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The discovery of structural elements and zones of hydrothermal alterations by using aster satellite data in the margins of Gadabay and Murovdağ ore districts (Lesser Caucasus Azerbaijan)

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Abstract. The article considers the discovery of structural elements, zones of hydrothermal alterations and mineralization in the margins of Gadabay and Murovdag regions and the study of prospective areas for mineralization characterized by them by using ASTER satellite data. The main purpose of the research is the definition of the lithological

composition of rocks, ring and linear structures and zones of hydrothermal alterations with the help of remote-sensing methods and by better technological development of special radiometric data. In order to detect the lithological composition of associated rocks of alteration zone of endogenous ores, 14 channel data of ASTER has been used. By using stereoscopic images obtained from ASTER data, it was determined that hydrothermal alterations are mainly represented by alunitization, kaolinization, sericitization, silicification, pyrophyllitization and silification in the studied ore regions. These changes were shown to be characteristic for copper-porphyry, gold-copper pyrite, copper-polymetal and gold-copper-porphyry deposits. Strip ratios, principal component analysis (PCA), minimum of noise fraction (MNF) and selection method for least squares (LS) have been used to map hydrothermal alteration zones. The ring structures detected in the area, different fault fractures and lineaments are assessed as favourable geological structural factors for alteration and mineralization. The results obtained by ASTER image analysis confirm the presence of derivative minerals which are considered to be the product of hydrothermal alterations which are densely concentrated (kaolinization, kaolinization, sericitization, pyrophyllitization, alunitization) has been confirmed. The points each with private coordinates have been determined (defined) within separate areas with the help of remote data and relevant anomalous maps prepared. These points are considered favourable geological condition in terms of the type and intensity of hydrothermal alterations in the area. Such areas are considered a sign of indirect search significant for the detection of copper-polymetallic, copper-porphyry, copper-pyrite and gold-pyrite type of mineralization with epithermal origin in the region.

Keywords: Gadabay and Murovdag, ASTER, structural elements, hydrothermal alteration, mineralization, prediction.

Виявлення структурних елементів та зон гідротермальних змін за допомогою супутникових даних ASTER на окраїнах Гадабайського та Муровдазького рудних районів (Малій Кавказ, Азербайджан)

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Анотація. У статті розглядається відкриття структурних елементів, зон гідротермальних змін та мінералізації на окраїнах регіонів Гадабай та Муровдаг та дослідження перспективних районів мінералізації, що характеризуються ними, за допомогою супутникових даних ASTER. Основною метою дослідження є визначення літологічного складу гірських порід, кільцевих та лінійних структур та зон гідротермальних змін за допомогою методів дистанційного зондування та кращої технологічної розробки спеціальних радіометричних даних. З метою встановлення літологічного складу вміщувачих порід зони зміни ендеген-

них руд використані 14-канальні дані ASTER. За допомогою стереоскопічних зображень, отриманих за даними ASTER, було визначено, що гідротермальні зміни в основному представлені алуїнізацією, каоїнізацією, серіцитизацією, силікатизацією, піропїлітизацією та силіфікацією у досліджуваних рудних регіонах. Показано, що ці зміни характерні для мідно-порфірових, золото-мідно-піритових, мідно-поліметалевих та золото-мідно-порфірових родовищ. Співвідношення смуг, аналіз основних компонентів (PCA), мінімум шумової частки (MNF) та метод вибору для менших квадратів (LS) використовувались для картографування зон гідротермальних змін. Кільцеві структури, виявлені в районі, різні тетконічні порушення та дінаменти оцінюються як сприятливі геологічні структурні фактори для зміни та мінералізації. В результаті отриманого за допомогою аналізу зображень ASTER підтверджено наявність похідних мінералів, що вважаються продуктом гідротермальних змін, які цілком розташовані на території (калішпатизація, каоїнізація, серіцитизація, піропїлітизація, алуїнізація). Точки, кожна з своїх координатами, були визначені (розділені) в окремих районах за допомогою віддалених даних та підготовлені відповідні карти аномалій. Ці пункти вважаються сприятливим геологічним середовищем з точки зору типу та інтенсивності гідротермальних змін на даній території. Такі райони вважаються ознакою непрямого пошуку, значущими для виявлення мідно-поліметалічного, мідно-порфірового, мідно-піритового та золото-піритового типу мінералізації з епітермальним походженням в регіоні.

Ключові слова: Кедабек і Муровдаг, ASTER, структурні елементи, гідротермальні зміни, мінералізація, прогноз.

Introduction.

Cosmic, multi-spectral systems such as Landsat MSS, TM and SPOT possess spectral channels ranging from 4 to 7. Landsat MSS data is mainly applied during the structural and geomorphological interpretation on a regional scale (Goetz et al., 1983; Abrams et al., 1983; Perry, 2004).

Using ASTER (Advanced Spaceborne Thermal Emission and Reflection) data, the wide application of the potential opened up by the discovery of ore deposits within ore regions and areas and application of satellite spectrometers in the spatial definition of mineral indicators in various geological conditions have been observed in recent times (Abrams et al., 2000; Sabins 1999; Spatz et al., 1994; Watson et al., 1990; Tommaso et al., 2007). ASTER covers visible, near infrared (VNIR), short-wave infrared (SWIR) and thermal infrared (TIR) spectral areas with 14 channels possessing high spatial, spectral and radiometric solubility properties. (Yamaguchi et al., 1998; Abdelsalam et al., 2000; Abrams and Hook, 2001).

In recent years, the use of ASTER images, especially the high spatial and spectral results of ASTER, as well as the availability of obtaining three-dimensional stereoscopic images allow us to apply this method widely in various spheres of geology. By applying spectral and thermal features of ASTER data, they are used in the investigation of geological features, the definition of hydrothermal –metasomatic alteration zones and mineralization zones which were formed associated with ore deposits, in the discovery of various tectonic structural elements, particularly linear and ring structures and in the solution of other geological problems (Rowan et al., 1977; Goetz et al., 1983; Boardman et al., 1995; Abdelsalam et al., 2000; Papp and Cudahy, 2002; Kruse et al., 2003; Perry, 2004). ASTER data are widely applied in the search and exploration of ore mineral deposits, two channels of SWIR are applied in the discovery of mineralization areas associated with altered rocks (Podwysocki et al., 1984; Okada et al., 1993; Sabins, 1996; Sabine, 1997; Abdelsalam et al., 2000).

According to the data on VNIR/SWIR surface reflection features, alteration processes of minerals, such as alunitization, kaolinization, sericitization, silicification and propylitization have been recorded.

As is known, the Gadabay and Murovdag ore regions are characterized by wide development of copper-porphyry, gold-copper-pyrite and copper-polymetallic, copper-arsenic and other ores and their proper hydrothermal alterations. The detectability of hydrothermal alterations and mineralization zones based on remote-sensing data create wide opportunities for conducting effective geological researches in this area.

The main purpose of the research is to discover hydrothermal alteration and mineralization zones, ring and linear structural elements, playing a significant role in the localization of noble and non-ferrous metal mineralization in the Gadabay and Murovdag mining districts by using ASTER data.

Materials and research methods.

The images related to a ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) receiver which was set over a TERRA satellite platform have been used in the article. ASTER module has resolution accuracy consisting of totally 14 spectral bands including 3 spectral bands in Visible Near Infrared (VNIR), 6 spectral bands in Short Wave Infrared (SWIR) and 5 spectral bands in Thermal Infrared field. VNIR bands of ASTER have resolution of 15 meters, SWIR bands-30 meters and TIR bands 90 meters. A single ASTER image covers an area of 3600 km² within the frame of 60km x 60 km. The data shown here allow us to study the mineralization and alteration in detail.

The examination of promising areas separated by remote sensing has been checked as a result of field observations and testing work and results were assessed.

Remote sensing analysis of the ASTER data used in the preparation of the article was carried out in three stages: In the first stage, preprocessing analysis was carried out combining spectral bands dealing with initial satellite data. In the second stage, the analysis

directed to the definition of tectonic elements, obtaining stereoscopic image and mineralogical mapping, as well as lithological mapping analysis were carried out. In the third stage, combining all the data acquired from the results of analysis in the environment of the geographical information system, the work was carried out in the direction of definition of structural elements and hydrothermal alteration zones.

Remote sensing was carried out in the region by complex research consisting of a special program complex, facilitation and image processing technique.

Geological position of the research area. The research area is located in the territory of Shamkir and Gadabay regions on the north-eastern slope of the Lesser Caucasus between longitudes $45^{\circ} 05' 20''$ E and latitudes $40^{\circ} 02' 80''$ – $40^{\circ} 04' 40''$ N (Fig. 1). Gadabay ore district is located in the axial zone of the large Shamkir horst uplift of the Lok-Karabakh zone. The complexity of its tectonic development and its position in the large block structure of the Lesser Caucasus depend on the occurrence forms and scale of fault structures. (Geology of Azerbaijan, 2005; Shikhalibeyli, 1996). It was mentioned that deep fault structures of the ore district are hereditary beginning from the Baikalian structure to the Hercynian epoch (Shikhalibeyli, 1996). The main feature characterizing the region is extensive development of Bajocian-

Barthian volcanogenic occurrences and plagiogranite – gabbro-diorite-granodiorite formation intrusively cutting through them (Geology of Azerbaijan, 2001). As the oldest mining region of the Caucasus, Gadabay ore district is characterized by gold-copper-pyrite, copper-gold porphyry, copper-polymetallic and copper-arsenic mineralization.

The Murovdag anticlinorium is located south-west of Dashkesan and north of Toragachay. As a boundary structure separating two facial tectonic zones with different properties, the Murovdag anticlinorium is located between two structure-formation zones (Lok-Karabakh and Goycha-Hakari) of different ages and different geological history of development (Shikhalibeyli, 1996; Abdullayev et al., 1988). This structure composes of mainly Middle Jurassic volcanogenic genesis and granitoid massifs cutting them through (Geology of Azerbaijan, 2001). This ore district is characterized by copper-gold-porphyry, copper-pyrite, copper-polymetallic and gold-polymetallic mineralization.

Due to the wide development of metasomatic alterations and epithermal mineralization associated with them both in Gadabay and Murovdag ore regions, the remote sensing data like ASTER is significant in the lithological mapping and initial stage of the investigation work.

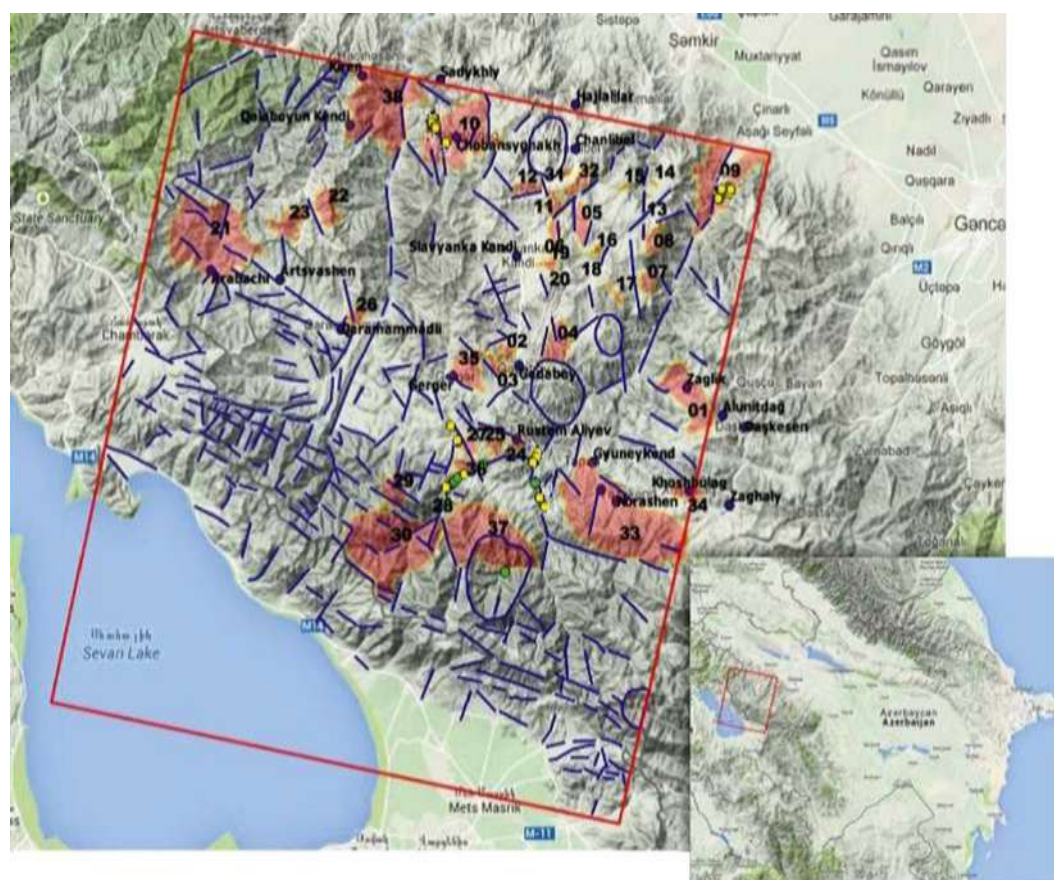


Fig. 1. Geological and tectonic position of Gadabay and Murovdag ore areas

The analysis of stereoscopic image.

There exists an infrared telescope which provides the view of ASTER satellite in the vertical direction from the sky and receives the backward image in the same spectral band. This infrared telescope captures obtain pairs of stereo images (3N and 3B) with 27.6° angle and 0.6 high ratio percentage. This peculiarity has been used in the formation of numerical elevation model and obtaining three-dimensional stereoscopic image (Fig. 2 and 3). Two individual telescopes were set to the VNIR receiver in order to reduce breakages in the images and to obtain a nadir view and backward view.

VNIR, possessing totally 3 bands (1–2–3) and a single band with stereo image features is received in $0.52\ \mu\text{m}$ – $0.86\ \mu\text{m}$ wave length (Yamaguchi et al., 1998; Abrams and Hook, 2001). Stereoscopic image receivers have capacity of showing the other three-dimensional band receiver 27.6° backward which was set in the orbits. The basic height ratio in the stereo images is $B/H=0.6$. VNIR possesses $\pm 24^\circ$ image capacity from the vertical direction towards the cross. The area of the image is $60\ \text{km} \times 60\ \text{km}$, the resolution of the image is 15 meters (Abrams, 2000; Abrams et al., 2001).

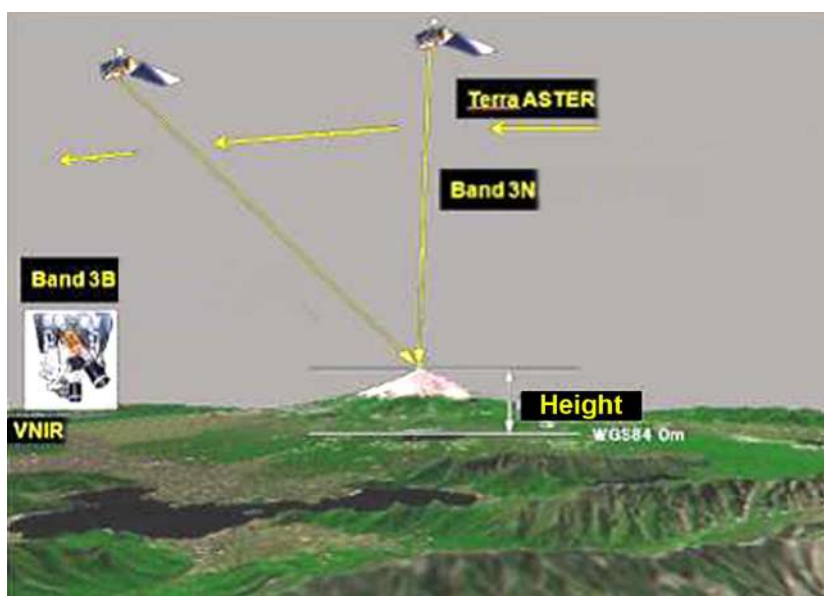


Fig. 2. Stereoscopic images obtained by using 2 pieces of VNIR receivers belonging to ASTER.

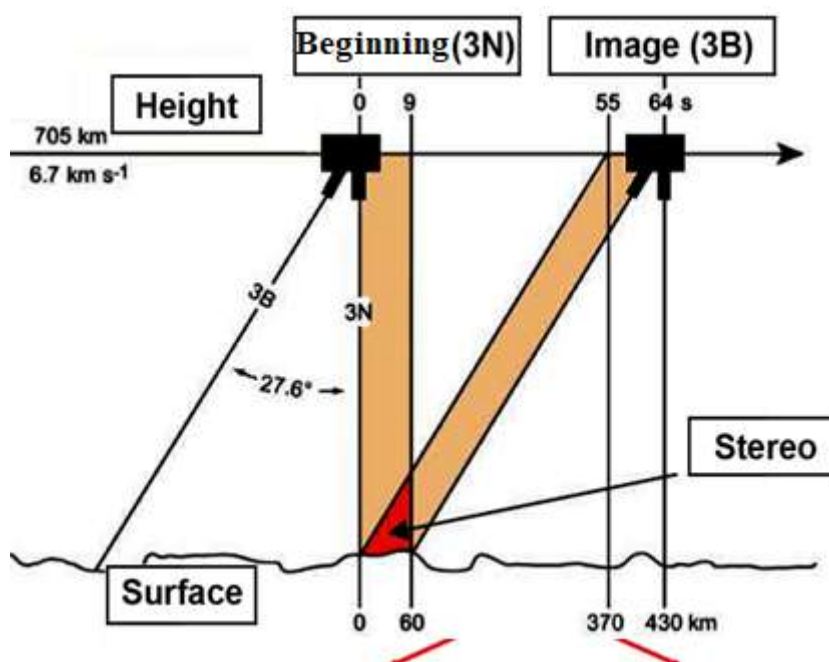


Fig. 3. The geometrical form of ASTER VNIR stereo image.

Note in Fig. 3 **Beginnig** should be **Beginning**

The standard surface radiance data product for all 14 channels was used in the classification. The 15-meter VNIR channels and 90-meter TIR channels

were resampled and registered to the 30-meter spatial resolution of the SWIR channels (Zhang et al., 2007). A flowchart of the classification process is illustrated in Fig. 4.

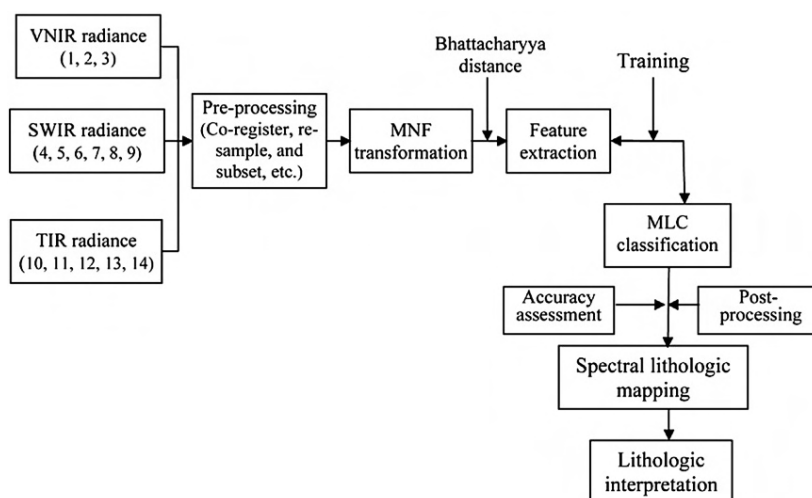


Fig. 4. Flowchart for lithologic information retrieval from ASTER data (Zhang et al., 2007).

The limitation of tectonic structural elements by using stereoscopic analysis. The obtainment of tectonic structural elements is possible by using stereoscopic images based on the analysis of accurate and precise stereoscopic images (Yamaguchi et al., 1998; Abrams and Hook, 2001).

For the purpose of discovering new linear and ring structures in the tectonic setting of the research area, the classification of structural elements and definition of strike directions are significant in the region. Stereoscopic images allow us to carry out accurate work approximately up to 1–35,000 scale. The greatest advantage of stereoscopic images is the detection of structural elements and the survey of hydrothermal alteration zones within the area of 3,600 km. From this point of view, by obtaining photogeological data from stereoscopic images, the structural elements have been mapped taking into account the fractures, caldera-type structures, linear and ring structures, different lithological units and compositions. These structural elements belonging to the region were studied by using geomorphological elements in the earth (Crosta and Filho, 2003; Zhang and Pazner, 2007; San et al., 2004).

The other method used in the definition of geological features of ASTER images is the discovery of geological structures by stereo image analysis. Fault systems and fault zones, caldera type structures, fracture structures like anticlinal and synclinal are defined by stereoscopic analysis (Babazade et al., 2018). The definition of the features of tectonic faults in the area outside the minerals in hydrothermal alteration zones is potentially promising as the discovery and survey of ore mineral

deposits in remote sensing work are considered the main factors from the point of view of investigating the areas selected as a target for exploration work (Koronovski and Dmitrieva, 1990; Milovskiy et al., 2018).

Based on the ASTER data, particularly by obtaining stereo images and analyzing them, the definition of structural elements belonging to the Gadabay ore region, especially ring structures, are considered the basic structural factor in the determination of ore distribution and determining structures (Babazade et al., 2018; Milovskiy et al., 2018). As a result of decipherment of cosmic, medium and large-scale height images of the area surrounding the Gadabay ore region and ground control strips, the fault fractures bordering tectonic blocks with small size (5–10 km.) are separated. These structures look much better over Middle Jurassic age rocks and they are visible in the form of narrow, rectilinear stripe, forming dark photo shades on account of the hydrothermally altered rocks, as well as plant cover (Babazade et al., 2018).

Within the boundaries of the Jayirchay copper-porphyry deposit entering the Gadabay ore region, a concentrically micro circular structure was defined. Different parts of this structure are visible in the form of a series of arched fault fractures in the erosional section. The width of alteration zones varies between 10–15 km. along the fault fractures. Here the rocks have been exposed to cataclysmic hydrothermal alterations such as silification, kaolinization and cutting. Here, sericite facies of derivative quartzites play a significant role in the localization and concentration of copper-porphyry mineralization (Babazade et al., 2015).

Caldera-type ring structures playing a positive role in the localization of endogenous type mineralization in the area of volcanic edifices of Karadag Khar-Khar ore district have been mentioned. These structures are considered significant from the point of view of the determination of promising areas of mineral potential (Babazade et al., 2015).

The Shamkir ring structure is considered the largest one among the studied structures in the research area. Along with the Shamkir ring structure, several, relatively small-sized circular, ellipsoid and arched structures are located here (Gadabay, Slavyanka, Zahmatkend, Kharkhar, Karadag). Their sizes are 2–5 km in the width section. Along the fractures striking in the meridional (transversal) direction, outcrops of Atabey-Slavyanka plagiogranite, Gadabay and Jayirdag intrusive are observed in these structures (Geology of Azerbaijan, 2003). The above-mentioned ring structures are interesting from the point of view of mineralization. The rock complexes cut by them have been exposed to different formational types of hydrothermal-metasomatic alterations in most cases and they are observed with various types of mineralization (copper-polymetallic, copper-porphyry, gold-pyrite, copper-arsenic, sulphur-pyrite) (Abdullayev et al., 1988).

The Asrikchay volcanic-plutonic ring structure is located in the north-eastern part of the Shamkir ring structure, in the basins of Tovuzchay and Asrikchay. The size of the structure along the width section is 15 km. Paleozoic metamorphic shales, Lower Jurassic terrigenous-sedimentary rocks and subvolcanoes with acid content cutting them through participate in the central part of the structure. As a result of crossing fault fractures of different directions, a block-like structure was formed in this area. The contact zones of the majority of ring structures are limited with volcanogenic and volcanogenic-sedimentary rock complexes with different content. Most of the revealed ring structures (fractures) are of magmatic origin and in their central part stand relatively ancient magmatic complexes with deep source (Atabey-Slavyanka, Gadabay, Gianbyr and other intrusives). Small scaled ring structures are bordered with separate volcanic edifices, subvolcanic masses and small intrusives in the area (Geology of Azerbaijan, 2003). In places some ring structures of unknown origin stand out separately in the region. They are distinguished by better decipherment in a form of concentric lines in cosmic images for their geomorphological features (Babazade et al., 2018).

Along the tectonic structures revealed within the boundaries of the Murovdag ore region, spatially and genetically hydrothermal-metasomatic alterations of the surrounding rocks (silification, pyritization, kaolinization, sericitization and etc.) are observed. More intensive concentration of Au, Cu, Mo, Pb,

Zn and other mineralizations with epithermal origin associated with these alterations occurred under the impact of postmagmatic activity of the intrusive with plagiogranite and gabbro-granodiorite content and solfatara processes. This process is in close genetic relation with Middle-later Bajocian Middle underlying rocks with acid content which possess post-magmatic activity of acid vulcanites and granitoids (Geology of Azerbaijan, 2001).

The detection of hydrothermal alteration zones and mineralization areas. The rocks located in the areas where extrusive and volcanic-dome edifices have developed and also in the contact parts of hypo volcanic and subvolcanic masses have undergone to hydrothermal-metasomatic alterations in the Gadabay ore region.

The possibility of the detection of hydrothermal alteration zones based on remote sensing data creates a wide scope for conducting effective geological researches in this area. From this point of view, by using remote sensing data the detection and research of alteration zones have been carried out in the Gadabay and Murovdag ore regions. Components of variability have been defined according to diagnostic spectral band among basic components (Boardman, 1988; Boardman et al., 1995). Alteration zones defined by remote sensing, geological survey and field inspections have been accurately analyzed.

The results show that OH alterations are mainly represented by k-spars, kaolinization, sericitization, silification, pyrophyllitization. Such alterations are considered characteristic for copper-porphyry, gold-copper-porphyry deposits Fe^{2+} (Fe^{3+}) alterations are referred as a result of pyritization. Such kinds of alterations are estimated as an indicator of polymetallic deposits in the area (Arnott and Zentilli, 2006; Sabins, 1999).

ASTER data was widely used in the detection of minerals in the hydrothermal alteration zones. One of the most significant methods for mineralogical cartographical analysis is band areas. This method has been applied in two different ways (Abdelsalam et al., 2000; Abrams, 1983). The first method is band areas obtained by using mineral spectral information from spectral archives in the programs used for remote sensing analysis. The second method is the band areas created by using spectral information obtained from the rock samples in the territory and areal spectrometry. The technique of band area is applied particularly to multispectral and hyperspectral satellite data. Each mineral possesses in its nature different chemical and physical properties. Due to this difference, each mineral shows different spectral features (Fig. 5). These spectral peculiarities are the most significant features used for distinguishing minerals from one another (Ninomia,

2003; Goetz et al., 1983). The technique of band area uses these differences. The most significant factor applied in the band area method using this spectral information is reversible and absorption differences in the spectral graphics related to the minerals. Using the programs of the remote-sensing analysis of these differences, in the image of the reversible belt appearing in the ratio with the absorption band against ASTER diapason, they were defined by obtaining light-coloured

areas (Watson et al., 1990; Gupta, 2003). For example, light-coloured zones are obtained in the new image to be created in the ratio of the fourth band with the fifth band for detecting alunite mineralization. These zones have been determined as the areas of anomaly of the alunite mineral. The mineralogical cartography is carried out by the technique of the band area, which is considered an easy and significant method (Okada, et al., 1993; Papp and Cuday, 2002).

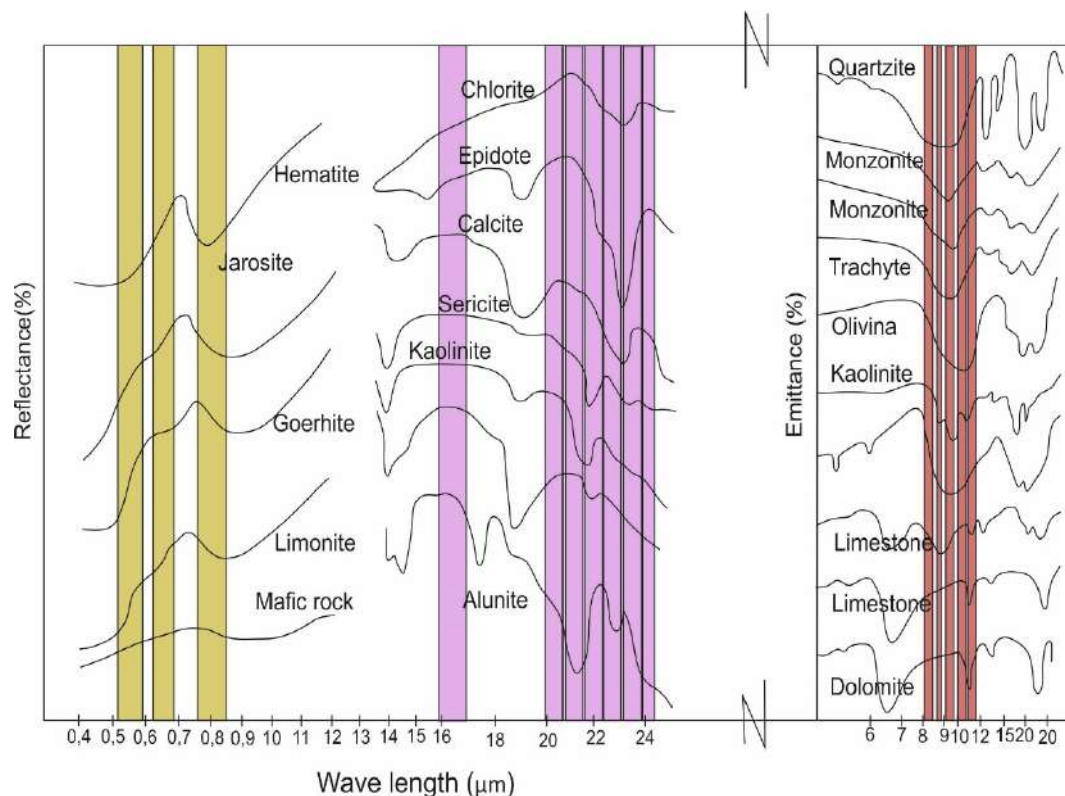


Fig. 5. Samples with the bands used for the discovery of different minerals and rocks in ASTER, VNIR, SWIR and TIR diapasons.

During the investigation and survey of ore deposits, kaolinite, alunite, sericite, calcite, muscovite, iron oxides give significant information in terms of mineral alterations, particularly the definition of the type of hydrothermal alterations. (Morton, 1977; Lillesand and Kiefer, 2004). For that reason, for the purpose of creating the distribution map of the hydrothermal alteration zones, anomalies were determined. The density of anomalies is observed in the distribution map of the obtained iron oxide anomaly in separate areas of the Gadabay ore district (Babazade et al., 2018).

Density is observed in the Gadabay and Murovdag regions in the obtained distribution map of iron oxide anomaly. The extension of these anomalies continues up to the borders of Armenia and the distribution of anomalies in larger areas attracts attention (Fig. 6).

As it is known, the significance of alunite minerals is important in the definition of epithermal and hydrothermal ore deposits. The distribution is observed in many areas in the distribution map related to the revealed alunite mineralization anomaly (Fig. 7). The anomalies observed in Goyche Lake and around it can be false. The cause of these anomalies can be associated with clay minerals which appeared as a result of the lake drying up, its traces can be found there (Rowan et al., 1977; Sabine, 1977).

The distribution of kaolinite obtained by the application of the kaolinite index method is observed in larger areas based on the result obtained by the band area. (Tommasa and Rubinstein, 2007; Crosta and Filho, 2003). In the conducted field research work these areas occupied a place among the spheres which are essential targets for hydrothermal zones (Fig. 9).

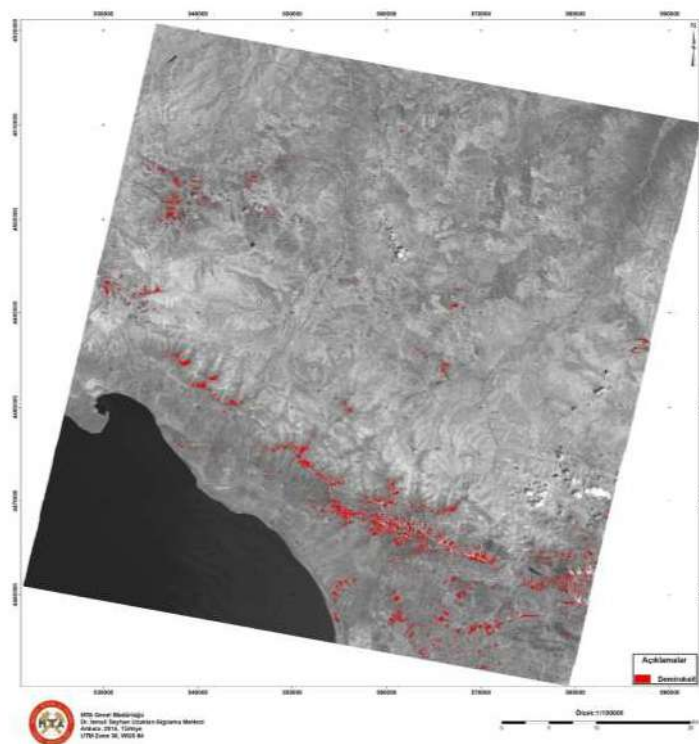


Fig. 6. The anomaly map related to iron oxide mineral in the Gadabay-Dashkesan area.

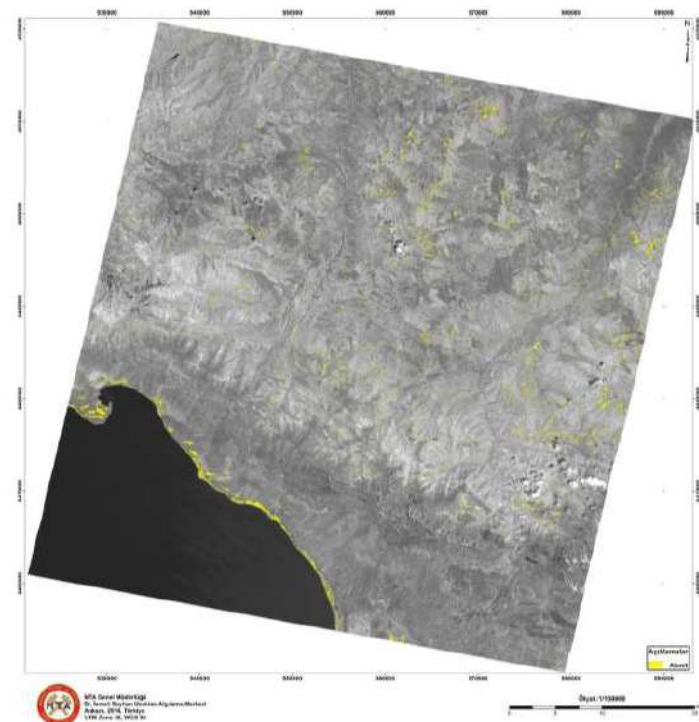


Fig. 7. The anomaly map related to the alunite mineral in the Gadabay-Dashkesan area.

The anomaly distribution related to the dolomite mineral has been observed in the north-south directions (Fig. 8). The dolomite anomalies with Mg characteristics restricted along the area are of great importance. The anomalies recorded in this area give us reason to think that they are sourced by the high amount of Mg in the content of rocks.

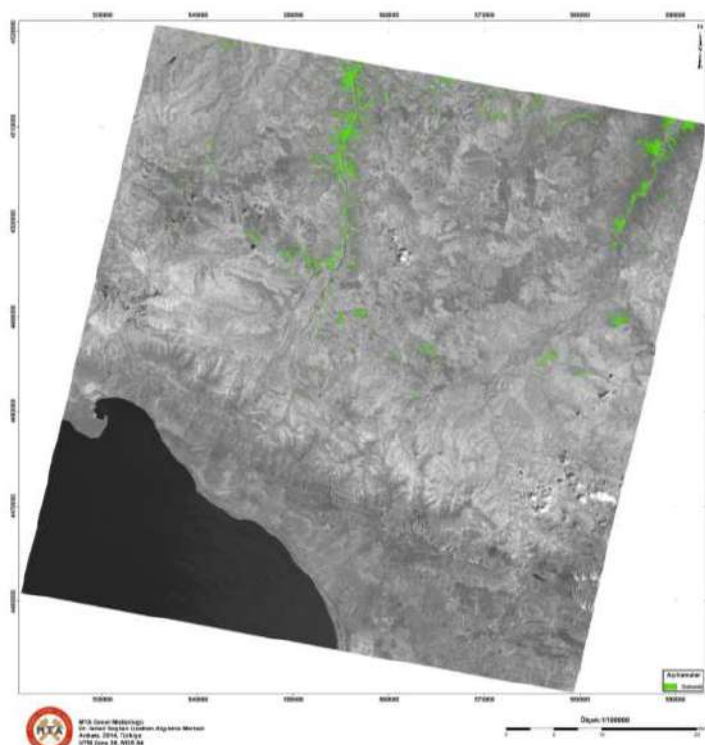


Fig. 8. The anomaly distribution map related to the dolomite mineral in the Gadabay- Murovdag area.

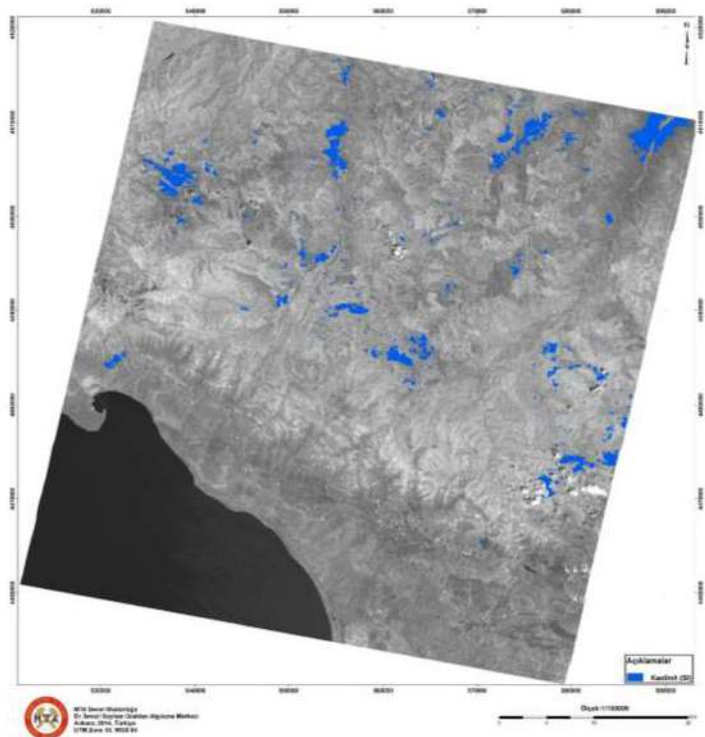


Fig. 9. Kaolinite mineral map obtained by spectral index method.

In the analysis made for the purpose of determining the distribution of calcite minerals by spectral index method, it was defined that calcite minerals are distributed approximately in the same spheres with band area (Abrams, 2000; Abrams et al, 2001). The

density of the anomalies is observed more widely in the south of the area we have studied, particularly within the territory of Armenia. The distribution of this anomaly shown by us in the region is assumed to be sourced from limestone (Fig. 10).

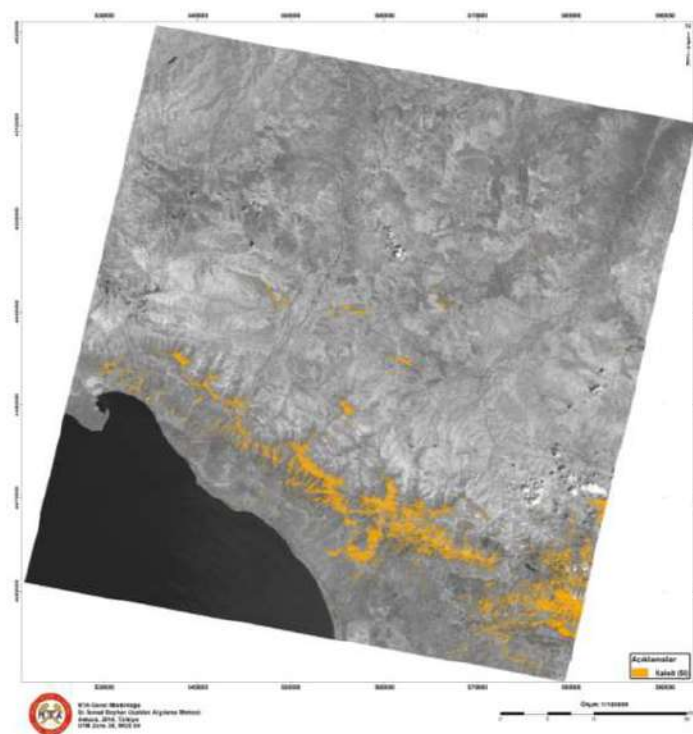


Fig. 10. Calcite mineral map obtained by spectral index method.

As known, like other alterations, the significance of kaolinite and alunite mineralization is great in definition of epithermal and hydrothermal ore deposits, in the planning of investigation work. The map was compiled on both revealed mineralization anomalies. As we can see, tight distribution is observed in many spheres on both distribution maps. The dense network of kaolinite anomaly limited in larger areas draws special attention here. Like other anomalies, these anomalies are followed up to Goyche Lake and its surroundings. But these anomalies can be false. It is assumed that the main cause of supposing these anomalies to be false can be sedimentogenous clay and kaolinite minerals which were left as a result of the lake drying up (Abrams, 2000; Abrams et al., 2001).

Allocation of prospective areas for field observations and testing work. For the purpose of

studying the Gadabay ore district by remote-sensing method, the relevant territory has been divided into twelve squares with equal-area and each square has been studied individually. First, ASTER data was deciphered by relevant methods, ring and linear structures were allocated and being analyzed were classified in detail (Fig. 11). Later, on the basis of the panchromatic colours on the satellite images, the areas with vegetation cover of the territory, zones of mineralization and hydrothermal alterations were separated for their suitable colours (Crowley et al., 1989; Sabine, 1997; Gupta, 2003; Zhang and Panzer, 2007). On the basis of the acquired information, the sites characterized by hydrothermal alterations were allocated within each square. It is recommended to carry out geological observations and testing work at these sites and assess them from the point of view of prospects of mineralization.

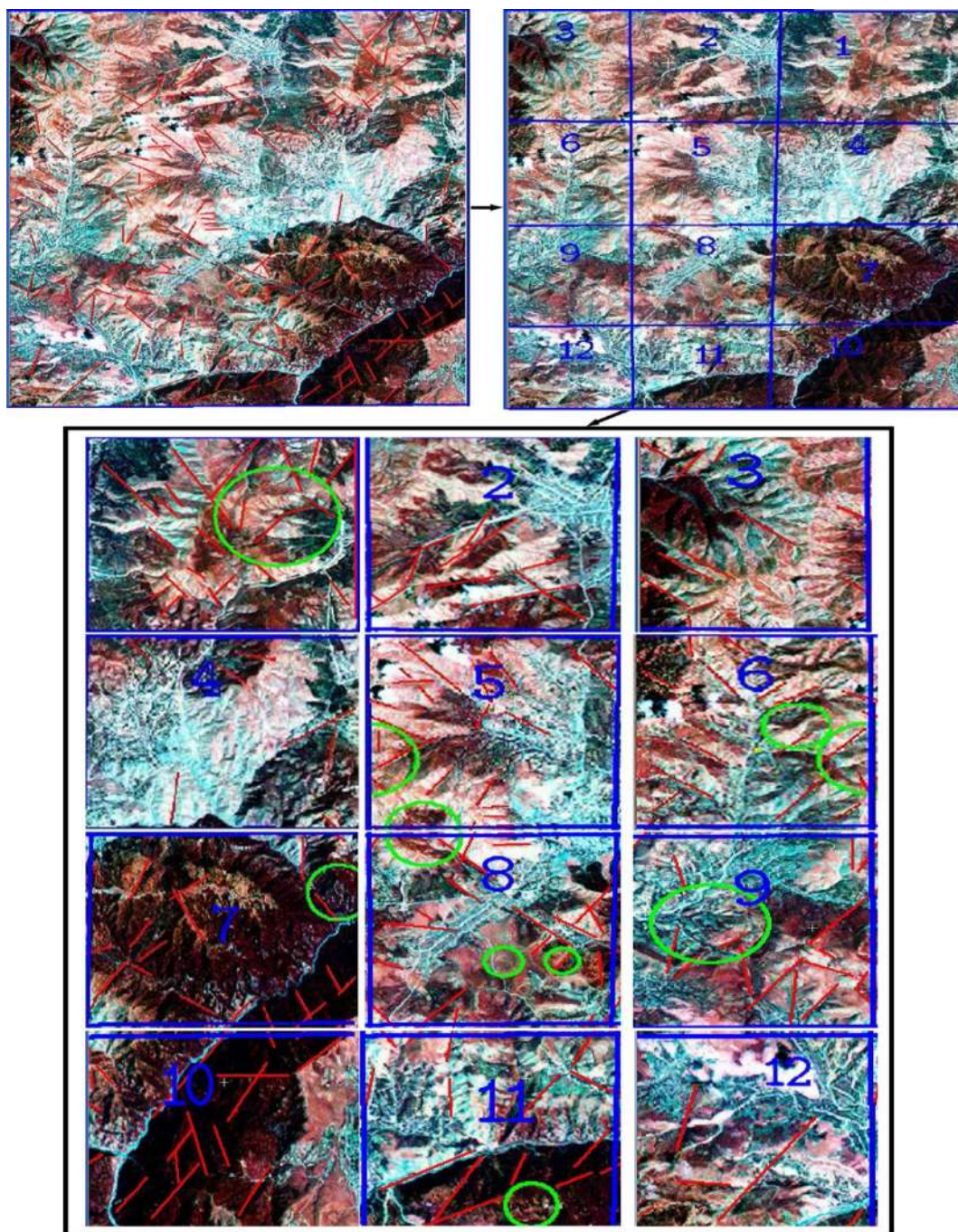


Fig. 11. The map – diagrams of lines and coloured structures Gadabay mine district

According to the analysis we have conducted on the basis of ASTER data, 37 potential hydrothermal alteration zones have been revealed through the Gadabay ore district. Seven areas among them were examined by geological exploration or investigation of the south-west of Misginli territory of Gadabay in the recorded zones № 27, 28 and 36, alteration and mineralization zones with dense network were observed (Fig. 12). At the sites of 1208141 numbers located

within the zone № 28, andesites containing kaolinized and iron-oxidizing combinations occur. Pyrite, hematite, limonite and small-grained chalcopryrite mineralizations occur in the hydrothermal alteration zones accompanied by kaolinization and silification (Perry, 2004). The unmixing results from the ASTER reflectance data are very similar to the findings of other geological and mineralization studies in the same area (Willis, 1988; Durning et al., 1998; Babazade et al., 2018).

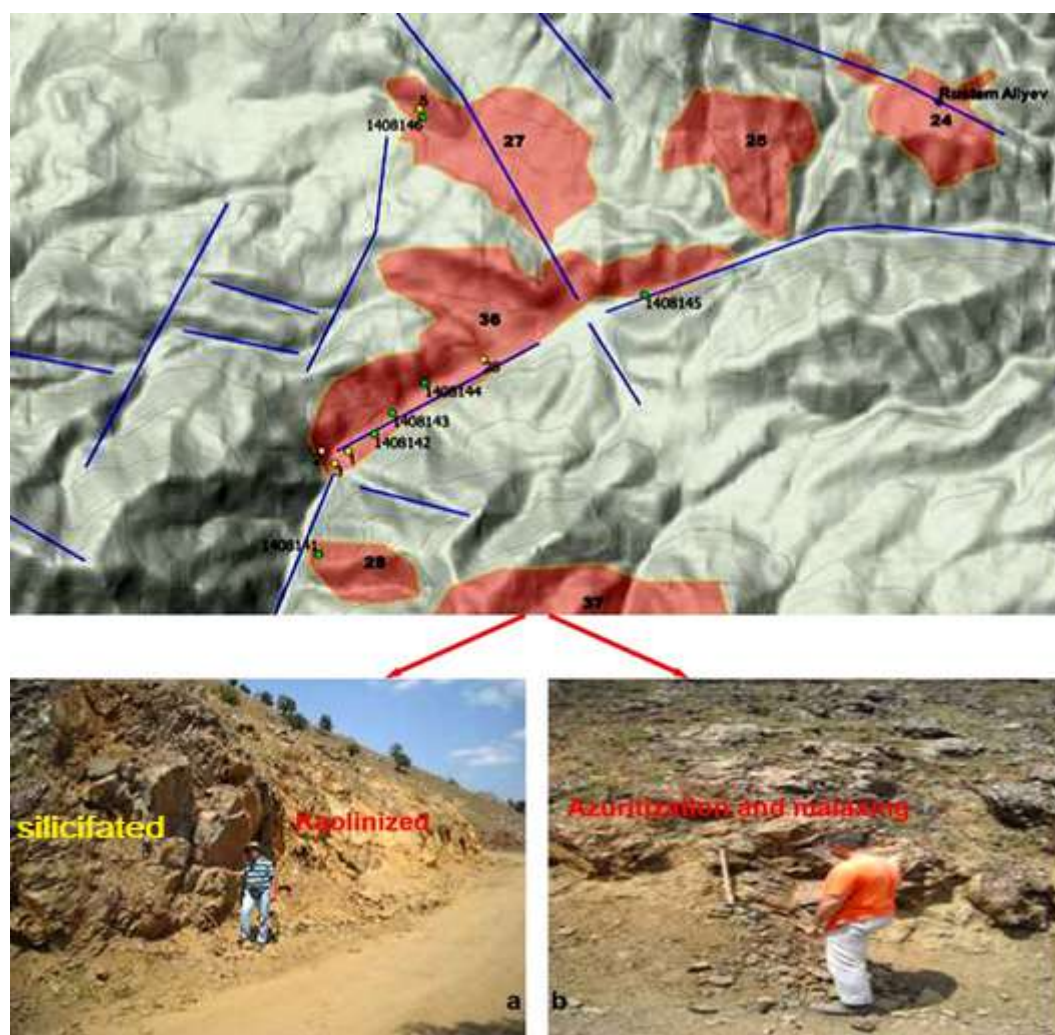


Fig. 12. Alteration zones along the territory in the areas № 27, 28 and 36 (1:55 000). a) silicified and kaolinized zones NOTE in a “silicified “ should be in place of “silenced “; b) malachite and azurite mineralization observed together with silicification.

Dense networks of hydrothermal alterations were traced in the same region, within the zone № 36, particularly in the area № 1408142. Here small-grained pyrite mineralization occurred within the areas of silicified rocks with mafic property enriched in feldspar and cinnabaric minerals were found within red veinlets enriched in iron.

According to the results of ASTER image analysis at the site № 1408143 recorded within the same zone, hydrothermal alterations have developed extremely widely and kaolinization, tight iron-oxide anomalies and silicification occur here. Small-grained pyrite minerals have been traced within the grey, brown silicified zone. The other mineralization observed in the zone № 36 is the alteration zone enriched in malachite and azurite minerals. The observation of this mineralization is considered a significant indirect sign of search for

discovery of copper-polymetallic, copper-porphyry and copper-pyrite type of mineralizations within the mentioned area. For this reason, it is recommended to carry out systematic testing work and conduct different (chemical, spectral and etc.) analysis within the region.

Samples have been obtained from 5 points along the Shamkir River, southwards, within the zone № 37 separated upstream of the Kukurdly Valley joining the Shamkir River from the left. Moving forward along the Shamkir River intensively altered and silicified andesites are observed in the area № 1608141. Alterations reflect dense pyrite phenocrysts, small amount of chalcopyrite mineralization. Associated with the alteration zones in the Kukurdly Valley in the south of the zone № 37 red ankeritolites ($\text{CaCO}_3\text{FeCO}_3$) are observed among brown limestones in the area № 1608142. For this reason, iron-oxide anomaly occurred in the region (Fig. 13).



Fig. 13. The observation of silicified andesites (a) and ankeritized limestones (b) in Shamkir River and Kukurdly Valley zone (1:75000). NOTE in b Anchored should be ankeritized

Based on the satellite data, the area has been registered where very frequent hydrothermal alterations (kaolinite, alunite, montmorillonite, sericite and etc.)

and iron-oxide mineralization are observed within the zone № 9 recorded in the north-western part of the ASTER image of the territory (Figure14).

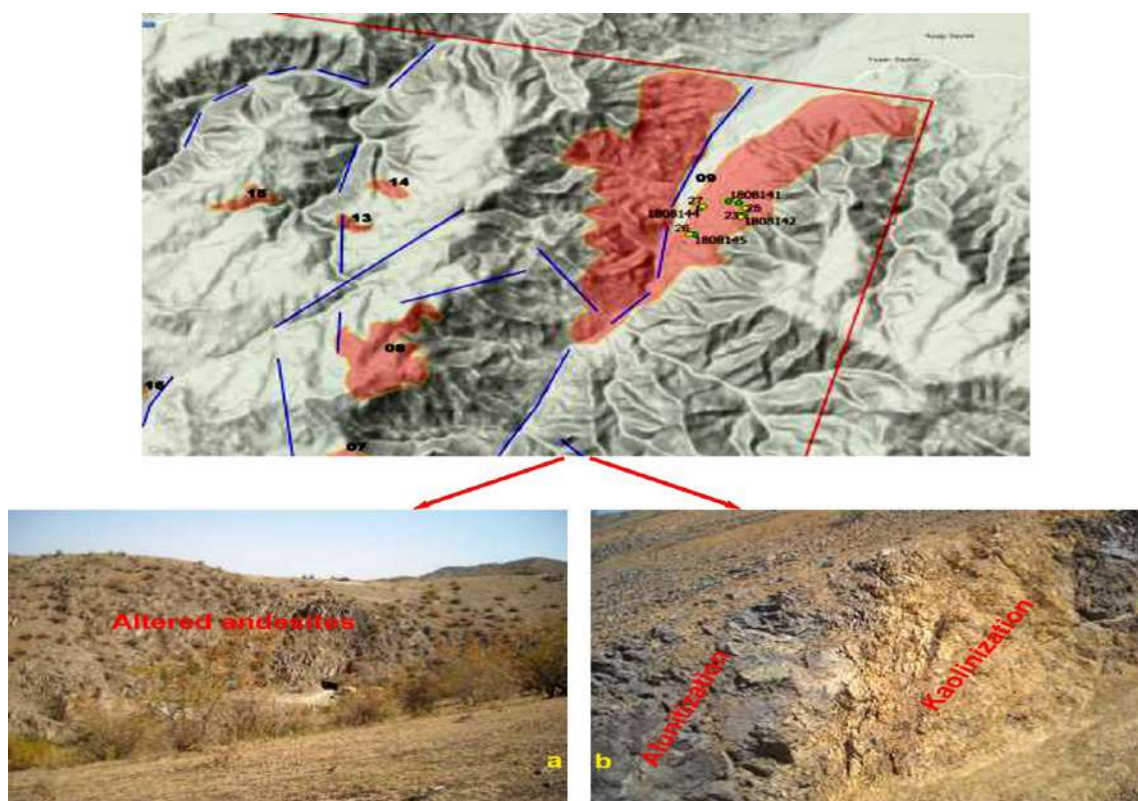


Fig. 14. The general view of kaolinized, silicified and altered andesites with abundant pyrite mineralization (a) and alunite, kaolinite mineralizations and silicifications within the zone № 9 located in the north-eastern part of the territory (Scale 1:100000).

As seen from the image, the region has been cut by a north-eastwards “free air” reduction. Along with widespread silicification, sericite, biotite, chlorite minerals, as well as mineralization of the oxidized zone exemplified by malachite and azurite occurred in the footprint area. Along with that, as a result of the information acquired by ASTER image analysis, the presence of minerals which is the product of hydrothermal alteration has been confirmed in the area.

At the site № 1808145 of the conducted research work, the areas characterised by kaolinization, alunization, intensive hematitization and pyritization have been revealed within the rocks where hydrothermal alterations take place. Along with that, sometimes chalcopryite mineralization was observed too. Here, wide observation of sulphide mineralization is a significant evidence for the search of epithermal ore deposits, the formation of which is supposed (expected) to exist in the region, and for making a systematic geochemical analysis.

By remote information and with the help of the relevant compiled anomaly maps, within separate areas, the points with special coordinates were allocated. These points are considered promising for geological research and testing from the point of view of intensity and types of hydrothermal alterations. The factors standing on the basis of the selection principles of this type of point are as follows: 1) the composition of rocks identified by comparison with remote-sensing data and other researchers' information; 2) according to the relevant analysis methods, based on the remote-sensing data, the detection of alteration zones; 3) intrusive mass, different-sized ring structures, different-sized fault fractures and lineaments in the territory, favourable areas for hydrothermal alterations and mineralization; 4) structure units, magmatic mass (intrusives, subvolcanoes, dykes, stocks, etc) defined on the basis of cosmic images and the existence of hydrothermal alteration zones accompanied by them.

Conclusions.

1. Based on the conducted research work, the conformity between the results obtained by ASTER image analysis and the conclusions drawn as a result of field work were confirmed.

2. Using stereoscopic images obtained from ASTER satellite data, existing or supposed tectonic structures in the region have been detected. These structures are considered to be significant from the point of view of defining potentially promising areas for mineralization.

3. The rock complexes cut by the tectonic structures have undergone various formational types of hydrothermal-metasomatic alterations and they are associated by different-type of mineralization.

4. Chalcopryite, malachite, azurite, pyrite, cinnabar and the compounds of iron oxide accompanied by kaolinization, alunization, silicification, sericitization, iron-oxidation and other hydrothermal alterations have been macroscopically defined in the discovered alteration zones. These mineralizations can be considered as probable sites for the localization of ores during prospecting and evaluation works.

5. The zones of hydrothermal alteration mentioned in the region are significant from the point of view of mineralization. The presence of high sulphide mineralization in the area creates conditions for carrying out complex geological-mineralogical work systematically in order to detect ore deposits in the region in future.

6. The experience of the conducted work shows that the application of ASTER data allows us to allocate potentially promising areas for the mineralization in the initial stage of the geological-exploration process and it reduces the cost of the exploration work of the ore minerals in the region.

Conflict of Interest

The authors state that they are not involved in any conflict of interest.

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