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RECOGNITION OF THE PANAGYURISHTE RING MORPHOSTRUCTURE BY SATELLITE STEREO-IMAGES

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ABSTRACT. The aim of this paper is the structural study of the Panagyurishte ring morphostructure by interpretation of satellite stereo-images. Two types of data are used. The first type is stereo-images, acquired directly by the ASTER instrument and the second type is combination of the Landsat 7 ETM+ imagery with digital elevation model, acquired by the space shuttle (STRM DEM). All data is prepared in anaglyph format to ensure the stereoscopic visualization capability. Specialized remote sensing software is used and the interpretation is done within geographic information system environment. The Panagyurishte ring morphostructure is clearly defined by the relief and the drainage systems as well as by the linear structures. Typical radial-concentric development of the lineaments and streams is observed. The radial structures are very clear, while the concentric faulting is not so well developed. The NW-SE faults predominate in its northwestern parts, while the NE-SW faults are more typical for the northeastern and southwestern areas. The southeastern part of the morphostructure is lowered and covered by young sediments, which mask the spreading of the faults. Two main superimposed fault systems are determined – longitudinal and diagonal, which define the block type development of the morphostructure. They are represented by mutually conjugated fault groups, which partially inherit the radial-concentric faulting in the individual parts of the morphostructure. The superimposed longitudinal E-SE oriented fault system cross the central parts of the Panagyurishte ring morphostructure. The later diagonal faults cut and displace the longitudinal faults. The diagonal faults most obvious inherit the radial structures along the periphery of the morphostructure. The areas of intersection between the faults from different systems and groups are characterized by increased permeability and they control the development of hydrothermal ore-forming processes.

ДЕШИФРИРАНЕ НА ПАНАГЮРСКАТА КРЪГОВА МОРФОСТРУКТУРА ПО СПЪТНИКОВИ СТЕРЕОИЗОБРАЖЕНИЯ

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РЕЗЮМЕ. Статията разглежда структурните изследвания на Панагюрската кръгова морфоструктура чрез интерпретация на сателитни стереоизображения. Използвани са два типа стереоизображения. Първият тип са директно заснети от инструмента ASTER, а вторият тип представлява комбинация от Landsat 7 ETM+ изображения и цифров модел на релефа, заснет от космическата совалка (SRTM DEM). За получаване на стереоскопичен ефект, всички данни са подготвени във вид на анаглифни изображения. Използван е специализиран софтуер за дистанционни изследвания, а интерпретацията е извършена в среда на географска информационна система. Панагюрската кръгова морфоструктура се очертава ясно както от релефа и дренажните системи, така и от линейните структури. Наблюдава се характерно радиално-концентрично развитие на линеаментите и потоците. Радиалните структури са ясно обособени, докато концентричното разломяване има по-ограничено развитие. В северозападните участъци преобладават СЗ-ЮИ ориентираните разломи, докато СИ-ЮЗ разломи са по-характерни за североизточните и югозападните участъци. Югоизточната част на морфоструктурата е понижена и покрита от млади наслаги, което маскира разпространението на разломите. Обособяват се две основни наложени разломни системи – надлъжна и диагонална, които определят блоковия строеж на морфоструктурата. Те са съставени от взаимно спрегнати групи разломи, които частично унаследяват радиално-концентричното разломяване в отделните части на морфоструктурата. Централните части на Панагюрската кръгова морфоструктура са разсечени от наложената надлъжна И-ЮИ ориентирана разломна система. По-късните диагонални разломи секат и разместват надлъжните разломи. Диагоналните разломи най-отчетливо унаследяват радиалните структури по периферията на морфоструктурата. Участъците на пресичане на разломите от различните системи и групи се характеризират с повишена проницаемост и имат контролиращо значение за развитието на хидротермалните рудообразуващи процеси.

Introduction

The Panagyurishte ring morphostructure is located in the Central Sredna Gora Mountain (Fig.1) as characteristic of its geological setting it is that it is part of the Apuseni-Banat-Timok-Srednogorie magmatic and metallogenic belt (Popov et al., 2000; 2002). The morphostructure covers Sushtinska Sredna Gora Mt., also known as Panagyurishte Sredna Gora Mt. It is analytically defined and described on cosmic photographs and topographic maps by Popov and Spiridonov (1990). Spiridonov (1999) presents detailed description of the characteristic morphological features, geological setting and geophysical data related to this ring morphostructure. This paper aims to represent a new study of the morphological features of the Panagyurishte ring structure based on medium to high resolution satellite and space shuttle data. Stereo images from ASTER instrument as well as anaglyphs prepared from Landsat 7 satellite and space shuttle relief data (SRTM DEM) were used to recognize and map the fault-like lineaments and to determine their predominant orientations.

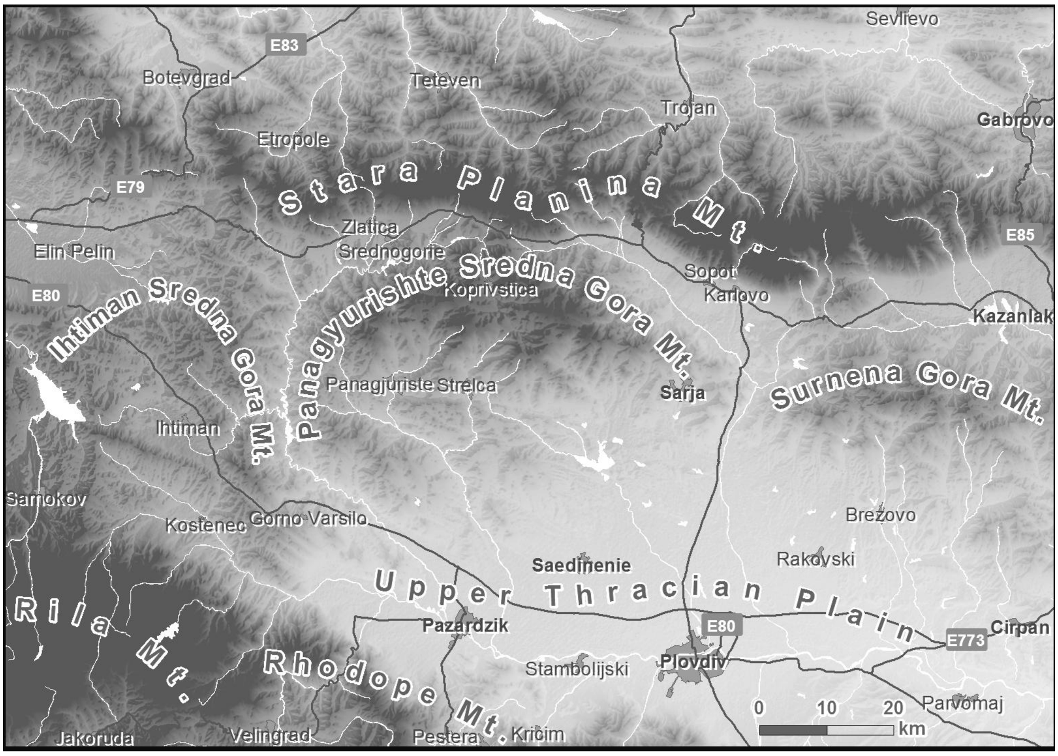

Fig. 1. Overview map of the central parts of Sredna Gora Mountain

Computerized analysis of the drainage basins on the SRTM DEM was used also to study and prove the radial and concentric character of the stream systems in the area.

The previous investigations (Popov, Spiridonov, 1990; Spiridonov, 1999) determined a larger area of the Panagyurishte ring morphostructure including parts from Ihtiman Sredna Gora Mt. to the west. Based on the interpreted radial and concentric features, the study presented in this paper suggests that the area of Panagyurishte ring morphostructure is limited between the Topolnitsa and Stryama rivers and coincides with the Panagyurishte Sredna Gora Mt., as the Ihtiman Sredna Gora Mt. could be considered as neighbor and separate ring morphostructure with similar geological setting. The southern limits are not very clear because the Panagyurishte morphostructure lowers in elevation and it is covered by younger Neogene and Quaternary deposits.

Geological Setting

The oldest and widely exposed rocks in the study area build the Pre Cambrian (?) high-grade metamorphic complex and are present by gneiss and amphibolite assigned to the Boturche and Ardino groups (Katskov, Iliev, 1993; Fig. 2). The Upper Carboniferous – Permian South Bulgarian granites are also widespread in the central and northern parts of the morphostructure and they are intruded within the Pre Cambrian rocks. The Triassic dolomite and dolomite limestone from Bosnek Formation are limited outcropped at the northwest.

The Upper Cretaceous rocks are important part in the geology and metallogenic characteristic of the region. They cut the western parts of the area. Turonian Coal-bearing formation (breccia conglomerate, conglomerate, sandstone) and Sandstone formation (sandstone, aleurolite) build the base of the Upper Cretaceous section. The effusive rocks from several volcanoes set up the Lower Senonian Panagyurishte volcano-sedimentary group (K. Popov, 2001). They are presented by andesitic and dacitic variations mainly. The comagmatic subvolcanic to hypoabyssal intrusives and dykes cut the effusive rocks, as the Elshitsa pluton located in the southwestern part of the morphostructure forms the biggest intrusive body. The volcanic and intrusive rocks are overlaid by Upper Cretaceous sediments of Mirkovo Formation (clayey limestone) and Chugovitsa Formation (marl, clayey limestone, calcareous sandstone).

The Upper Cretaceous and older rocks are transgressively covered by Paleogene, Pliocene and Quaternary sediments. The conglomerates and limited quantities of sandstone from Paleogene Conglomerate formation is exposed mainly along Kalavashtitsa river valley. Widespread in the southeastern and southern areas of the Panagyurishte ring morphostructure are the Pliocene gravelite, sandstone and sandy aleurite from Ahmatovo Formation, whereas the Breccia conglomerate – sandstone formation is limited in the southwestern parts along Topolnitsa River. The Quaternary boulder, gravel, sand and clay are deposited in the Upper Thracian Plain mainly and along the river valleys and at the foot of mountainsides.

Although the Upper Cretaceous magmatic and tectonic activity have important role, the main contribution to the current landscape appearance belongs to the Laramian deformations. The Chelopech syncline (Antonov, Moev, 1978; Katskov, Iliev, 1993) is followed along the southern slopes of Stara Planina Mountain, northern from the Panagyurishte ring structure. The Srednogorie anticlinorium (Bonchev, Karagyuleva, 1961) is spread over the northern, northeastern and eastern areas of the ring morphostructure, where its core from Pre Cambrian metamorphic and Paleozoic intrusive rocks is exposed. The stripe of Upper Cretaceous rocks set up the Baylovo-Panagyurishte synclinoruim (Boyadjiev, 1965). The Pre Cambrian metamorphic and Paleozoic intrusive core of the Ihtiman block-anticlinorium (Karagyuleva et al., 1974) is developed to the southwest and the Neotectonic Upper Thracian depression is located to the south and southeast.

Data used

Three types of remote sensing data were used in this study: ASTER and Landsat7 imagery and SRTM relief data. Two types of stereo-images are compound by these data.

The ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is an optical instrument on board of the TERRA satellite, launched in December 1999 on sun-synchronous orbit at 705 km altitude. It receives imagery in three wavelength ranges: visible to near infrared (VNIR), short wave infrared (SWIR) and thermal infrared (TIR) and snapshots Earth's surface with ground resolutions of 15, 30 and 90 m respectively (ASTER Ref. Guide, 2003). Its images comprise 4+1 bands in VNIR, 6 bands in SWIR and 5 bands in TIR ranges. ASTER is a cooperative effort between US National Aeronautics and Space Administration NASA, Japan's Ministry of Economy, Trade and Industry (METI) and Japan's Earth Remote Sensing Data Analysis Center (ERSDAC) (http://asterweb.jpl.nasa.gov/). The advantage of ASTER system which is used in this paper is the capability to capture stereo-image pairs in near infrared range by its nadir and backward looking sensors acquiring 3n and 3b bands respectively.

The Landsat 7 ETM+ instrument was launched by NASA in April 1999 on board of the Delta II vehicle. The ETM+ sensor acquires data in 3 visible, 2 near infrared, 1 mid-infrared, 1 thermal and 1 panchromatic band (Fig. 3). The image resolutions are 15 m for panchromatic, 30 m for visible and infrared and 60m for thermal bands. The satellite circles on sun-synchronous orbit at altitude of 705 km, and the typical scene size covers 170 km x 185 km (http://landsat7.usgs.gov/).

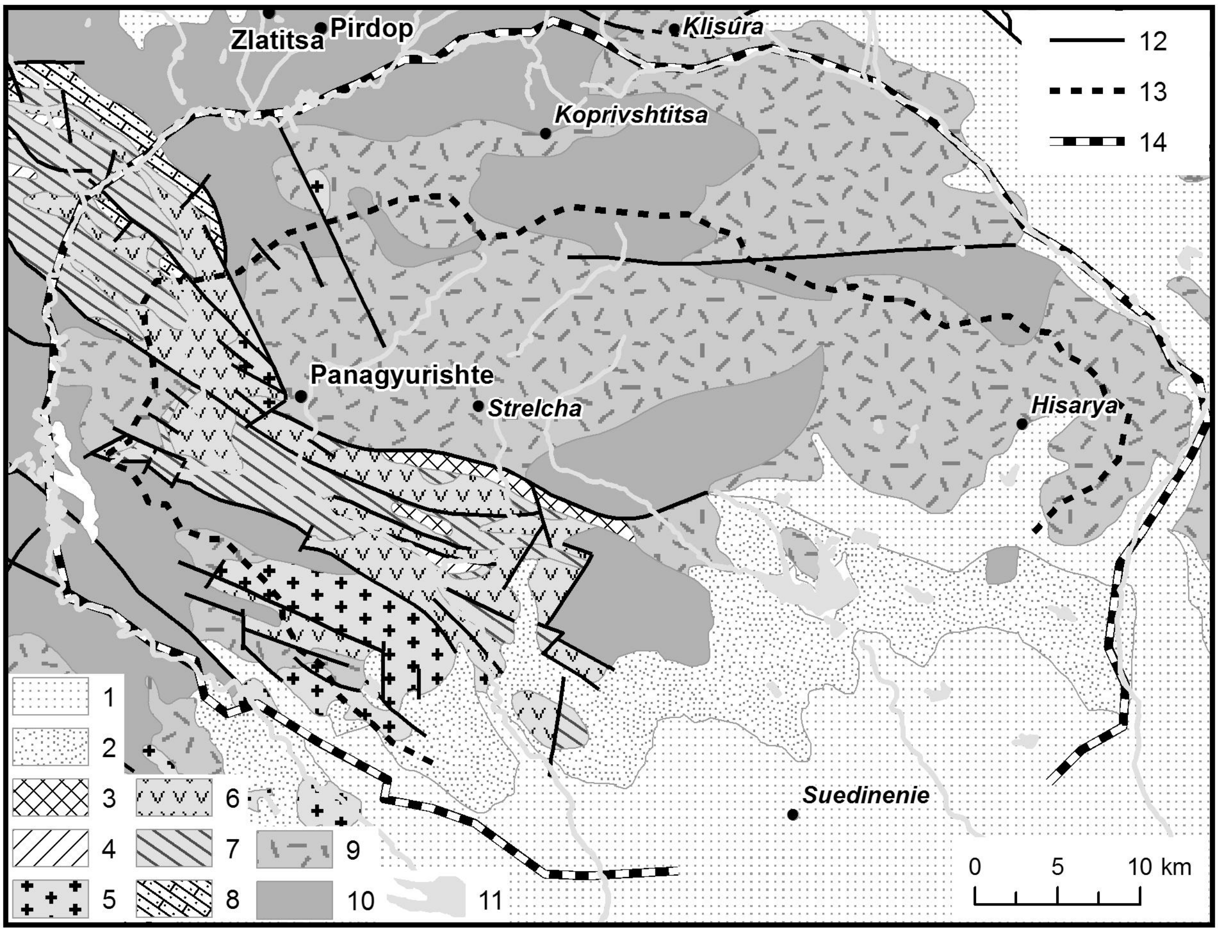

Fig. 2. Simplified geological map of the Sushtinska Sredna Gora Mountain (based on the Metallogenic Map of Bulgaria in scale 1 : 500000 by P. Popov and K. Popov, unpubl., and on the Geological Map of Bulgaria, scale 1 : 100000 by Katskov and Iliev, 1993): 1 – Quaternary deposits, 2 – Ahmatovo Formation (Pliocene), 3 – Conglomerate formation (Paleogene), 4 – Mirkovo and Chugovitsa Formations (U. Santonian-Maastrichtian), 5 – Intrusive complex of Ca-alkaline and sub-alkaline intrusives (Santonian-Campanian), 6 – Panagyurishre volcano-sedimentary complex (Coniasian-Santonian), 7 – Coal-bearing formation and Sandstone formation (Turonian), 8 – Bosnek carbonate Formation (Triassic), 9 – South Bulgarian granite (U. Carboniferous-Permian), 10 - High-grade metamorphic rocks (Pre Cambrian ?), 11 – rivers and dams, 12 – faults, 13 – outer border of the Panagyurishte ring morphostructure, 14 – mountain ridge of the morphostructure

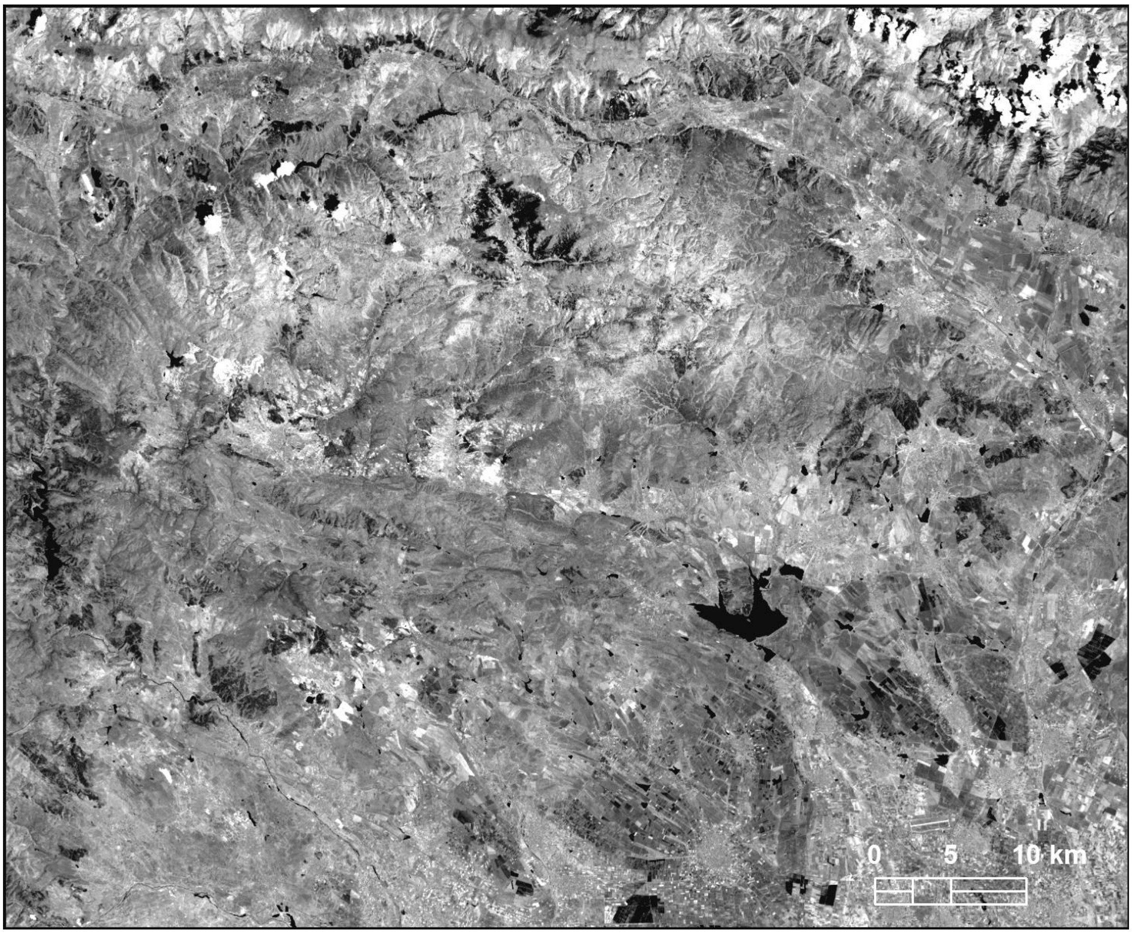

Fig. 3. Landsat 7 ETM+ panchromatic image of the Panagyurishte Sredna Gora Mt. and the ring morphostructure

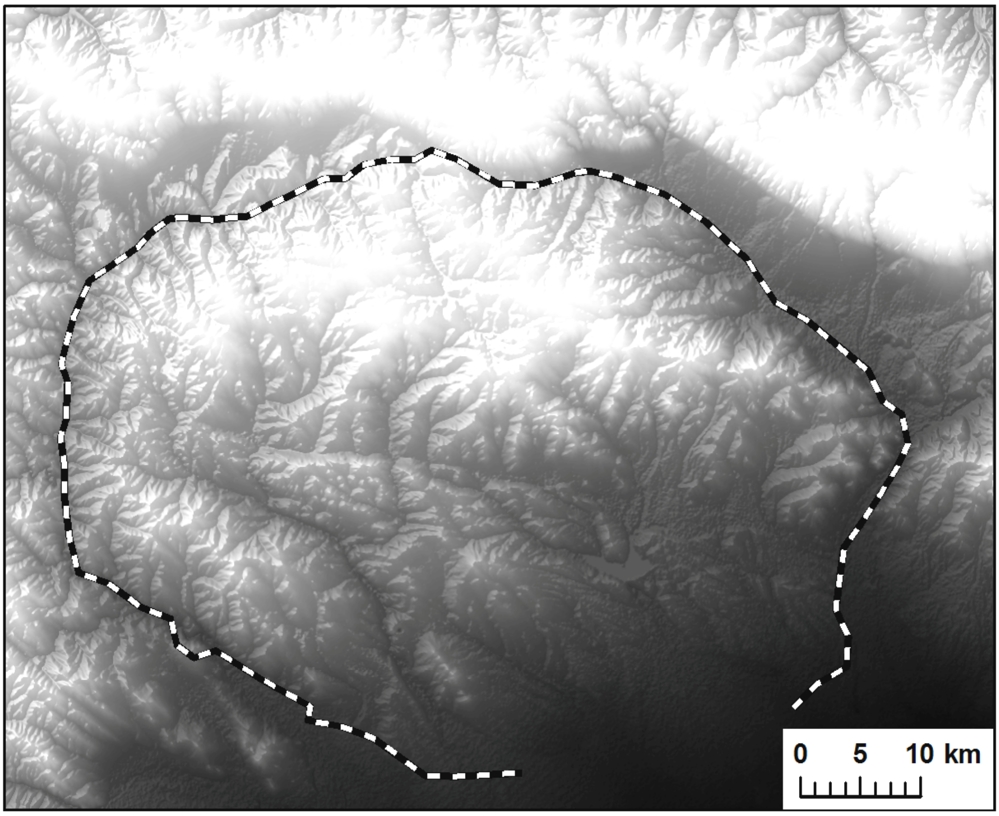

Fig. 4. SRTM Digital Elevation Model of the Central Sredna Gora Mt. area. The white shades represent higher altitudes and the dashed line shows the border of the interpreted ring morphostructure area

The relief data used in this paper is acquired during the Shuttle Radar Topography Mission (SRTM) in February 2000. The SRTM used C-band radar data to obtain a near-global scale digital elevation model (DEM) with ground resolution of about 90 m (Fig. 4). To acquire topographic (elevation) data, the SRTM instrument was outfitted with two radar antennas. One antenna was located in the shuttle's payload bay, the other on the end of a 60-meter mast that extended from the instrument once the shuttle was in space. SRTM is an international project spearheaded by the US National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA) (http://www2.jpl.nasa.gov/srtm/).

Image processing and interpretation

The present study is based mainly on the interpretation of stereo-images obtained by 3n and 3b bands of ASTER instrument. Several ASTER L1B and L1A scenes acquired in 2003 and 2007 respectively were used to ensure the cloud free cover of the studied area. The ASTER images were provided by the Land Processes Distributed Active Archive Center (LP DAAC) at the U.S. Geological Survey. In general, it is enough to geo-reference individual 3n and 3b band pairs with the ground control points included in ASTER HDF data file and prepare an RGB image with 3n/3b/3b band combination to receive on screen stereo effect visible with red/cyan 3D stereo glasses. The ASTER anaglyph image should be rotated 90° counter clockwise to see in 3D. The creation of epipolar image pair with usage of additional tie points to co-register 3n and 3b bands provides more control on the stereo image preparation process and more precise and contrast visual 3D effect for the interpretation. Epipolar stereo images with about 30 tie points were mainly used in this study as the tie points were automated collected by correlation between 3n and 3b bands and were manually checked for errors.

Different and also useful method is the generation of pseudo stereo images by combination of image with relief data. Landsat 7 optical images which don't have built in stereo capabilities and SRTM terrain data were used in this paper to produce anaglyph image of the studied area. The Landsat 7 ETM+ images were provided by the European Commission Joint Research Centre, Institute for Environment and Sustainability in frame of the Image 2000 & Corine Land Cover 2000 Project (http://image2000.jrc.ec.europa.eu/). The Product 1 level ortho-rectified panchromatic and multispectral Landsat 7 ETM+ scenes were used. The RGB 321 multispectral band combination was applied to obtain near natural color composite image of the area with 25m ground resolution. It was pan-sharpened with the panchromatic band to obtain natural color image with resolution of 12.5 m. The last one was combined with the SRTM DEM to produce anaglyph image of the Central Sredna Gora Mt. area.

All ASTER and Landsat 7 images and SRTM relief data were georeferenced to UTM zone 35N WGS-84 projection. The figures in this paper are in this projection as well.

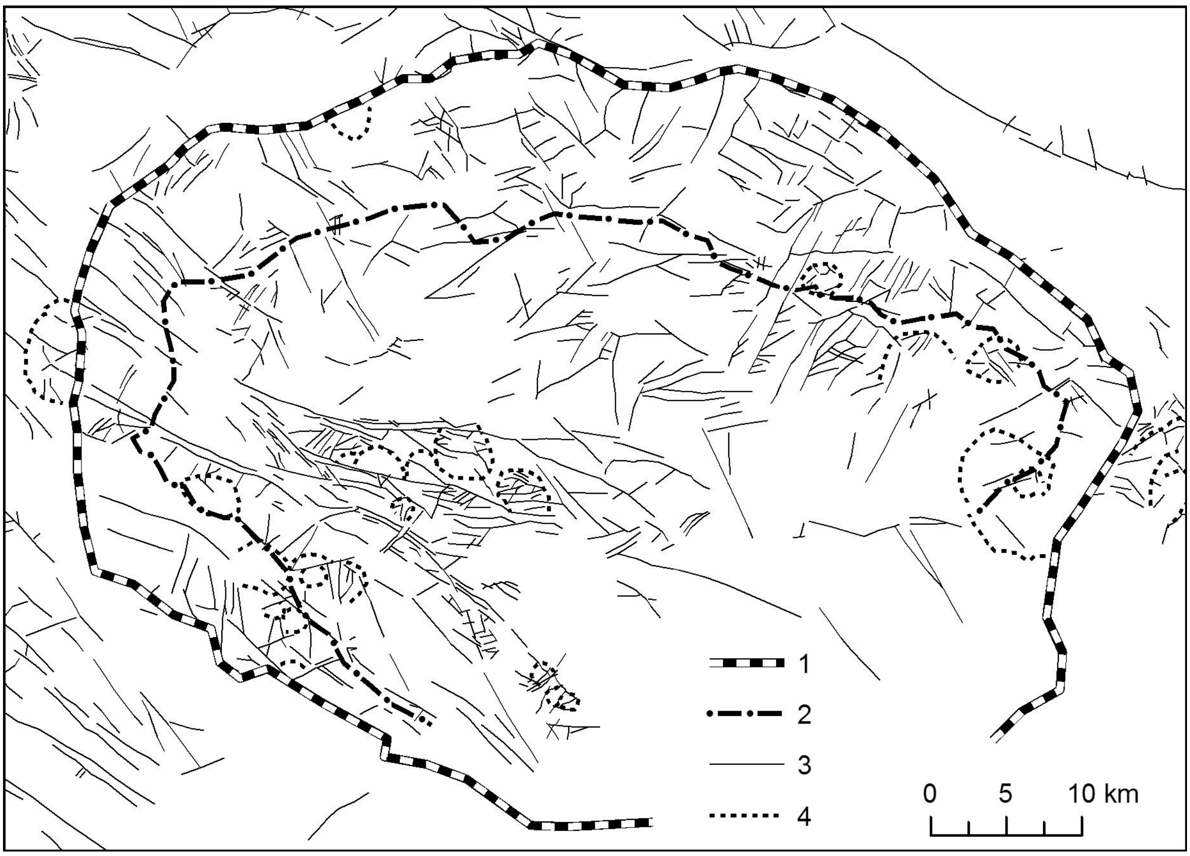

Fig. 5. Linear and ring morphostructures interpreted on the stereo images. 1 – outer border of the Panagyurishte ring morphostructure, 2 – mountain ridge delineating the concentric morphostructure, 3 – lineaments, 4 – ring morphostructures of minor order

Both ASTER and Lansat7 anaglyph products were used in the interpretation of lineament features in the Panagyurishte morphostructure. The task was to draw the faults and other distinguishable linear morpho structures in the area and to assess their predominant orientations. The stereo interpretation was visually done on screen with stereo glasses in ArcGIS software and the outlined linear features are shown on figure 5. Many of the drawn lineaments could not be considered as truly proved faults as the displacements are not observed on the images, because of the vegetation and soil cover and the working scale. Nevertheless, lots of the lineaments coincide with known faults determined by geological mapping. Figure 6 displays bidirectional rose diagram of the lineaments which fall within the border of the Panagyurishte ring morphostructure.

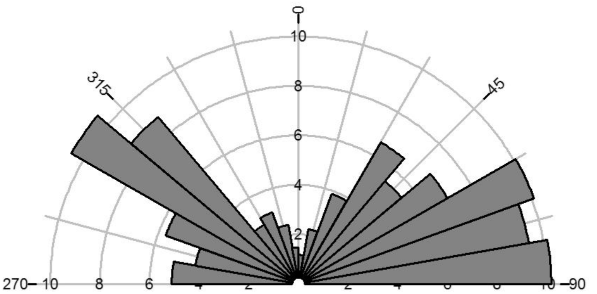

Fig. 6. Bidirectional rose diagram of the lineaments' directions in the Panagyurishte ring morphostructure

Two main lineament systems with diagonal (NE and NW) and longitudinal directions are defined by the stereo interpretation. The two diagonal NE and NW conjugated groups predominate at the periphery of the ring morpho structure demonstrating its radial and concentric faulting. The longitudinal fault system cuts the central to western part of the ring morphostructure where it is related to the Upper Cretaceous volcanism and subsequent tectonic activities. The longitudinal system is composed by two mutually conjugated groups with WNW and ENE directions. It is supposed that the major faults in the area are older and reactivated during the Upper Cretaceous and later tectonic activities. The longitudinal faults are displaced by the diagonal faults in some places. Numerous massive sulphide and porphyry copper deposits in Panagyurishte Ore Region (Popov et al., 2003) were formed in the places of intersection of the faults from these systems and groups, where the dense faulting contributes to the intensive development of hydrothermal activity.

Several small concentric morphostructures of minor order were interpreted on the stereo images as well (Fig. 5). Some of them are located in the central parts of the Panagyurishte ring morphostructure and they are formed by some volcano-intrusive structures as the Pesovets, Petelovo and Tangur volcanoes (K. Popov, 2001; 2005). Other mark the elevated mountain areas formed during the raising of rocks.

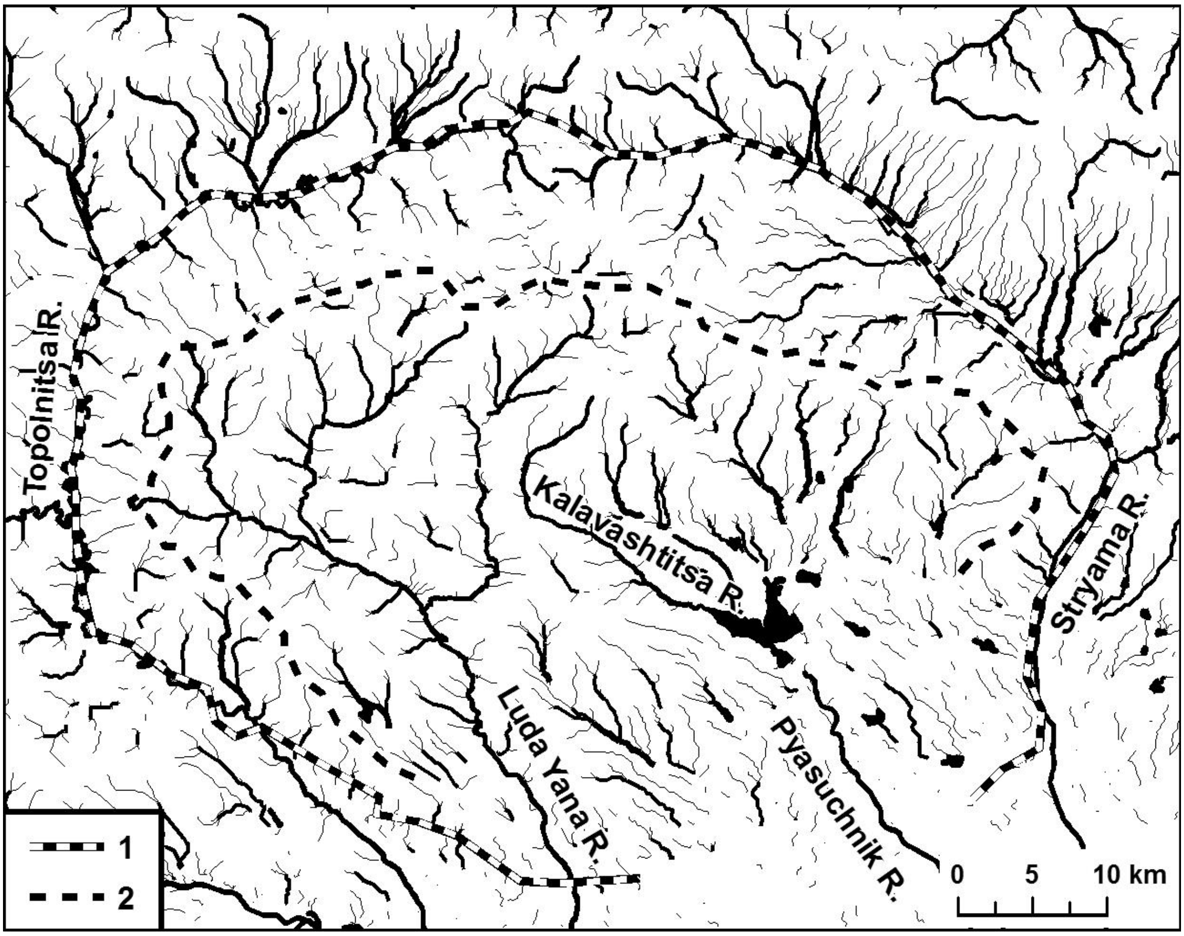

Fig. 7. Stream network model in the Panagyurishte ring morphostructure and neighbor areas: 1 – outer border of the ring morphostructure, 2 – mountain ridge delineating the concentric morphostructure

Drainage system analysis

The SRTM digital elevation model covering Central Sredna Gora Mt. area (Fig. 4) was used for computerized hydrological modeling of the stream pattern. The applied processing sequence is based on flow direction analysis and flow accumulation modeling tools, which are included in the ESRI' ArcGIS Hydrology toolset (ESRI, 2011). The flow direction tool creates a raster file from each DEM cell to represent its steepest downslope neighbor. Using flow direction model, the flow accumulation tool creates a raster model of accumulated flow into each DEM cell. Based on flow accumulation model, the stream network vector file was build (Fig. 7) to represent the drainage system properties. The information about directions of stream segments was processed and presented as rose diagram on Figure 8.

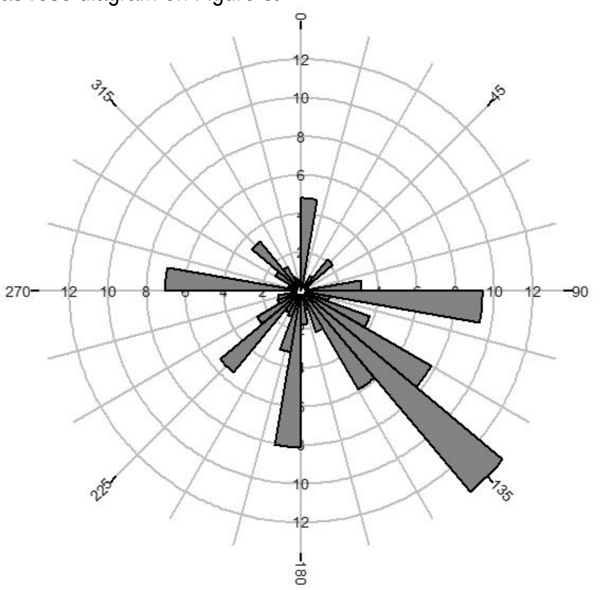

Fig. 8. Rose diagram of the stream directions within the Panagyurishte ring morphostructure

As it is shown on Figure 7, the interpreted border of the ring morphostructure coincide with the concentric spreading of Topolnitsa and Stryama rivers and the watersheds of Luda Yana, Kalavashtitsa and Pyasuchnik rivers reflect the formation of the inner parts of the morphostructure. The main streams of both Topolnitsa and Stryama rivers form the concentric outer frame of the ridge of morphostructue, as the feeders in their drainage basins are radially oriented along the outer flank of the ridges. The drainage basins of the upper courses of Luda Yana, Kalavashtitsa and Pyasuchnik rivers are radially oriented also and delineate the inner flank of the main concentric ridge of the morphostructure. The radial and concentric orientations of the streams is obvious for almost whole morphostructure area except in the southeastern part, where it is masked by the younger sediment cover and the rivers courses are oriented to SE direction.

The presence of several peaks in the streams' directions statistical distribution shown on rose diagram (Fig. 8) proves the radial character of the morphostructure. The most frequently observed direction is SE coinciding with the downstreams of the main rivers. The other maximums occur in ESE, WNW, SSW, NNE and SW in reflect to the radial character of the upstream drainage networks.

The results of the performed drainage analysis show that the radial and concentric development of stream pattern clearly expresses the Panagyurishte ring morphostructure developed in Central Sredna Gora Mt. area.

Conclusions

The nowadays medium to high resolution satellite data provides advanced and powerful tools for medium to detail scale geological interpretations. The capabilities to produce stereo images vastly assist the structural recognition of the remotely sensed data. Presented here the structural interpretation of the lineament morphistructures in the Sushtinska Sredna Gora Mountain confirms the development of the Panagyuristhe ring morphostructure between the Topolnitsa and Stryama rivers. Radial and concentric lineaments forming two main groups with diagonal (NE and NW) and longitudinal directions were outlined, as they correspond to the main fault systems determined by the geological investigations in the area.

The performed drainage system analysis proves the radial and concentric development of the streams which clearly delineates the ring morphostructure. The streams orientations are somewhat identical to the lineaments orientations, as the SE, N-S and longitudinal streams are often observed.

The present appearance of the studied ring morpho structure is due to the Laramian deformations mainly when the Paleozoic South Bulgarian granites were raised and the Srednogorie anticlinorium and Baylovo-Panagyurishte synclinoruim were formed. Less intensive and mainly block type displacements were developed during the Tertiary, and the ring morphostructure was covered by young sediments of the Upper Thracian Plain to the south and southeast. The Paleozoic South Bulgarian granites are relatively low in density and light which is marked as negative anomalies on the gravimetric maps (Radichev, Dimovski, 2006). The mutually conjugated fault systems define the block type development of the morphostructure. Numerous massive sulphide and porphyry copper deposits were formed in the places of faults intersection, where the dense faulting contributes to the intensive development of hydrothermal activity (Popov et al., 2003).

The recognition of lineament features on stereo images contributes to the mineral prospecting and exploration as the known copper deposits are related to the post volcanic tectonic and hydrothermal activity in the area and are spatially attached to the intensively faulted zones of interception of different fault systems.

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