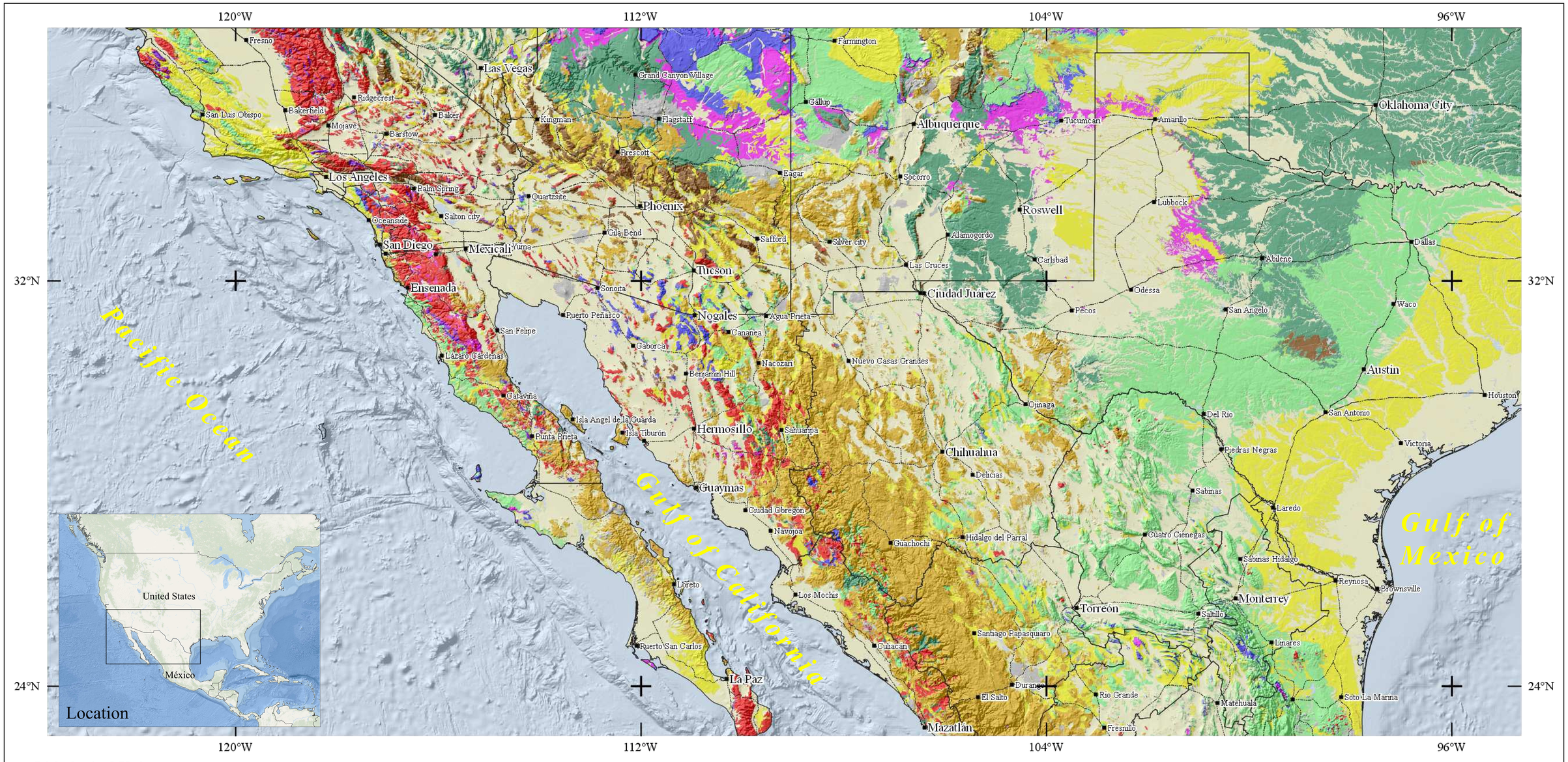

Lithological Units

- 11. Quaternary sediments
- 10. Quaternary volcanic rocks
- 9. Paleogene and Neogene sediments and sedimentary rocks
- 8. Paleogene and Neogene volcanic and plutonic rocks
- 7. Cretaceous and Paleogene igneous rocks
- 6. Cretaceous metamorphic rocks
- 5. Cretaceous Sedimentary rocks
- 4. Jurassic rocks
- 3. Triassic rocks
- 2. Paleozoic Rocks
- 1. Precambrian rocks

Elements

- Water
- City/Town
- Highways

Scale

1:1,000,000

0 200 400 km

Geographic Coordinate System

DATUM: WGS84
Units: Meters

4. Discussion and conclusions

The generalization and simplification of geological units has been sometimes criticized for losing details and degrading the original information on a geological map. However, the process of combining many units to create generalized ones could be useful in the analysis of geological processes at a regional scale, because a smaller number of units provides a general view and simplifies interpretation. As a consequence, it is possible to observe the distribution of one kind of rock formed in a particular event in a specific area. For this reason, this publication presents the first generalized and simplified lithological map of northern Mexico and southwestern US, that shows eleven informal units which allow to observe the rocks formed during specific geological events in this part of the North American continent. The eleven units highlight: (1) the location of the oldest rocks of Precambrian age, (2) the distribution of the Paleozoic rocks that were formed mainly due to sedimentary process along a passive margin, (3) the main places where Triassic rocks could be found, (4) the most significant outcrops of Jurassic rocks (sedimentary and igneous), (5) the distribution of Cretaceous sedimentary rocks (continental and marine), (6) the location of rocks formed during the possible collision of fringing or exotic arcs, (7) distribution of rocks associated with the Laramide magmatic arc, (8) distribution of rocks produced during the Paleogene-Neogene magmatic event of siliceous and bimodal magmatism, (9) outcrops of Paleogene and Neogene sediments and sedimentary rocks, (10) the main places where Quaternary basaltic rocks and (11) Quaternary sediments could be found.

5. Digital products

The generalized lithological map of northern Mexico and southwestern US consists of an interactive map and three downloadable shapefiles. The first shapefile has the geographical information of the lithological units with their respective attribute tables and symbology; the second one incorporates the main roads; and the third has the geographical location of cities and towns shown on the map. Additionally, we include a geotiff file that could be loaded into mobile and tablet devices, and the hill-shade (digital elevation model) used to improve the shapes of polygons used in this publication.

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