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Remote sensing capability in structural geology analysis of different geodynamic settings: the example of Al Qarqaf Arch (Libya)

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Nowadays advances in remote sensing techniques allows improved and detailed geological mapping by mean of satellite image data analyses. This paper focuses on the application of optical remote sensing techniques to geological structures recognition and analysis, according to defined morphostructural criterions. Hence, monoscopic and stereoscopic approach allowed a good identification and classification of faults, folds and fractures affecting different areas. In particular, stereoscopic measurements denoted a good agreement with field data, confirming the potentiality of satellite stereoscopic analyses in geological studies. Further integration of the results in a GIS-based environment permitted the creation of a series of morphostructural maps which supported the geologic interpretation of areas characterized by different geodynamic settings.

1 Introduction

At now well consolidated and improved satellite optical sensors technologies are able to provide cheap and high spatial resolution image data. Moreover, these images are used in many land management projects in order to extract useful regional and detailed land information. Hence, the main topics of this research is to verify the qualitative and quantitative potentiality of remote sensing applied to morphostructural analysis of different geodynamic areas. Traditional approaches included the use of aerial photographs and satellite and radar images to map geological features (folds, faults, fractures, etc..) [1]. More quantitative methods have included the use of stereoscopic aerial photographs to estimates bed attitudes from topographic slopes [2–5]. With the advent of stereoscopic satellite data, such as ASTER and SPOT imagery, these methods have also been applied to satellite data and used successfully to obtain quantitative measurements over large areas [6, 7]. Qualitative analysis of the geological structures has been also conducted by synthetic stereoscopic view of monoscopic Landsat satellite images by applying an artificial parallax [7] and by creating some 3D models of the geological structures, thanks to digital terrain models availability.

This paper describes a methodology for remote recognition and mapping of geological structures that involves the integration of monoscopic, stereoscopic and topographic data analyses together with geologic field and geophysical subsurface data. For this purpose a series of morphostructural indicators have been shortlisted to investigate different areas. The morphostructural indicators have been divided in “linear remote structures” and “areal remote structures”, referring to brittle geologic structures (faults, fractures, lineaments, joints, etc..) and areal-defined geologic structures (folds, thrust sheets, hörst and graben, etc..), respectively.

The effective and intensive analysis of several remote sensed data available for each studied zone, allowed the extraction of a number of lineaments [10] ascribed to faults, fractures or joints and permitted the real geometric definition of folds axes, hörst and graben structures and thrusts. All features derived from the analyses have been implemented in a GIS (Geographic Information System) in order to obtain the related tectonic maps, useful for the tectonic interpretation.

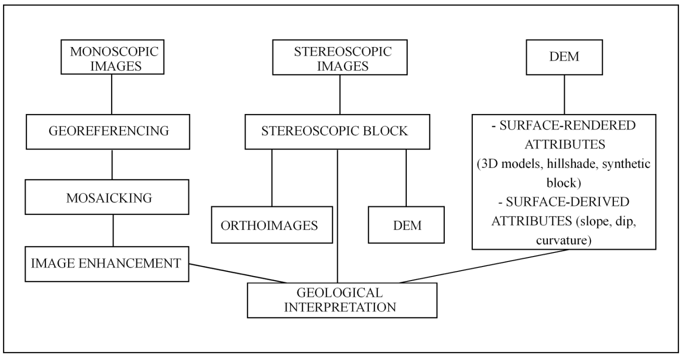

Fig. 1: SBlock diagram of the methodological process applied to satellite image data in order to provide a geological interpretation of the different areas.

2 Data, methodology and results

Remote sensing analyses have been conducted with different kind of data, according to the purpose and the geologic context. Anyway, particular attention has been devoted to satellite imagery together with aerial photographs. The figure 1 shows the methodological process of elaboration applied to the different data sets in order to provide a geological interpretation of the different areas. Monoscopic viewable images (i.e. Landsat ETM+, TERRA-ASTER, orthophotographs, etc..) have been georeferenced and geocoded and subsequently mosaicked. Enhancement filtering has been applied in order to better identify geologic features. Particularly, Landsat ETM+ (Enhanced thematic Mapper) and TERRA-ASTER (Advanced Superborne Thermal Emission and Reflection Radiometer) multispectral images permitted a monoscopic tectonic analysis by using appropriate band combinations. Furthermore, digital elevation models such as SRTM (Shuttle Radar Topographic Mapper) have been exploited to get topographic informations, through hillshade, curvature, slope and aspect parameters (surface-derived attributes) [9] together with the building of 3D models and real and synthetic stereoscopic blocks. TERRA-ASTER and HRSC-MEX (High Resolution Stereo Camera-Mars Express mission) imagery, that includes also two stereoscopic bands, have been processed in order to obtain related georeferenced stereoscopic blocks. So, "linear remote structures" and "areal remote structures" have been recognized and mapped in a real 3D coordinates system by stereoscopic views and high resolution ASTER-DEM and orthoimages have been extracted. The recognized structures have been implemented in a GIS and analyzed by their azimuth and dip, so that every investigated area underwent to a tectonic setting definition. Figure 2 shows an example of azimuth and dip measurements results. The described methodology have been applied to different geological setting, including a portion of the Atlas Fold Belt in central Tunisia, an intracratonic arch locate in the central western Libya and a region on Mars planet. For all these areas a related database including raster (images, DEMs, geological maps, etc..) and vector layers (lineaments, faults, fractures, joints, fold axes, lithologic boundary, etc..) have been created. As example the tectonic analysis of the Al Qarqaf Arch is presented.

The Al Qarqaf Arch (Libya) is a WSW-ENE trending, regional warping of the cratonic Saharan Platform characterized by very gentle limbs (1° or less). This broad (25,000 km^2), low-relief structural high of basement and Paleozoic rocks separates the intracratonic Ghadames Basin to the north from the Murzuq Basin to the south. In the area a Cambrian to Carboniferous clastic succession of continental and shallow marine environment is unconformably covered by Meso-Cenozoic shallow marine carbonate sediments in the basins. The zone is virtually lacking of soil and vegetation, except for the sand sea covering most of the Murzuq Basin.

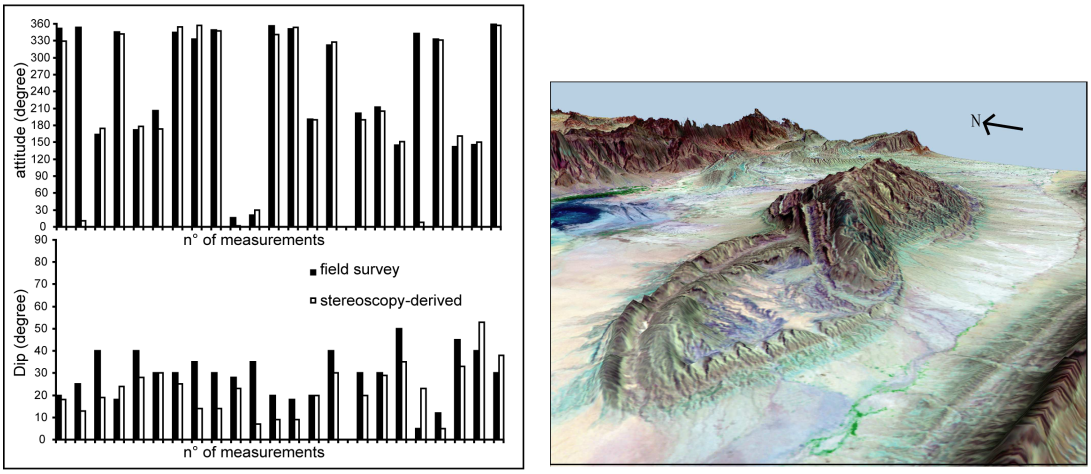

Fig. 2: Stereoscopic measurements of attitude and dip (a) of the strata affecting the limbs of an anticline located in southern front of the Atlas Fold Belt (Tunisia) (b).

The tectonic style and the principal structural lineaments of the area have been detected by remote sensing analysis performed with ASTER stereoscopic images, multispectral Landsat 7 scenes and a SRTM-90 m digital elevation model of the area, integrated with existing geological maps. 3D and stereoscopic views allowed the identification of the fault planes and the tectonic lineaments and the determination of their attitude.

The whole arch has revealed a general WSW-ENE trending anticline conformation with an axis plunging towards WSW and very gentle plunges of the strata (only few degrees, with local plunges up to about 20°, close to the faults).

The numerous tectonic lineaments detected are characterized by consistent variations in trend, length and density when they affect the different lithological units outcropping in the study area. Most of the fractures cutting the Cambrian and Ordovician rocks occur as positive linear features (ridges), as they are quartzite ridges developed from silicified fault zones by selective weathering [10]. Conversely, the lineaments in Tertiary formations occur as negative features (trenches), probably indicating crashed and uncemented, and hence more erodible fault zones. Most of the tectonic lineaments affecting the Palaeozoic formations are sutured by the unconformable Cretaceous-Tertiary succession forming the so-called “Hercynian unconformity”. In figure 3 a 3D model of Hercynian unconformity is shown.

The fracture analysis shows three principal structural trends (ENE-WSW, ESE-WNW and SW-NE), with a less expressed trend around N-S, that is present in the SW sector of the Arch. The ENE-WSW and ESE-WNW trends prevail in the Cambrian and in the Ordovician formations, while in the Tertiary formations the SE-NW direction is the best represented. The maximum length of the lineaments is about 8-10 km. 3D analysis reveals that these lineaments correspond in many cases to normal faults delimiting horst and graben structures, visible on a local scale, with blocks of a few kilometers in width downdropped or uplifted by few tens of meters (up to 50-100 m).

The structural analysis seems to confirm that the major uplift of the Al Qarqaf Arch occurred in an intraplate setting during the late Carboniferous collision between Gondwana and Laurussia (“Hercynian event”) [11]. However, most of the lineaments in lower Paleozoic rocks may be partly related to an Infracambrian-Cambrian extensional system and partly to a possible extensional warping occurred during the Middle Silurian-Lower Devonian. The uplifting history of the Al Qarqaf Arch should be better investigated in order to unravel the mechanisms of this cratonic lithosphere warping.

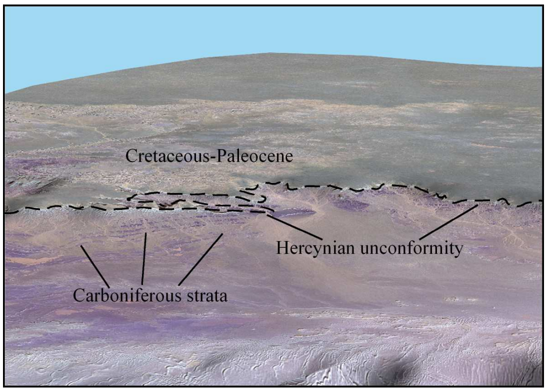

Fig. 3: 3D perspective showing the Carboniferous strata truncated by the Hercynian unconformity (dashed line) located in the NW sector of the Al Qarqaf Arch (Libya).

3 Conclusions

This research focused on the potentiality and usefulness of remote sensing in structural geology applications. Analysis of several monoscopic and stereoscopic imagery of areas characterized by different geologic and geodynamic settings, allowed a shortlisting of a series of criterions useful to recognize the "linear and "areal remote structures" corresponding to morphostructural indicators. The criterions have been applied to the analysis of Landsat ETM+ and TERRA-ASTER satellite images in monoscopic view, using different bands combinations and enhancement filters. Digital stereoscopic analyses of aerial photographs, HRSC-MEX and TERRA-ASTER stereoable bands permitted the extraction of a number of geological features in a real 3D world coordinates, allowing their positioning and geometric definition. Stereoscopic analysis made possible to obtain structural geologic measurements (strike, dip, etc..) on different fold limb strata, obtaining satisfying results after the comparison with field data. The automatic extraction of remote geological structures was also conducted by calculation of surface-derived attributes [9] conducted on the available DEMs. Tridimensional models creation by image draping on the digital terrain models, gave a comprehensive layout of the recognized structures. The GIS implementation of all mapped features permitted the creation of georeferenced morfostructural maps for all the investigated areas, which has been used to make hypothesis on the respective tectonic setting. Finally the integration of remote sensing techniques results with field, geological and geophysical data confirmed the value brought by the remote sensing application to geologic studies.

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