DIGITAL ELEVATION MODELS, A USEFUL TOOL FOR GEOLOGICAL MAPPING. SOME EXAMPLES FROM CATALONIA

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Introduction

Geological structures and rock unit boundaries showing a strong correlation with relief can be mapped with detailed topographic analysis. Digital Elevation Models (DEMs) are the most suitable tools for such kind of analysis because they yield an accurate representation of relief and can be processed with computers. Using DEMs, topographic attributes (elevation, slope, etc.) are easily quantified and can be displayed as output images called DEM derived surfaces. Through these images, DEMs display the relationships between topography and geology.

Although DEMs are currently being used for describing geological features related to geomorphology, hydrology and tectonics (see Onorati et al., 1992, Seber et al., 1996 and Spark & Williams, 1996) they still have not become a common tool in geological mapping projects. The aim of this contribution is to illustrate the importance of DEM images in providing valuable geological information that can be used as a guide in defining the geology of a given area. In this study, DEM derived surfaces have been made using a high-resolution (15 m) DEM of the entire Catalan Territory and Arc/Info GIS. The Digital Elevation Model has been compiled at the "Institut Cartogràfic the Catalunya" by means of photogrammetric measurements on aerial photographs at a scale of 1:22.000.

DEM derived surfaces

The software provides functions which can display different kinds of DEM derived surfaces. The following functions have been the most useful to depict geological information:

- *Slope*, displays the grade of steepness expressed in degrees or as percent slope. This image can reveal structural lineaments, fault scarps, fluvial terrace scarps, etc.
- *Aspect*, identifies the down-slope direction. Aspect images may enhance landforms such as fluvial networks, alluvial fans, faceted fault related scarps, etc.
- *Shaded topographic relief or hill-shading*, this image depicts relief by simulating the effect of the sun's illumination on the terrain. The direction and the altitude of the illumination can be changed in order to emphasize faults, lineaments, etc. This image is probably the most useful to display geological data related to landforms in terrains that show a close correlation between geology and topography.
- *Flow direction*, shows the direction of flow by finding the direction of the steepest descent or maximum drop. This DEM derived surface depicts the drainage pattern.
- *Basin*, function that uses a grid of flow direction (output of flowdirection) to determine the contributing area.

The software also allows us to combine a maximum of three DEM images. These kind of images can be useful to enhance a particular geological feature that cannot be visible using a single DEM derived surface. For example, a combination of slope, flow direction and basin is very useful to show stream networks.

In a GIS environment, three-dimensional (3-D) images can also be easily performed. In these images the relief can be exaggerated and any type of 2-D maps or data can be draped over (DEM derived surfaces, geological databases, etc.). The great usefulness of 3-D images is that they can visualize the geology of an area from any vantage-point.

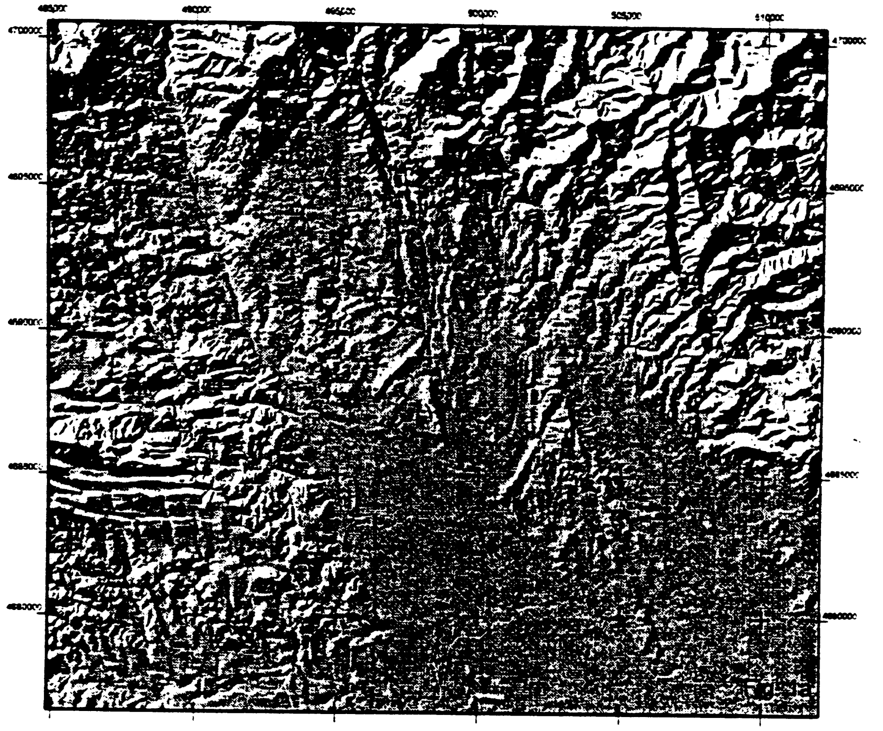
Correlation between DEM derived surfaces and geological maps

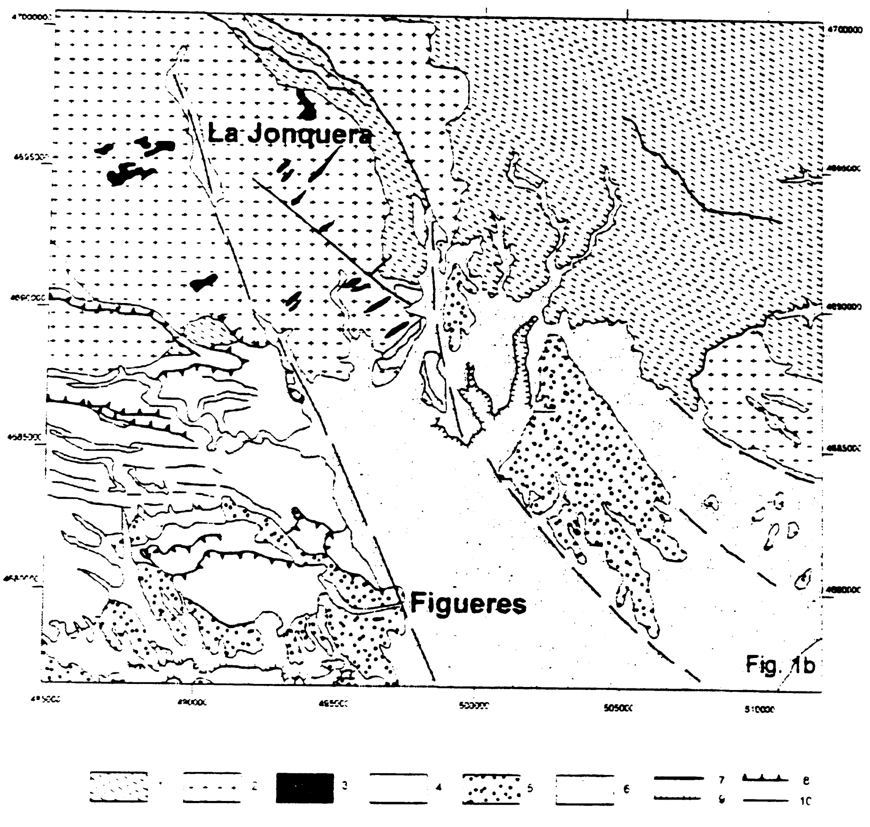
Since DEMs look at the surface from a strictly topographic point of view, only the geological features reflected in the topography can be visible in DEM images. An important characteristic of DEM images is the removing of both, vegetation and most man made constructions. This fact allows DEMs to recognize geological structures, rock boundaries and drainage patterns of highly vegetated or urban areas.

In order to show the close relationships between geological maps and DEM derived surfaces, two distinct areas, a well-exposed rural zone (Figueres-La Jonquera area) and a poorly-exposed urban area (Sabadell-Terrassa area), have been examined using the DEM of the Catalan Territory. Both areas have available geological maps at scales of 1:50.000 and 1:25.000.

Figueres-La Jonquera area

The relationships between a shaded topographic relief image and the geological map of this area can be observed in fig. 1. The DEM image enhances a NNW-SSE trending fault that cross-cuts the whole area and a Neogene alluvial fan visible in the bottom right hand side of the picture. In this image, bedding lines, leucogranite dykes and Quaternary fluvial terraces can also be seen. Note that on the geological map there are faults, thrusts and lithological boundaries which cannot be observed on the shaded relief image because there is no correlation between these structures and the topography. On the other hand, the DEM image shows lineaments, probably related to faults not shown on the geological map.

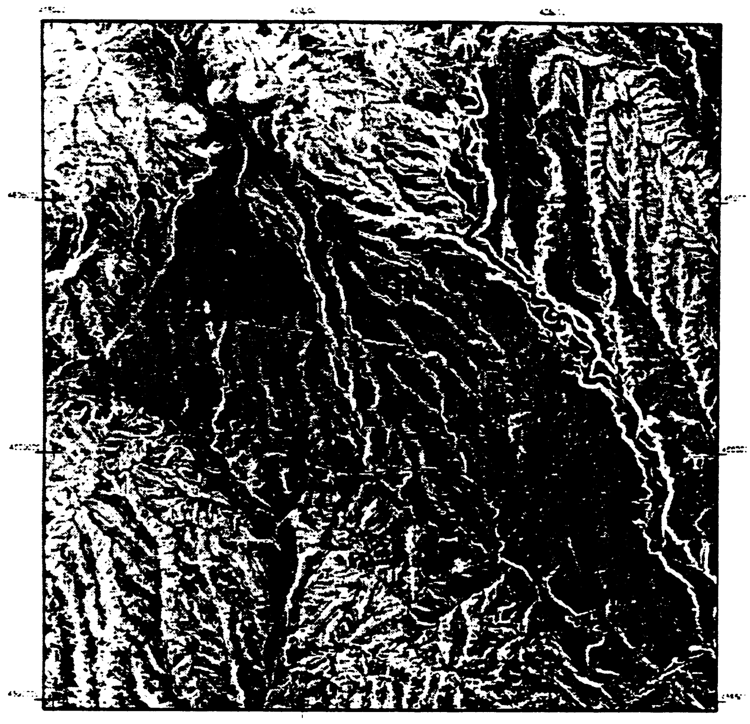


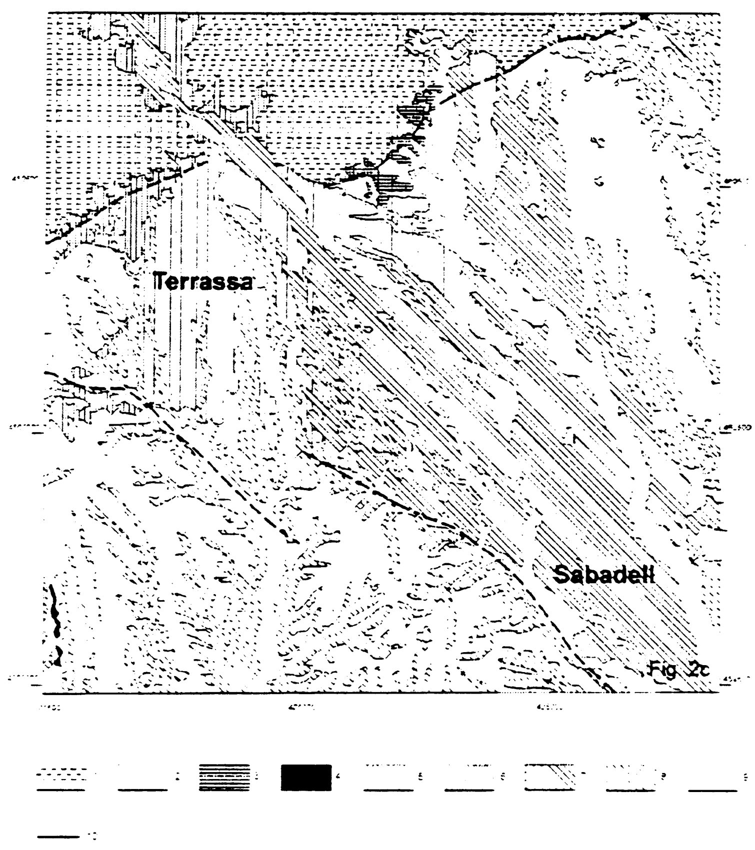

La Jonquera
Figueres
Fig. 1b

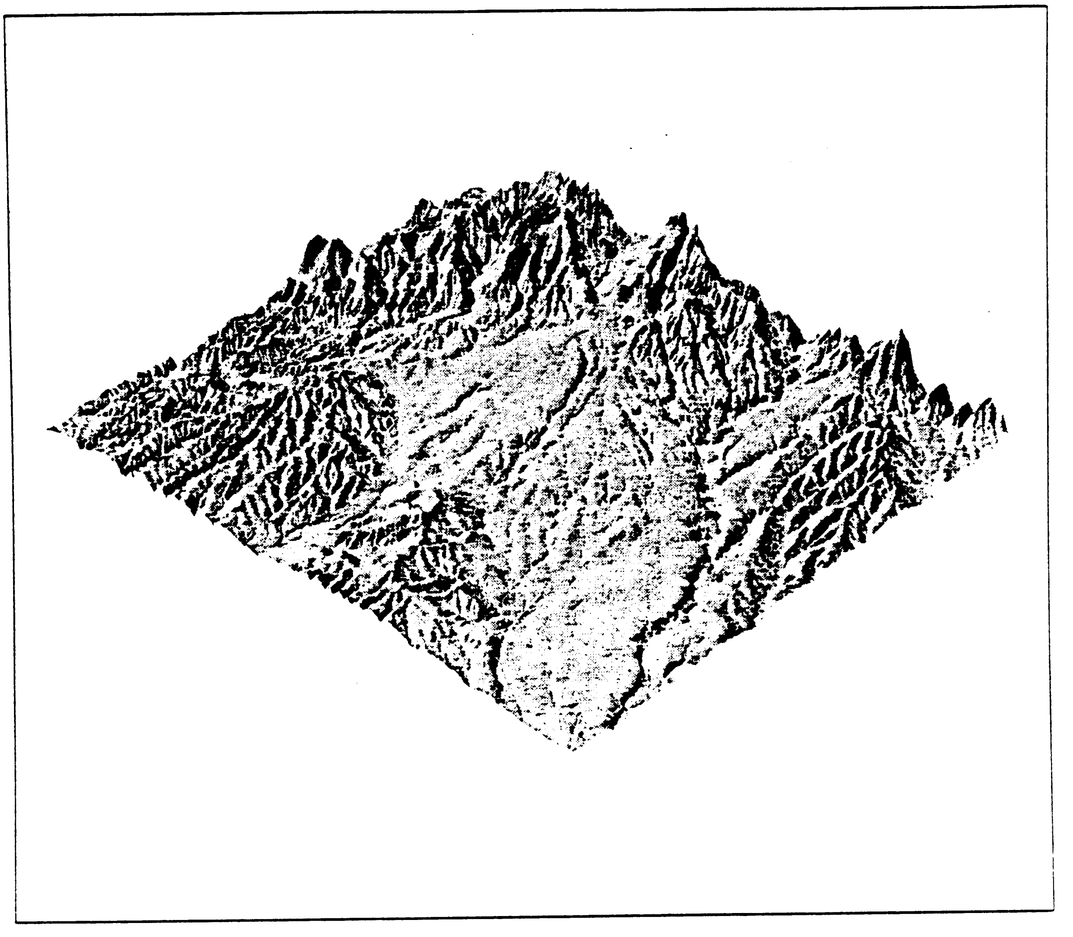
Sabadell-Terrassa area

Nearly 50 % of this zone is occupied by man made constructions (cities, residential and industrial zones) which, in most cases, make direct geological observation impossible (fig. 2a). In fig. 2b three DEM derived surfaces (slope, aspect and flow direction) have been combined. On the image the drainage network hidden by the cities of Sabadell and Terrassa can clearly be observed because the DEM has absolutely removed town buildings. The T4 and T3 alluvial fans and the faults shown on the geological map (fig. 2c), although not so clear, are also visible. These structures could probably be enhanced in slope, aspect or shaded topographic relief images.

A shaded topographic relief image draped over a 3-D view of the Sabadell-Terrassa area (fig.3) displays the relief of the whole zone and enhances the main geological characteristics shown on the geological map (fig 2b). In the center of the image, the alluvial fan on which the cities of Sabadell and Terrassa are built is clearly visible. The steep ridge and the hills respectively located at the top and at the lower part of the picture define the main faults of the zone.




Terrassa
Sabadell
Fig. 2c



Concluding remarks

DEM images have the ability to visualize structures and lithological boundaries which are reflected in the topography, especially those related to recent geological evolution (young faults and late Tertiary or Quarternary deposits). The use of DEMs has a marked interest for geological mapping of highly vegetated terrains and urban areas. DEM images eliminate vegetation and most man made constructions and display the geology covered by plants or hidden by cities.

The figures shown in this study point out that, on the examined areas, the 15 m DEM reflects the major geological features observed on the 1:50.000 and 1:25.000 geological maps. High resolution DEMs can provide accurate geological information and should be used as a base for geological mapping projects at such scales.

Working with DEMs, the entire mapping area can be analyzed in a relatively short period of time and it is possible to work interactively with digitized geological maps and databases. In addition, DEM images may also improve already published geological maps because they can depict lithological or tectonic boundaries not easily detected by conventional mapping methods.

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Figure captions

Figure 1. (a) Shaded topographic relief image of the Figueres-La Jonquera area, the illumination azimuth is 315º and the altitude is 45º. (b) Geological map of the area simplified from Cirés et al. (1994), Fleta et al. (1994) and Picart et al. (1996), 1 -Pre-Hercynian metasediments, 2 -Hercynian granitoids, 3 -Hercynian leucogranite dykes, 4 -Triassic, Jurassic, Cretaceous and Paleogene, 5 -Neogene, 6 -Quaternary, 7 -faults, 8 -thrusts, 9 -fluvial terrace scarps, 10 -bedding lines.

Figure 2. (a) Orthophotomap of the Sabadell-Terrassa area showing the strong human influence upon the zone. (c) Unpublished geological map simplified from Casanovas (in press). In this map Quaternary deposits have been grouped into 6 (T5 to T0) terrace related units. 1 -Pre-Neogene basement, 2 - Neogene, 3 -T5 colluvium deposits, 4 -T5 fluvial terraces, 5 -T4 alluvial fan, 6 -T4 colluvium sediments, 7 -T3 alluvial fan, 8 -T3 colluvium deposits and fluvial terraces, 9 -T2, T1 and T0 fluvial terraces, 10 -faults. (b) Image created by a composition of three DEM derived surfaces (slope, aspect, flow direction).

Figure 3. Shaded topographic relief image draped over a three-dimensional view of the Sabadell-Terrassa area. The image is viewed from an azimuth of 135º, an altitude of 8º and 40.000 m of distance. On this image the main geological features showed in fig. 2b (faults, alluvial fans and stream network) can be observed in 3-D.